08/23/01

Class	Subclass
385	24

ISSUE CLASSIFICATION

PATENT NUMBER

6625346

6625346

U.S. UTILITY Patent Application

O.I.P.E.

SCANNED HKM NS (3) Q.A. GW

PATENT DATE

SEP 23 2003

APPLICATION NO.	CONT/PRIOR	CLASS	SUBCLASS	ART UNIT	EXAMINER
09/938426	D	385	24	2874	Healy

Jeffrey Wilde

Reconfigurable optical add-drop multiplexers with servo control and dynamic spectral power management capabilities

PTO-2040 12/99

ISSUING CLASSIFICATION

ORIGINAL		CROSS REFERENCE(S)							
CLASS	SUBCLASS	CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)						
385	24	385	11	37	34				
INTERNATIONAL CLASSIFICATION		359	115	124					
02B	6/28								
04J	14/02								

☐ Continued on Issue Slip Inside File Jacket

8/11/03 Formal Drawings (12 shts) set 8/23/01

☐ TERMINAL DISCLAIMER

☐ The term of this patent subsequent to ______ has been disclaimed.

☐ The term of this patent shall not extend beyond the expiration date of U.S Patent. No. ______

☐ The terminal ____ months of this patent have been disclaimed.

DRAWINGS			CLAIMS ALLOWED	
Sheets Drwg.	Figs. Drwg.	Print Fig.	Total Claims	Print Claim for O.G.
12	12	1A	67	1 and 61

(Assistant Examiner) (Date)

Brian Healy 4/17/03
Brian Healy
Primary Examiner

(Primary Examiner) (Date)

(Legal Instruments Examiner) 4/22/03 (Date)

NOTICE OF ALLOWANCE MAILED

4/21/3

ISSUE FEE

Amount Due	Date Paid
1600	7-23-03

ISSUE BATCH NUMBER

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Formal Drawings(___shts) set_____

ISSUE FEE IN FILE

(FACE)

09938426

jc996 U.S. PTO
09/938426
08/23/01

INITIALS 9/4/01 12

CONTENTS

	Date Received (Incl. C. of M.) or Date Mailed		Date Received (Incl. C. of M.) or Date Mailed
1. Application 12 papers.		42.	
2. PTOL-37=	1/29/02 ck	43.	
3. Req. for RCE	10-15-02	44.	
4. IDS	10-15-02	45.	
5. Reject (3 mos.)	12/4/02 cn	46.	
6. IDS	12-16-02	47.	
2-4-03 7. Amt A	2/3/03	48.	
8. PTOL-37(=)	4/21/03 cn	49.	
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SEARCHED

Class	Sub.	Date	Exmr.
385	11 *	7/12/02	[illegible]
	24 *		
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	34 *		
	31		
359	115		
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up date		4/17/03	BUH

INTERFERENCE SEARCHED

Class	Sub.	Date	Exmr.
S/A/A		7/22/02	[illegible]
~~update~~ Interference files have been removed.			

SEARCH NOTES (INCLUDING SEARCH STRATEGY)

	Date	Exmr.
update "EAST" search strategies and databases used listed on printout.	4/17/03	BUH

ISSUE SLIP STAPLE AREA (for additional cross references)

POSITION	INITIALS	ID NO.	DATE
FEE DETERMINATION	[illegible]		
O.I.P.E. CLASSIFIER		UJ	9/4/01
FORMALITY REVIEW	m-h	1107	10/08/01
RESPONSE FORMALITY REVIEW			

INDEX OF CLAIMS

✓ .... Rejected
= .... Allowed
— (Through numeral)... Canceled
÷ .... Restricted
N .... Non-elected
I .... Interference
A .... Appeal
O .... Objected

Claim Final	Claim Original	Date 9/17/03
1	1	=
2	2	=
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Claim Final	Claim Original	Date 9/17/03
51	51	=
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Claim Final	Claim Original	Date
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If more than 150 claims or 10 actions
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PATENT APPLICATION SERIAL NO. ______________

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

08/28/2001 STEUNEL1 00000011 09938426

01 FC:201	355.00 OP
02 FC:203	423.00 OP
03 FC:202	120.00 OP

PTO-1556
(5/87)

*U.S. GPO: 1999-459-082/19144

UNITED STATES PATENT AND TRADEMARK OFFICE

COMMISSIONER FOR PATENTS
UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. 20231
www.uspto.gov

Bib Data Sheet

CONFIRMATION NO. 2587

SERIAL NUMBER	FILING DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
09/938,426	08/23/2001 RULE	385	2874	210393-991101

APPLICANTS

Jeffrey P. Wilde, Los Gatos, CA;

** CONTINUING DATA *************************

THIS APPLN CLAIMS BENEFIT OF 60/277,217 03/19/2001

** FOREIGN APPLICATIONS ********************

None

IF REQUIRED, FOREIGN FILING LICENSE GRANTED ** SMALL ENTITY **
** 10/08/2001

Foreign Priority claimed / 35 USC 119 (a-d) conditions met / Verified and Acknowledged		STATE OR COUNTRY	SHEETS DRAWING	TOTAL CLAIMS	INDEPENDENT CLAIMS
Foreign Priority claimed: ☐ yes ☑ no; 35 USC 119 (a-d) conditions met: ☐ yes ☑ no ☐ Met after Allowance; Verified and Acknowledged	Examiner's Signature / Initials	CA	12	67	6

ADDRESS

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto ,CA 94303

TITLE

Reconfigurable optical add-drop multiplexers with servo control and dynamic spectral power management capabilities

FILING FEE RECEIVED	FEES	
898	FEES: Authority has been given in Paper No. _________ to charge/credit DEPOSIT ACCOUNT No. _________ for following:	☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other ____________ ☐ Credit

08-27-01

Please type a plus sign (+) inside this box [+]

PTO/SB/05 (08-00)
Approved for use through 10/31/2002. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	2102393-991101
First Inventor	WILDE, Jeffrey P.
Title	RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXER WITH SERVO CONTROL AND DYNAMIC SPECTRAL ...
Express Mail Label No.	EL 904925981 US

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents

ADDRESS TO: Assistant Commissioner for Patents, Box Patent Application, Washington, DC 20231

1. ☒ Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original, and a duplicate for fee processing)
2. ☒ Applicant claims small entity status. See 37 CFR 1.27.
3. ☒ Specification [Total Pages: 34] (preferred arrangement set forth below)
   - Descriptive title of the invention
   - Cross Reference to Related Applications
   - Statement Regarding Fed sponsored R&D
   - Reference to sequence listing, a table or a computer program listing appendix
   - Background of the Invention
   - Brief Description of the Drawings (if filed)
   - Detailed description
   - Claim(s)
   - Abstract of the Disclosure
4. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 12] FORMAL
5. Oath or Declaration [Total Pages 3]
   a. ☒ Newly executed (original or copy)
   b. ☐ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional with Box 17 completed)
      i. ☐ DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. ☐ Application Data Sheet. See 37 CFR 1.76.
7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program (*Appendix*)
8. Nucleotide and/or Amino Acid Sequence Submission (*if applicable, all necessary*)
   a. ☐ Computer Readable Form (CRF)
   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies; or
      ii. ☐ paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. ☒ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement (*when there is an assignee*) ☒ Power of Attorney
11. ☐ English Translation Document (*if applicable*)
12. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503) (*Should be specifically itemized*)
15. ☐ Certified Copy of Priority Document(s) (*if foreign priority is claimed*)
16. ☐ Request and Certification under 35 U.S.C. 122 (b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. ☒ Other: Check No. 487207 $ 938.00

17. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: ______/______

Prior application information: Examiner______ Group/Art Unit:______

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

18. CORRESPONDENCE ADDRESS

☐ *Customer Number or Bar Code Label* (Insert Customer No. or Attach bar code label here) or ☐ *Correspondence address below*

Name	David Alberti				
Address	Gray Cary Ware & Freidenrich 1755 Embarcadero Road				
City	Palo Alto	State	CA	Zip Code	94303
Country	US	Telephone	650/320-2052	Fax	650/320-7401

NAME (Print/Type)	David Alberti	Registration No. (Attorney/Agent)	43,465
Signature	D Alberti	Date 8/23/01	

Gray Cary\EM\7085824.1
2102393-991100

PTO/SB/17 (09-00)
Approved for use through 10/31/2002. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT	($) 938.00

Complete If Known	
Application Number	Not Yet Assigned
Filing Date	Herewith
First Named Inventor	WILDE, Jeffrey P.
Examiner Name	Unknown
Group Art Unit	Unknown
Attorney Docket No.	2102393-991101

METHOD OF PAYMENT

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 07-1896

Deposit Account Name:

☒ Charge Any additional Fee Required Under 37 CFR 1.16 and 1.17

☒ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ **Payment Enclosed:** Check No. 487207

☒ Check ☐ Credit card ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	355.00
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 355.00

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	67	-20** =	47	X	9	=	423
Independent Claims	6	-3** =	3	X	40	=	120
Multiple Dependent				X		=	0

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 543.00

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	11	0240	55	Petition to revive – unavoidable	
141	1,240	241	620	Petition to revive – unavoidable	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	40
146	710	246	355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) ______________

* Reduced by Basic Filing Fee Paid **SUBTOTAL (3)** ($) 40

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	David Alberti	Registration No. (Attorney/Agent)	43,465	Telephone	650-320-2052
Signature	[signature]			Date	8/23/01

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, D.C. 20231. DO NOT SENT FEES OR COMPLETED FORM TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

Gray Cary\EM\7082448.1
2102393-990000

CERTIFICATE OF MAILING BY "EXPRESS MAIL" (37 CFR 1.10) Applicant: Capella Photonics, Inc.			Docket No. 2102393-991101
Serial No. Not Yet Assigned	Filing Date Herewith	Examiner N/A	Group Art Unit N/A

Invention:

RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

I hereby certify that this UTILITY PATENT APPLICATION
(Identify type of correspondence)
is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 in an envelope addressed to: The Commissioner of Patents and Trademarks, Washington, D.C., 20231-0001 on August 23, 2001
(Date)

Susan C. Pingue
(Typed or Printed Name of Person Mailing Correspondence)

Susan C. Pingue
(Signature of Person Mailing Correspondence)

EL 904925981 US
("Express Mail" Mailing Label Number)

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Gray Cary\EM\7082446.1
2102393-990000

Docket No. 2102393-991101

ABSTRACT OF THE DISCLOSURE

This invention provides a novel wavelength-separating-routing (WSR) apparatus that uses a diffraction grating to separate a multi-wavelength optical signal by wavelength into multiple spectral channels, which are then focused onto an array of corresponding channel micromirrors. The channel micromirrors are individually controllable and continuously pivotable to reflect the spectral channels into selected output ports. As such, the inventive WSR apparatus is capable of routing the spectral channels on a channel-by-channel basis and coupling any spectral channel into any one of the output ports. The WSR apparatus of the present invention may be further equipped with servo-control and spectral power-management capabilities, thereby maintaining the coupling efficiencies of the spectral channels into the output ports at desired values. The WSR apparatus of the present invention can be used to construct a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for WDM optical networking applications.

Docket No. 2102393-991101

PATENT APPLICATION

RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

INVENTOR

Jeffrey P. Wilde

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of U.S. Provisional Patent Application No. 60/277,217, filed 19 March 2001, which is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates generally to optical communication systems. More specifically, it relates to a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for wavelength division multiplexed optical networking applications.

BACKGROUND

As fiber-optic communication networks rapidly spread into every walk of modern life, there is a growing demand for optical components and subsystems that enable the fiber-optic communications networks to be increasingly scalable, versatile, robust, and cost-effective.

Contemporary fiber-optic communications networks commonly employ wavelength division multiplexing (WDM), for it allows multiple information (or data) channels to be simultaneously transmitted on a single optical fiber by using different wavelengths and thereby significantly enhances the information bandwidth of the fiber. The prevalence of WDM technology has made optical add-drop multiplexers indispensable building blocks of modern fiber-optic communication networks. An optical add-drop multiplexer (OADM) serves to selectively remove (or drop) one or more wavelengths from a multiplicity of wavelengths on an optical fiber, hence taking away one or more data channels from the traffic stream on the fiber. It further adds one or more wavelengths back onto the fiber, thereby inserting new data channels in the same stream of traffic. As such, an OADM makes it possible to launch and retrieve multiple data channels (each characterized by a distinct wavelength) onto and from an optical fiber respectively, without disrupting the overall traffic flow along the fiber. Indeed, careful placement of the OADMs can dramatically improve an optical communication network's flexibility and robustness, while providing significant cost advantages.

Conventional OADMs in the art typically employ multiplexers/demultiplexers (e.g, waveguide grating routers or arrayed-waveguide gratings), tunable filters, optical switches, and optical circulators in a parallel or serial architecture to accomplish the add and drop functions. In the parallel architecture, as exemplified in U.S. Patent 5,974,207, a demultiplexer (e.g., a waveguide grating router) first separates a multi-wavelength signal into its constituent spectral components. A wavelength switching/routing means (e.g., a combination of optical switches and optical circulators) then serves to drop selective wavelengths and add others. Finally, a multiplexer combines the remaining (i.e., the pass-through) wavelengths into an output multi-wavelength optical signal. In the serial architecture, as exemplified in U.S. Patent 6,205,269, tunable filters (e.g., Bragg fiber gratings) in combination with optical circulators are used to separate the drop wavelengths from the pass-through wavelengths and subsequently launch the add channels into the pass-through path. And if multiple wavelengths are to be added and dropped, additional multiplexers and demultiplexers are required to demultiplex the drop wavelengths and multiplex the add wavelengths, respectively. Irrespective of the underlying architecture, the OADMs currently in the art are characteristically high in cost, and prone to significant optical loss accumulation. Moreover, the designs of these OADMs are such that it is inherently difficult to reconfigure them in a dynamic fashion.

U.S. Patent 6,204,946 to Askyuk et al. discloses an OADM that makes use of free-space optics in a parallel construction. In this case, a multi-wavelength optical signal emerging from an input port is incident onto a ruled diffraction grating. The constituent spectral channels thus separated are then focused by a focusing lens onto a linear array of binary micromachined mirrors. Each micromirror is configured to operate between two discrete states, such that it either retroreflects its corresponding spectral channel back into the input port as a pass-through channel, or directs its spectral channel to an output port as a drop channel. As such, the pass-through signal (i.e., the combined pass-through channels) shares the same input port as the input signal. An optical circulator is therefore coupled to the input port, to provide necessary routing of these two signals. Likewise, the drop channels share the output port with the add channels. An additional optical circulator is thereby coupled to the output port, from which the drop channels exit and the add channels are introduced into the output port. The add channels are subsequently combined with the pass-through signal by way of the diffraction grating and the binary micromirrors.

Although the aforementioned OADM disclosed by Askyuk et al. has the advantage of performing wavelength separating and routing in free space and thereby incurring less optical loss, it suffers a number of limitations. First, it requires that the pass-through signal share the same port/fiber as the input signal. An optical circulator therefore has to be implemented, to provide necessary routing of these two signals. Likewise, all the add and drop channels enter and leave the OADM through the same output port, hence the need for another optical circulator. Moreover, additional means must be provided to multiplex the add channels before entering the system and to demultiplex the drop channels after exiting the system. This additional multiplexing/demultiplexing requirement adds more cost and complexity that can restrict the versatility of the OADM thus-constructed. Second, the optical circulators implemented in this OADM for various routing purposes introduce additional optical losses, which can accumulate to a substantial amount. Third, the constituent optical components must be in a precise alignment, in order for the system to achieve its intended purpose. There are, however, no provisions provided for maintaining the requisite alignment; and no mechanisms implemented for overcoming degradation in the alignment owing to environmental effects such as thermal and mechanical disturbances over the course of operation.

U.S. Patent 5,906,133 to Tomlinson discloses an OADM that makes use of a design similar to that of Aksyuk et al. There are input, output, drop and add ports implemented in this case. By positioning the four ports in a specific arrangement, each micromirror, notwithstanding switchable between two discrete positions, either reflects its corresponding channel (coming from the input port) to the output port, or concomitantly reflects its channel to the drop port and an incident add channel to the output port. As such, this OADM is able to perform both the add and drop functions without involving additional optical components (such as optical circulators used in the system of Aksyuk et al.). However, because a single drop port is designated for all the drop channels and a single add port is designated for all the add channels, the add channels would have to be multiplexed before entering the add port and the drop channels likewise need to be demutiplxed upon exiting from the drop port. Moreover, as in the case of Askyuk et al., there are no provisions provided for maintaining requisite optical alignment in the system, and no mechanisms implemented for combating degradation in the alignment due to environmental effects over the course of operation.

As such, the prevailing drawbacks suffered by the OADMs currently in the art are summarized as follows:

1) The wavelength routing is intrinsically static, rendering it difficult to dynamically reconfigure these OADMs.

2) Add and/or drop channels often need to be multiplexed and/or demultiplexed, thereby imposing additional complexity and cost.

3) Stringent fabrication tolerance and painstaking optical alignment are required. Moreover, the optical alignment is not actively maintained, rendering it susceptible to environmental effects such as thermal and mechanical disturbances over the course of operation.

4) In an optical communication network, OADMs are typically in a ring or cascaded configuration. In order to mitigate the interference amongst OADMs, which often

adversely affects the overall performance of the network, it is essential that the power levels of spectral channels entering and exiting each OADM be managed in a systematic way, for instance, by introducing power (or gain) equalization at each stage. Such a power equalization capability is also needed for compensating for non-uniform gain caused by optical amplifiers (e.g., erbium doped fiber amplifiers) in the network. There lacks, however, a systematic and dynamic management of the power levels of various spectral channels in these OADMs.

5) The inherent high cost and heavy optical loss further impede the wide application of these OADMs.

In view of the foregoing, there is an urgent need in the art for optical add-drop multiplexers that overcome the aforementioned shortcomings in a simple, effective, and economical construction.

SUMMARY

The present invention provides a wavelength-separating-routing (WSR) apparatus and method which employ an array of fiber collimators serving as an input port and a plurality of output ports; a wavelength-separator; a beam-focuser; and an array of channel micromirrors.

In operation, a multi-wavelength optical signal emerges from the input port. The wavelength-separator separates the multi-wavelength optical signal into multiple spectral channels, each characterized by a distinct center wavelength and associated bandwidth. The beam-focuser focuses the spectral channels into corresponding spectral spots. The channel micromirrors are positioned such that each channel micromirror receives one of the spectral channels. The channel micromirrors are individually controllable and movable, e.g., continuously pivotable (or rotatable), so as to reflect the spectral channels into selected ones of the output ports. As such, each channel micromirror is assigned to a specific spectral channel, hence the name "channel micromirror". And each output port may receive any number of the reflected spectral channels.

A distinct feature of the channel micromirrors in the present invention, in contrast to those used in the prior art, is that the motion, e.g., pivoting (or rotation), of each channel micromirror is under analog control such that its pivoting angle can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port.

In the WSR apparatus of the present invention, the wavelength-separator may be provided by a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a curved diffraction grating, a dispersing prism, or other wavelength-separating means known in the art. The beam-focuser may be a single lens, an assembly of lenses, or other beam-focusing means known in the art. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting means known in the art. And each channel micromirror may be pivotable about one or two axes. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional or two-dimensional array. In the latter case, the channel micromirrors must be pivotable biaxially.

The WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, in optical communication with the wavelength-separator and the fiber collimators, for adjusting the alignment of the input multi-wavelength signal and directing the spectral channels into the selected output ports by way of angular control of the collimated beams. Each collimator-alignment mirror may be rotatable about one or two axes. The collimator-alignment mirrors may be arranged in a one-dimensional or two-dimensional array. First and second arrays of imaging lenses may additionally be optically interposed between the collimator-alignment mirrors and the fiber collimators in a telecentric arrangement, thereby "imaging" the collimator-alignment mirrors onto the corresponding fiber collimators to ensure an optimal alignment.

The WSR apparatus of the present invention may further include a servo-control assembly, in communication with the channel micromirrors and the output ports. The servo-control assembly serves to monitor the power levels of the spectral channels coupled into the output ports and further provide control of the channel micromirrors on an individual basis, so as to maintain a predetermined coupling efficiency of each spectral channel in one of the output ports. As such, the servo-control assembly provides dynamic control of the coupling of the spectral channels into the respective output ports and actively manages the power levels of the spectral channels coupled into the output ports. (If the WSR apparatus includes an array of collimator-alignment mirrors as described above, the servo-control assembly may additionally provide dynamic control of the collimator-alignment mirrors.) Moreover, the utilization of such a servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during assembly of a WSR apparatus of the present invention, and further enables the system to correct for shift in optical alignment over the course of operation. A WSR apparatus incorporating a servo-control assembly thus described is termed a WSR-S apparatus, thereinafter in the present invention.

Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices, including a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs), as exemplified in the following embodiments.

One embodiment of an OADM of the present invention comprises an aforementioned WSR-S (or WSR) apparatus and an optical combiner. The output ports of the WSR-S apparatus include a pass-through port and one or more drop ports, each carrying any number of the spectral channels. The optical combiner is coupled to the pass-through port, serving to combine the pass-through channels with one or more add spectral channels. The combined optical signal constitutes an output signal of the system. The optical combiner may be an N×1 ($N \geq 2$) broadband fiber-optic coupler, for instance, which also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the system.

In another embodiment of an OADM of the present invention, a first WSR-S (or WSR) apparatus is cascaded with a second WSR-S (or WSR) apparatus. The output ports of the first WSR-S (or WSR) apparatus include a pass-through port and one or more drop ports.

The second WSR-S (or WSR) apparatus includes a plurality of input ports and an exiting port. The configuration is such that the pass-through channels from the first WSR-S apparatus and one or more add channels are directed into the input ports of the second WSR-S apparatus, and consequently multiplexed into an output multi-wavelength optical signal directed into the exiting port of the second WSR-S apparatus. That is to say that in this embodiment, one WSR-S apparatus (e.g., the first one) effectively performs a dynamic drop function, whereas the other WSR-S apparatus (e.g., the second one) carries out a dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped, other than those imposed by the overall communication system. Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of the WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions in a network environment.

Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Various changes, substitutions, and alternations can be made herein, without departing from the principles and the scope of the invention. Accordingly, a skilled artisan can design an OADM in accordance with the present invention, to best suit a given application.

All in all, the OADMs of the present invention provide many advantages over the prior art devices, notably:

1) By advantageously employing an array of channel micromirrors that are individually and continuously controllable, an OADM of the present invention is capable of routing the spectral channels on a channel-by-channel basis and directing any spectral channel into any one of the output ports. As such, its underlying operation is dynamically reconfigurable, and its underlying architecture is intrinsically scalable to a large number of channel counts.

2) The add and drop spectral channels need not be multiplexed and demultiplexed before entering and after leaving the OADM respectively. And there are not fundamental restrictions on the wavelengths to be added or dropped.

3) The coupling of the spectral channels into the output ports is dynamically controlled by a servo-control assembly, rendering the OADM less susceptible to environmental effects (such as thermal and mechanical disturbances) and therefore more robust in performance. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced.

4) The power levels of the spectral channels coupled into the output ports can be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) by way of the servo-control assembly. This spectral power-management capability as an integral part of the OADM will be particularly desirable in WDM optical networking applications.

5) The use of free-space optics provides a simple, low loss, and cost-effective construction. Moreover, the utilization of the servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during initial assembly, enabling the OADM to be simpler and more adaptable in structure, lower in cost and optical loss.

6) The underlying OADM architecture allows a multiplicity of the OADMs according to the present invention to be readily assembled (e.g., cascaded) for WDM optical networking applications.

The novel features of this invention, as well as the invention itself, will be best understood from the following drawings and detailed description.

BRIEF DESCRIPTION OF THE FIGURES

FIGS. **1A-1D** show a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention, and the modeling results demonstrating the performance of the WSR apparatus;

FIGS. **2A-2C** depict second and third embodiments of a WSR apparatus according to the present invention;

FIG. **3** shows a fourth embodiment of a WSR apparatus according to the present invention;

FIGS. **4A-4B** show schematic illustrations of two embodiments of a WSR-S apparatus comprising a WSR apparatus and a servo-control assembly, according to the present invention;

FIG. **5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention; and

FIG. **6** shows an alternative embodiment of an OADM according to the present invention.

DETAILED DESCRIPTION

In this specification and appending claims, a "spectral channel" is characterized by a distinct center wavelength and associated bandwidth. Each spectral channel may carry a unique information signal, as in WDM optical networking applications.

FIG. **1A** depicts a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention. By way of example to illustrate the general principles and the topological structure of a wavelength-separating-routing (WSR) apparatus of the present invention, the WSR apparatus **100** comprises multiple input/output ports which may be in the form of an array of fiber collimators **110**, providing an input port **110-1** and a plurality of output ports **110-2** through **110-N** ($N \geq 3$); a wavelength-separator which in one form may be a diffraction grating **101**; a beam-focuser in the form of a focusing lens **102**; and an array of channel micromirrors **103**.

In operation, a multi-wavelength optical signal emerges from the input port **110-1**. The diffraction grating **101** angularly separates the multi-wavelength optical signal into multiple spectral channels, which are in turn focused by the focusing lens **102** into a spatial array of distinct spectral spots (not shown in FIG. **1A**) in a one-to-one correspondence. The channel micromirrors **103** are positioned in accordance with the spatial array formed by the spectral spots, such that each channel micromirror receives one of the spectral channels. The channel micromirrors **103** are individually controllable and movable, e.g., pivotable (or rotatable) under analog (or continuous) control, such that, upon reflection, the spectral channels are directed into selected ones of the output ports **110-2** through **110-N** by way of the focusing lens **102** and the diffraction grating **101**. As such, each channel micromirror is assigned to a specific spectral channel, hence the name "channel micromirror". Each output port may receive any number of the reflected spectral channels.

For purposes of illustration and clarity, only a selective few (e.g., three) of the spectral channels, along with the input multi-wavelength optical signal, are graphically illustrated in FIG. **1A** and the following figures. It should be noted, however, that there can be any number of the spectral channels in a WSR apparatus of the present invention (so long as the number of spectral channels does not exceed the number of channel mirrors employed in the system). It should also be noted that the optical beams representing the spectral channels shown in FIG. **1A** and the following figures are provided for illustrative purpose only. That is, their sizes and shapes may not be drawn according to scale. For instance, the input beam and the corresponding diffracted beams generally have different cross-sectional shapes, so long as the angle of incidence upon the diffraction grating is not equal to the angle of diffraction, as is known to those skilled in the art.

In the embodiment of FIG. **1A**, it is preferable that the diffraction grating **101** and the channel micromirrors **103** are placed respectively at the first and second (i.e., the front and back) focal points (on the opposing sides) of the focusing lens **102**. Such a telecentric arrangement allows the chief rays of the focused beams to be parallel to each other and generally parallel to the optical axis. In this application, the telecentric configuration further allows the reflected spectral channels to be efficiently coupled into the respective output ports, thereby minimizing various translational walk-off effects that may otherwise arise. Moreover, the input multi-wavelength optical signal is preferably collimated and circular in cross-section. The corresponding spectral channels diffracted from the diffraction grating **101** are generally elliptical in cross-section; they may be of the same size as the input beam in one dimension and elongated in the other dimension.

It is known that the diffraction efficiency of a diffraction grating is generally polarization-dependent. That is, the diffraction efficiency of a grating in a standard mounting configuration may be considerably higher for P-polarization that is perpendicular to the groove lines on the grating than for S-polarization that is orthogonal to P-polarization, especially as the number of groove lines (per unit length) increases. To mitigate such polarization-sensitive effects, a quarter-wave plate **104** may be optically interposed between the diffraction grating **101** and the channel micromirrors **103**, and preferably placed between the diffraction grating **101** and the focusing lens **102** as is shown in FIG. **1A**. In this way, each spectral channel experiences a total of approximately 90-degree rotation in polarization upon traversing the quarter-wave plate **104** twice. (That is, if a beam of light has P-polarization when first encountering the diffraction grating, it would have predominantly (if not all) S-polarization upon the second encountering, and vice versa.) This ensures that all the spectral channels incur nearly the same amount of round-trip polarization dependent loss.

In the WSR apparatus **100** of FIG. **1A,** the diffraction grating **101**, by way of example, is oriented such that the focused spots of the spectral channels fall onto the channel micromirrors **103** in a horizontal array, as illustrated in FIG. **1B**.

Depicted in FIG. **1B** is a close-up view of the channel micromirrors **103** shown in the embodiment of FIG. **1A**. By way of example, the channel micromirrors **103** are arranged in a one-dimensional array along the **x**-axis (i.e., the horizontal direction in the figure), so as to receive the focused spots of the spatially separated spectral channels in a one-to-one correspondence. (As in the case of FIG. **1A**, only three spectral channels are illustrated, each represented by a converging beam.) Let the reflective surface of each channel micromirror lie in the **x-y** plane as defined in the figure and be movable, e.g., pivotable (or deflectable) about the **x**-axis in an analog (or continuous) manner. Each spectral channel, upon reflection, is deflected in the **y**-direction (e.g., downward) relative to its incident direction, so to be directed into one of the output ports **110-2** through **110-N** shown in FIG. **1A**.

As described above, a unique feature of the present invention is that the motion of each channel micromirror is individually and continuously controllable, such that its position, e.g., pivoting angle, can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port. To illustrate this capability, FIG. **1C** shows a plot of coupling efficiency as a function of a channel micromirror's pivoting angle θ, provided by a ray-tracing model of a WSR apparatus in the embodiment of FIG. **1A**. As used herein, the coupling efficiency for a spectral channel is defined as the ratio of the amount of optical power coupled into the fiber core in an output port to the total amount of optical power incident upon the entrance surface of the fiber (associated with the fiber collimator serving as the output port). In the ray-tracing model, the input optical signal is incident upon a diffraction grating with 700 lines per millimeter at a grazing angle of 85 degrees, where the grating is blazed to optimize the diffraction efficiency for the "–1" order. The focusing lens has a focal length of 100 mm. Each output port is provided by a quarter-pitch GRIN lens (2 mm in diameter) coupled to an optical fiber (see FIG. **1D**). As displayed in FIG. **1C**, the coupling efficiency varies with the pivoting angle θ, and it requires about a 0.2-degree change in θ for the coupling efficiency to become practically negligible in this exemplary case. As such, each spectral channel may practically acquire any coupling efficiency value by way of controlling the pivoting angle of its corresponding channel micromirror. This is also to say that variable optical attenuation at the granularity of a single wavelength can be obtained in a WSR apparatus of the present invention. FIG. **1D** provides ray-tracing illustrations of two extreme points on the coupling efficiency vs. θ curve of FIG. **1C**: on-axis coupling corresponding to θ = 0, where the coupling efficiency is maximum; and off-axis coupling corresponding to θ = 0.2 degrees, where the representative collimated beam (representing an exemplary spectral channel) undergoes a significant translational walk-off and renders the coupling efficiency practically negligible. All in all, the exemplary modeling results thus described demonstrate the unique capabilities of the WSR apparatus of the present invention.

FIG. **1A** provides one of many embodiments of a WSR apparatus according to the present invention. In general, the wavelength-separator is a wavelength-separating means that may be a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a dispersing prism, or other types of spectral-separating means known in the art. The beam-focuser may be a focusing lens, an assembly of lenses, or other beam-focusing means known in the art. The focusing function may also be accomplished by using a curved diffraction grating as the wavelength-separator. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting elements known in the art. And each micromirror may be pivoted about one or two axes. What is important is that the pivoting (or rotational) motion of each channel micromirror be individually controllable in an analog manner, whereby the pivoting angle can be continuously adjusted so as to enable the channel micromirror to scan a spectral channel across all possible output ports. The underlying fabrication techniques for micromachined mirrors and associated actuation mechanisms are well documented in the art, see U.S. Patent 5,629,790 for example. Moreover, a fiber collimator is typically in the form of a collimating lens (such as a GRIN lens) and a ferrule-mounted fiber packaged together in a mechanically rigid stainless steel (or glass) tube. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional array, a two-dimensional array, or other desired spatial pattern. For instance, they may be conveniently mounted in a linear array along a V-groove fabricated on a substrate made of silicon, plastic, or ceramic, as commonly practiced in the art. It should be noted, however, that the input port and the output ports need not necessarily be in close spatial proximity with each other, such as in an array configuration (although a close packing would reduce the rotational range required for each channel micromirror). Those skilled in the art will know how to design a WSR apparatus according to the present invention, to best suit a given application.

A WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, for adjusting the alignment of the input multi-wavelength optical signal and facilitating the coupling of the spectral channels into the respective output ports, as shown in FIGS. **2A-2B** and **3**.

Depicted in FIG. **2A** is a second embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **200** is built upon and hence shares a number of the elements used in the embodiment of FIG. **1A**, as identified by those labeled with identical numerals. Moreover, a one-dimensional array **220** of collimator-alignment mirrors

220-1 through **220-N** is optically interposed between the diffraction grating **101** and the fiber collimator array **110**. The collimator-alignment mirror **220-1** is designated to correspond with the input port **110-1**, for adjusting the alignment of the input multi-wavelength optical signal and therefore ensuring that the spectral channels impinge onto the corresponding channel micromirrors. The collimator-alignment mirrors **220-2** through **220-N** are designated to the output ports **110-2** through **110-N** in a one-to-one correspondence, serving to provide angular control of the collimated beams of the reflected spectral channels and thereby facilitating the coupling of the spectral channels into the respective output ports according to desired coupling efficiencies. Each collimator-alignment mirror may be rotatable about one axis, or two axes.

The embodiment of FIG. **2A** is attractive in applications where the fiber collimators (serving as the input and output ports) are desired to be placed in close proximity to the collimator-alignment mirror array **220**. To best facilitate the coupling of the spectral channels into the output ports, arrays of imaging lenses may be implemented between the collimator-alignment mirror array **220** and the fiber collimator array **110**, as depicted in FIG. **2B**. By way of example, WSR apparatus **250** of FIG. **2B** is built upon and hence shares many of the elements used in the embodiment of FIG. **2A**, as identified by those labeled with identical numerals. Additionally, first and second arrays **260, 270** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the collimator-alignment mirror array **220** and the fiber collimator array **110**. The dashed box **280** shown in FIG. **2C** provides a top view of such a telecentric arrangement. In this case, the imaging lenses in the first and second arrays **260, 270** all have the same focal length f. The collimator-alignment mirrors **220-1** through **220-N** are placed at the respective first (or front) focal points of the imaging lenses in the first array **260**. Likewise, the fiber collimators **110-1** through **110-N** are placed at the respective second (or back) focal points of the imaging lenses in the second array **270**. And the separation between the first and second arrays **260, 270** of imaging lenses is 2f. In this way, the collimator-alignment mirrors **220-1** through **220-N** are effectively imaged onto the respective entrance surfaces (i.e., the front focal planes) of the GRIN lenses in the corresponding fiber collimators **110-1** through **110-N**. Such a telecentric imaging system substantially eliminates translational walk-off of the collimated beams at the output ports that may otherwise occur as the mirror angles change.

FIG. **3** shows a fourth embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **300** is built upon and hence shares a number of the elements used in the embodiment of FIG. **2B**, as identified by those labeled with identical numerals. In this case, the one-dimensional fiber collimator array **110** of FIG. **2B** is replaced by a two-dimensional array **350** of fiber collimators, providing for an input-port and a plurality of output ports. Accordingly, the one-dimensional collimator-alignment mirror array **220** of FIG. **2B** is replaced by a two-dimensional array **320** of collimator-alignment mirrors, and first and second one-dimensional arrays **260**, **270** of imaging lenses of FIG. **2B** are likewise replaced by first and second two-dimensional arrays **360**, **370** of imagining lenses respectively. As in the case of the embodiment of FIG. **2B**, the first and second two-dimensional arrays **360**, **370** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the two-dimensional collimator-alignment mirror array **320** and the two-dimensional fiber collimator array **350**. The channel micromirrors **103** must be pivotable biaxially in this case (in order to direct its corresponding spectral channel to any one of the output ports). As such, the WSR apparatus **300** is equipped to support a greater number of the output ports.

In addition to facilitating the coupling of the spectral channels into the respective output ports as described above, the collimator-alignment mirrors in the above embodiments also serve to compensate for misalignment (e.g., due to fabrication and assembly errors) in the fiber collimators that provide for the input and output ports. For instance, relative misalignment between the fiber cores and their respective collimating lenses in the fiber collimators can lead to pointing errors in the collimated beams, which may be corrected for by the collimator-alignment mirrors. For these reasons, the collimator-alignment mirrors are preferably rotatable about two axes. They may be silicon micromachined mirrors, for fast rotational speeds. They may also be other types of mirrors or beam-deflecting elements known in the art.

To optimize the coupling of the spectral channels into the output ports and further maintain the optimal optical alignment against environmental effects such as temperature variations and mechanical instabilities over the course of operation, a WSR apparatus of the present invention may incorporate a servo-control assembly, for providing dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis. A WSR apparatus incorporating a servo-control assembly is termed a WSR-S apparatus, thereinafter in this specification.

FIG. **4A** depicts a schematic illustration of a first embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **400** comprises a WSR apparatus **410** and a servo-control assembly **440**. The WSR **410** may be in the embodiment of FIG. **1A**, or any other embodiment in accordance with the present invention. The servo-control assembly **440** includes a spectral monitor **460**, for monitoring the power levels of the spectral channels coupled into the output ports **420-1** through **420-N** of the WSR apparatus **410**. By way of example, the spectral monitor **460** is coupled to the output ports **420-1** through **420-N** by way of fiber-optic couplers **420-1-C** through **420-N-C**, wherein each fiber-optic coupler serves to tap off a predetermined fraction of the optical signal in the corresponding output port. The servo-control assembly **440** further includes a processing unit **470**, in communication with the spectral monitor **460** and the channel micromirrors **430** of the WSR apparatus **410**. The processing unit **470** uses the power measurements from the spectral monitor **460** to provide feedback control of the channel micromirrors **430** on an individual basis, so as to maintain a desired coupling efficiency for each spectral channel into a selected output port. As such, the servo-control assembly **440** provides dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis and thereby manages the power levels of the spectral channels coupled into the output ports. The power levels of the spectral channels in the output ports may be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) in the present invention. Such a spectral power-management capability is essential in WDM optical networking applications, as discussed above.

FIG. **4B** depicts a schematic illustration of a second embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **450** comprises a WSR apparatus **480** and a servo-control assembly **490**. In addition to the channel micromirrors **430** (and other elements identified by the same numerals as those used in FIG. **4A**), the WSR apparatus **480** further includes a plurality of collimator-alignment mirrors **485**, and may be configured according to the embodiment of FIG. **2A, 2B, 3**, or any other embodiment in accordance with the present invention. By way of example, the servo-control assembly **490** includes the spectral monitor **460** as described in the embodiment of FIG. **4A**, and a processing unit **495**. In this case, the processing unit **495** is in communication with the channel micromirrors **430** and the collimator-alignment mirrors **485** of the WSR apparatus **480**, as well as the spectral monitor **460**. The processing unit **495** uses the power measurements from the spectral monitor **460** to provide dynamic control of the channel micromirrors **430** along with the collimator-alignment mirrors **485**, so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values.

In the embodiment of FIG. **4A** or **4B**, the spectral monitor **460** may be one of spectral power monitoring devices known in the art that is capable of detecting the power levels of spectral components in a multi-wavelength optical signal. Such devices are typically in the form of a wavelength-separating means (e.g., a diffraction grating) that spatially separates a multi-wavelength optical signal by wavelength into constituent spectral components, and one or more optical sensors (e.g., an array of photodiodes) that are configured such to detect the power levels of these spectral components. The processing unit **470** in FIG. **4A** (or the processing unit **495** in FIG. **4B**) typically includes electrical circuits and signal processing programs for processing the power measurements received from the spectral monitor **460** and generating appropriate control signals to be applied to the channel micromirrors **430** (and the collimator-alignment mirrors **485** in the case of FIG. **4B**), so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values. The electronic circuitry and the associated signal processing algorithm/software for such processing unit in a servo-control system are known in the art. A skilled artisan will know how to implement a suitable spectral monitor along with an appropriate processing unit to provide a servo-control assembly in a WSP-S apparatus according to the present invention, for a given application.

The incorporation of a servo-control assembly provides additional advantages of effectively relaxing the requisite fabrication tolerances and the precision of optical alignment during initial assembly of a WSR apparatus of the present invention, and further enabling the system to correct for shift in the alignment over the course of operation. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced. As such, the WSR-S apparatus thus constructed is simpler and more adaptable in structure, more robust in performance, and lower in cost and optical loss. Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices and utilized in many applications.

For instance, by directing the spectral channels into the output ports in a one-channel-per-port fashion and coupling the output ports of a WSR-S (or WSR) apparatus to an array of optical sensors (e.g., photodiodes), or a single optical sensor that is capable of scanning across the output ports, a dynamic and versatile spectral power monitor (or channel analyzer) is provided, which would be highly desired in WDM optical networking applications. Moreover, a novel class of optical add-drop multiplexers (OADMs) may be built upon the WSR-S (or WSR) apparatus of the present invention, as exemplified in the following embodiments.

FIG. **5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **500** comprises a WSR-S (or WSR) apparatus **510** and an optical combiner **550**. An input port **520** of the WSR-S apparatus **510** transmits a multi-wavelength optical signal. The constituent spectral channels are subsequently separated and routed into a plurality of output ports, including a pass-through port **530** and one or more drop ports **540-1** through **540-N** ($N \geq 1$). The pass-through port **530** may receive any number of the spectral channels (i.e., the pass-through spectral channels). Each drop port may also receive any number of the spectral channels (i.e., the drop spectral channels). The pass-through port **530** is optically coupled to the optical combiner **550**, which serves to combine the pass-through spectral channels with one or more add spectral channels provided by one or more add ports **560-1** through **560-M** ($M \geq 1$). The combined optical signal is then routed into an existing port **570**, providing an output multi-wavelength optical signal.

In the above embodiment, the optical combiner **550** may be a K×1 ($K \geq 2$) broadband fiber-optic coupler, wherein there are K input-ends and one output-end. The pass-through spectral channels and the add spectral channels are fed into the K input-ends (e.g., in a one-to-one correspondence) and the combined optical signal exits from the output-end of the K×1 fiber-optic coupler as the output multi-wavelength optical signal of the system. Such a multiple-input coupler also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the OADM **500**. If the power levels of the spectral channels in the output multi-wavelength optical signal are desired to be actively managed, such as being equalized at a predetermined value, two spectral monitors may be utilized. As a way of example, the first spectral monitor may receive optical signals tapped off from the pass-through port **530** and the drop ports **540-1** through **540-N** (e.g., by way of fiber-optic couplers as depicted in FIG. **4A** or **4B**). The second spectral monitor receives optical signals tapped off from the exiting port **570**. A servo-control system may be constructed accordingly for monitoring and controlling the pass-through, drop and add spectral channels. As such, the embodiment of FIG. **5** provides a versatile optical add-drop multiplexer in a simple and low-cost assembly, while providing multiple physically separate drop/add ports in a dynamically reconfigurable fashion.

FIG. **6** depicts an alternative embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **600** comprises a first WSR-S apparatus **610** optically coupled to a second WSR-S apparatus **650**. Each WSR-S apparatus may be in the embodiment of FIG. **4A** or **4B**. (A WSR apparatus of the embodiment of FIG. **1A**, **2A**, **2B**, or **3** may be alternatively implemented.) The first WSR-S apparatus **610** includes an input port **620**, a pass-through port **630**, and one or more drop ports **640-1** through **640-N** ($N \geq 1$). The pass-through spectral channels from the pass-through port **630** are further coupled to the second WSR-S apparatus **650**, along with one or more add spectral channels emerging from add ports **660-1** through **660-M** ($M \geq 1$). In this exemplary case, the pass-through port **630** and the add ports **660-1** through **660-M** constitute the input ports for the second WSR-S apparatus **650**. By way of its constituent wavelength-separator (e.g., a diffraction grating) and channel micromirrors (not shown in FIG. **6**), the second WSR-S apparatus **650** serves to multiplex the pass-through spectral channels and the add spectral channels, and route the multiplexed optical signal into an exiting port **770** to provide an output signal of the system.

In the embodiment of FIG. **6**, one WSR-S apparatus (e.g., the first WSR-S apparatus **610**) effectively performs dynamic drop function, whereas the other WSR-S apparatus (e.g., the second WSR-S apparatus **650**) carries out dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped (other than those imposed by the overall communication system). Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of cascaded WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions. Additionally, the OADM of FIG. **6** may be operated in reverse direction, by using the input ports as the output ports, the drop ports as the add ports, and vice versa.

Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Those skilled in the art will also appreciate that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention as defined in the appended claims. Accordingly, a skilled artisan can design an OADM in accordance with the principles of the present invention, to best suit a given application.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention. Accordingly, the scope of the present invention should be determined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A wavelength-separating-routing apparatus, comprising:
   a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;
   b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;
   c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and
   d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports.

2. The wavelength-separating-routing apparatus of claim 1 further comprising a servo-control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

3. The wavelength-separating-routing apparatus of claim 2 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

4. The wavelength-separating-routing apparatus of claim 3 wherein said servo-control assembly maintains said power levels at a predetermined value.

5. The wavelength-separating-routing apparatus of claim 1 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

6. The wavelength-separating-routing apparatus of claim 5 wherein each collimator-alignment mirror is rotatable about one axis.

7. The wavelength-separating-routing apparatus of claim 5 wherein each collimator-alignment mirror is rotatable about two axes.

8. The wavelength-separating-routing apparatus of claim 5 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

9. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is continuously pivotable about one axis.

10. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is pivotable about two axes.

11. The wavelength-separating-routing apparatus of claim 10 wherein said fiber collimators are arranged in a two-dimensional array.

12. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is a silicon micromachined mirror.

13. The wavelength-separating-routing apparatus of claim 1 wherein said fiber collimators are arranged in a one-dimensional array.

14. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises a focusing lens having first and second focal points.

15. The wavelength-separating-routing apparatus of claim 14 wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points of said focusing lens.

16. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises an assembly of lenses.

17. The wavelength-separating-routing apparatus of claim 1 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

18. The wavelength-separating-routing apparatus of claim 1 further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

19. The wavelength-separating-routing apparatus of claim 1 wherein each output port carries a single one of said spectral channels.

20. The wavelength-separating-routing apparatus of claim 19 further comprising one or more optical sensors, optically coupled to said output ports.

21. A servo-based optical apparatus comprising:

a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a servo-control assembly, in communication with said channel micromirrors and said output ports, for maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

22. The servo-based optical apparatus of claim 21 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

23. The servo-based optical apparatus of claim 22 wherein said servo-control assembly maintains said power levels at a predetermined value.

24. The servo-based optical apparatus of claim 21 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

25. The servo-based optical apparatus of claim 24 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

26. The servo-based optical apparatus of claim 24 wherein each collimator-alignment mirror is rotatable about at least one axis.

27. The servo-based optical apparatus of claim 21 wherein each channel micromirror is continuously pivotable about at least one axis.

28. The servo-based optical apparatus of claim 21 wherein each channel micromirror is a silicon micromachined mirror.

29. The servo-based optical apparatus of claim 21 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

30. The servo-based optical apparatus of claim 21 wherein said beam-focuser comprises one or more lenses.

31. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a one-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

32. The optical apparatus of claim 31 further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

33. The optical apparatus of claim 32 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

34. The optical apparatus of claim 31 wherein each channel micromirror is continuously pivotable about at least one axis.

35. The optical apparatus of claim 31 wherein each collimator-alignment mirror is rotatable about at least one axis.

36. The optical apparatus of claim 31 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

37. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a two-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

38. The optical apparatus of claim 37 further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

39. The optical apparatus of claim 38 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

40. The optical apparatus of claim 37 wherein each collimator-alignment mirror is rotatable about at least one axis.

41. The optical apparatus of claim 37 wherein each channel micromirror is continuously pivotable about at least one axis.

42. The optical apparatus of claim 41 wherein each channel micromirrors is pivotable about two axes, and wherein said fiber collimators are arranged in a two-dimensional array.

43. The optical apparatus of claim 37 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

44. An optical system comprising a wavelength-separating-routing apparatus, wherein said wavelength-separating-routing apparatus includes:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports including a pass-through port and one or more drop ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously pivotable to reflect said spectral channels into selected ones of said output ports, whereby said pass-through port receives a subset of said spectral channels.

45. The optical system of claim 44 further comprising a servo-control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

46. The optical system of claim 45 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

47. The optical system of claim 44 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

48. The optical system of claim 47 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

49. The optical system of claim 47 wherein each collimator-alignment mirror is rotatable about at least one axis.

50. The optical system of claim 44 wherein each channel micromirror is pivotable about at least one axis.

51. The optical system of claim 44 wherein each channel micromirror is a silicon micromachined mirror.

52. The optical system of claim 44 wherein said beam-focuser comprises a focusing lens having first and second focal points, and wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points.

53. The optical system of claim 44 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

54. The optical system of claim 44 further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

55. The optical system of claim 44 further comprising an auxiliary wavelength-separating-routing apparatus, including:

a) multiple auxiliary fiber collimators, providing a plurality of auxiliary input ports and an exiting port;

b) an auxiliary wavelength-separator;

c) an auxiliary beam-focuser; and

d) a spatial array of auxiliary channel micromirrors;

wherein said subset of said spectral channels in said pass-through port and one or more add spectral channels are directed into said auxiliary input ports, and multiplexed into an output optical signal directed into said exiting port by way of said auxiliary wavelength-separator, said auxiliary beam-focuser and said auxiliary channel micromirrors.

56. The optical system of claim 55 wherein said auxiliary channel micromirrors are individually pivotable.

57. The optical system of claim 55 wherein each auxiliary channel micromirror is pivotable continuously about at least one axis.

58. The optical system of claim 55 wherein each auxiliary channel micromirror is a silicon micromachined mirror.

59. The optical system of claim 55 wherein said auxiliary wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

60. The optical system of claim 55 wherein said pass-through port constitutes one of said auxiliary input ports.

61. A method of performing dynamic wavelength separating and routing, comprising:

a) receiving a multi-wavelength optical signal from an input port;

b) separating said multi-wavelength optical signal into multiple spectral channels;

c) focusing said spectral channels onto a spatial array of corresponding beam-deflecting elements, whereby each beam-deflecting element receives one of said spectral channels; and

d) dynamically and continuously controlling said beam-deflecting elements, thereby directing said spectral channels into a plurality of output ports.

62. The method of claim 61 further comprising the step of providing feedback control of said beam-deflecting elements, thereby maintaining a predetermining coupling of each spectral channel directed into one of said output ports.

63. The method of claim 62 further comprising the step of maintaining power levels of said spectral channels directed into said output ports at a predetermining value.

64. The method of claim 61 wherein each spectral channel is directed into a separate output port.

65. The method of claim 61 wherein a subset of said spectral channels is directed into one of said output ports, thereby providing one or more pass-through spectral channels.

66. The method of claim 65 further comprising the step of multiplexing said pass-through spectral channels with one or more add spectral channels, so as to provide an output optical signal.

67. The method of claim 61 wherein said beam-deflecting elements comprise an array of silicon micromachined mirrors.

DECLARATION AND POWER OF ATTORNEY

DECLARATION:

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe, I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES:**

_X_ is attached hereto.

__ was filed as United States Application
Serial No. __________ on
and was amended on ______________________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) on which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:			
Country (If PCT, indicate PCT)	**Application Number**	**Date Filed**	**Priority Claimed (Yes/No)**

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:					
U.S. APPLICATIONS			STATUS (check one)		
U.S. APPLICATION NUMBER	U.S. FILING DATE		PATENTED	PENDING	ABANDONED
60/277,217	3/19/2001			X	
PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NUMBERS ASSIGNED (if any)			

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) with full power of substitution to act exclusively to prosecute this application and transact all business in the Patent and Trademark Office connected there with: Barry N. Young (Reg. No. 27,744); Timothy W. Lohse (Reg. No. 35,255); Stephen E. Reiter (Reg. No. 31,192); Steven R. Sprinkle (Reg. No. 40,825); Terrance A. Meador (Reg. No. 30,298); Ramsey R. Stewart (Reg. No. 38,322); June M. Learn (Reg. No. 31,238); John Oskorep (Reg. No. 41,234); Timothy N. Ellis (Reg. No. 41,734); William G. Goldman (Reg. No. 42,590); Sheila Kirschenbaum (Reg. No. 44,835); Travis L. Dodd (Reg. No. 42,491); Charles D. Gavrilovich, Jr. (Reg. No. 41,031); Gerald W. Maliszewski (Reg. No. 38054); Hayward A. Verdun (Reg. No. 43,223); Armando Pastrana, Jr. (Reg. No. 44,997); Richard M. Goldman (Reg. No. 25,585); Lisa A. Haile (Reg. No. 38,347); Sal Lim (Reg. No. 45,706); Joseph R. Baker, Jr. (Reg. No. 40,900); Richard J. Imbra (Reg. No. 37,643); Mark L. Berrier (Reg. No. 35,066); Mark M. Takahashi (Reg. No. 38,631); James P. Cleary (Reg. No. 45,843); Karl A. Limbach (Reg. No. 18689); Gerald T. Sekimura (Reg. No. 30,103); Kyla L. Harriel (Reg. No. 41,816); Eric N. Hoover (Reg. No. 37,355); George C. Limbach (Reg. No. 19,305); Ronald L. Yin (Reg. No. 27,607); Alan A. Limbach (Reg. No. 39,749); Edward B. Weller (Reg. No. 37,468); Jian Ma (Reg. No. 48,088)
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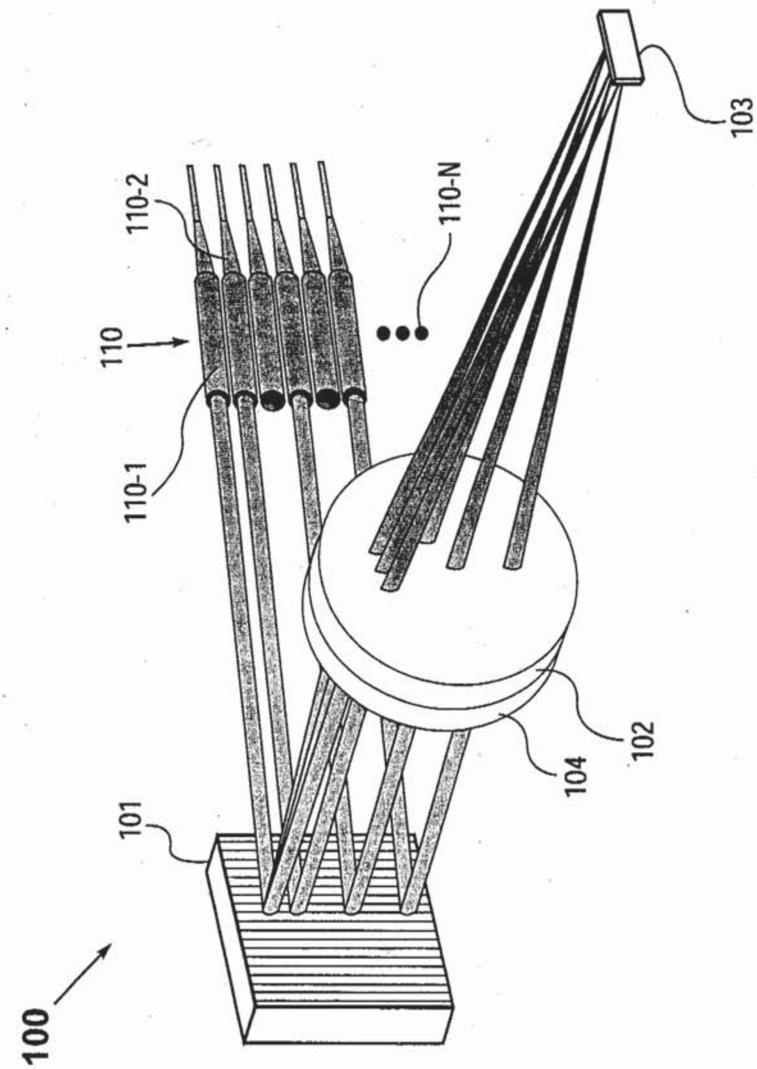

Fig. 1A

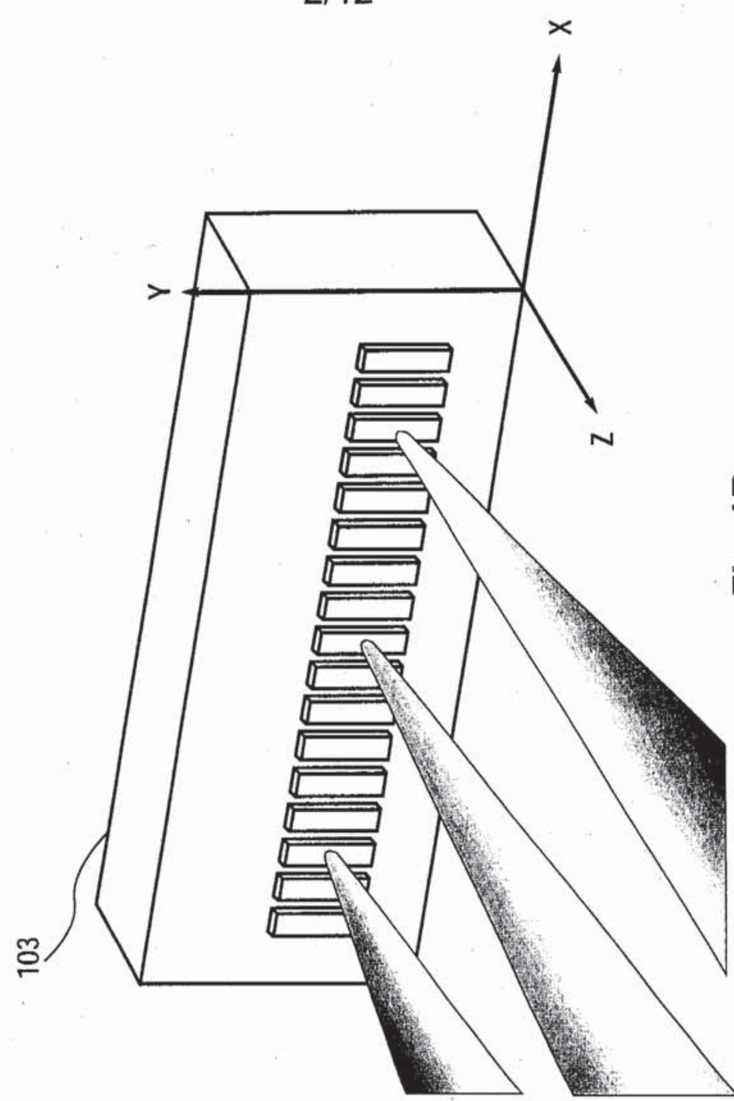

Fig. 1B

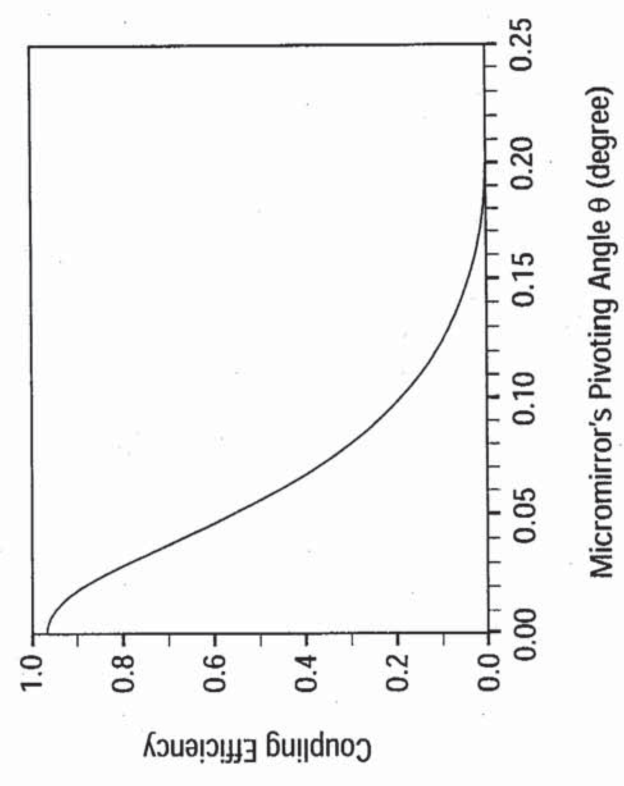
Coupling Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
Micromirror's Pivoting Angle θ (degree)

Fig. 1C

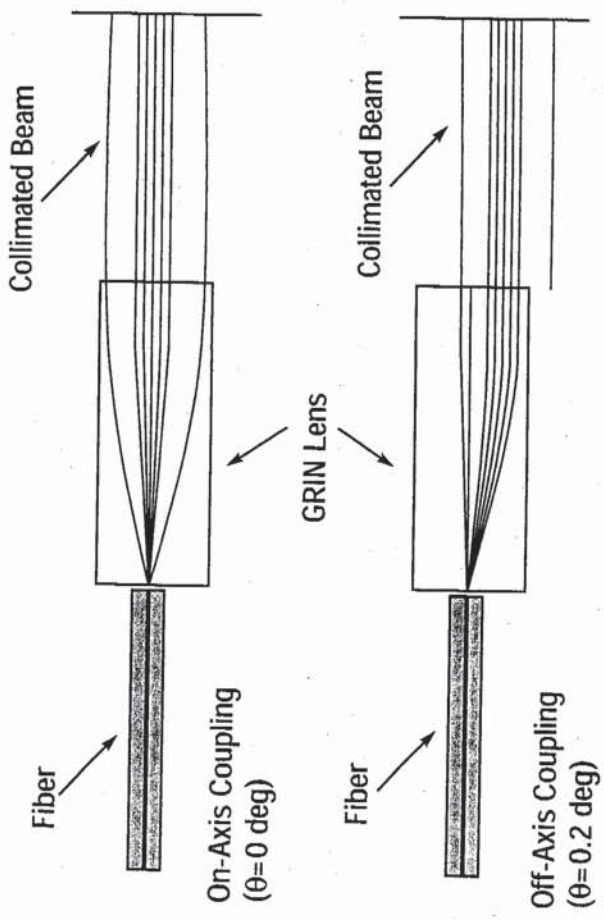
Collimated Beam
GRIN Lens
Fiber
On-Axis Coupling
(θ=0 deg)
Collimated Beam
Fiber
Off-Axis Coupling
(θ=0.2 deg)

Fig. 1D

PRINT OF DRAWING
AS ORIGINALLY FILED

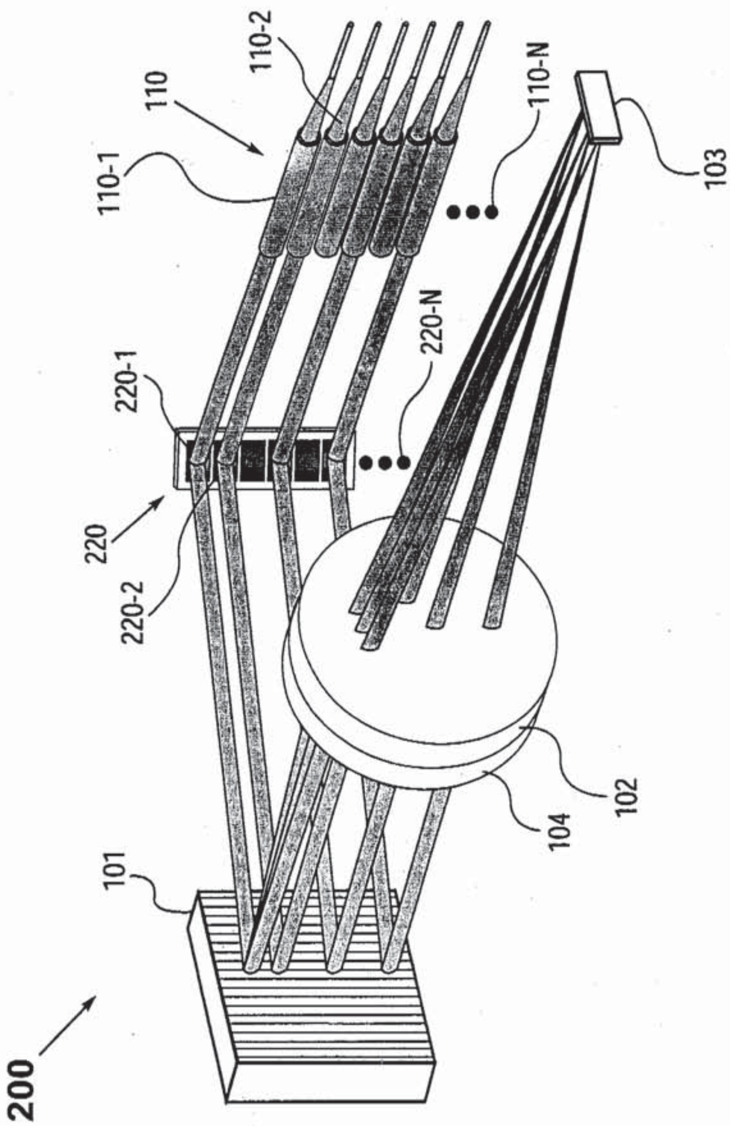

Fig. 2A

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AS ORIGINALLY FIL

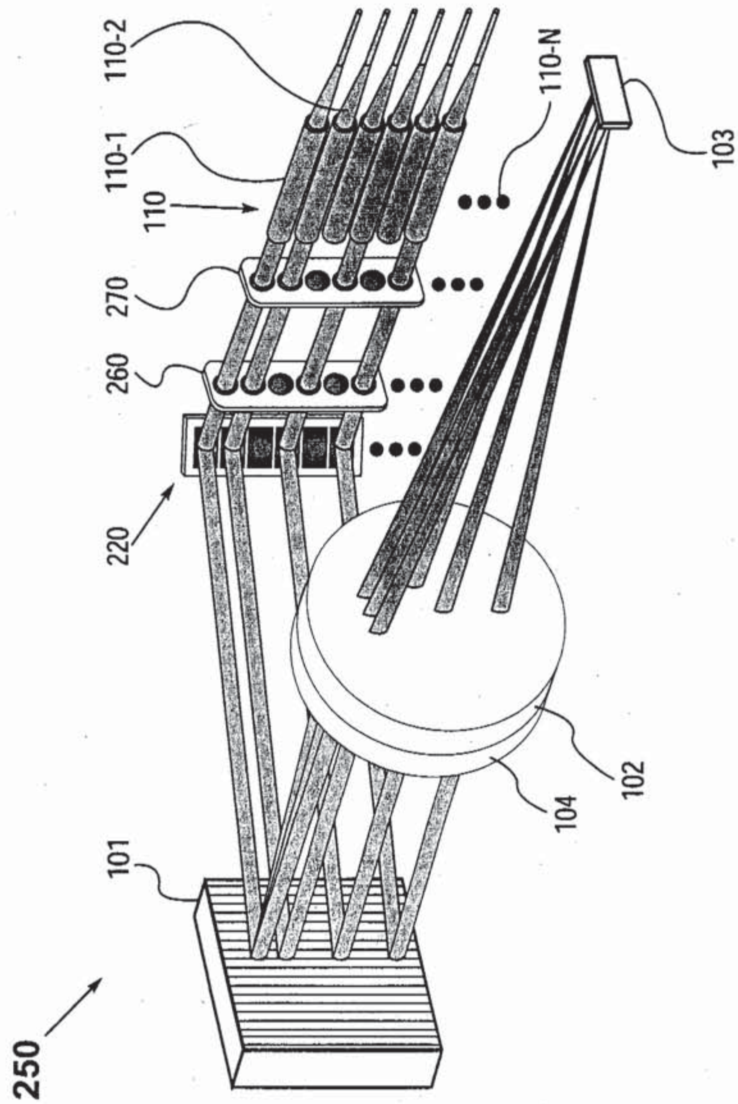

Fig. 2B

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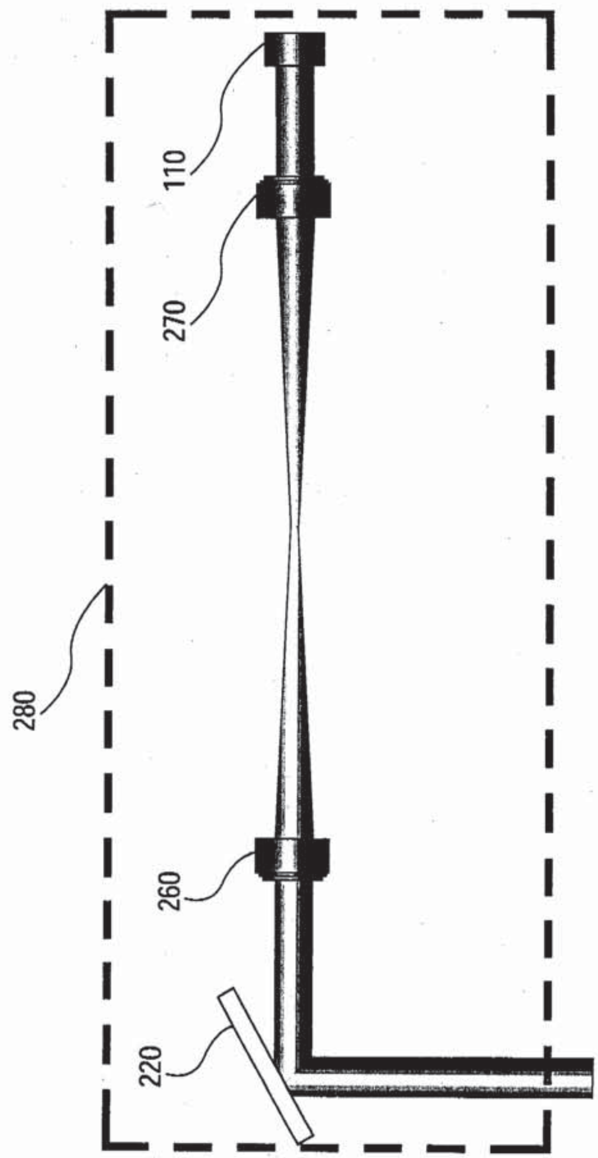

Fig. 2C

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AS ORIGINALLY FILED

8/12

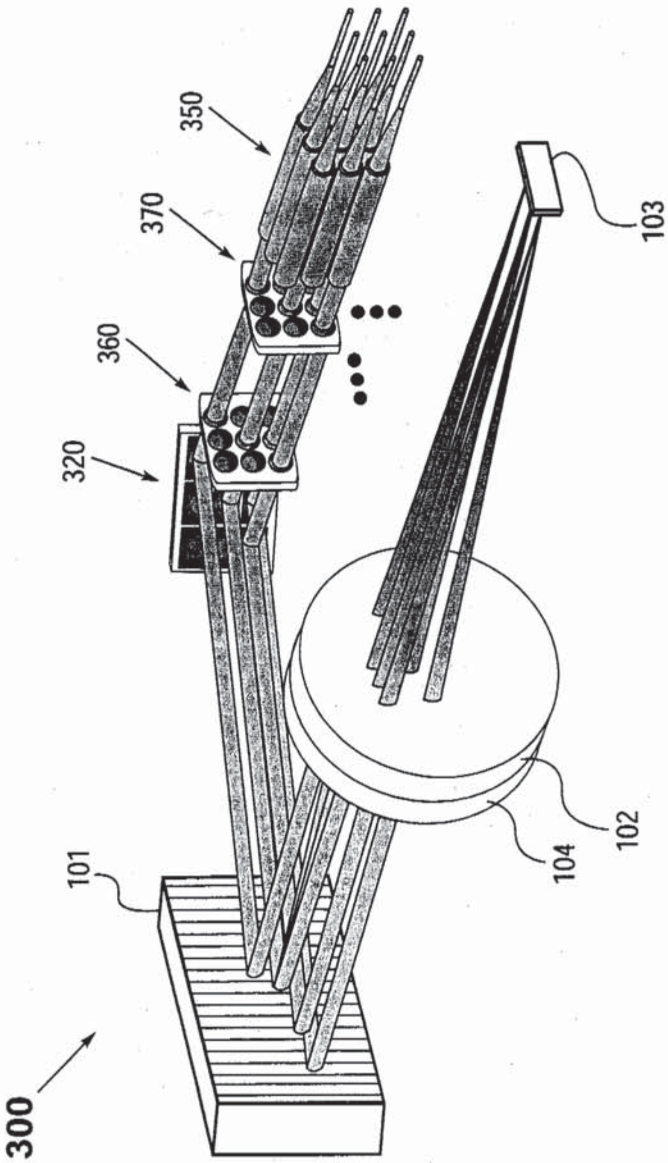

Fig. 3

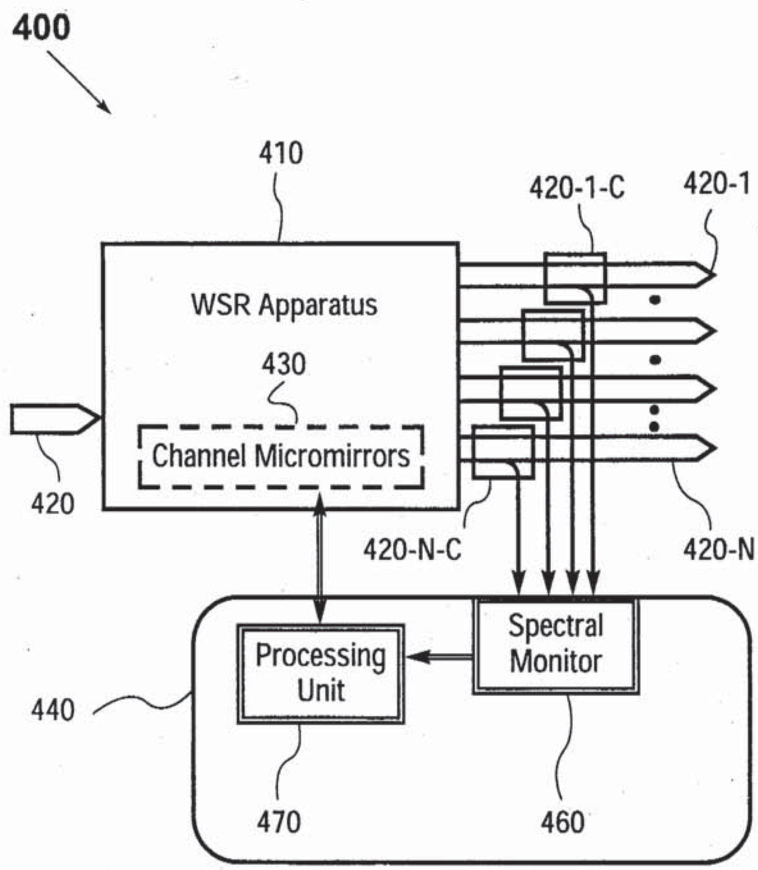
400
410
420-1-C
420-1
WSR Apparatus
430
Channel Micromirrors
420
420-N-C
420-N
Processing Unit
Spectral Monitor
440
470
460

Fig. 4A

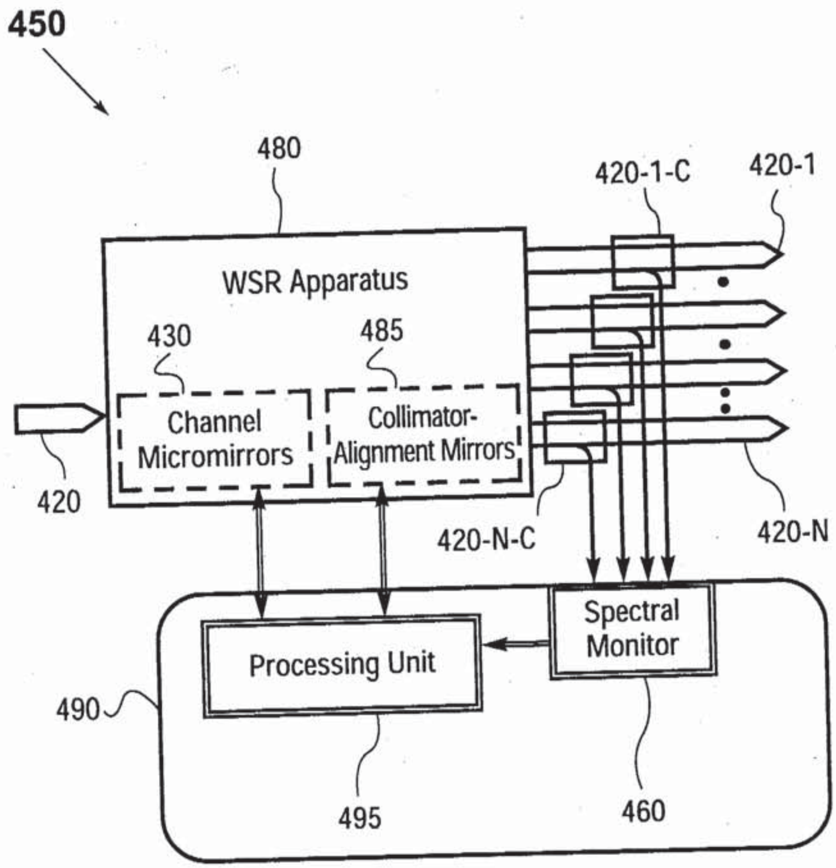
450
480
420-1-C
420-1
WSR Apparatus
430
485
Channel Micromirrors
Collimator-Alignment Mirrors
420
420-N-C
420-N
Spectral Monitor
Processing Unit
490
495
460

Fig. 4B

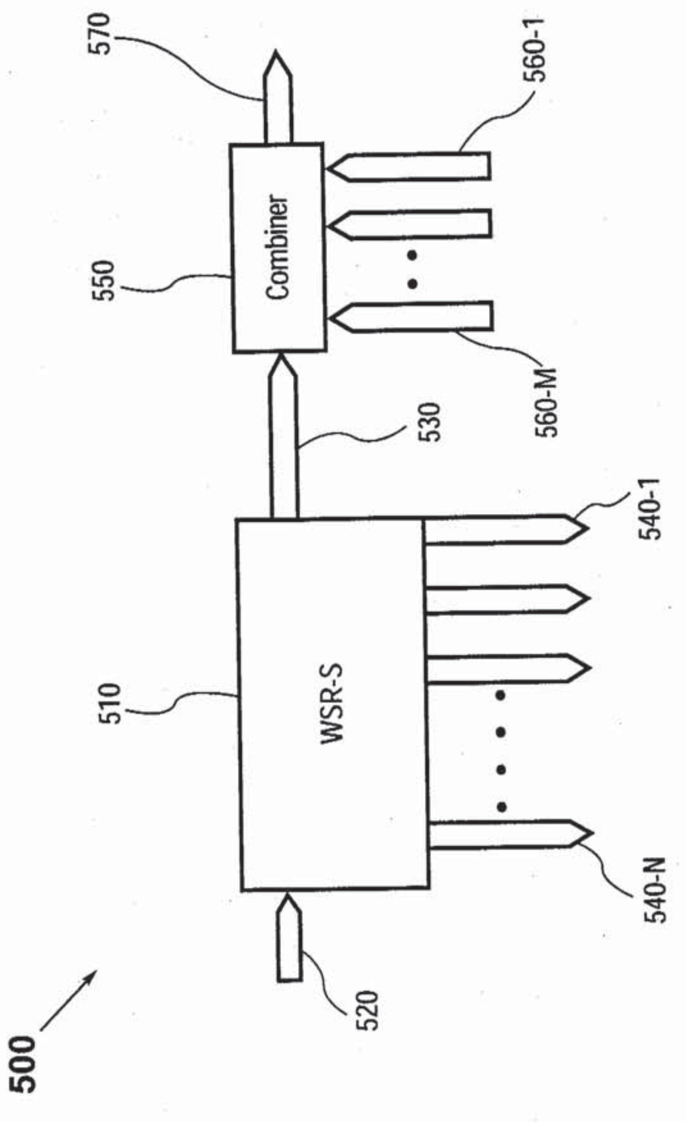

Fig. 5

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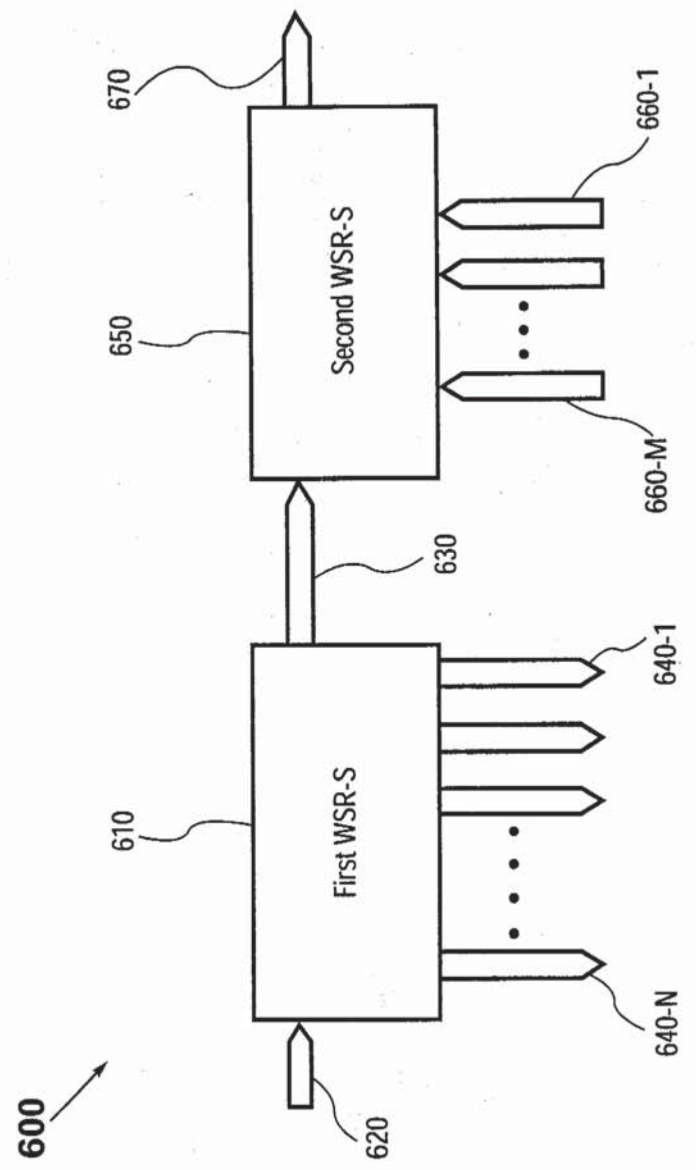
600
610
First WSR-S
620
630
640-1
640-N
650
Second WSR-S
660-1
660-M
670

Fig. 6

Notice of Allowability	Application No.	Applicant(s)	
	09/938,426	WILDE, JEFFREY P.	
	Examiner	Art Unit	
	Hung N Ngo	2874	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☐ This communication is responsive to _____.
2. ☒ The allowed claim(s) is/are *1-67*.
3. ☒ The drawings filed on *23 August 2001* are accepted by the Examiner.
4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
   a) ☐ All b) ☐ Some* c) ☐ None of the:
   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____.
5. ☒ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).
   (a) ☐ The translation of the foreign language provisional application has been received.
6. ☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application. **THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.**

7. ☐ A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.

8. ☐ CORRECTED DRAWINGS must be submitted.
   (a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached
   1) ☐ hereto or 2) ☐ to Paper No. ____.
   (b) ☐ including changes required by the proposed drawing correction filed _____, which has been approved by the Examiner.
   (c) ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No. _____.

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the top margin (not the back) of each sheet. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftsperson.

9. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1☒ Notice of References Cited (PTO-892)
3☐ Notice of Draftperson's Patent Drawing Review (PTO-948)
5☐ Information Disclosure Statements (PTO-1449), Paper No. ____.
7☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material

2☐ Notice of Informal Patent Application (PTO-152)
4☐ Interview Summary (PTO-413), Paper No.____ .
6☐ Examiner's Amendment/Comment
8☐ Examiner's Statement of Reasons for Allowance
9☐ Other

Hung N Ngo
Primary Examiner
Art Unit: 2874

Notice of References Cited	Application/Control No. 09/938,426	Applicant(s)/Patent Under Reexamination WILDE, JEFFREY P.	
	Examiner Hung N Ngo	Art Unit 2874	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
	A	US-6,263,135	07-2001	Wade, Robert Kent	359/130
	B	US-6,289,155	09-2001	Wade, Robert Kent	385/33
	C	US-6,418,250	07-2002	Corbosiero et al.	359/124
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231
www.uspto.gov

C7

NOTICE OF ALLOWANCE AND FEE(S) DUE

7590 04/21/2003

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

EXAMINER	
HEALY, BRIAN	
ART UNIT	CLASS-SUBCLASS
2874	385-024000

DATE MAILED: 04/21/2003

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

TITLE OF INVENTION: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1300	$300	$1600	07/21/2003

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE REFLECTS A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE APPLIED IN THIS APPLICATION. THE PTOL-85B (OR AN EQUIVALENT) MUST BE RETURNED WITHIN THIS PERIOD EVEN IF NO FEE IS DUE OR THE APPLICATION WILL BE REGARDED AS ABANDONED.

HOW TO REPLY TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

A. If the status is the same, pay the TOTAL FEE(S) DUE shown above.

B. If the status is changed, pay the PUBLICATION FEE (if required) and twice the amount of the ISSUE FEE shown above and notify the United States Patent and Trademark Office of the change in status, or

If the SMALL ENTITY is shown as NO:

A. Pay TOTAL FEE(S) DUE shown above, or

B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check the box below and enclose the PUBLICATION FEE and 1/2 the ISSUE FEE shown above.

☐ Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

II. PART B - FEE(S) TRANSMITTAL should be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). Even if the fee(s) have already been paid, Part B - Fee(s) Transmittal should be completed and returned. If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Box ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PTOL-85 (REV. 04-02) Approved for use through 01/31/2004.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail Box ISSUE FEE
Commissioner for Patents
Washington, D.C. 20231
Fax (703)746-4000

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 4 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Legibly mark-up with any corrections or use Block 1)

7590 04/21/2003

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Box Issue Fee address above, or being facsimile transmitted to the USPTO, on the date indicated below.

(Depositor's name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

TITLE OF INVENTION: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1300	$300	$1600	07/21/2003

EXAMINER	ART UNIT	CLASS-SUBCLASS
HEALY, BRIAN	2874	385-024000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 ____________

2 ____________

3 ____________

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the USPTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) ❑ individual ❑ corporation or other private group entity ❑ government

4a. The following fee(s) are enclosed:

❑ Issue Fee

❑ Publication Fee

❑ Advance Order - # of Copies ____________

4b. Payment of Fee(s):

❑ A check in the amount of the fee(s) is enclosed.

❑ Payment by credit card. Form PTO-2038 is attached.

❑ The Commissioner is hereby authorized by charge the required fee(s), or credit any overpayment, to Deposit Account Number ____________ (enclose an extra copy of this form).

Commissioner for Patents is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above.

(Authorized Signature) (Date)

NOTE: The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

This collection of information is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Washington, D.C. 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, Washington, DC 20231.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMIT THIS FORM WITH FEE(S)

PTOL-85 (REV. 04-02) Approved for use through 01/31/2004. OMB 0651-0033 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

BEST COPY

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	2103-9911..	2587

7590 04/21/2003

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

EXAMINER

ART UNIT | PAPER NUMBER

DATE MAILED: 04/21/2003

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The patent term adjustment to date is 0 days. If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the term adjustment will be 0 days.

If a continued prosecution application (CPA) was filed in the above-identified application, the filing date that determines patent term adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) system. (http://pair.uspto.gov)

Any questions regarding the patent term extension or adjustment determination should be directed to the Office of Patent Legal Administration at (703)305-1383.

PTOL-85 (REV. 04-02) Approved for use through 01/31/2004.

UNITED STATES PATENT AND TRADEMARK OFFICE

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

7590 04/21/2003

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303
UNITED STATES

EXAMINER	
HEALY, BRIAN	
ART UNIT	PAPER NUMBER
2874	

DATE MAILED: 04/21/2003

Notice of Fee Increase on January 1, 2003

If a reply to a "Notice of Allowance and Fee(s) Due" is filed in the Office on or after January 1, 2003, then the amount due will be higher than that set forth in the "Notice of Allowance and Fee(s) Due" since there will be an increase in fees effective on January 1, 2003. See Revision of Patent and Trademark Fees for Fiscal Year 2003; Final Rule, 67 Fed. Reg. 70847, 70849 (November 27, 2002).

The current fee schedule is accessible from: http://www.uspto.gov/main/howtofees.htm.

If the issue fee paid is the amount shown on the "Notice of Allowance and Fee(s) Due," but not the correct amount in view of the fee increase, a "Notice to Pay Balance of Issue Fee" will be mailed to applicant. In order to avoid processing delays associated with mailing of a "Notice to Pay Balance of Issue Fee," if the response to the Notice of Allowance and Fee(s) due form is to be filed on or after January 1, 2003 (or mailed with a certificate of mailing on or after January 1, 2003), the issue fee paid should be the fee that is required at the time the fee is paid. If the issue fee was previously paid, and the response to the "Notice of Allowance and Fee(s) Due" includes a request to apply a previously-paid issue fee to the issue fee now due, then the difference between the issue fee amount at the time the response is filed and the previously paid issue fee should be paid. See Manual of Patent Examining Procedure, Section 1308.01 (Eighth Edition, August 2001).

Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at (703) 305-8283.

PTOL-85 (REV. 04-02) Approved for use through 01/31/2004.

Attorney D(ɜt No. 2102393-991101

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Wilde

Serial No. 09/938,426 Group Art Unit: 2874

Filed: August 23, 2001 Examiner: Garland, Steven R

Title: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as FIRST CLASS MAIL in an envelope addressed to: Commissioner of Patents and Trademarks, Washington, D.C. 20231, BOX RCE on October 8, 2002.

Date: October 8, 2002 *Signature* [signature] *Susan C. Pingue*

REQUEST FOR CONTINUED EXAMINATION
PURSUANT TO 37 C.F.R. §1.114

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir/Madam:

Applicant hereby requests, pursuant to 37 C.F.R. §1.114, continued examination of the above-identified application for consideration of the references listed on the Information Disclosure Statement being submitted herewith on PTO form 1499. Copies of those references are enclosed.

One of the references, i.e., U.S. Patent No. 6,204,946 of Aksyuk et al., was used to reject claims in co-pending, related U.S. application serial number 10/005,714. This reference and all other references contained in the Information Disclosure Statement were cited and discussed in the specification of the present application. However, out of an abundance of caution, Applicant is nevertheless submitting these references in the form of an Information Disclosure Statement, and respectfully requests that the Examiner consider them in this application. Applicant's submission of these references should not be construed, however, as an admission that they ar from analogous arts or material. Applicant specifically reserves the right to argue that any of these references are not material at a later date should the need arise.

Applicant encloses herewith a check in the amount of $370.00 to cover the fee set forth in 37 C.F.R. §1.17(e). Applicant hereby authorizes the commissioner to charge any other fees required to the PTO Deposit Account Number 07-1896.

If the Examiner has any questions, the Examiner is invited to contact Applicant's attorney at the following address or telephone number:

David Alberti
c/o Patent Department
GRAY CARY WARE & FREIDENRICH LLP
1755 Embarcadero Road
Palo Alto, CA 94303
Telephone: (650) 833-2052

Respectfully submitted,

Dated: October 8, 2002

David Alberti /sp
David Alberti
Reg. No. 43,465

FM RCE/2800 #3 RCE 11/1/02

OIPE JC98 OCT 15 2002 PATENT & TRADEMARK OFFICE

Based on PTO/SB/30 (10-01)

REQUEST for CONTINUED EXAMINATION (RCE) TRANSMITTAL

Subsection (b) of 35 U.S.C. § 132, effective on May 29, 2000, provides for continued examination of an utility or plant application filed on or after June 8, 1995.
See The American Inventors Protection Act of 1999 (AIPA).

Application Number	09/938,426
Filing Date	August 23, 2001
First Named Inventor	Jeffrey Wilde
Group Art Unit	2874
Examiner Name	Garland, Steven
Attorney Docket Number	2102393-991101

This is a Request for Continued Examination (RCE) under 37 C.F.R. § 1.114 of the above-identified application.
NOTE: 37 C.F.R. § 1.114 is effective on May 29, 2000. If the above-identified application was filed prior to May 29, 2000, applicant may wish to consider filing a continued prosecution application (CPA) under 37 C.F.R. § 1.53(d) (PTO/SB/29) instead of a RCE to be eligible for the patent term adjustment provisions of the AIPA. See Changes to Application Examination and Provisional Application Practice, Final Rule, 65 Fed. Reg. 50092 (Aug. 16, 2000); Interim Rule, 65 Fed. Reg. 14865 (Mar. 20, 2000), 1233 Off. Gaz. Pat. Office 47 (Apr. 11, 2000), which established RCE practice.

1. **Submission required under 37 C.F.R. § 1.114**

☐ Previously submitted
- i. ☐ Consider the amendment(s)/reply under 37 C.F.R. § 1.116 previously filed on ______ (Any unentered amendment(s) referred to above will be entered).
- ii. ☐ Consider the arguments in the Appeal Brief or Reply Brief previously filed on ______
- iii. ☐ Other ______

b. ☒ Enclosed
- i. ☐ Amendment/Reply
- ii. ☐ Affidavit(s)/Declaration(s)
- iii. ☒ Information Disclosure Statement (IDS)
- iv. ☐ Other ______

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2. **Miscellaneous**

a. ☐ Suspension of action on the above-identified application is requested under 37 C.F.R. § 1.103(c) for a period of ______ months. (Period of suspension shall not exceed 3 months; Fee under 37 C.F.R. § 1.17(i) **required**)

b. ☐ Other ______

3. **Fees** The RCE fee under 37 C.F.R. § 1.17(e) is required by 37 C.F.R. § 1.114 when the RCE is filed.

a. ☒ The Commissioner is hereby authorized to charge the following fees, or credit any overpayments, to Deposit Account No. 07-1896
- i. ☒ RCE fee required under 37 C.F.R. § 1.17(e)
- ii. ☐ Extension of time fee (37 C.F.R. §§ 1.136 and 1.17)
- iii. ☐ Other ______

b. ☒ Check in the amount of enclosed $ 370.00 is enclosed.

Respectfully submitted,
GRAY CARY WARE & FREIDENRICH LLP

Dated: 10/7/2002

By: [signature]
Attorney Name David L. Alberti
Reg. No. 43.465
Attorneys for Applicant(s)
Gray Cary Ware & Freidenrich
1755 Embarcadero Road, Palo Alto, CA 94303
650-833-2052

10/16/2002 CNGUYEN 00000109 09938426
01 FC:2801 370.00 OP

CERTIFICATE OF MAILING OR TRANSMISSION

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner of Patents and Trademarks, Box RCE, Washington, DC 20231, or facsimile transmitted to the U.S. Patent and Trademark Office on:

Name (Print/Type)	Susan Pingue		
Signature	[signature]	Date	October 8, 2002

Gray Cary\EM\7123913.1

OIPE JC106 JUL 2 3 2003 PATENT & TRADEMARK OFFICE

B

PTO/SB/05 (05-03)
Approved for use through 04/30/2003. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMITTAL FORM (to be used for all correspondence after initial filing)		Application Number	09/938,426
		Filing Date	August 23, 2001
		First Named Inventor	Jeffrey P Wilde
		Art Unit	2874
		Examiner	Healy, Brian
Total Number of Pages in This Submission	6	Attorney Docket Number	2102393-991101

ENCLOSURES *(Check all that apply)*

- [x] Fee Transmittal Form
  - [x] Fee Attached - $962.00
- [ ] Amendment/Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Response to Missing Parts/ Incomplete Application
  - [ ] Response to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s)
- [ ] After Allowance Communication to Group
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to Group (Appeal Notice, Brief, Reply Brief)
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please identify below):
  1. Part B - Fee(s) Transmittal (+ copy);
  2. Return Postcard

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm or Individual	David Alberti, Reg. No. 43,465
Signature	D Alberti
Date	July 16, 2003

CERTIFICATE OF TRANSMISSION/MAILING

I hereby certify that this correspondence is being facsimile transmitted to the USPTO or deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below.

Typed or printed	Rosa A. Caviedes		
Signature	Rosa A. Caviedes	Date	July 16, 2003

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 (1-800-786-9199) and select option 2.

PTO/SB/05 (05-03)
Approved for u... ugh 04/30/2003. OMB 0651-0032
U.S. Patent and Trademark Office, U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

OIPE JUL 2 3 2003

FEE TRANSMITTAL for FY 2003

Effective 01/01/2003. Patent fees are subject to annual revision.

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 962.00

Complete if Known	
Application Number	09/938,426
Filing Date	August 23, 2001
First Named Inventor	Jeffrey P. Wilde
Examiner Name	Healy, Brian
Art Unit	2874
Attorney Docket No.	2102393-991101

METHOD OF PAYMENT *(check all that apply)*

☒ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None

☒ Deposit Account:

Deposit Account Number: 07-1896

Deposit Account Name: Gray Cary Ware & Freidenrich LLP

The Director is authorized to: *(check all that apply)*

☐ Charge fee(s) indicated below ☐ Credit any overpayments

☒ Charge any additional fee(s) during the pendency of this application

☐ Charge fee(s) indicated below, except for the filing fee to the above-identified deposit account.

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1001	750	2001	375	Utility filing fee	
1002	330	2002	165	Design filing fee	
1003	520	2003	260	Plant filing fee	
1004	750	2004	375	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	
				SUBTOTAL(1)	($)

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

			Extra Claims		Fee from below		Fee Paid
Total Claims		-20** =		X		=	
Independent Claims		-3** =		X		=	
Multiple Dependent						=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	84	2201	42	Independent claims in excess of 3
1203	280	2203	140	Multiple dependent claim, if not paid
1204	84	2204	42	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)

***or number previously paid, if greater; For Reissues, see above*

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for *ex parte* reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	410	2252	205	Extension for reply within second month	
1253	930	2253	465	Extension for reply within third month	
1254	1,450	2254	725	Extension for reply within fourth month	
1255	1,970	2255	985	Extension for reply within fifth month	
1401	320	2401	160	Notice of Appeal	
1402	320	2402	160	Filing a brief in support of an appeal	
1403	280	2403	140	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,300	2453	650	Petition to revive - unintentional	650
1501	1,300	2501	650	Utility issue fee (or reissue)	
1502	470	2502	235	Design issue fee	
1503	630	2503	315	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	750	2809	375	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	750	2810	375	For each additional invention to be examined (37 CFR 1.129(b))	
1801	750	2801	375	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	
Other fee (specify)				Publication fee ($300) and 4 soft copies of issued patent	312

*Reduced by Basic Filing Fee Paid SUBTOTAL (3) ($) 962

SUBMITTED BY				(Complete *(if applicable)*)	
Name (Print/Type)	David Alberti	*Registration No. (Attorney/Agent)*	43,465	*Telephone*	(650) 833-2052
Signature	[signature]			*Date*	July 16, 2003

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

This collection of information is required by 37 CFR 1.17 and 1.27. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 (1-800-786-9199) and select option 2.

American LegalNet, Inc. www.USCourtForms.com

OIPE JC95
OCT 1 5 2002
PATENT & TRADEMARK OFFICE

ATTORNEY DOCKET NO. 2102393-991104

Form PTO-1449 (modified 2/91) U.S. DEPT. OF COMMERCE Patent and Trademark Office **INFORMATION DISCLOSURE CITATION** (Use several sheets if necessary)	Attorney Docket Number: **2102393-991101**	Serial Number: **09/938,426**
	Applicants: J. Wilde	
	Filing date: August 23, 2001	Group art unit: 2874

#4/IDS
/mg 10/1/02

U.S. PATENT DOCUMENTS

Examiner Initial	Patent number	Date	Name	Class	Sub-class	Filing date if appropriate
lm	5,629,790	05-13-97	Neukermans, et al.	359	198	——
lm	5,960,133	05-25-99	Gilbert	385	18	——
lm	5,974,207	10-26-99	Aksyuk, et al.	385	24	——
lm	6,204,946	03-20-01	Aksyuk, et al.	359	131	——
lm	6,205,269	03-20-01	Morton	385	24	

FOREIGN PATENT DOCUMENTS

	Document number	Date	Country	Class	Sub-class	Translation YES	NO

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

Examiner: lm [signature]	Date Considered: 11/26/02

EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to the applicant.

Gray Cary\EM\71
2102393-991101

IDS

PTO/SB/17 (10-01)

OIPE JC36 OCT 1 5 2002 PATENT & TRADEMARK OFFICE

FEE TRANSMITTAL for FY 2002

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT ($) 370.00

Complete if Known	
Application Number	09/938,426
Filing Date	August 23, 2001
First Named Inventor	J. Wilde
Examiner Name	Garland, Steven
Group Art Unit	2874
Attorney Docket No.	2102393-991101

RECEIVED OCT 18 2002 TECHNOLOGY CENTER 2800

METHOD OF PAYMENT

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number: 07-1896

Deposit Account Name: Gray Cary Ware & Freidenrich LLP

☒ Charge Any additional Fee Required Under 37 CFR 1.16 and 1.17

☒ Applicant claims small entity status. See 37 CFR 1.27

2. ☒ **Payment Enclosed:**

☒ Check in the amount of $ 370.00

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	740	201	370	Utility filing fee	
106	330	206	165	Design filing fee	
107	510	207	255	Plant filing fee	
108	740	208	370	Reissue filing fee	
114	160	214	80	Provisional filing fee	

SUBTOTAL (1) ($)

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims		-20** =		X	9	=	
Independent Claims		-3** =		X	42	=	
Multiple Dependent				X		=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	84	202	42	Independent claims in excess of 3
104	280	204	140	Multiple dependent claim, if not paid
109	80	209	42	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($)

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for *ex parte* reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	400	216	200	Extension for reply within second month	
117	920	217	460	Extension for reply within third month	
118	1,440	218	720	Extension for reply within fourth month	
128	1,960	228	980	Extension for reply within fifth month	
119	320	219	160	Notice of Appeal	
120	320	220	160	Filing a brief in support of an appeal	
121	280	221	140	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive – unavoidable	
141	1,280	241	640	Petition to revive – unintentional	
142	1,280	242	640	Utility issue fee (or reissue)	
143	460	243	230	Design issue fee	
144	620	244	310	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Processing fee under 37 CFR 1.17(q)	
126	180	126	180	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	740	246	370	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	740	249	370	For each additional invention to be examined (37 CFR § 1.129(b))	
179	740	279	370	Request for Continued Examination (RCE)	370.00
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) ______

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 370.00

SUBMITTED BY					
Name (Print/Type)	David L. Alberti	*Registration No. (Attorney/Agent)*	43,465	*Telephone*	650-833-2052
Signature	[signature]			*Date*	Oct. 7,2001

Gray Cary\EM\7123934.1
2102393-991101

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

7590 12/04/2002

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

EXAMINER	
NGO, HUNG NHAT	
ART UNIT	**PAPER NUMBER**
2874	

DATE MAILED: 12/04/2002

Please find below and/or attached an Office communication concerning this application or proceeding.

PTO-90C (Rev. 07-01)

Office Action Summary	Application No.	Applicant(s)
	09/938,426	WILDE, JEFFREY P.
	Examiner	**Art Unit**
	Hung N Ngo	2874

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☐ Responsive to communication(s) filed on _____ .

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-67* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1,21,31,37 and 61* is/are rejected.

7)☒ Claim(s) *2-20,22-30,32-36,38-43,45-60 and 62-67* is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

11)☐ The proposed drawing correction filed on _____ is: a)☐ approved b)☐ disapproved by the Examiner.

If approved, corrected drawings are required in reply to this Office action.

12)☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. §§ 119 and 120

13)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____ .

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

14)☒ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).

a) ☐ The translation of the foreign language provisional application has been received.

15)☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

3) ☒ Information Disclosure Statement(s) (PTO-1449) Paper No(s) _____ .

4) ☐ Interview Summary (PTO-413) Paper No(s). _____ .

5) ☐ Notice of Informal Patent Application (PTO-152)

6) ☐ Other:

1. The following is a quotation of the appropriate paragraph of 35 U.S.C. 102 that form the ... is for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –

(e) the invention was described in ... patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraphs (1), (2), and (4) of section 371(c) of this title before the invention thereof by the applicant for patent.

The changes made to 35 U.S.C. 102(e) by the American ... Protection Act of 1999 (AIPA) do not apply to the examination of this application as the application being examined was not (1) filed on or after November 29, 2000, or (2) voluntarily published under 35 U.S.C. 122(b). Therefore, this application is examined under 35 U.S.C. 102(e) prior to the amendment by the AIPA (pre-AIPA 35 U.S.C. 102(e)).

2. Claims 1, 21, 31, 37 and 61 are rejected under 35 U.S.C. 102(e) as being anticipated by Aksyul et al (6,204,946). Aksyul et al discloses a polarizaton rotating unit (56) and a wavelength separator (12).

3. Claims 2-20, 22-30, 32-36, 38-43, 45-60 and 62-67 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Hung N Ngo whose telephone number is (703) 308-0297. The examiner can normally be reached on M-F (8:30-5:00).

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Rodney Bovernick can be reached on 703-308-4819. The fax phone numbers for the organization where this application or proceeding is assigned are 703-308-7724 for regular communications and 703-308-7724 for After Final communications.

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is 703-308-0956.

Hung N Ngo
Primary Examiner
Art Unit 2874

hn
November 27, 2002

Notice of References Cited	Application/Control No. 09/938,426	Applicant(s)/Patent Under Reexamination WILDE, JEFFREY P.	
	Examiner Hung N Ngo	Art Unit 2874	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
	A	US-5,835,458	11-1998	Bischel et al.	369/44.12
	B	US-			
	C	US-			
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

ATTORNEY DOCKET NO. 2102393-991101

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

OIPE DEC 1 6 2002 JC12 PATENT & TRADEMARK OFFICE

APPLICANTS: Jeffrey P. Wilde

SERIAL NO.: 09/938,426 GROUP NO.: 2587

FILING DATE: August 23, 2001

TITLE: *Reconfigurable Optical Add-Drop Multiplexers With Servo Control And Dynamic Spectral Power Management Capabilities*

INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Box DD
Washington, D.C. 20231

Dear Sir:

In accordance with the provisions of 37 C.F.R. § 1.97, Applicants hereby make of record the references listed on the accompanying Form PTO-1449 for consideration by the Examiner in connection with the examination of the above-identified patent application. Copies of the references are enclosed.

RECEIVED DEC 18 2002 TECHNOLOGY CENTER 2800

REMARKS

In accordance with the provisions of 37 C.F.R, § 1.97, this statement is being filed (CHECK ONE).

[X] (1) within three (3) months of the **Filing Date** or before the mailing date of a **First Office Action** on the merits; or

[ ] (2) after the period defined in (1) but before the mailing date of a **Final Rejection** or **Notice of Allowance**, and

[ ] the requisite Statement is below, **OR**

[ ] the requisite fee under Rule 1.17(p), namely **$180.00**, is included herein, or

[ ] (3) after the mailing date of a **Final Rejection** or **Notice of Allowance** but before the payment of the **Issued Fee, AND**

[ ] Applicant hereby Petitions the Commissioner to accept and consider the attached Information Disclosure Statement, **AND**

[ ] the requisite Statement is below, **AND**

[ ] the requisite petition fee due under Rule 1.17(i), namely **$130.00** is included herein.

It is respectfully requested that each of the references shown on the attached Form PTO-1449 be made of record in this application.

STATEMENT

As required under §1.97(e), Applicants, through the undersigned, hereby state either that [check the appropriate space]:

[ ] 1. [E]ach item of information contained in the Information Disclosure Statement was cited in a communication from a foreign patent office in a counterpart foreign application **not more than** three months prior to the filing date of the Information Disclosure Statement; or

[ ] 2. [N]o item of information contained in the Information Disclosure Statement was cited in a communication from a foreign patent office in a counterpart foreign application, and to the knowledge of the person signing this Statement after making reasonable inquiry, no item of information contained in the Information Disclosure Statement was known to **any** individual designated in §1.56(c) **more than** three months prior to the filing of the Information Disclosure Statement.

FEE AUTHORIZATION

Should any fee associated with the submission of this paper not be attached hereto as a check, the Commissioner is authorized to charge the missing fee to our Deposit Account No. **07-1896**. Any overpayments should be credited to said Deposit Account.

Respectfully submitted,

Date: December 6, 2002

David Alberti
Reg. No. 43,465
Attorney for Assignee

GRAY CARY WARE & FREIDENRICH
1755 Embarcadero Road
Palo Alto, CA 94303-3340
Telephone No.: 650-320-7400
Facsimile No.: 650-320-7401

OIPE JC12
DEC 1 6 2002
PATENT & TRADEMARK OFFICE

Based on PTO/SB/08A (10-01)

Substitute for form 1449A/PTO	Complete If Known	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	**Application Number**	09/938,426
	Filing Date	August 23, 2001
	First Named Inventor	Jeffrey P. Wilde
	Group Art Unit	2587
(use as many sheets as necessary)	Examiner Name	Garland, Steven
Sheet 1 of 2	Attorney Docket Number	2102393-991101

U.S. PATENT DOCUMENTS

Examiner Initials	Cite No.	Document Number: Number	Kind Code (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	CLASS	SUB-CLASS
Healy	BMH	US-6,263,135 B1		7/01	LightChip, Inc.	385	37
Ngo	BMH	US-6,289,155 B1		9/01	LightChip, Inc.	385	37
Spyrou	BMH	US-6,418,250 B1		7/02	Corning Incorporated	385	24
		US-					
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		US-					

FOREIGN PATENT DOCUMENTS

Examiner Initials	Cite No.	Country Code	Number	Kind Code (if known)	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear	T

Examiner Signature	B. Healy	Date Considered	4/17/03

26379
PATENT TRADEMARK OFFICE

OIPE JC12
DEC 1 6 2002
PATENT & TRADEMARK OFFICE

PTO/SB/08B (08-00)

Substitute for form 1449A/PTO	Complete If Known	
INFORMATION DISCLOSURE STATEMENT BY APPLICANT	**Application Number**	09/938,426
(use as many sheets as necessary)	**Filing Date**	August 23, 2001
	First Named Inventor	Jeffrey P. Wilde
	Group Art Unit	2874
	Examiner Name	Garland, Steven
Sheet 2 of 2	Attorney Docket Number	2102393-991101

OTHER PRIOR ART -- NON PATENT LITERATURE DOCUMENTS

Examiner Initials	Cite No.	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T

Examiner Signature		Date Considered	

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as FIRST CLASS MAIL in an envelope addressed to: Commissioner of Patents & Trademarks; Washington, DC 20231.

12/16/02 Linda M. West

Date Signature

\EM7129172.1

2874 ~~2587~~ #6

Please type a plus sign (+) inside this box [+]

PTO/SB/21 (08-00)

OIPE JC12 DEC 1 6 2002 PATENT & TRADEMARK OFFICE

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application Number	09/938,426
Filing Date	August 23, 2001
First Named Inventor	Jeffrey P. Wilde
Group Art Unit	2587
Examiner Name	Garland, Steven
Attorney Docket Number	2102393-991101

Total Number of Pages in This Submission 58

ENCLOSURES *(check all that apply)*

- [ ] Fee Transmittal Form
  - [ ] Fee attached
- [ ] Amendment/Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [ ] Extension of Time Request
- [ ] Express Abandonment Request
- [X] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Response to Missing Parts/ Incomplete Application
  - [ ] Response to Missing Parts under 37 CFR 1.52 or 1.53
- [ ] Assignment Papers *(for an Application)*
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) ________
- [ ] After Allowance Communication to Group
- [ ] Appeal Communication to Board of Appeals and Interferences
- [ ] Appeal Communication to Group *(Appeal Notice, Brief, Reply Brief)*
- [ ] Proprietary Information
- [ ] Status Letter
- [X] Other Enclosure(s) *(please identify below):*

Return postcard

Remarks

RECEIVED DEC 18 2002 TECHNOLOGY CENTER 2800

- [ ] *Customer Number or Bar Code Label* *(Insert Customer No. or Attach bar code label here)*

26379 PATENT TRADEMARK OFFICE

The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. ________________. A duplicate copy of this sheet is enclosed.

Respectfully submitted,

GRAY CARY WARE & FREIDENRICH LLP

Dated: December 6, 2002

By: [signature]

David Alberti
Reg. No. 43,465
Attorneys for Applicant(s)

GRAY CARY WARE & FREIDENRICH LLP
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Signature	[signature]	Date	December 6, 2002

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2102393-991101

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PATENT & TRADEMARK OFFICE

Attorney Docket Number 2102393-991101

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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TECHNOLOGY CENTER 2800

#7A Amdt
M. Brunson
2/6/03

Applicant: Wilde

Serial No. 09/938,426 Group Art Unit: 2874

Filed: August 23, 2001 Examiner: Ngo, Hung Nhat

Title: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

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January 24, 2003 [signature]
Date *Signature*

* * *

AMENDMENT AND RESPONSE TO OFFICE ACTION

Commissioner of Patents and Trademarks
Washington, DC 20231

Sir/Madam:

Applicant responds to the outstanding Office Action mailed on December 4, 2002 as follows:

IN THE CLAIMS:

Please amend claims 31 and 37 as follows (a marked up versions of these claims are attached hereto as Appendix A):

Claim 31 (amended, clean version)

An optical apparatus comprising:

A1

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

Gray Cary\EM\7132730.1
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b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

A1 amd.

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

e) a one-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

Claim 37 (amended, clean version)

An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

A2

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

e) a two-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

REMARKS

The Examiner rejected claims 1, 21, 31, 37 and 61 under 35 U.S.C. §102(e) as being anticipated by United States Patent No. 6,204,946 of Aksyuk et al. ("Aksyuk"). While the Examiner did not specifically indicate that claim 44 was rejected (or on what grounds it was rejected), the Examiner did not state that claim 44 was allowable. Thus, Applicant will treat the claim as rejected based on Aksyuk for the purposes of this office action. Claims 2-20, 22-30, 32-36, 38-43, 45-60 and 62-67 were determined to be allowable if rewritten independent form. Claims 31 and 37 have been amended to clarify that each micromirror in the array is continuously controllable. For the reasons stated below, Applicant asserts that all of claims 1-67 are allowable in the present form over Aksyuk.

As discussed more fully and completely below, Aksyuk does not teach an optical method or apparatus including all of the elements of Applicant's claimed inventions. Particularly, Aksyuk does not teach an optical method or apparatus, which uses an array of micromirrors (or beam deflecting elements) that are individually and continuously controllable to reflect a plurality of spectral channels into a plurality of output ports, as recited in claims 1, 31, 37, 44 and 61. Furthermore, Aksyuk does not teach the use of a servo-control assembly in communication with the micromirrors for maintaining a predetermined coupling, as recited in claim 21. Therefore, Aksyuk can neither anticipate nor render obvious any of claims 1, 21, 31, 37, 44 and 61.

Claims 1, 31, 37, 44 and 61

Aksyuk does not disclose nor suggest the novel optical apparatus of independent claims 1, 31, 37, 44 and 61. Independent claims 1, 31, 37, and 44 each require an optical (or wavelength-separating-routing) apparatus or system having an input port, a plurality of output ports (which may include a pass-through port and one or more drop ports) and an array of micromirrors that are individually and continuously controllable to reflect a plurality of spectral channels into selected output ports.

First, Aksyuk does not teach an apparatus that includes an input port and a plurality of output ports (e.g., drop and pass-through ports). In contrast, Aksyuk teaches that the pass-through wavelengths are reflected back into the input port and input fiber rather than to a separate port and fiber. As discussed in column 3, line 51 – column 4, line 5 of Aksyuk, the WDM switch 10 operates to reflect the pass-through signals back to the input port 16, while the reflected drop signals are all sent to a single second port 26. Thus, in order to implement an add/drop multiplexer, circulators are required at the input and output ports of the claimed WDM switch 10. (See Aksyuk Figure 3, column 4, lines 6 – 48).

Moreover, Aksyuk does not disclose an array of micromirrors that are continuously controllable. Rather, the micromirrors of Aksyuk operate in a "binary" or discrete manner. That is each micromirror is configured to be positionable between two discrete states, such that it either retroreflects its corresponding wavelength back into the input port as a pass-through channel, or directs its wavelength to a single output port as a drop channel. (Aksyuk at column 3, lines 30 – 40). As a result, the pass-through channels share the same input port as the input signal, and the drop channels share the same output port as the add channels, thereby requiring optical circulators to be coupled to both ports in order to provide an add/drop multiplexer application.

Applicant describes these fundamental limitations of Aksyuk on page 3 of the pending application:

> … Each micromirror [of Aksyuk] is configured to operate between two discrete states, such that it either retroreflects its corresponding spectral channel back into the input port as a pass-through channel, or directs its spectral channel to an output port as a drop channel. As such, the pass-through signal (i.e., the combined pass-through channels) shares the same input port as the input signal. An optical circulator is therefore coupled to the input port, to provide necessary routing of these two signals. Likewise, the drop channels share the output port with the add channels. An additional optical circulator is thereby coupled to the output port, from which the drop channels exit and the add channels are introduced into the output port. The add channels are subsequently combined with the pass-through signal by way of the diffraction grating and the binary micromirrors.
>
> Although the aforementioned OADM disclosed by Aksyuk et al. has the advantage of performing wavelength separating and routing in free space and thereby incurring less optical loss, it suffers a number of limitations. First, it requires that the pass-through signal share the same port/fiber as the input signal. An optical circulator therefore has to be implemented, to provide necessary routing of these two signals. Likewise, all the add and drop channels enter and leave the OADM through the same output port, hence the need for another optical circulator. Moreover, additional means must be provided to multiplex the add channels before entering the system and to demultiplex the drop channels after exiting the system. This additional multiplexing/demultiplexing requirement adds more cost and complexity that can

restrict the versatility of the OADM thus-constructed. Second, the optical circulators implemented in this OADM for various routing purposes introduce additional optical losses, which can accumulate to a substantial amount.

Applicant also describes the advantages of the claimed optical apparatus, including multiple output ports and micromirrors that are continuously controllable to direct the spectral channels into selected output ports, in the pending application. As explained by Applicant on pages 12 and 13 of the pending application, "a unique feature of the present invention is that the motion of each channel micromirror is individually and continuously controllable, such that its position, e.g., pivoting angle, can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port." By reflecting all of the pass-through wavelengths as well as the dropped wavelengths to separate fibers from the input fiber, the claimed devices do not reuse the same optical fiber used to input the WDM signal. This avoids the necessity for circulators for combining or separating the multiple wavelengths on a single input and output port as does the claimed devices. Therefore, the claimed devices have the advantage of being significantly less complicated than the devices disclosed in the Aksyuk patent.

Further advantages of Applicant's novel, claimed configuration are described on pages 8 and 9 of the pending application:

1) By advantageously employing an array of channel micromirrors that are individually and continuously controllable, an OADM of the present invention is capable of routing the spectral channels on a channel-by-channel basis and directing any spectral channel into any one of the output ports. As such, its underlying operation is dynamically reconfigurable, and its underlying architecture is intrinsically scalable to a large number of channel counts.

2) The add and drop spectral channels need not be multiplexed and demultiplexed before entering and after leaving the OADM respectively. And there are not fundamental restrictions on the wavelengths to be added or dropped.

In summary, Aksyuk entirely fails to disclose or suggest multiple elements of claims 1, 31, 37 and 44 (e.g., an input and multiple output ports and an array of micromirrors that are individually and continuously controllable to reflect a plurality of spectral channels into selected output ports). For at least these reasons, claims 1, 31, 37 and 44, are patentable over Aksyuk.

Claim 61 recites a method for performing dynamic wavelength separating and routing. Like claims 1, 31, 37 and 44, claim 61 requires the use of a separate input port and a plurality of output ports, and beam-deflecting elements that are dynamically and continuously controlled to direct a plurality of spectral channels into a plurality of output ports. As set forth above, Aksyuk does not disclose or suggest the use of a separate input port and a plurality of output ports, or continuously controllable beam deflecting elements. For at least these reasons, claim 61 is allowable over the prior art of record.

Claim 21

Claim 21 recites a servo-based optical apparatus including an input port, a plurality of output ports, a micromirror array and a "**servo-control assembly**, in communication with the micromirrors and said output ports, for maintaining a predetermined coupling for each reflected spectral channel into one of said output ports." The servo-control assembly is shown for example in Figure 4A and is described on pages 17 and 18 of the pending application. The servo-control assembly allows the power levels of the spectral channels coupled into the output ports to be dynamically managed. Aksyuk neither discloses or suggests any type of servo-control assembly whatsoever. Because this element is completely missing from Aksyuk, Aksyuk can neither anticipate nor render obvious any of claim 21.

CONCLUSIONS

Applicant's invention is both novel and nonobvious over the prior art for the reasons set forth above. None of the prior art of record, either alone or in combination, teaches each and every element of Applicant's claimed invention.

For all of these reasons, Applicant respectfully asserts that claims 1-67 are in condition for allowance. The Examiner's early reconsideration is respectfully requested. If the Examiner has any questions, the Examiner is invited to contact Applicant's attorney at the following address or telephone number:

David Alberti
c/o Patent Department
GRAY CARY WARE & FREIDENRICH LLP
1755 Embarcadero Road
Palo Alto, CA 94303
Telephone: (650) 833-2052

Respectfully submitted,

Dated: January 24, 2003

David Alberti
Reg. No. 43,465

Appendix A

Claim 31 (amended, marked up version)

An optical apparatus comprising:

f) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

g) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

h) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

i) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

j) a one-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

Claim 37 (amended, marked-up version)

An optical apparatus comprising:

f) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

g) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

h) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

i) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

j) a two-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

2874

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PTO/SB/21 (08-00)

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Total Number of Pages in This Submission

Application Number	09/938,426
Filing Date	August 23, 2001
First Named Inventor	Jeffrey P. Wilde
Group Art Unit	2874
Examiner Name	Ngo, Hung Nhat
Attorney Docket Number	2102393-991101

ENCLOSURES *(check all that apply)*

- ☐ Fee Transmittal Form
  - ☐ Fee attached
- ☒ Amendment/Reply
  - ☐ After Final
  - ☐ Affidavits/declaration(s)
- ☐ Extension of Time Request
- ☐ Express Abandonment Request
- ☐ Information Disclosure Statement
- ☐ Certified Copy of Priority Document(s)
- ☐ Response to Missing Parts/ Incomplete Application
  - ☐ Response to Missing Parts under 37 CFR 1.52 or 1.53
- ☐ Assignment Papers (for an Application)
- ☐ Drawing(s)
- ☐ Licensing-related Papers
- ☐ Petition to Convert to a Provisional Application
- ☐ Power of Attorney, Revocation Change of Correspondence Address
- ☐ Terminal Disclaimer
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- ☐ CD, Number of CD(s) ________
- ☐ After Allowance Communication to Group
- ☐ Appeal Communication to Board of Appeals and Interferences
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Respectfully submitted,

GRAY CARY WARE & FREIDENRICH LLP

Dated: January 24, 2003

By: [signature]

Attorney Name: David Alberti
Reg. No. 43,465
Attorneys for Applicant(s)
1755 Embarcadero Road
Palo Alto, California 94303-3340
650/320-7400

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Typed or printed name	Yvette Renee Killingham		
Signature	[signature]	Date	January 24. 2003

Gray Cary\EM\7127806.1

Notice of Allowability	Application No.	Applicant(s)
	09/938,426	WILDE, JEFFREY P.
	Examiner	**Art Unit**
	Brian M. Healy	2874

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

laims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included with (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS 'ICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative e Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

☑ This communication is responsive to *the amendment filed 2/3/03*.

☑ The allowed claim(s) is/are *1-67*.

☑ The drawings filed on *23 August 2001* are accepted by the Examiner.

] Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a) ☐ All b) ☐ Some* c) ☐ None of the:

1. ☐ Certified copies of the priority documents have been received.
2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

* Certified copies not received: _____.

] Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).

(a) ☐ The translation of the foreign language provisional application has been received.

☑ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

icant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted w. Failure to timely comply will result in ABANDONMENT of this application. **THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.**

] A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF)RMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.

] CORRECTED DRAWINGS must be submitted.

(a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached

1) ☐ hereto or 2) ☐ to Paper No. ____.

(b) ☐ including changes required by the proposed drawing correction filed _____, which has been approved by the Examiner.

(c) ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No. _____.

lentifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the top margin (not the back) f each sheet. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftsperson.

] DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the :hed Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

chment(s)

Notice of References Cited (PTO-892)

Notice of Draftperson's Patent Drawing Review (PTO-948)

Information Disclosure Statements (PTO-1449), Paper No. 8.

Examiner's Comment Regarding Requirement for Deposit of Biological Material

2☐ Notice of Informal Patent Application (PTO-152)

4☐ Interview Summary (PTO-413), Paper No.____.

6☐ Examiner's Amendment/Comment

8☐ Examiner's Statement of Reasons for Allowance

9☐ Other

Brian Healy
Primary Examiner

Brian M. Healy
Primary Examiner
Art Unit: 2874

Notice of References Cited	Application/Control No. 09/938,426	Applicant(s)/Patent Under Reexamination WILDE, JEFFREY P.	
	Examiner Brian M. Healy	Art Unit 2874	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-6,222,954	04-2001	Riza, Nabeel Agha	385/18
*	B	US-6,205,269	03-2001	Morton, Paul A.	385/24
	C	US-			
	D	US-			
	E	US-			
	F	US-			
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FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
*	U	U.S. Patent Application Publication No. U.S. 2002/0131691A1, (GARRETT ET. AL.), 09/19/2002.
*	V	U.S. Patent Application Publication No. 2003/0043471A1 (BELSER ET. AL.), 03/06/2003.
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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7590 04/21/2003

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
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Rosa A. Caviedes (Depositor's name)
Rosa A. Caviedes (Signature)
July 16, 2003 (Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

TITLE OF INVENTION: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1300	$300	$1600	07/21/2003

EXAMINER	ART UNIT	CLASS-SUBCLASS
HEALY, BRIAN	2874	385-024000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 Gray Cary Ware & Freidenrich LLP
2 ______
3 ______

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the USPTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: Capella Photonics, Inc.

(B) RESIDENCE: (CITY and STATE OR COUNTRY): San Jose, California

Please check the appropriate assignee category or categories (will not be printed on the patent) ☐ individual ☒ corporation or other private group entity ☐ government

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David Alberti, Reg. No. 43,465

(Authorized Signature) D. Alberti (Date) July 16, 2003

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01 FC:2501 650.00 OP
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03 FC:8001 12.00 OP

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7590 07/29/2002

David Alberti
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1755 Embarcadero Road
Palo Alto, CA 94303

EXAMINER	
NGO, HUNG NHAT	
ART UNIT	CLASS-SUBCLASS
2874	385-024000

DATE MAILED: 07/29/2002

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

TITLE OF INVENTION: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1280	$300	$1580	10/29/2002

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE REFLECTS A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE APPLIED IN THIS APPLICATION. THE PTOL-85B (OR AN EQUIVALENT) MUST BE RETURNED WITHIN THIS PERIOD EVEN IF NO FEE IS DUE OR THE APPLICATION WILL BE REGARDED AS ABANDONED.

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If the SMALL ENTITY is shown as NO:

A. Pay TOTAL FEE(S) DUE shown above, or

B. If applicant claimed SMALL ENTITY status before, or is now claiming SMALL ENTITY status, check the box below and enclose the PUBLICATION FEE and 1/2 the ISSUE FEE shown above.

☐ Applicant claims SMALL ENTITY status. See 37 CFR 1.27.

II. PART B - FEE(S) TRANSMITTAL should be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). Even if the fee(s) have already been paid, Part B - Fee(s) Transmittal should be completed and returned. If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Box ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

TOL-85 (REV. 04-02) Approved for use through 01/31/2004

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), to: Mail Box ISSUE FEE
Commissioner for Patents
Washington, D.C. 20231
Fax (703)746-4000

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 4 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Legibly mark-up with any corrections or use Block 1)

7590 07/29/2002

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Box Issue Fee address above, or being facsimile transmitted to the USPTO, on the date indicated below.

(Depositor's name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

TITLE OF INVENTION: RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

APPLN. TYPE	SMALL ENTITY	ISSUE FEE	PUBLICATION FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	NO	$1280	$300	$1580	10/29/2002

EXAMINER	ART UNIT	CLASS-SUBCLASS
NGO, HUNG NHAT	2874	385-024000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-02 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1__________

2__________

3__________

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the USPTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) ❑ individual ❑ corporation or other private group entity ❑ government

4a. The following fee(s) are enclosed:

❑ Issue Fee

❑ Publication Fee

❑ Advance Order - # of Copies __________

4b. Payment of Fee(s):

❑ A check in the amount of the fee(s) is enclosed.

❑ Payment by credit card. Form PTO-2038 is attached.

❑ The Commissioner is hereby authorized by charge the required fee(s), or credit any overpayment, to Deposit Account Number __________ (enclose an extra copy of this form).

Commissioner for Patents is requested to apply the Issue Fee and Publication Fee (if any) or to re-apply any previously paid issue fee to the application identified above.

(Authorized Signature) (Date)

NOTE; The Issue Fee and Publication Fee (if required) will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the United States Patent and Trademark Office.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

7590 07/29/2002

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303

EXAMINER	
NGO, HUNG NHAT	
ART UNIT	**PAPER NUMBER**
2874	

DATE MAILED: 07/29/2002

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)

(application filed on or after May 29, 2000)

The patent term adjustment to date is 0 days. If the issue fee is paid on the date that is three months after the mailing date of this notice and the patent issues on the Tuesday before the date that is 28 weeks (six and a half months) after the mailing date of this notice, the term adjustment will be 0 days.

If a continued prosecution application (CPA) was filed in the above-identified application, the filing date that determines patent term adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) system. (http://pair.uspto.gov)

PTOL-85 (REV. 04-02) Approved for use through 01/31/2004.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/938,426	08/23/2001	Jeffrey P. Wilde	210393-991101	2587

7590 07/29/2002

EXAMINER	
NGO, HUNG NHAT	
ART UNIT	PAPER NUMBER
2874	

David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303
UNITED STATES

DATE MAILED: 07/29/2002

Notice of Fee Increase on October 1, 2002

If a reply to a "Notice of Allowance and Fee(s) Due" is filed in the Office on or after October 1, 2002, then the amount due may be higher than that set forth in the "Notice of Allowance and Fee(s) Due" since there will be an increase in fees effective on October 1, 2002. See Revision of Patent and Trademark Fees for Fiscal Year 2003; Notice of Proposed Rulemaking, 67 Fed. Reg. 30634, 30636 (May 7, 2002). Although a change to the amount of the publication fee is not currently proposed for October 2002, if the issue fee or publication fee is to be paid on or after October 1, 2002, applicant should check the USPTO web site for the current fees before submitting the payment. The USPTO Internet address for the fee schedule is: http://www.uspto.gov/main/howtofees.htm.

If the issue fee paid is the amount shown on the "Notice of Allowance and Fee(s) Due," but not the correct amount in view of the fee increase, a "Notice to Pay Balance of Issue Fee" will be mailed to applicant. In order to avoid processing delays associated with mailing of a "Notice to Pay Balance of Issue Fee," if the response to the Notice of Allowance and Fee(s) due form is to be filed on or after October 1, 2002 (or mailed with a certificate of mailing on or after October 1, 2002), the issue fee paid should be the fee that is required at the time the fee is paid. If the issue fee was previously paid, and the response to the "Notice of Allowance and Fee(s) Due" includes a request to apply a previously-paid issue fee to the issue fee now due, then the difference between the issue fee amount at the time the response is filed and the previously paid issue fee should be paid. See Manual of Patent Examining Procedure, Section 1308.01 (Eighth Edition, August 2001).

Effective October 1, 2002, 37 CFR 1.18 is proposed to be revised to change the patent issue fees as set forth below. As stated above, the final fees may be a different amount, and applicant should check the web site given above when paying the fee.

(a) Issue fee for issuing each original or reissue patent, except a design or plant patent:

By a small entity (Sec. 1.27(a))--$655.00
By other than a small entity--$1,310.00

(b) Issue fee for issuing a design patent:

By a small entity (Sec. 1.27(a))--$235.00
By other than a small entity--$470.00

(c) Issue fee for issuing a plant patent:

By a small entity (Sec. 1.27(a))--$315.00
By other than a small entity--$630.00

Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at (703) 305-8283.

APPROVED	O.G. FIG. 1A	
BY	CLASS	SUBCLASS
DRAFTSMAN	385	24

6625346

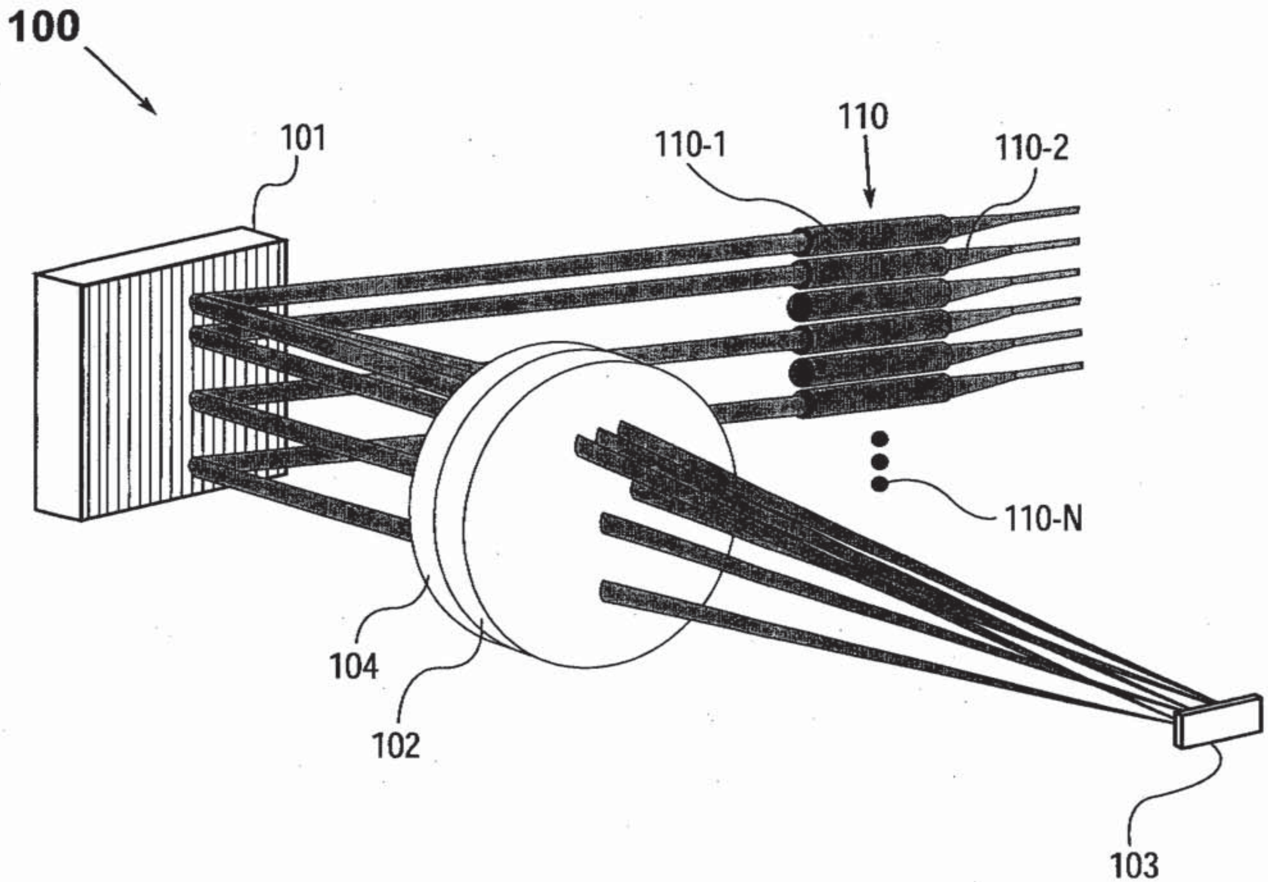

Fig. 1A

09938426.082301

APPROVED BY DRAFTSMAN | O.G. FIG. | CLASS | SUBCLASS

2/12

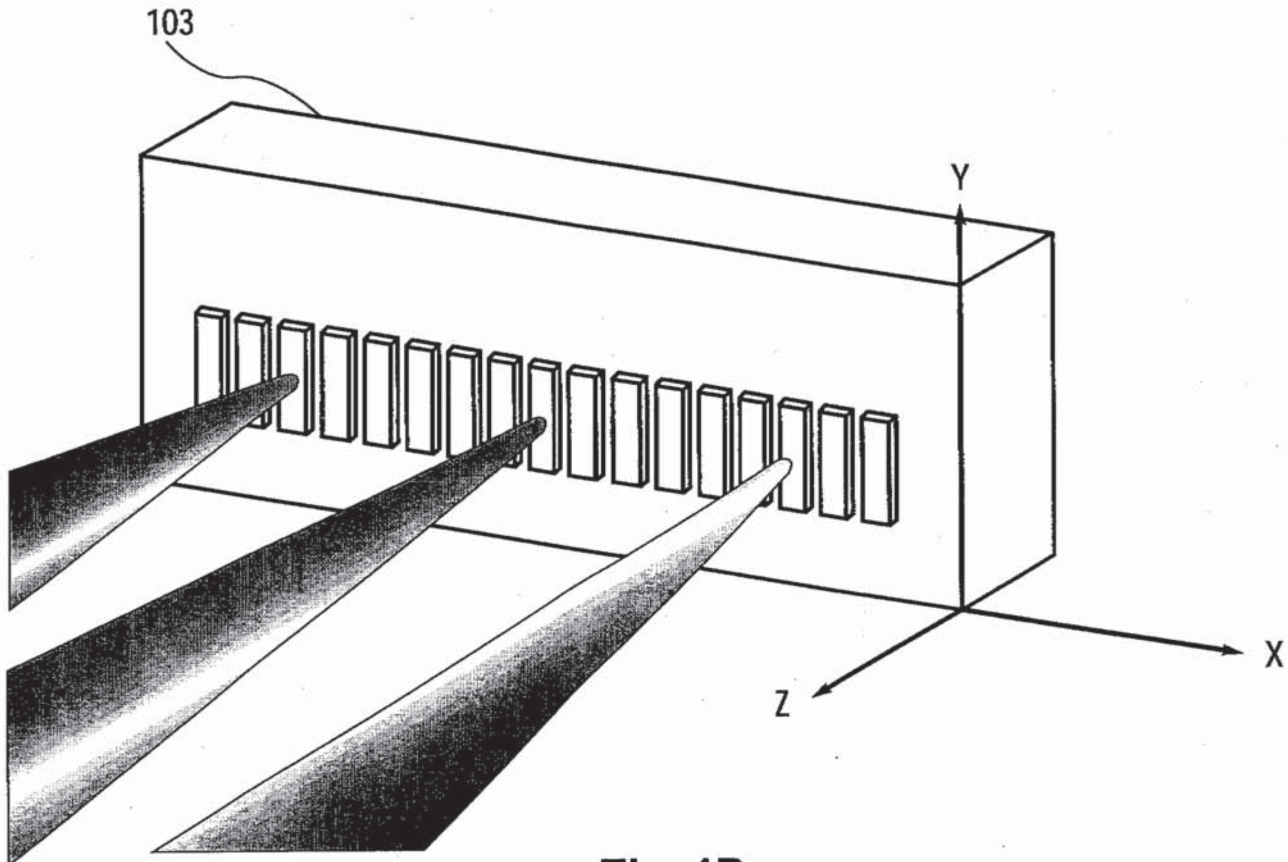

Fig. 1B

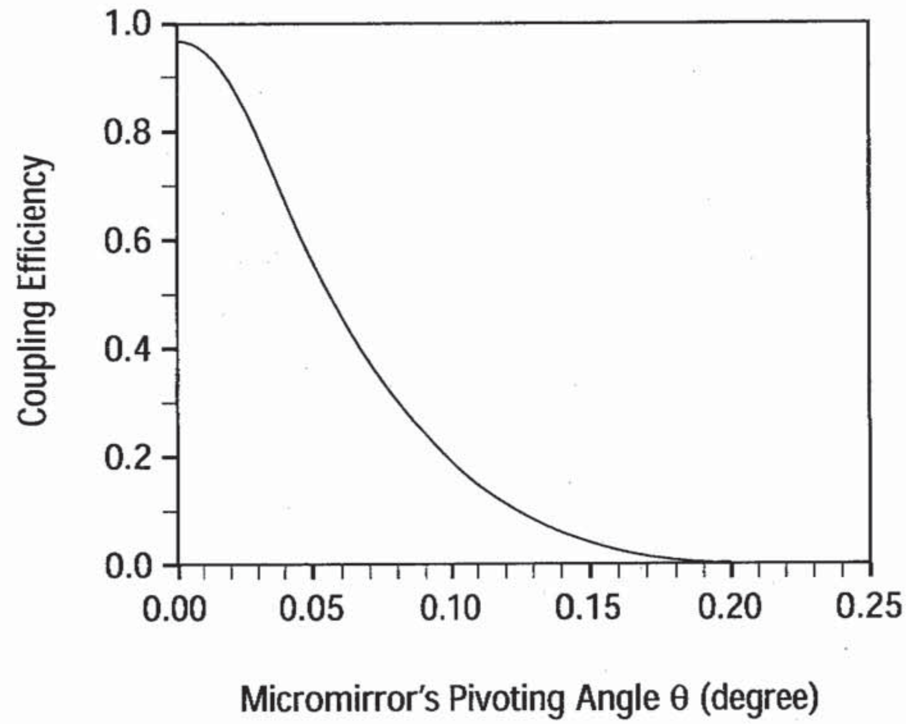
Coupling Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
Micromirror's Pivoting Angle θ (degree)

Fig. 1C

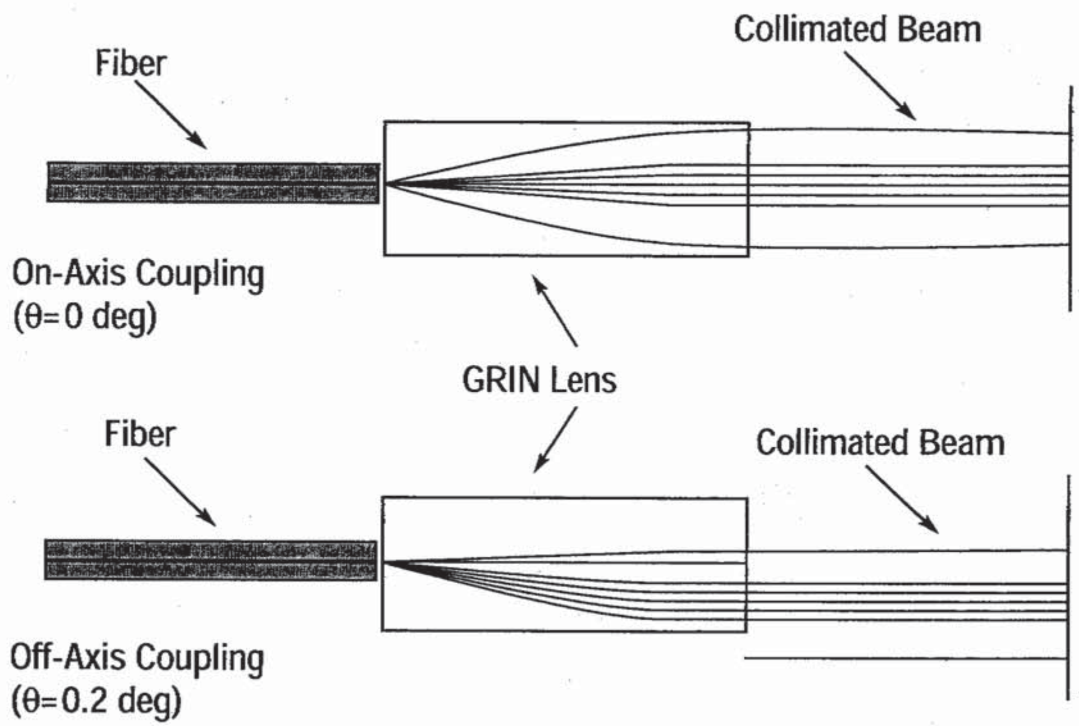
Fiber
Collimated Beam
On-Axis Coupling
(θ=0 deg)
GRIN Lens
Fiber
Collimated Beam
Off-Axis Coupling
(θ=0.2 deg)

Fig. 1D

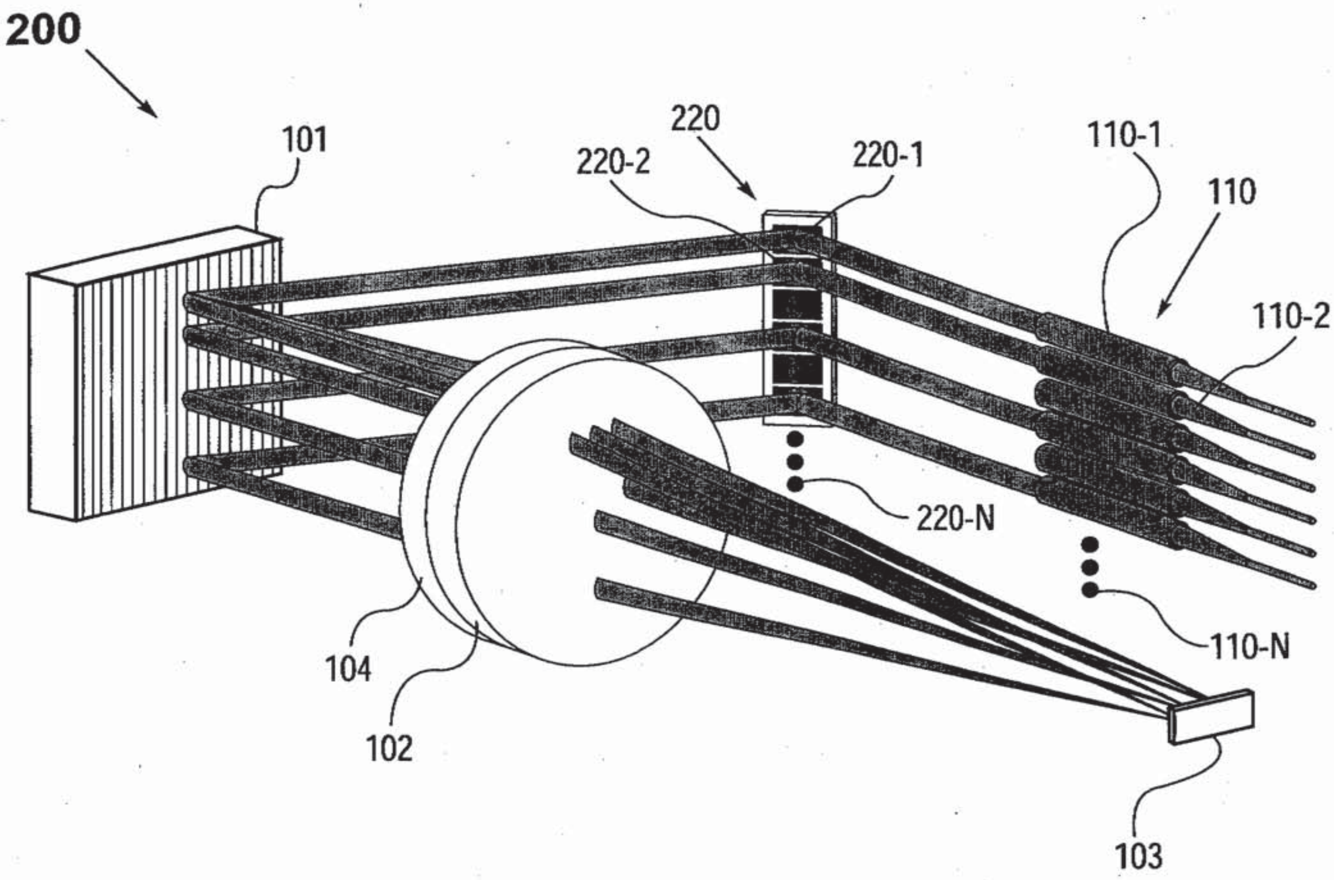

Fig. 2A

APPROVED	O.G. FIG.	
BY	CLASS	SUBCLASS
DRAFTSMAN		

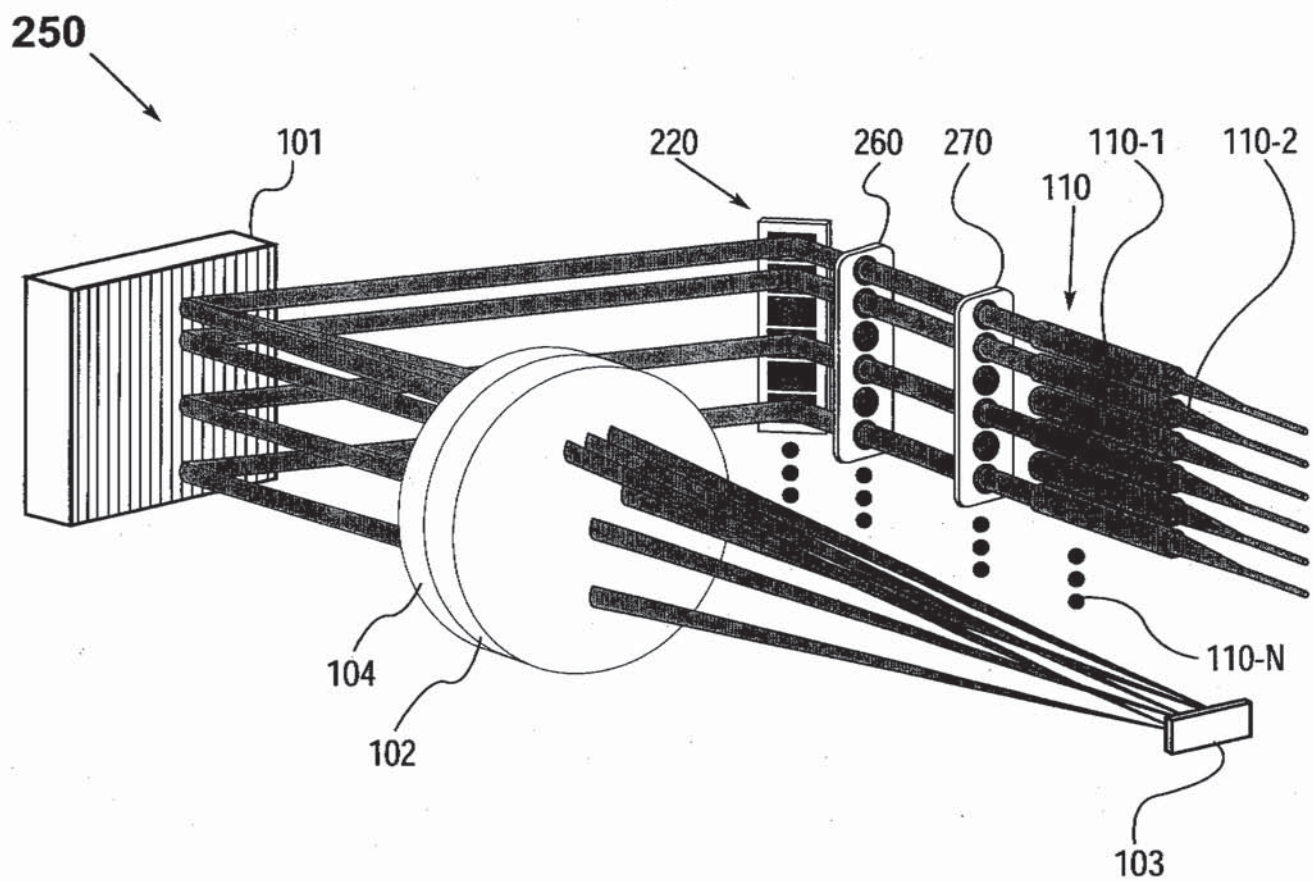

Fig. 2B

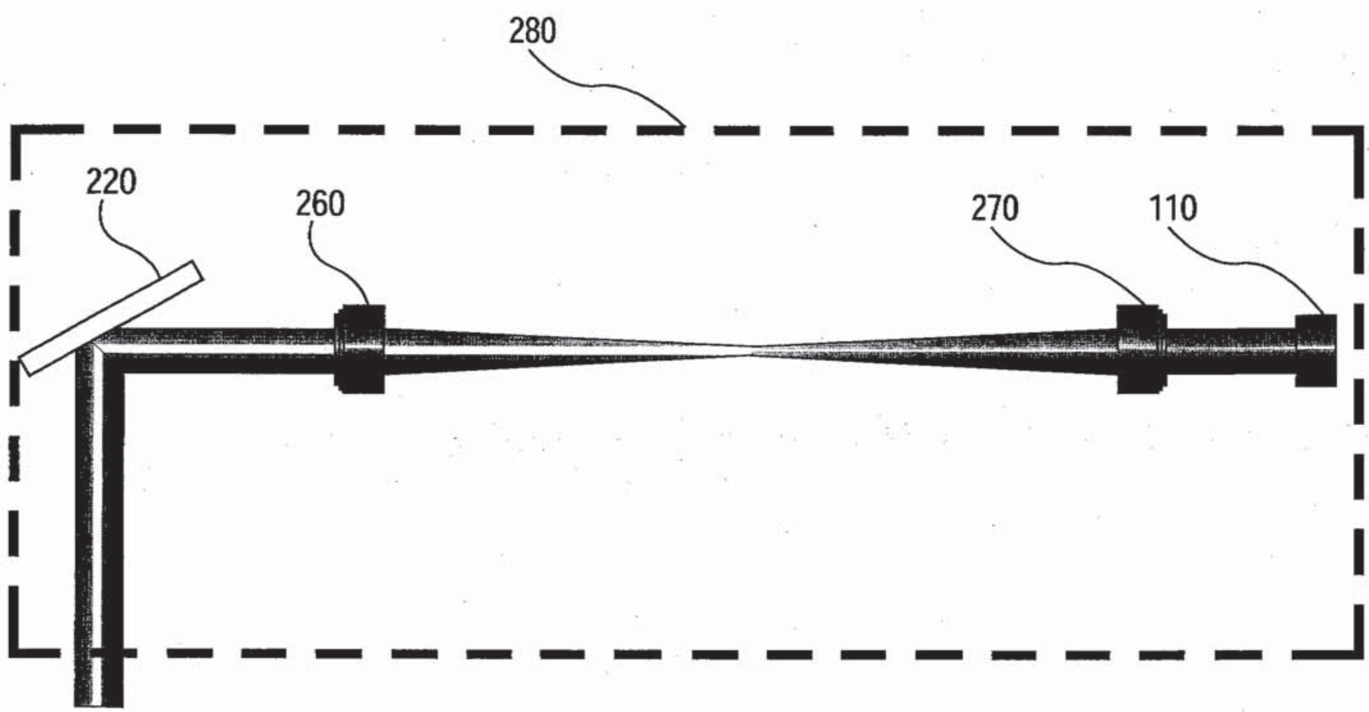

Fig. 2C

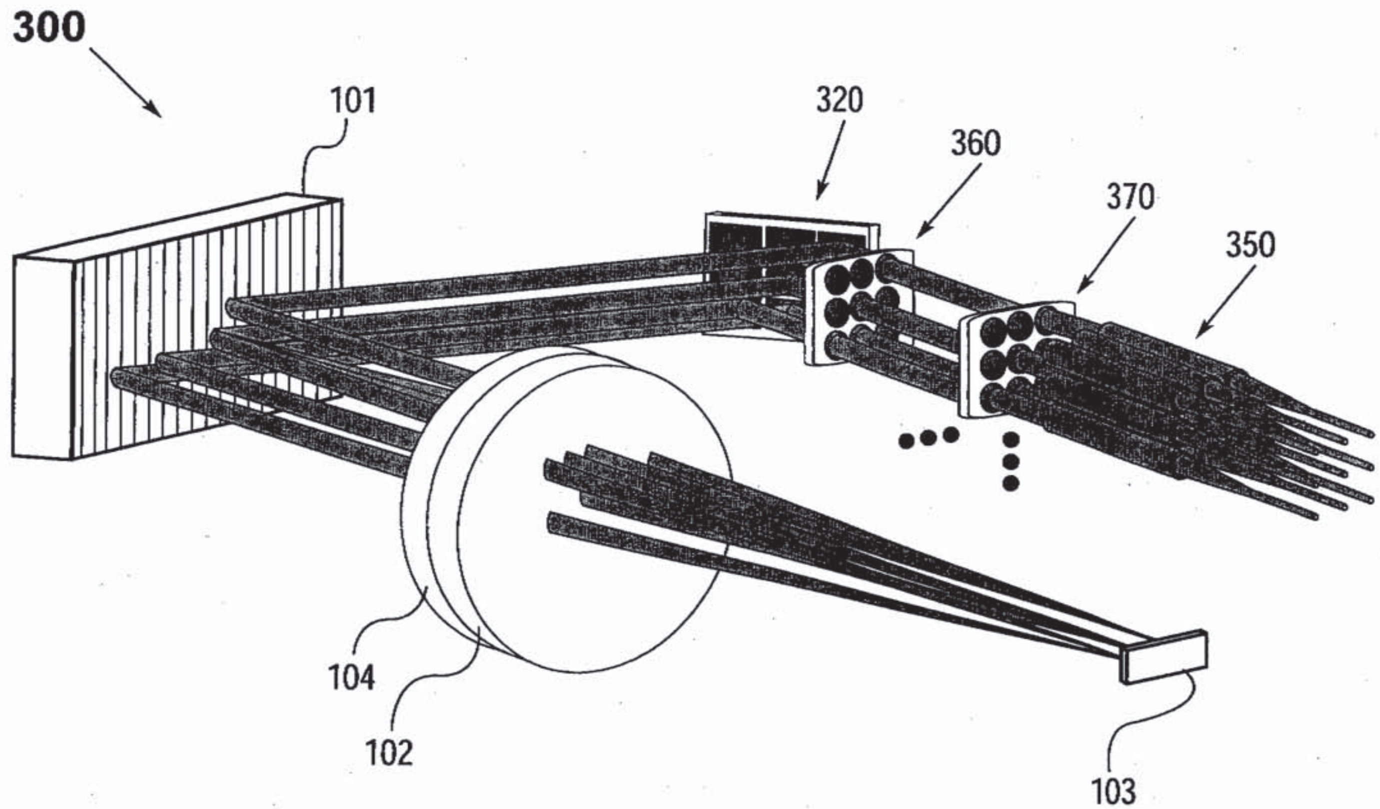

Fig. 3

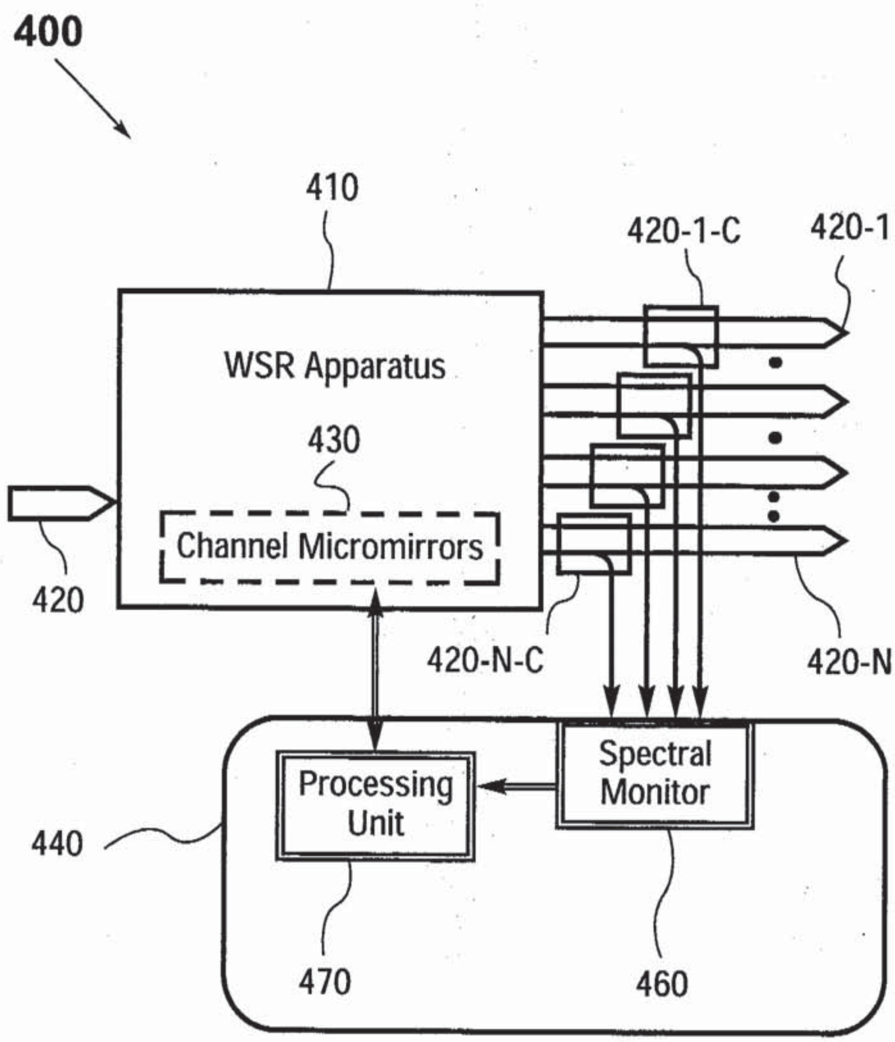
400
410
WSR Apparatus
430
Channel Micromirrors
420
420-1-C
420-1
420-N-C
420-N
440
Processing Unit
Spectral Monitor
470
460

Fig. 4A

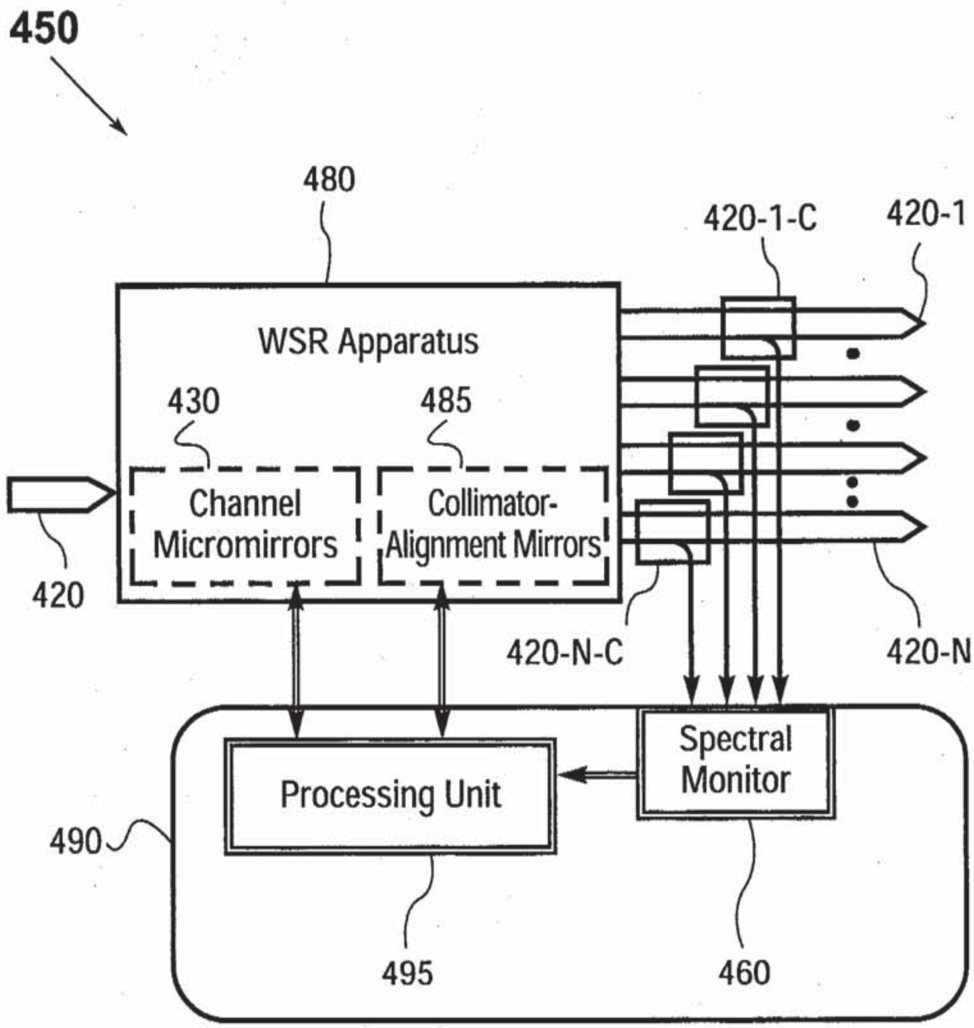
450
480
WSR Apparatus
430
485
Channel Micromirrors
Collimator-Alignment Mirrors
420
420-1-C
420-1
420-N-C
420-N
Spectral Monitor
Processing Unit
490
495
460

Fig. 4B

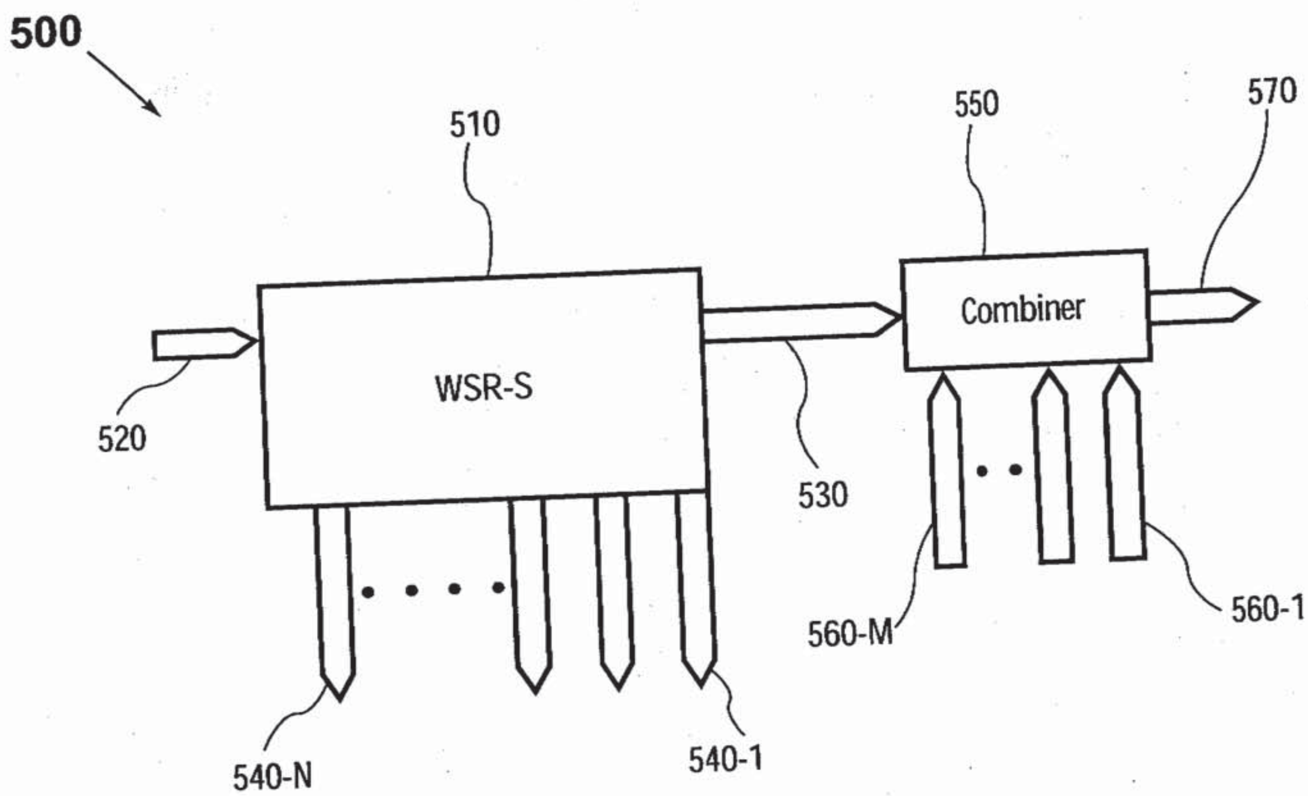

Fig. 5

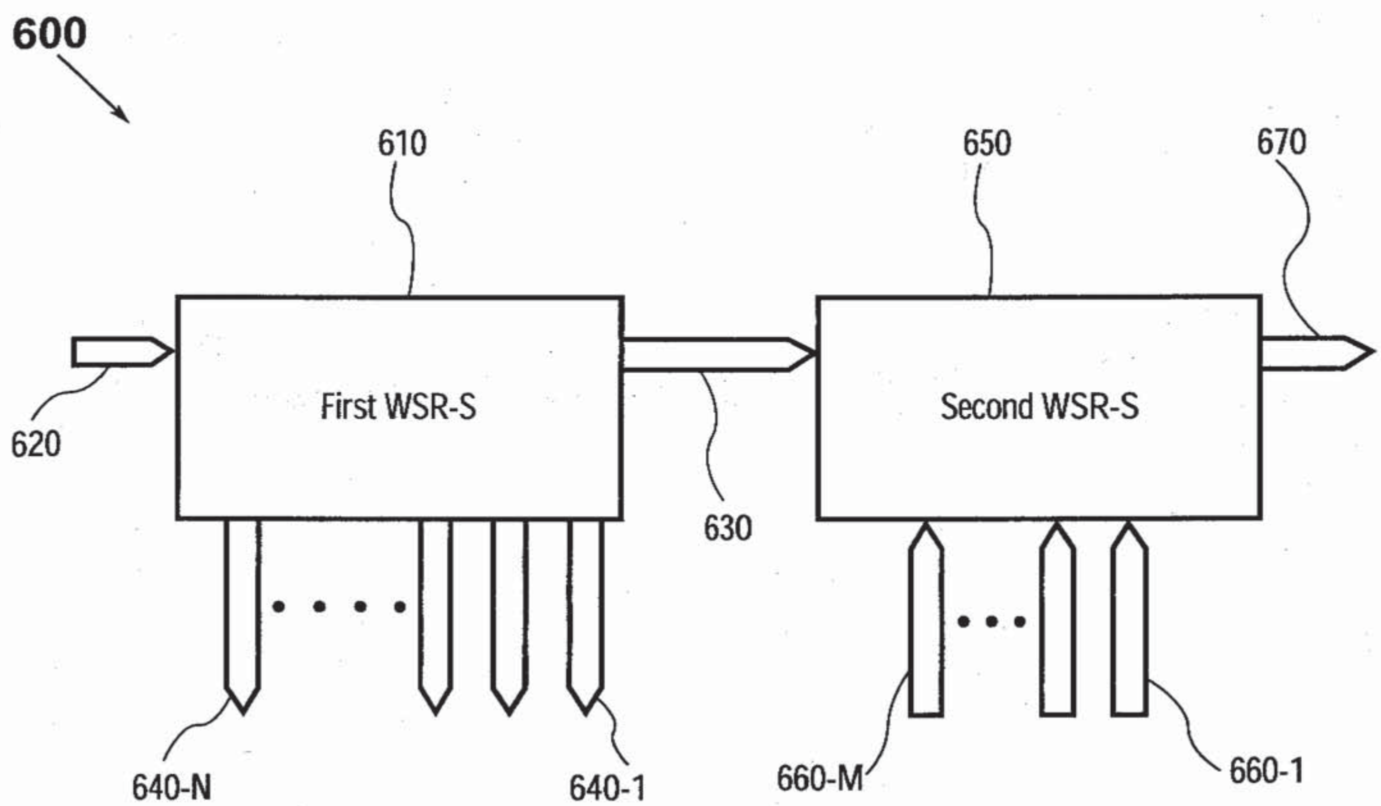
600
610
650
670
620
First WSR-S
Second WSR-S
630
640-N
640-1
660-M
660-1

Fig. 6

PATENT APPLICATION FEE DETERMINATION RECORD
Effective October 1, 2001

Application or Docket Number

CLAIMS AS FILED - PART I

RCE

	(Column 1)	(Column 2)
TOTAL CLAIMS		
FOR	NUMBER FILED	NUMBER EXTRA
TOTAL CHARGEABLE CLAIMS	minus 20=	*
INDEPENDENT CLAIMS	minus 3 =	*
MULTIPLE DEPENDENT CLAIM PRESENT		☐

* If the difference in column 1 is less than zero, enter "0" in column 2

SMALL ENTITY TYPE ☐ RATE	FEE	OR	OTHER THAN SMALL ENTITY RATE	FEE
BASIC FEE	370.00	OR	BASIC FEE	740.00
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL	370	OR	TOTAL	

pd

CLAIMS AS AMENDED - PART II

AMENDMENT A

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
Total	*	Minus	**	=
Independent	*	Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT B

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
Total	*	Minus	**	=
Independent	*	Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT C

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
Total	*	Minus	**	=
Independent	*	Minus	***	=
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

RATE	ADDITIONAL FEE	OR	RATE	ADDITIONAL FEE
X$ 9=		OR	X$18=	
X42=		OR	X84=	
+140=		OR	+280=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

ORM PTO-875 (Rev. 8/01)

☆U.S.GPO:2001 482-124/59197

Patent and Trademark Office, U.S. DEPARTMENT OF COMMERCE

Application or Docket Number

2102393-991101

PATENT APPLICATION FEE DETERMINATION RECORD

Effective October 1, 2000

CLAIMS AS FILED - PART I

	(Column 1)	(Column 2)	SMALL ENTITY TYPE RATE	FEE	OR	OTHER THAN SMALL ENTITY RATE	FEE
TOTAL CLAIMS	67						
FOR	NUMBER FILED	NUMBER EXTRA	BASIC FEE	355.00	OR	BASIC FEE	710.00
TOTAL CHARGEABLE CLAIMS	67 minus 20=	* 47	X$ 9=	423.00	OR	X$18=	
INDEPENDENT CLAIMS	6 minus 3 =	* 3	X40=	120.00	OR	X80=	
MULTIPLE DEPENDENT CLAIM PRESENT ☐			+135=		OR	+270=	
			TOTAL	898.00	OR	TOTAL	

* If the difference in column 1 is less than zero, enter "0" in column 2

CLAIMS AS AMENDED - PART II

AMENDMENT A

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
Total	*	Minus	**	=	X$ 9=		OR	X$18=	
Independent	*	Minus	***	=	X40=		OR	X80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐					+135=		OR	+270=	
					TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT B

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
Total	*	Minus	**	=	X$ 9=		OR	X$18=	
Independent	*	Minus	***	=	X40=		OR	X80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐					+135=		OR	+270=	
					TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

AMENDMENT C

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE	ADDITIONAL FEE	OR	OTHER THAN SMALL ENTITY RATE	ADDITIONAL FEE
Total	*	Minus	**	=	X$ 9=		OR	X$18=	
Independent	*	Minus	***	=	X40=		OR	X80=	
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM ☐					+135=		OR	+270=	
					TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

CLAIMS ONLY

SERIAL NO. 09938426

FILING DATE

APPLICANT(S)

CLAIMS

	AS FILED		AFTER 1st AMENDMENT		AFTER 2nd AMENDMENT	
	IND.	DEP.	IND.	DEP.	IND.	DEP.
1	/					
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47		/				
48		/				
49		/				
50		/				
TOTAL IND.	6					
TOTAL DEP.	61					
TOTAL CLAIMS	67					

	*		*		*	
	IND.	DEP.	IND.	DEP.	IND.	DEP.
51		/				
52		/				
53		/				
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94						
95						
96						
97						
98						
99						
100						
TOTAL IND.						
TOTAL DEP.						
TOTAL CLAIMS						

*MAY BE USED FOR ADDITIONAL CLAIMS OR ADMENDMENTS

US 20020131687A1

(19) United States
(12) Patent Application Publication
Wilde
(10) Pub. No.: US 2002/0131687 A1
(43) Pub. Date: Sep. 19, 2002

(54) RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

(76) Inventor: Jeffrey P. Wilde, Los Gatos, CA (US)

Correspondence Address:
David Alberti
Gray Cary Ware & Freidenrich
1755 Embarcadero Road
Palo Alto, CA 94303 (US)

(21) Appl. No.: 09/938,426

(22) Filed: Aug. 23, 2001

Related U.S. Application Data

(60) Provisional application No. 60/277,217, filed on Mar. 19, 2001.

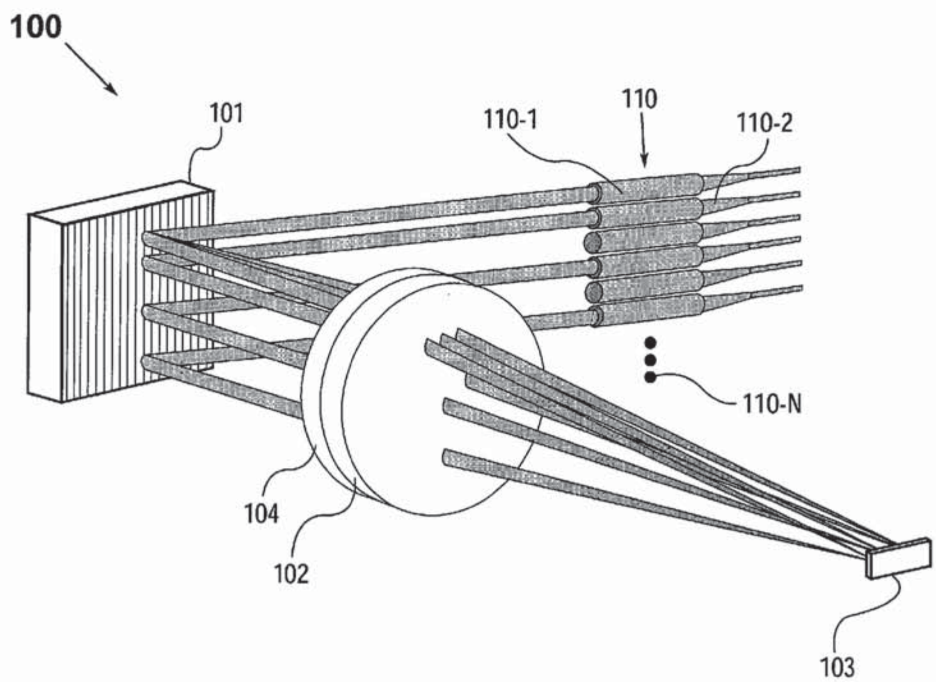
Publication Classification

(51) Int. Cl.[7] G02B 6/293

(52) U.S. Cl. 385/24; 385/33; 385/47

(57) ABSTRACT

This invention provides a novel wavelength-separating-routing (WSR) apparatus that uses a diffraction grating to separate a multi-wavelength optical signal by wavelength into multiple spectral channels, which are then focused onto an array of corresponding channel micromirrors. The channel micromirrors are individually controllable and continuously pivotable to reflect the spectral channels into selected output ports. As such, the inventive WSR apparatus is capable of routing the spectral channels on a channel-by-channel basis and coupling any spectral channel into any one of the output ports. The WSR apparatus of the present invention may be further equipped with servo-control and spectral power-management capabilities, thereby maintaining the coupling efficiencies of the spectral channels into the output ports at desired values. The WSR apparatus of the present invention can be used to construct a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for WDM optical networking applications.



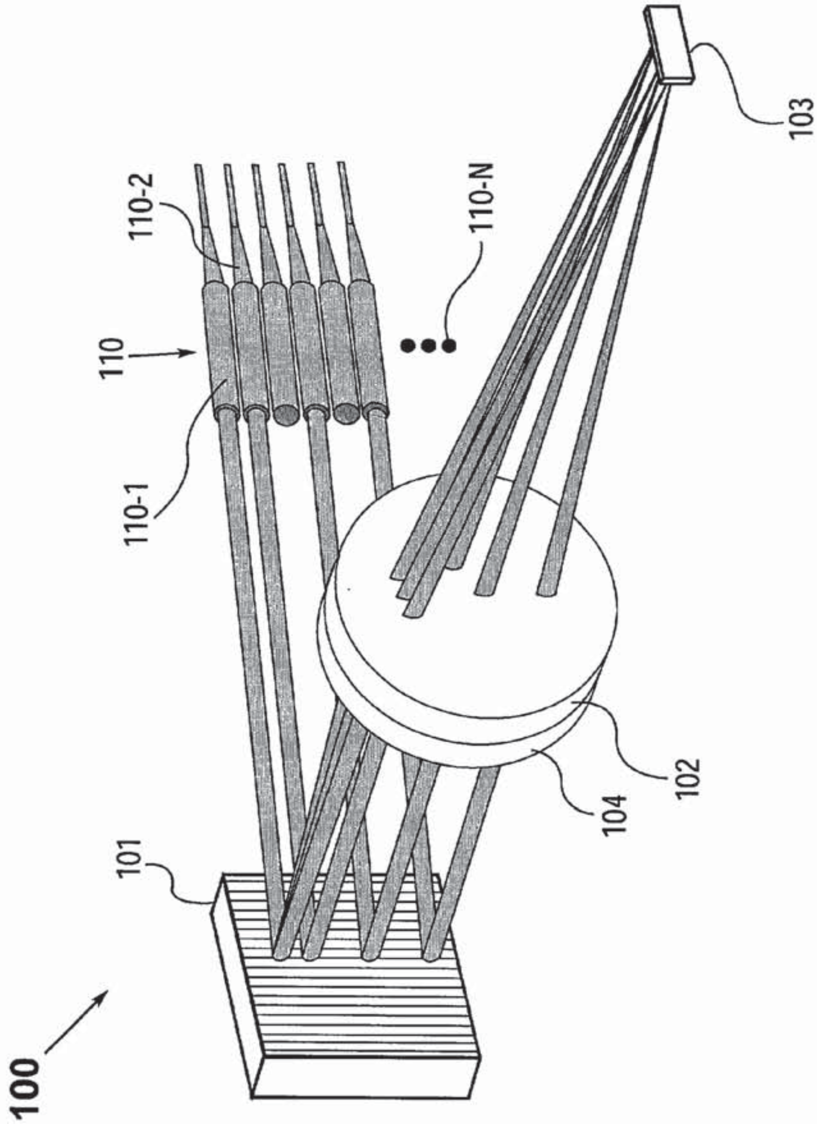


Fig. 1A

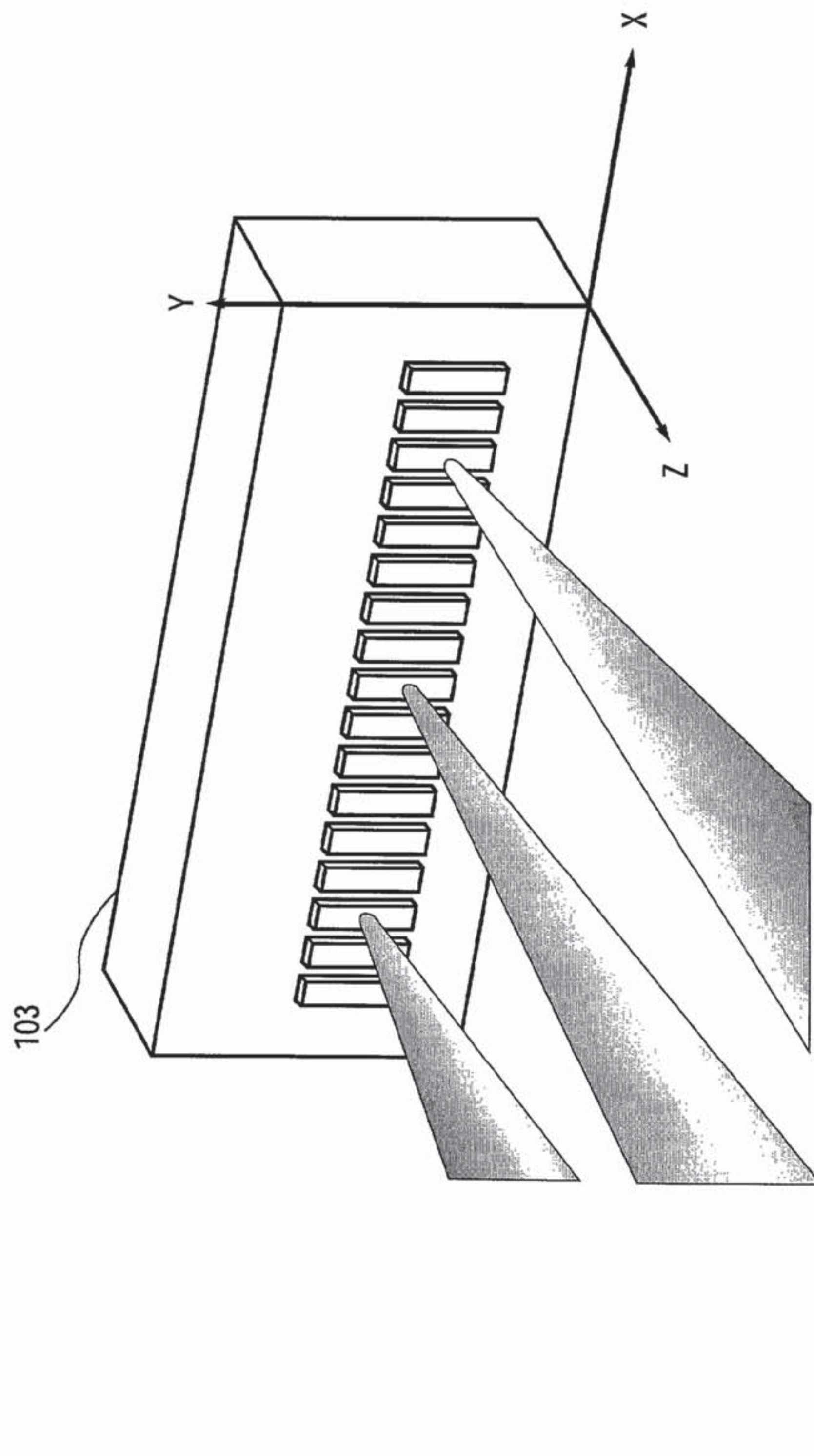


Fig. 1B

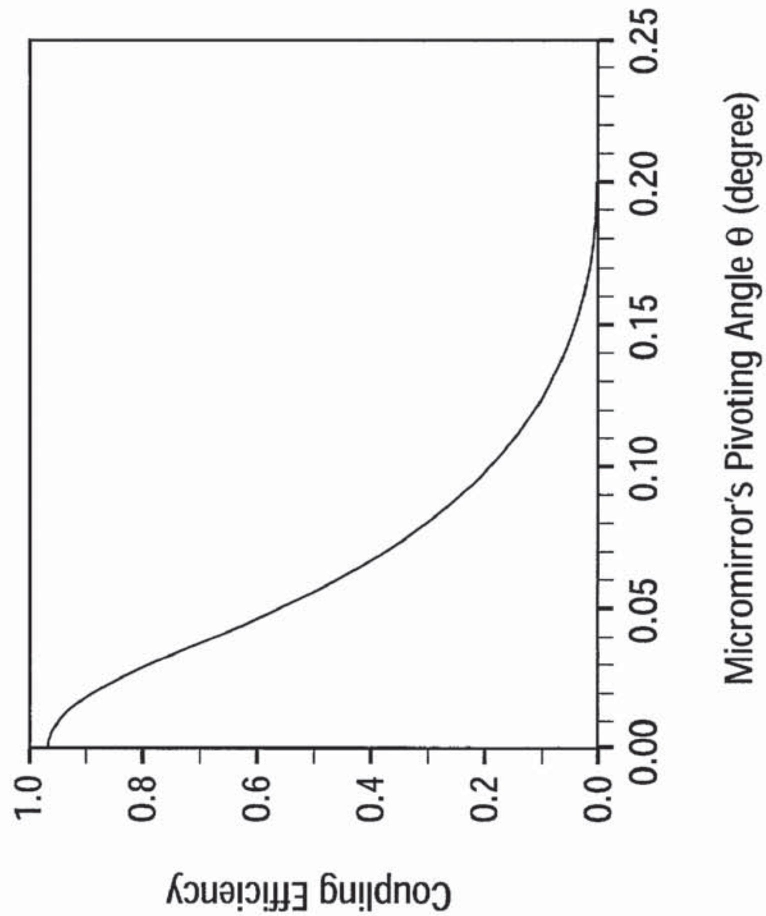

Coupling Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
Micromirror's Pivoting Angle θ (degree)

Fig. 1C

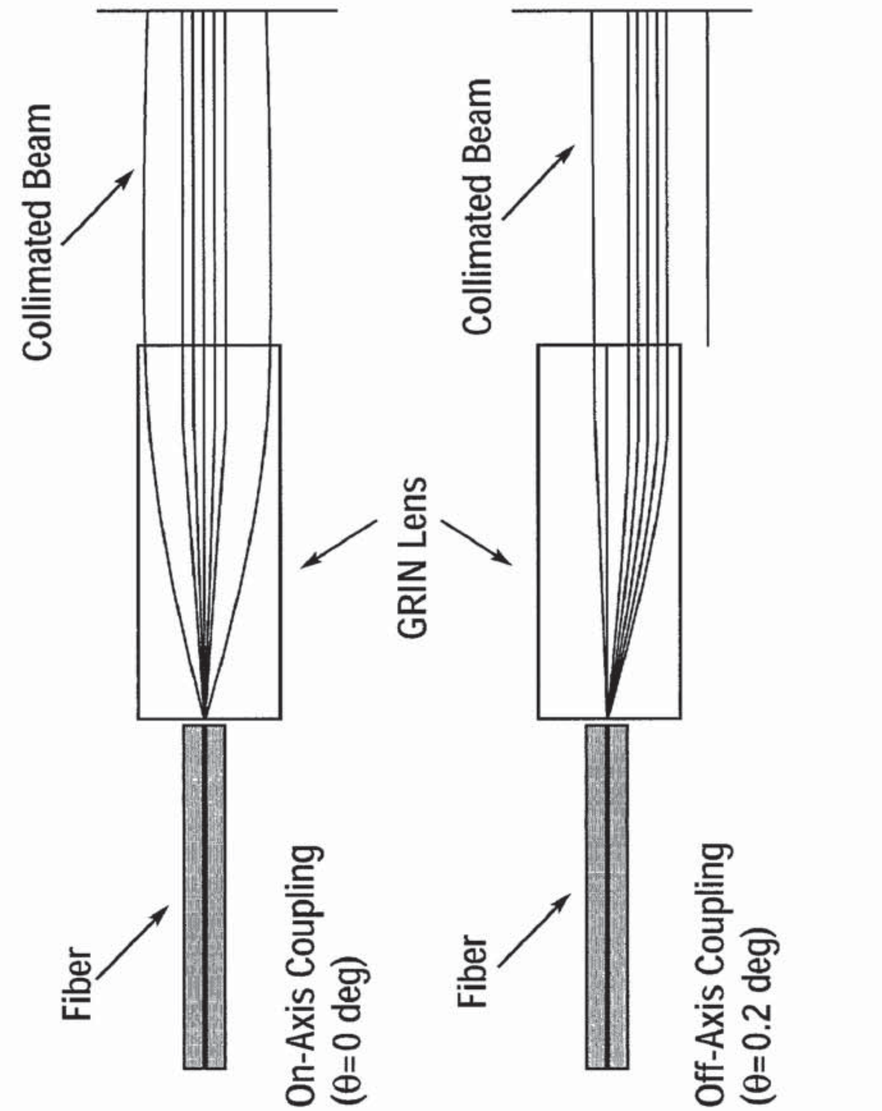

Collimated Beam
GRIN Lens
Fiber
On-Axis Coupling
(θ=0 deg)
Collimated Beam
Fiber
Off-Axis Coupling
(θ=0.2 deg)

Fig. 1D

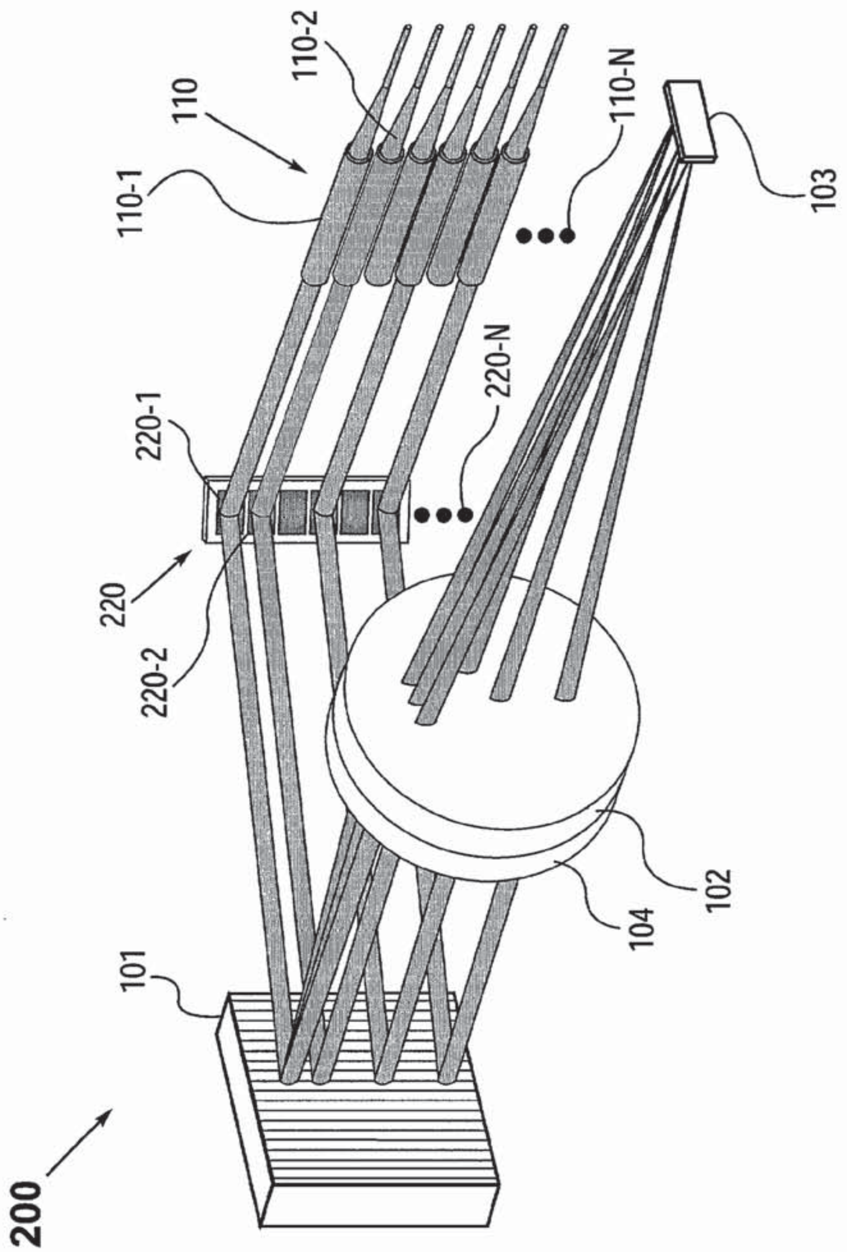


Fig. 2A

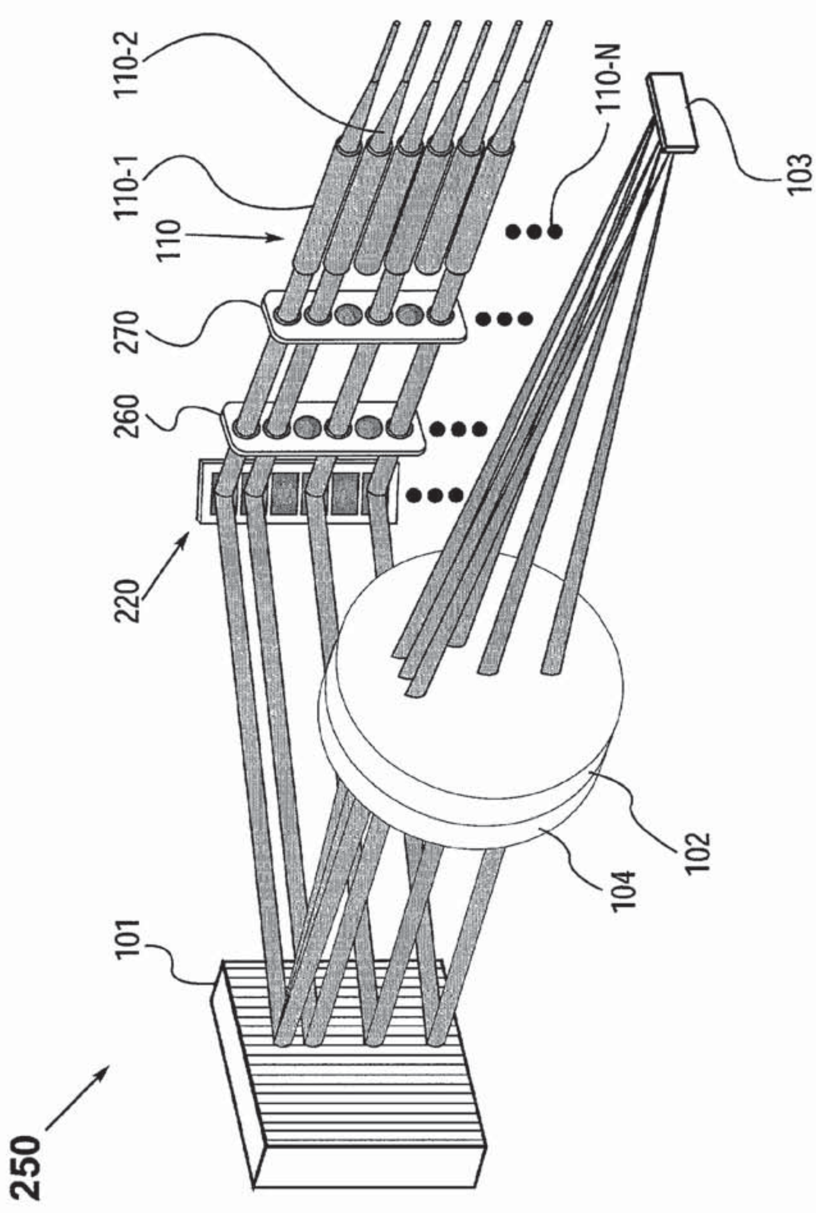


Fig. 2B

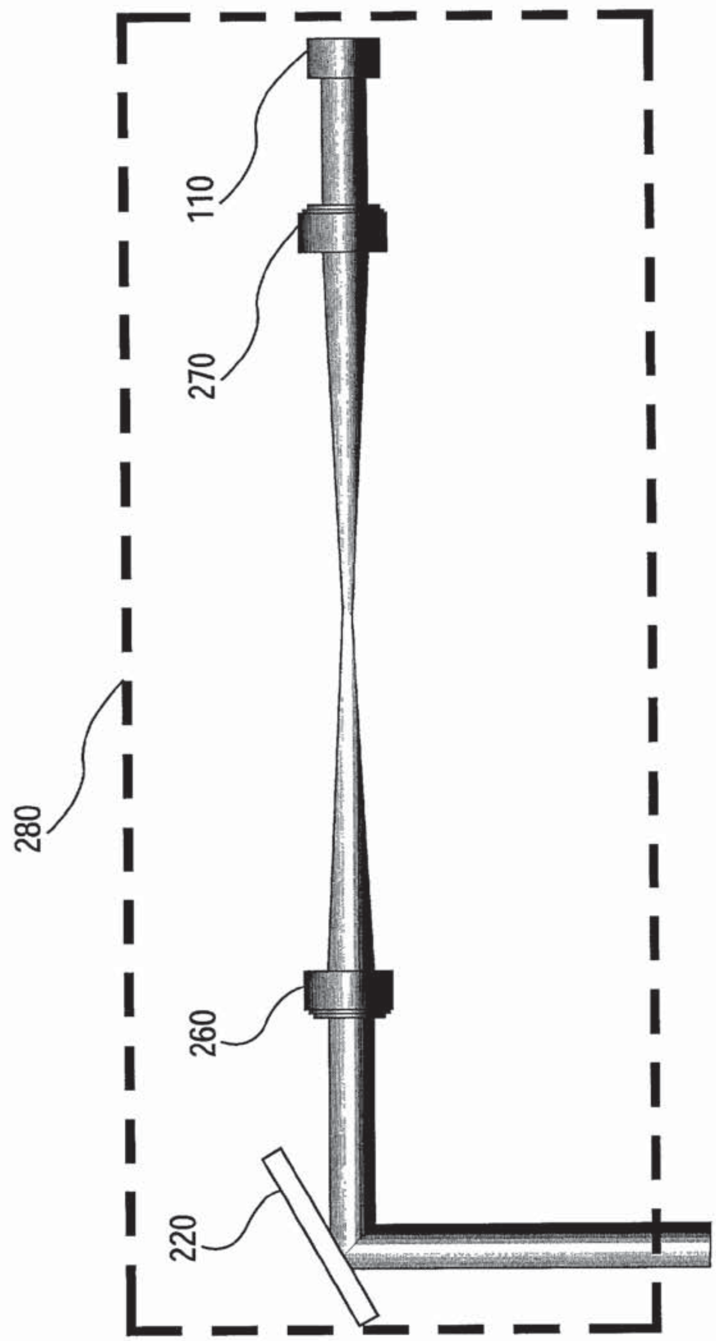


Fig. 2C

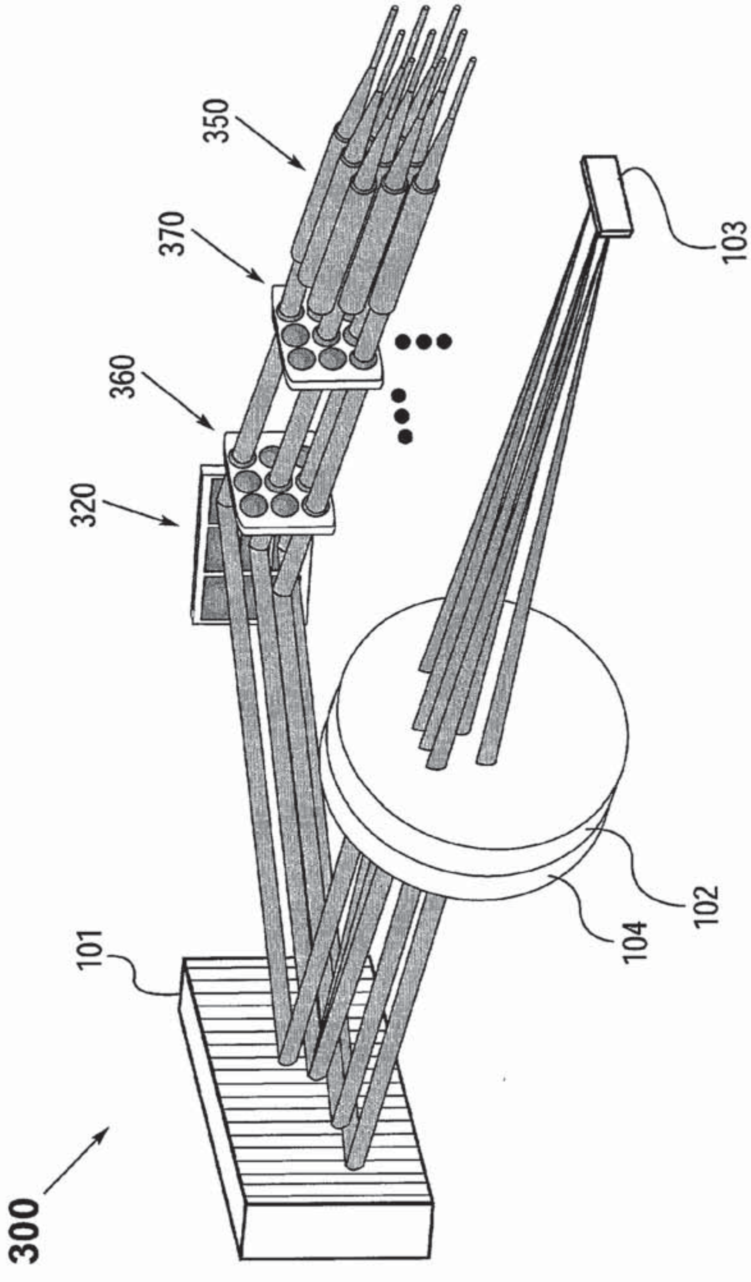


Fig. 3

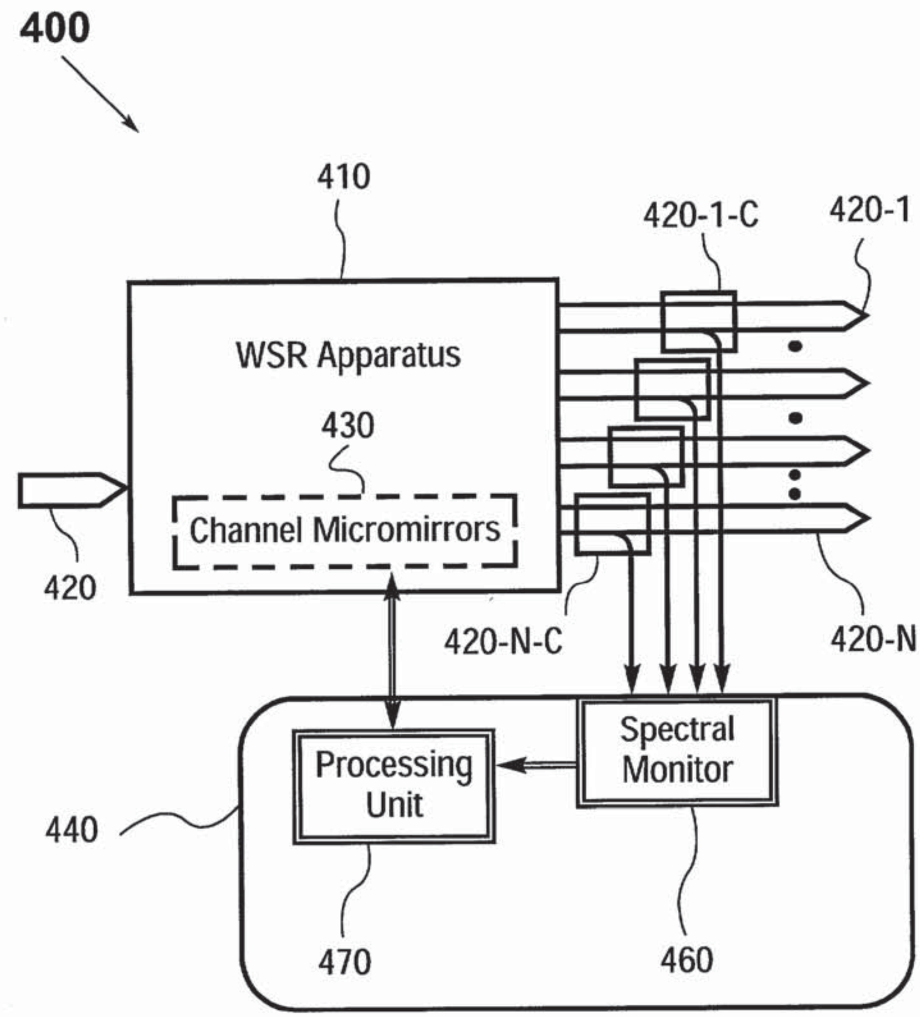

400
410
WSR Apparatus
430
Channel Micromirrors
420
420-1-C
420-1
420-N-C
420-N
440
Processing Unit
Spectral Monitor
470
460

Fig. 4A

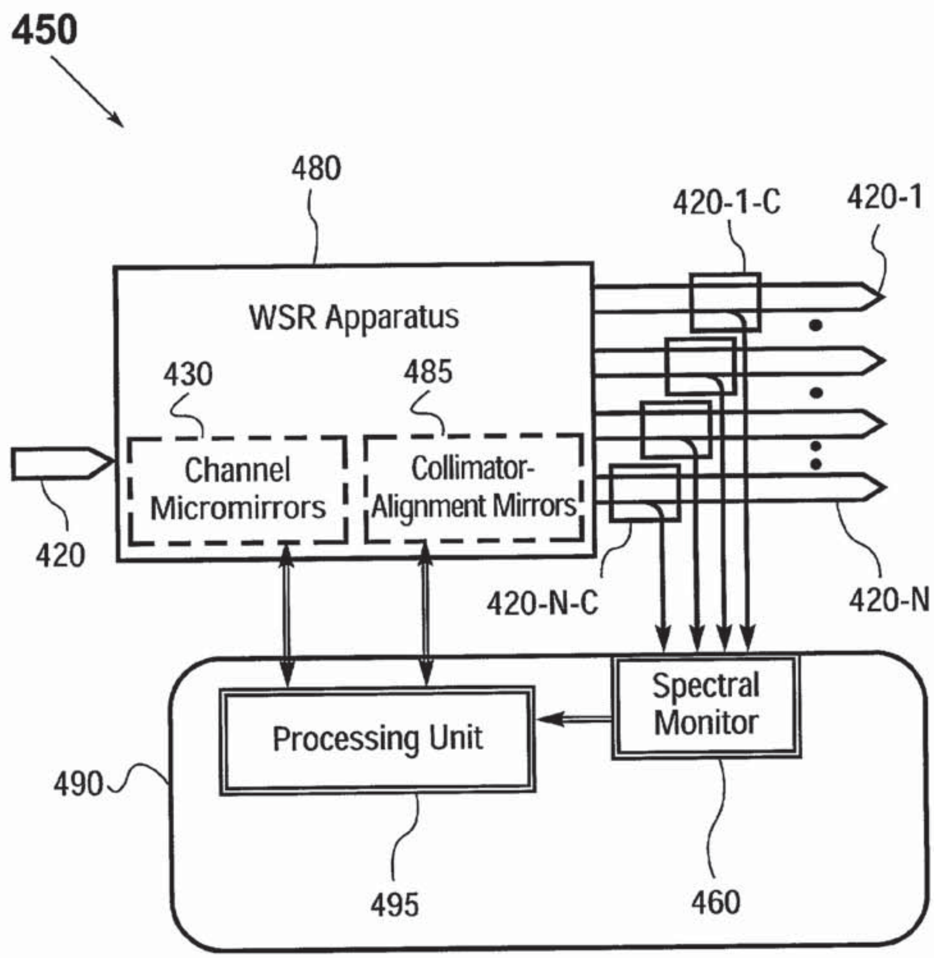

450
480
420-1-C
420-1
WSR Apparatus
430
485
Channel Micromirrors
Collimator-Alignment Mirrors
420
420-N-C
420-N
Spectral Monitor
Processing Unit
490
495
460

Fig. 4B

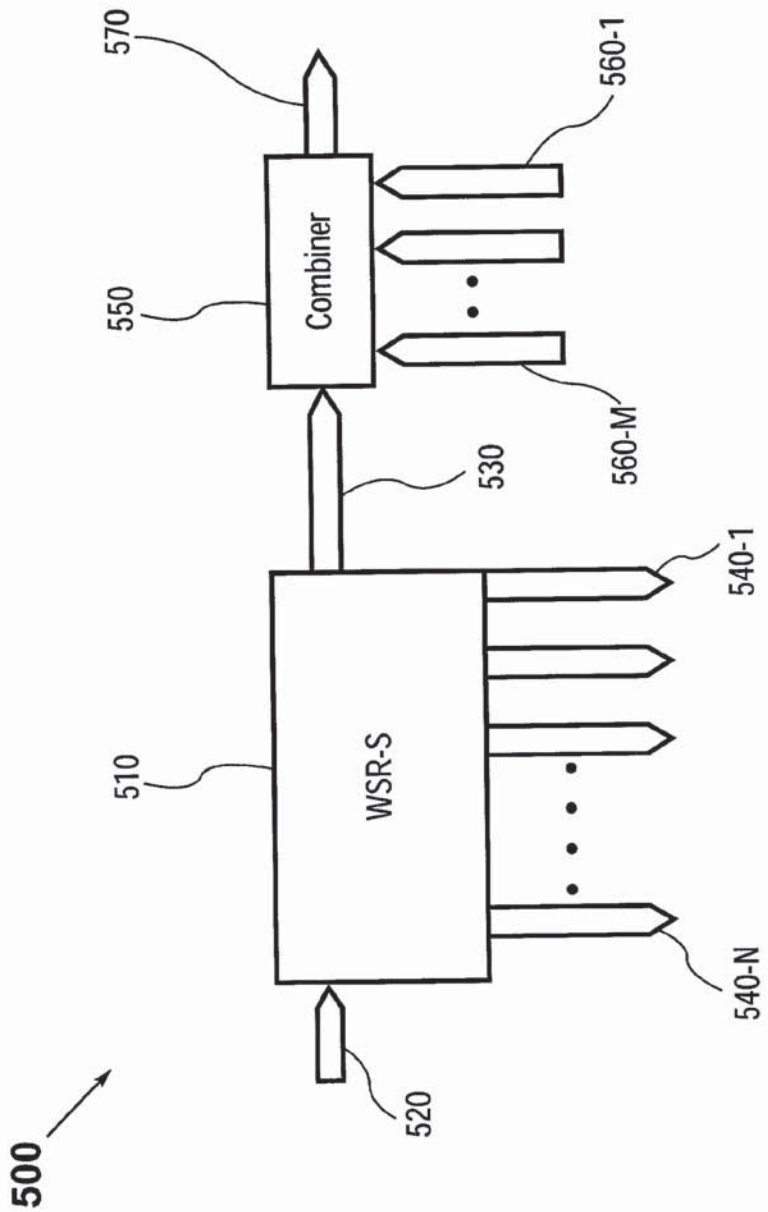


Fig. 5

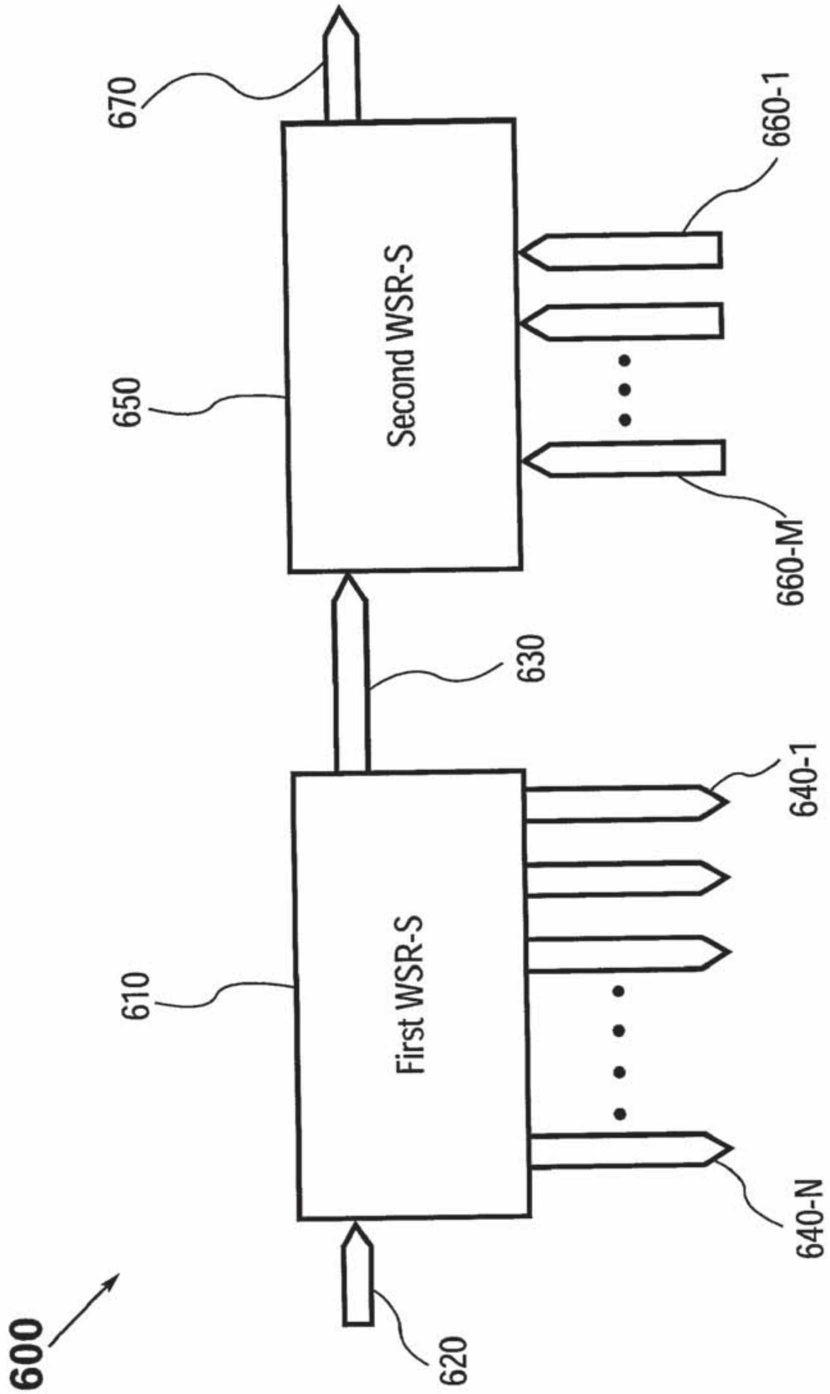

600
620
610
First WSR-S
640-1
640-N
630
650
Second WSR-S
670
660-1
660-M

Fig. 6

RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of U.S. Provisional Patent Application No. 60/277,217, filed Mar. 19, 2001, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates generally to optical communication systems. More specifically, it relates to a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for wavelength division multiplexed optical networking applications.

BACKGROUND

[0003] As fiber-optic communication networks rapidly spread into every walk of modem life, there is a growing demand for optical components and subsystems that enable the fiber-optic communications networks to be increasingly scalable, versatile, robust, and cost-effective.

[0004] Contemporary fiber-optic communications networks commonly employ wavelength division multiplexing (WDM), for it allows multiple information (or data) channels to be simultaneously transmitted on a single optical fiber by using different wavelengths and thereby significantly enhances the information bandwidth of the fiber. The prevalence of WDM technology has made optical add-drop multiplexers indispensable building blocks of modem fiber-optic communication networks. An optical add-drop multiplexer (OADM) serves to selectively remove (or drop) one or more wavelengths from a multiplicity of wavelengths on an optical fiber, hence taking away one or more data channels from the traffic stream on the fiber. It further adds one or more wavelengths back onto the fiber, thereby inserting new data channels in the same stream of traffic. As such, an OADM makes it possible to launch and retrieve multiple data channels (each characterized by a distinct wavelength) onto and from an optical fiber respectively, without disrupting the overall traffic flow along the fiber. Indeed, careful placement of the OADMs can dramatically improve an optical communication network's flexibility and robustness, while providing significant cost advantages.

[0005] Conventional OADMs in the art typically employ multiplexers/demultiplexers (e.g, waveguide grating routers or arrayed-waveguide gratings), tunable filters, optical switches, and optical circulators in a parallel or serial architecture to accomplish the add and drop functions. In the parallel architecture, as exemplified in U.S. Pat. No. 5,974,207, a demultiplexer (e.g., a waveguide grating router) first separates a multi-wavelength signal into its constituent spectral components. A wavelength switching/routing means (e.g., a combination of optical switches and optical circulators) then serves to drop selective wavelengths and add others. Finally, a multiplexer combines the remaining (i.e., the pass-through) wavelengths into an output multi-wavelength optical signal. In the serial architecture, as exemplified in U.S. Pat. No. 6,205,269, tunable filters (e.g., Bragg fiber gratings) in combination with optical circulators are used to separate the drop wavelengths from the pass-through wavelengths and subsequently launch the add channels into the pass-through path. And if multiple wavelengths are to be added and dropped, additional multiplexers and demultiplexers are required to demultiplex the drop wavelengths and multiplex the add wavelengths, respectively. Irrespective of the underlying architecture, the OADMs currently in the art are characteristically high in cost, and prone to significant optical loss accumulation. Moreover, the designs of these OADMs are such that it is inherently difficult to reconfigure them in a dynamic fashion.

[0006] U.S. Pat. No. 6,204,946 to Askyuk et al. discloses an OADM that makes use of free-space optics in a parallel construction. In this case, a multi-wavelength optical signal emerging from an input port is incident onto a ruled diffraction grating. The constituent spectral channels thus separated are then focused by a focusing lens onto a linear array of binary micromachined mirrors. Each micromirror is configured to operate between two discrete states, such that it either retroreflects its corresponding spectral channel back into the input port as a pass-through channel, or directs its spectral channel to an output port as a drop channel. As such, the pass-through signal (i.e., the combined pass-through channels) shares the same input port as the input signal. An optical circulator is therefore coupled to the input port, to provide necessary routing of these two signals. Likewise, the drop channels share the output port with the add channels. An additional optical circulator is thereby coupled to the output port, from which the drop channels exit and the add channels are introduced into the output port. The add channels are subsequently combined with the pass-through signal by way of the diffraction grating and the binary micromirrors.

[0007] Although the aforementioned OADM disclosed by Askyuk et al. has the advantage of performing wavelength separating and routing in free space and thereby incurring less optical loss, it suffers a number of limitations. First, it requires that the pass-through signal share the same port/fiber as the input signal. An optical circulator therefore has to be implemented, to provide necessary routing of these two signals. Likewise, all the add and drop channels enter and leave the OADM through the same output port, hence the need for another optical circulator. Moreover, additional means must be provided to multiplex the add channels before entering the system and to demultiplex the drop channels after exiting the system. This additional multiplexing/demultiplexing requirement adds more cost and complexity that can restrict the versatility of the OADM thus-constructed. Second, the optical circulators implemented in this OADM for various routing purposes introduce additional optical losses, which can accumulate to a substantial amount. Third, the constituent optical components must be in a precise alignment, in order for the system to achieve its intended purpose. There are, however, no provisions provided for maintaining the requisite alignment; and no mechanisms implemented for overcoming degradation in the alignment owing to environmental effects such as thermal and mechanical disturbances over the course of operation.

[0008] U.S. Pat. No. 5,906,133 to Tomlinson discloses an OADM that makes use of a design similar to that of Aksyuk et al. There are input, output, drop and add ports implemented in this case. By positioning the four ports in a specific arrangement, each micromirror, notwithstanding switchable between two discrete positions, either reflects its corresponding channel (coming from the input port) to the output port, or concomitantly reflects its channel to the drop port and an incident add channel to the output port. As such, this OADM is able to perform both the add and drop functions without involving additional optical components (such as optical circulators used in the system of Aksyuk et al.). However, because a single drop port is designated for all the drop channels and a single add port is designated for all the add channels, the add channels would have to be multiplexed before entering the add port and the drop channels likewise need to be demutiplxed upon exiting from the drop port. Moreover, as in the case of Askyuk et al., there are no provisions provided for maintaining requisite optical alignment in the system, and no mechanisms implemented for combating degradation in the alignment due to environmental effects over the course of operation.

[0009] As such, the prevailing drawbacks suffered by the OADMs currently in the art are summarized as follows:

[0010] 1) The wavelength routing is intrinsically static, rendering it difficult to dynamically reconfigure these OADMs.

[0011] 2) Add and/or drop channels often need to be multiplexed and/or demultiplexed, thereby imposing additional complexity and cost.

[0012] 3) Stringent fabrication tolerance and painstaking optical alignment are required. Moreover, the optical alignment is not actively maintained, rendering it susceptible to environmental effects such as thermal and mechanical disturbances over the course of operation.

[0013] 4) In an optical communication network, OADMs are typically in a ring or cascaded configuration. In order to mitigate the interference amongst OADMs, which often adversely affects the overall performance of the network, it is essential that the power levels of spectral channels entering and exiting each OADM be managed in a systematic way, for instance, by introducing power (or gain) equalization at each stage. Such a power equalization capability is also needed for compensating for non-uniform gain caused by optical amplifiers (e.g., erbium doped fiber amplifiers) in the network. There lacks, however, a systematic and dynamic management of the power levels of various spectral channels in these OADMs.

[0014] 5) The inherent high cost and heavy optical loss further impede the wide application of these OADMs.

[0015] In view of the foregoing, there is an urgent need in the art for optical add-drop multiplexers that overcome the aforementioned shortcomings in a simple, effective, and economical construction.

SUMMARY

[0016] The present invention provides a wavelength-separating-routing (WSR) apparatus and method which employ an array of fiber collimators serving as an input port and a plurality of output ports; a wavelength-separator; a beam-focuser; and an array of channel micromirrors.

[0017] In operation, a multi-wavelength optical signal emerges from the input port. The wavelength-separator separates the multi-wavelength optical signal into multiple spectral channels, each characterized by a distinct center wavelength and associated bandwidth. The beam-focuser focuses the spectral channels into corresponding spectral spots. The channel micromirrors are positioned such that each channel micromirror receives one of the spectral channels. The channel micromirrors are individually controllable and movable, e.g., continuously pivotable (or rotatable), so as to reflect the spectral channels into selected ones of the output ports. As such, each channel micromirror is assigned to a specific spectral channel, hence the name "channel micromirror". And each output port may receive any number of the reflected spectral channels.

[0018] A distinct feature of the channel micromirrors in the present invention, in contrast to those used in the prior art, is that the motion, e.g., pivoting (or rotation), of each channel micromirror is under analog control such that its pivoting angle can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port.

[0019] In the WSR apparatus of the present invention, the wavelength-separator may be provided by a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a curved diffraction grating, a dispersing prism, or other wavelength-separating means known in the art. The beam-focuser may be a single lens, an assembly of lenses, or other beam-focusing means known in the art. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting means known in the art. And each channel micromirror may be pivotable about one or two axes. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional or two-dimensional array. In the latter case, the channel micromirrors must be pivotable biaxially.

[0020] The WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, in optical communication with the wavelength-separator and the fiber collimators, for adjusting the alignment of the input multi-wavelength signal and directing the spectral channels into the selected output ports by way of angular control of the collimated beams. Each collimator-alignment mirror may be rotatable about one or two axes. The collimator-alignment mirrors may be arranged in a one-dimensional or two-dimensional array. First and second arrays of imaging lenses may additionally be optically interposed between the collimator-alignment mirrors and the fiber collimators in a telecentric arrangement, thereby "imaging" the collimator-alignment mirrors onto the corresponding fiber collimators to ensure an optimal alignment.

[0021] The WSR apparatus of the present invention may further include a servo-control assembly, in communication with the channel micromirrors and the output ports. The servo-control assembly serves to monitor the power levels of the spectral channels coupled into the output ports and further provide control of the channel micromirrors on an individual basis, so as to maintain a predetermined coupling efficiency of each spectral channel in one of the output ports. As such, the servo-control assembly provides dynamic control of the coupling of the spectral channels into the respective output ports and actively manages the power levels of the spectral channels coupled into the output ports. (If the WSR apparatus includes an array of collimator-alignment mirrors as described above, the servo-control assembly may additionally provide dynamic control of the collimator-alignment mirrors.) Moreover, the utilization of such a servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during assembly of a WSR apparatus of the present invention, and further enables the system to correct for shift in optical alignment over the course of operation. A WSR apparatus incorporating a servo-control assembly thus described is termed a WSR-S apparatus, thereinafter in the present invention.

[0022] Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices, including a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs), as exemplified in the following embodiments.

[0023] One embodiment of an OADM of the present invention comprises an aforementioned WSR-S (or WSR) apparatus and an optical combiner. The output ports of the WSR-S apparatus include a pass-through port and one or more drop ports, each carrying any number of the spectral channels. The optical combiner is coupled to the pass-through port, serving to combine the pass-through channels with one or more add spectral channels. The combined optical signal constitutes an output signal of the system. The optical combiner may be an N×1 (N≧2) broadband fiber-optic coupler, for instance, which also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the system.

[0024] In another embodiment of an OADM of the present invention, a first WSR-S (or WSR) apparatus is cascaded with a second WSR-S (or WSR) apparatus. The output ports of the first WSR-S (or WSR) apparatus include a pass-through port and one or more drop ports.

[0025] The second WSR-S (or WSR) apparatus includes a plurality of input ports and an exiting port. The configuration is such that the pass-through channels from the first WSR-S apparatus and one or more add channels are directed into the input ports of the second WSR-S apparatus, and consequently multiplexed into an output multi-wavelength optical signal directed into the exiting port of the second WSR-S apparatus. That is to say that in this embodiment, one WSR-S apparatus (e.g., the first one) effectively performs a dynamic drop function, whereas the other WSR-S apparatus (e.g., the second one) carries out a dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped, other than those imposed by the overall communication system. Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of the WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions in a network environment.

[0026] Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Various changes, substitutions, and alternations can be made herein, without departing from the principles and the scope of the invention. Accordingly, a skilled artisan can design an OADM in accordance with the present invention, to best suit a given application.

[0027] All in all, the OADMs of the present invention provide many advantages over the prior art devices, notably:

[0028] 1) By advantageously employing an array of channel micromirrors that are individually and continuously controllable, an OADM of the present invention is capable of routing the spectral channels on a channel-by-channel basis and directing any spectral channel into any one of the output ports. As such, its underlying operation is dynamically reconfigurable, and its underlying architecture is intrinsically scalable to a large number of channel counts.

[0029] 2) The add and drop spectral channels need not be multiplexed and demultiplexed before entering and after leaving the OADM respectively. And there are not fundamental restrictions on the wavelengths to be added or dropped.

[0030] 3) The coupling of the spectral channels into the output ports is dynamically controlled by a servo-control assembly, rendering the OADM less susceptible to environmental effects (such as thermal and mechanical disturbances) and therefore more robust in performance. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced.

[0031] 4) The power levels of the spectral channels coupled into the output ports can be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) by way of the servo-control assembly. This spectral power-management capability as an integral part of the OADM will be particularly desirable in WDM optical networking applications.

[0032] 5) The use of free-space optics provides a simple, low loss, and cost-effective construction. Moreover, the utilization of the servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during initial assembly, enabling the OADM to be simpler and more adaptable in structure, lower in cost and optical loss.

[0033] 6) The underlying OADM architecture allows a multiplicity of the OADMs according to the present invention to be readily assembled (e.g., cascaded) for WDM optical networking applications.

[0034] The novel features of this invention, as well as the invention itself, will be best understood from the following drawings and detailed description.

BRIEF DESCRIPTION OF THE FIGURES

[0035] FIGS. 1A-1D show a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention, and the modeling results demonstrating the performance of the WSR apparatus;

[0036] FIGS. 2A-2C depict second and third embodiments of a WSR apparatus according to the present invention;

[0037] **FIG. 3** shows a fourth embodiment of a WSR apparatus according to the present invention;

[0038] FIGS. **4**A-**4**B show schematic illustrations of two embodiments of a WSR-S apparatus comprising a WSR apparatus and a servo-control assembly, according to the present invention;

[0039] **FIG. 5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention; and

[0040] **FIG. 6** shows an alternative embodiment of an OADM according to the present invention.

DETAILED DESCRIPTION

[0041] In this specification and appending claims, a "spectral channel" is characterized by a distinct center wavelength and associated bandwidth. Each spectral channel may carry a unique information signal, as in WDM optical networking applications.

[0042] **FIG. 1A** depicts a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention. By way of example to illustrate the general principles and the topological structure of a wavelength-separating-routing (WSR) apparatus of the present invention, the WSR apparatus **100** comprises multiple input/output ports which may be in the form of an array of fiber collimators **110**, providing an input port **110-1** and a plurality of output ports **110-2** through **110**-N (N≧3); a wavelength-separator which in one form may be a diffraction grating **101**; a beam-focuser in the form of a focusing lens **102**; and an array of channel micromirrors **103**.

[0043] In operation, a multi-wavelength optical signal emerges from the input port **110-1**. The diffraction grating **101** angularly separates the multi-wavelength optical signal into multiple spectral channels, which are in turn focused by the focusing lens **102** into a spatial array of distinct spectral spots (not shown in **FIG. 1A**) in a one-to-one correspondence. The channel micromirrors **103** are positioned in accordance with the spatial array formed by the spectral spots, such that each channel micromirror receives one of the spectral channels. The channel micromirrors **103** are individually controllable and movable, e.g., pivotable (or rotatable) under analog (or continuous) control, such that, upon reflection, the spectral channels are directed into selected ones of the output ports **110-2** through **110**-N by way of the focusing lens **102** and the diffraction grating **101**. As such, each channel micromirror is assigned to a specific spectral channel, hence the name **37** channel micromirror **38**. Each output port may receive any number of the reflected spectral channels.

[0044] For purposes of illustration and clarity, only a selective few (e.g., three) of the spectral channels, along with the input multi-wavelength optical signal, are graphically illustrated in **FIG. 1**A and the following figures. It should be noted, however, that there can be any number of the spectral channels in a WSR apparatus of the present invention (so long as the number of spectral channels does not exceed the number of channel mirrors employed in the system). It should also be noted that the optical beams representing the spectral channels shown in **FIG. 1**A and the following figures are provided for illustrative purpose only. That is, their sizes and shapes may not be drawn according to scale. For instance, the input beam and the corresponding diffracted beams generally have different cross-sectional shapes, so long as the angle of incidence upon the diffraction grating is not equal to the angle of diffraction, as is known to those skilled in the art.

[0045] In the embodiment of **FIG. 1**A, it is preferable that the diffraction grating **101** and the channel micromirrors **103** are placed respectively at the first and second (i.e., the front and back) focal points (on the opposing sides) of the focusing lens **102**. Such a telecentric arrangement allows the chief rays of the focused beams to be parallel to each other and generally parallel to the optical axis. In this application, the telecentric configuration further allows the reflected spectral channels to be efficiently coupled into the respective output ports, thereby minimizing various translational walk-off effects that may otherwise arise. Moreover, the input multi-wavelength optical signal is preferably collimated and circular in cross-section. The corresponding spectral channels diffracted from the diffraction grating **101** are generally elliptical in cross-section; they may be of the same size as the input beam in one dimension and elongated in the other dimension.

[0046] It is known that the diffraction efficiency of a diffraction grating is generally polarization-dependent. That is, the diffraction efficiency of a grating in a standard mounting configuration may be considerably higher for P-polarization that is perpendicular to the groove lines on the grating than for S-polarization that is orthogonal to P-polarization, especially as the number of groove lines (per unit length) increases. To mitigate such polarization-sensitive effects, a quarter-wave plate **104** may be optically interposed between the diffraction grating **101** and the channel micromirrors **103**, and preferably placed between the diffraction grating **101** and the focusing lens **102** as is shown in **FIG. 1A**. In this way, each spectral channel experiences a total of approximately 90-degree rotation in polarization upon traversing the quarter-wave plate **104** twice. (That is, if a beam of light has P-polarization when first encountering the diffraction grating, it would have predominantly (if not all) S-polarization upon the second encountering, and vice versa.) This ensures that all the spectral channels incur nearly the same amount of round-trip polarization dependent loss.

[0047] In the WSR apparatus **100** of **FIG. 1**A, the diffraction grating **101**, by way of example, is oriented such that the focused spots of the spectral channels fall onto the channel micromirrors **103** in a horizontal array, as illustrated in **FIG. 1B**.

[0048] Depicted in **FIG. 1B** is a close-up view of the channel micromirrors **103** shown in the embodiment of **FIG. 1A**. By way of example, the channel micromirrors **103** are arranged in a one-dimensional array along the x-axis (i.e., the horizontal direction in the figure), so as to receive the focused spots of the spatially separated spectral channels in a one-to-one correspondence. (As in the case of **FIG. 1A**, only three spectral channels are illustrated, each represented by a converging beam.) Let the reflective surface of each channel micromirror lie in the x-y plane as defined in the figure and be movable, e.g., pivotable (or deflectable) about the x-axis in an analog (or continuous) manner. Each spectral channel, upon reflection, is deflected in the y-direction (e.g., downward) relative to its incident direction, so to be directed into one of the output ports **110-2** through **110**-N shown in **FIG. 1A**.

[0049] As described above, a unique feature of the present invention is that the motion of each channel micromirror is individually and continuously controllable, such that its position, e.g., pivoting angle, can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port. To illustrate this capability, **FIG. 1C** shows a plot of coupling efficiency as a function of a channel micromirror's pivoting angle θ, provided by a ray-tracing model of a WSR apparatus in the embodiment of **FIG. 1A**. As used herein, the coupling efficiency for a spectral channel is defined as the ratio of the amount of optical power coupled into the fiber core in an output port to the total amount of optical power incident upon the entrance surface of the fiber (associated with the fiber collimator serving as the output port). In the ray-tracing model, the input optical signal is incident upon a diffraction grating with 700 lines per millimeter at a grazing angle of 85 degrees, where the grating is blazed to optimize the diffraction efficiency for the "−1" order. The focusing lens has a focal length of 100 mm. Each output port is provided by a quarter-pitch GRIN lens (2 mm in diameter) coupled to an optical fiber (see **FIG. 1D**). As displayed in **FIG. 1**C, the coupling efficiency varies with the pivoting angle θ, and it requires about a 0.2-degree change in θ for the coupling efficiency to become practically negligible in this exemplary case. As such, each spectral channel may practically acquire any coupling efficiency value by way of controlling the pivoting angle of its corresponding channel micromirror. This is also to say that variable optical attenuation at the granularity of a single wavelength can be obtained in a WSR apparatus of the present invention. **FIG. 1D** provides ray-tracing illustrations of two extreme points on the coupling efficiency vs. θ curve of **FIG. 1**C: on-axis coupling corresponding to θ=0, where the coupling efficiency is maximum; and off-axis coupling corresponding to θ=0.2 degrees, where the representative collimated beam (representing an exemplary spectral channel) undergoes a significant translational walk-off and renders the coupling efficiency practically negligible. All in all, the exemplary modeling results thus described demonstrate the unique capabilities of the WSR apparatus of the present invention.

[0050] **FIG. 1A** provides one of many embodiments of a WSR apparatus according to the present invention. In general, the wavelength-separator is a wavelength-separating means that may be a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a dispersing prism, or other types of spectral-separating means known in the art. The beam-focuser may be a focusing lens, an assembly of lenses, or other beam-focusing means known in the art. The focusing function may also be accomplished by using a curved diffraction grating as the wavelength-separator. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting elements known in the art. And each micromirror may be pivoted about one or two axes. What is important is that the pivoting (or rotational) motion of each channel micromirror be individually controllable in an analog manner, whereby the pivoting angle can be continuously adjusted so as to enable the channel micromirror to scan a spectral channel across all possible output ports. The underlying fabrication techniques for micromachined mirrors and associated actuation mechanisms are well documented in the art, see U.S. Pat. No. 5,629,790 for example. Moreover, a fiber collimator is typically in the form of a collimating lens (such as a GRIN lens) and a ferrule-mounted fiber packaged together in a mechanically rigid stainless steel (or glass) tube. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional array, a two-dimensional array, or other desired spatial pattern. For instance, they may be conveniently mounted in a linear array along a V-groove fabricated on a substrate made of silicon, plastic, or ceramic, as commonly practiced in the art. It should be noted, however, that the input port and the output ports need not necessarily be in close spatial proximity with each other, such as in an array configuration (although a close packing would reduce the rotational range required for each channel micromirror). Those skilled in the art will know how to design a WSR apparatus according to the present invention, to best suit a given application.

[0051] A WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, for adjusting the alignment of the input multi-wavelength optical signal and facilitating the coupling of the spectral channels into the respective output ports, as shown in FIGS. **2**A-**2**B and **3**.

[0052] Depicted in **FIG. 2A** is a second embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **200** is built upon and hence shares a number of the elements used in the embodiment of **FIG. 1**A, as identified by those labeled with identical numerals. Moreover, a one-dimensional array **220** of collimator-alignment mirrors **220-1** through **220**-N is optically interposed between the diffraction grating **101** and the fiber collimator array **110**. The collimator-alignment mirror **220-1** is designated to correspond with the input port **110-1**, for adjusting the alignment of the input multi-wavelength optical signal and therefore ensuring that the spectral channels impinge onto the corresponding channel micromirrors. The collimator-alignment mirrors **220-2** through **220**-N are designated to the output ports **110-2** through **110**-N in a one-to-one correspondence, serving to provide angular control of the collimated beams of the reflected spectral channels and thereby facilitating the coupling of the spectral channels into the respective output ports according to desired coupling efficiencies. Each collimator-alignment mirror may be rotatable about one axis, or two axes.

[0053] The embodiment of **FIG. 2A** is attractive in applications where the fiber collimators (serving as the input and output ports) are desired to be placed in close proximity to the collimator-alignment mirror array **220**. To best facilitate the coupling of the spectral channels into the output ports, arrays of imaging lenses may be implemented between the collimator-alignment mirror array **220** and the fiber collimator array **110**, as depicted in **FIG. 2B**. By way of example, WSR apparatus **250** of **FIG. 2B** is built upon and hence shares many of the elements used in the embodiment of **FIG. 2**A, as identified by those labeled with identical numerals. Additionally, first and second arrays **260**, **270** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the collimator-alignment mirror array **220** and the fiber collimator array **110**. The dashed box **280** shown in **FIG. 2C** provides a top view of such a telecentric arrangement. In this case, the imaging lenses in the first and second arrays **260, 270** all have the same focal length f. The collimator-alignment mirrors **220-1** through **220**-N are placed at the respective first (or front) focal points of the imaging lenses in the first array **260**. Likewise, the fiber collimators **110-1** through **110**-N are placed at the respective second (or back) focal points of the imaging lenses in the second array **270**. And the separation between the first and second arrays **260, 270** of imaging lenses is 2f. In this way, the collimator-alignment mirrors **220-1** through **220**-N are effectively imaged onto the respective entrance surfaces (i.e., the front focal planes) of the GRIN lenses in the corresponding fiber collimators **110-1** through **110**-N. Such a telecentric imaging system substantially eliminates translational walk-off of the collimated beams at the output ports that may otherwise occur as the mirror angles change.

[0054] **FIG. 3** shows a fourth embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **300** is built upon and hence shares a number of the elements used in the embodiment of **FIG.** 2B, as identified by those labeled with identical numerals. In this case, the one-dimensional fiber collimator array **110** of **FIG. 2B** is replaced by a two-dimensional array **350** of fiber collimators, providing for an input-port and a plurality of output ports. Accordingly, the one-dimensional collimator-alignment mirror array **220** of **FIG. 2B** is replaced by a two-dimensional array **320** of collimator-alignment mirrors, and first and second one-dimensional arrays **260, 270** of imaging lenses of **FIG. 2B** are likewise replaced by first and second two-dimensional arrays **360, 370** of imagining lenses respectively. As in the case of the embodiment of **FIG.** 2B, the first and second two-dimensional arrays **360, 370** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the two-dimensional collimator-alignment mirror array **320** and the two-dimensional fiber collimator array **350**. The channel micromirrors **103** must be pivotable biaxially in this case (in order to direct its corresponding spectral channel to any one of the output ports). As such, the WSR apparatus **300** is equipped to support a greater number of the output ports.

[0055] In addition to facilitating the coupling of the spectral channels into the respective output ports as described above, the collimator-alignment mirrors in the above embodiments also serve to compensate for misalignment (e.g., due to fabrication and assembly errors) in the fiber collimators that provide for the input and output ports. For instance, relative misalignment between the fiber cores and their respective collimating lenses in the fiber collimators can lead to pointing errors in the collimated beams, which may be corrected for by the collimator-alignment mirrors. For these reasons, the collimator-alignment mirrors are preferably rotatable about two axes. They may be silicon micromachined mirrors, for fast rotational speeds. They may also be other types of mirrors or beam-deflecting elements known in the art.

[0056] To optimize the coupling of the spectral channels into the output ports and further maintain the optimal optical alignment against environmental effects such as temperature variations and mechanical instabilities over the course of operation, a WSR apparatus of the present invention may incorporate a servo-control assembly, for providing dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis. A WSR apparatus incorporating a servo-control assembly is termed a WSR-S apparatus, thereinafter in this specification.

[0057] **FIG. 4A** depicts a schematic illustration of a first embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **400** comprises a WSR apparatus **410** and a servo-control assembly **440**. The WSR **410** may be in the embodiment of **FIG. 1**A, or any other embodiment in accordance with the present invention. The servo-control assembly **440** includes a spectral monitor **460**, for monitoring the power levels of the spectral channels coupled into the output ports **420-1** through **420**-N of the WSR apparatus **410**. By way of example, the spectral monitor **460** is coupled to the output ports **420-1** through **420**-N by way of fiber-optic couplers **420-1**-C through **420**-N-C, wherein each fiber-optic coupler Has: serves to tap off a predetermined fraction of the optical signal in the corresponding output port. The servo-control assembly **440** further includes a processing unit **470**, in communication with the spectral monitor **460** and the channel micromirrors **430** of the WSR apparatus **410**. The processing unit **470** uses the power measurements from the spectral monitor **460** to provide feedback control of the channel micromirrors **430** on an individual basis, so as to maintain a desired coupling efficiency for each spectral channel into a selected output port. As such, the servo-control assembly **440** provides dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis and thereby manages the power levels of the spectral channels coupled into the output ports. The power levels of the spectral channels in the output ports may be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) in the present invention. Such a spectral power-management capability is essential in WDM optical networking applications, as discussed above.

[0058] **FIG. 4B** depicts a schematic illustration of a second embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **450** comprises a WSR apparatus **480** and a servo-control assembly **490**. In addition to the channel micromirrors **430** (and other elements identified by the same numerals as those used in **FIG. 4A**), the WSR apparatus **480** further includes a plurality of collimator-alignment mirrors **485**, and may be configured according to the embodiment of **FIG. 2A, 2B, 3**, or any other embodiment in accordance with the present invention. By way of example, the servo-control assembly **490** includes the spectral monitor **460** as described in the embodiment of **FIG.** 4A, and a processing unit **495**. In this case, the processing unit **495** is in communication with the channel micromirrors **430** and the collimator-alignment mirrors **485** of the WSR apparatus **480**, as well as the spectral monitor **460**. The processing unit **495** uses the power measurements from the spectral monitor **460** to provide dynamic control of the channel micromirrors **430** along with the collimator-alignment mirrors **485**, so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values.

[0059] In the embodiment of **FIG. 4A** or 4B, the spectral monitor **460** may be one of spectral power monitoring devices known in the art that is capable of detecting the power levels of spectral components in a multi-wavelength optical signal. Such devices are typically in the form of a wavelength-separating means (e.g., a diffraction grating) that spatially separates a multi-wavelength optical signal by wavelength into constituent spectral components, and one or more optical sensors (e.g., an array of photodiodes) that are configured such to detect the power levels of these spectral components. The processing unit **470** in **FIG. 4A** (or the processing unit **495** in **FIG. 4B**) typically includes electrical circuits and signal processing programs for processing the power measurements received from the spectral monitor **460** and generating appropriate control signals to be applied to the channel micromirrors **430** (and the collimator-alignment mirrors **485** in the case of **FIG. 4B**), so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values. The electronic circuitry and the associated signal processing algorithm/software for such processing unit in a servo-control system are known in the art. A skilled artisan will know how to implement a suitable spectral monitor along with an appropriate processing unit to provide a servo-control assembly in a WSP-S apparatus according to the present invention, for a given application.

[0060] The incorporation of a servo-control assembly provides additional advantages of effectively relaxing the requisite fabrication tolerances and the precision of optical alignment during initial assembly of a WSR apparatus of the present invention, and further enabling the system to correct for shift in the alignment over the course of operation. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced. As such, the WSR-S apparatus thus constructed is simpler and more adaptable in structure, more robust in performance, and lower in cost and optical loss. Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices and utilized in many applications.

[0061] For instance, by directing the spectral channels into the output ports in a one-channel-per-port fashion and coupling the output ports of a WSR-S (or WSR) apparatus to an array of optical sensors (e.g., photodiodes), or a single optical sensor that is capable of scanning across the output ports, a dynamic and versatile spectral power monitor (or channel analyzer) is provided, which would be highly desired in WDM optical networking applications. Moreover, a novel class of optical add-drop multiplexers (OADMs) may be built upon the WSR-S (or WSR) apparatus of the present invention, as exemplified in the following embodiments.

[0062] **FIG. 5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **500** comprises a WSR-S (or WSR) apparatus **510** and an optical combiner **550**. An input port **520** of the WSR-S apparatus **510** transmits a multi-wavelength optical signal. The constituent spectral channels are subsequently separated and routed into a plurality of output ports, including a pass-through port **530** and one or more drop ports **540-1** through **540**-N ($N \geqq 1$). The pass-through port **530** may receive any number of the spectral channels (i.e., the pass-through spectral channels). Each drop port may also receive any number of the spectral channels (i.e., the drop spectral channels). The pass-through port **530** is optically coupled to the optical combiner **550**, which serves to combine the pass-through spectral channels with one or more add spectral channels provided by one or more add ports **560-1** through **560**-M ($M \geqq 1$). The combined optical signal is then routed into an existing port **570**, providing an output multi-wavelength optical signal.

[0063] In the above embodiment, the optical combiner **550** may be a K×1 ($K \geqq 2$) broadband fiber-optic coupler, wherein there are K input-ends and one output-end. The pass-through spectral channels and the add spectral channels are fed into the K input-ends (e.g., in a one-to-one correspondence) and the combined optical signal exits from the output-end of the K×1 fiber-optic coupler as the output multi-wavelength optical signal of the system. Such a multiple-input coupler also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the OADM **500**. If the power levels of the spectral channels in the output multi-wavelength optical signal are desired to be actively managed, such as being equalized at a predetermined value, two spectral monitors may be utilized. As a way of example, the first spectral monitor may receive optical signals tapped off from the pass-through port **530** and the drop ports **540-1** through **540**-N (e.g., by way of fiber-optic couplers as depicted in **FIG. 4A** or **4**B). The second spectral monitor receives optical signals tapped off from the exiting port **570**. A servo-control system may be constructed accordingly for monitoring and controlling the pass-through, drop and add spectral channels. As such, the embodiment of **FIG. 5** provides a versatile optical add-drop multiplexer in a simple and low-cost assembly, while providing multiple physically separate drop/add ports in a dynamically reconfigurable fashion.

[0064] **FIG. 6** depicts an alternative embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **600** comprises a first WSR-S apparatus **610** optically coupled to a second WSR-S apparatus **650**. Each WSR-S apparatus may be in the embodiment of **FIG. 4A** or 4B. (A WSR apparatus of the embodiment of **FIG. 1A, 2A, 2B**, or **3** may be alternatively implemented.) The first WSR-S apparatus **610** includes an input port **620**, a pass-through port **630**, and one or more drop ports **640-1** through **640**-N ($N \geqq 1$). The pass-through spectral channels from the pass-through port **630** are further coupled to the second WSR-S apparatus **650**, along with one or more add spectral channels emerging from add ports **660-1** through **660**-M ($M \geqq 1$). In this exemplary case, the pass-through port **630** and the add ports **660-1** through **660-M** constitute the input ports for the second WSR-S apparatus **650**. By way of its constituent wavelength-separator (e.g., a diffraction grating) and channel micromirrors (not shown in **FIG. 6**), the second WSR-S apparatus **650** serves to multiplex the pass-through spectral channels and the add spectral channels, and route the multiplexed optical signal into an exiting port **770** to provide an output signal of the system.

[0065] In the embodiment of **FIG. 6**, one WSR-S apparatus (e.g., the first WSR-S apparatus **610**) effectively performs dynamic drop function, whereas the other WSR-S apparatus (e.g., the second WSR-S apparatus **650**) carries out dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped (other than those imposed by the overall communication system). Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of cascaded WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions. Additionally, the OADM of **FIG. 6** may be operated in reverse direction, by using the input ports as the output ports, the drop ports as the add ports, and vice versa.

[0066] Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Those skilled in the art will also appreciate that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention as defined in the appended claims. Accordingly, a skilled artisan can design an OADM in accordance with the principles of the present invention, to best suit a given application.

[0067] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention. Accordingly, the scope of the present invention should be determined by the following claims and their legal equivalents.

What is claimed is:

1. A wavelength-separating-routing apparatus, comprising:

a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports.

2. The wavelength-separating-routing apparatus of claim 1 further comprising a servo control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

3. The wavelength-separating-routing apparatus of claim 2 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

4. The wavelength-separating-routing apparatus of claim 3 wherein said servo-control assembly maintains said power levels at a predetermined value.

5. The wavelength-separating-routing apparatus of claim 1 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

6. The wavelength-separating-routing apparatus of claim 5 wherein each collimator-alignment mirror is rotatable about one axis.

7. The wavelength-separating-routing apparatus of claim 5 wherein each collimator-alignment mirror is rotatable about two axes.

8. The wavelength-separating-routing apparatus of claim 5 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

9. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is continuously pivotable about one axis.

10. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is pivotable about two axes.

11. The wavelength-separating-routing apparatus of claim 10 wherein said fiber collimators are arranged in a two-dimensional array.

12. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is a silicon micromachined mirror.

13. The wavelength-separating-routing apparatus of claim 1 wherein said fiber collimators are arranged in a one-dimensional array.

14. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises a focusing lens having first and second focal points.

15. The wavelength-separating-routing apparatus of claim 14 wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points of said focusing lens.

16. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises an assembly of lenses.

17. The wavelength-separating-routing apparatus of claim 1 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

18. The wavelength-separating-routing apparatus of claim 1 further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

19. The wavelength-separating-routing apparatus of claim 1 wherein each output port carries a single one of said spectral channels.

20. The wavelength-separating-routing apparatus of claim 19 further comprising one or more optical sensors, optically coupled to said output ports.

21. A servo-based optical apparatus comprising:

a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a servo-control assembly, in communication with said channel micromirrors and said output ports, for maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

22. The servo-based optical apparatus of claim 21 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

23. The servo-based optical apparatus of claim 22 wherein said servo-control assembly maintains said power levels at a predetermined value.

24. The servo-based optical apparatus of claim 21 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

25. The servo-based optical apparatus of claim 24 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

26. The servo-based optical apparatus of claim 24 wherein each collimator-alignment mirror is rotatable about at least one axis.

27. The servo-based optical apparatus of claim 21 wherein each channel micromirror is continuously pivotable about at least one axis.

28. The servo-based optical apparatus of claim 21 wherein each channel micromirror is a silicon micromachined mirror.

29. The servo-based optical apparatus of claim 21 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

30. The servo-based optical apparatus of claim 21 wherein said beam-focuser comprises one or more lenses.

31. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a one-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

32. The optical apparatus of claim 31 further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

33. The optical apparatus of claim 32 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

34. The optical apparatus of claim 31 wherein each channel micromirror is continuously pivotable about at least one axis.

35. The optical apparatus of claim 31 wherein each collimator-alignment mirror is rotatable about at least one axis.

36. The optical apparatus of claim 31 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

37. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a two-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

38. The optical apparatus of claim 37 further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

39. The optical apparatus of claim 38 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

40. The optical apparatus of claim 37 wherein each collimator-alignment mirror is rotatable about at least one axis.

41. The optical apparatus of claim 37 wherein each channel micromirror is continuously pivotable about at least one axis.

42. The optical apparatus of claim 41 wherein each channel micromirrors is pivotable about two axes, and wherein said fiber collimators are arranged in a two-dimensional array.

43. The optical apparatus of claim 37 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

44. An optical system comprising a wavelength-separating-routing apparatus, wherein said wavelength-separating-routing apparatus includes:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports including a pass-through port and one or more drop ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously pivotable to reflect said spectral channels into selected ones of said output ports, whereby said pass-through port receives a subset of said spectral channels.

45. The optical system of claim 44 further comprising a servo-control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

46. The optical system of claim 45 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

47. The optical system of claim 44 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

48. The optical system of claim 47 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

49. The optical system of claim 47 wherein each collimator-alignment mirror is rotatable about at least one axis.

50. The optical system of claim 44 wherein each channel micromirror is pivotable about at least one axis.

51. The optical system of claim 44 wherein each channel micromirror is a silicon micromachined mirror.

52. The optical system of claim 44 wherein said beam-focuser comprises a focusing lens having first and second focal points, and wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points.

53. The optical system of claim 44 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

54. The optical system of claim 44 further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

55. The optical system of claim 44 further comprising an auxiliary wavelength-separating-routing apparatus, including:

a) multiple auxiliary fiber collimators, providing a plurality of auxiliary input ports and an exiting port;

b) an auxiliary wavelength-separator;

c) an auxiliary beam-focuser; and

d) a spatial array of auxiliary channel micromirrors;

wherein said subset of said spectral channels in said pass-through port and one or more add spectral channels are directed into said auxiliary input ports, and multiplexed into an output optical signal directed into said exiting port by way of said auxiliary wavelength-separator, said auxiliary beam-focuser and said auxiliary channel micromirrors.

56. The optical system of claim 55 wherein said auxiliary channel micromirrors are individually pivotable.

57. The optical system of claim 55 wherein each auxiliary channel micromirror is pivotable continuously about at least one axis.

58. The optical system of claim 55 wherein each auxiliary channel micromirror is a silicon micromachined mirror.

59. The optical system of claim 55 wherein said auxiliary wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

60. The optical system of claim 55 wherein said pass-through port constitutes one of said auxiliary input ports.

61. A method of performing dynamic wavelength separating and routing, comprising:

a) receiving a multi-wavelength optical signal from an input port;

b) separating said multi-wavelength optical signal into multiple spectral channels;

c) focusing said spectral channels onto a spatial array of corresponding beam-deflecting elements, whereby each beam-deflecting element receives one of said spectral channels; and

d) dynamically and continuously controlling said beam-deflecting elements, thereby directing said spectral channels into a plurality of output ports.

62. The method of claim 61 further comprising the step of providing feedback control of said beam-deflecting elements, thereby maintaining a predetermining coupling of each spectral channel directed into one of said output ports.

63. The method of claim 62 further comprising the step of maintaining power levels of said spectral channels directed into said output ports at a predetermining value.

64. The method of claim 61 wherein each spectral channel is directed into a separate output port.

65. The method of claim 61 wherein a subset of said spectral channels is directed into one of said output ports, thereby providing one or more pass-through spectral channels.

66. The method of claim 65 further comprising the step of multiplexing said pass-through spectral channels with one or more add spectral channels, so as to provide an output optical signal.

67. The method of claim 61 wherein said beam-deflecting elements comprise an array of silicon micromachined mirrors.

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(54) **RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES**

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(52) **U.S. Cl.** **385/24**; 385/11; 385/37; 385/34

(58) **Field of Search** 385/11, 24, 37, 385/34

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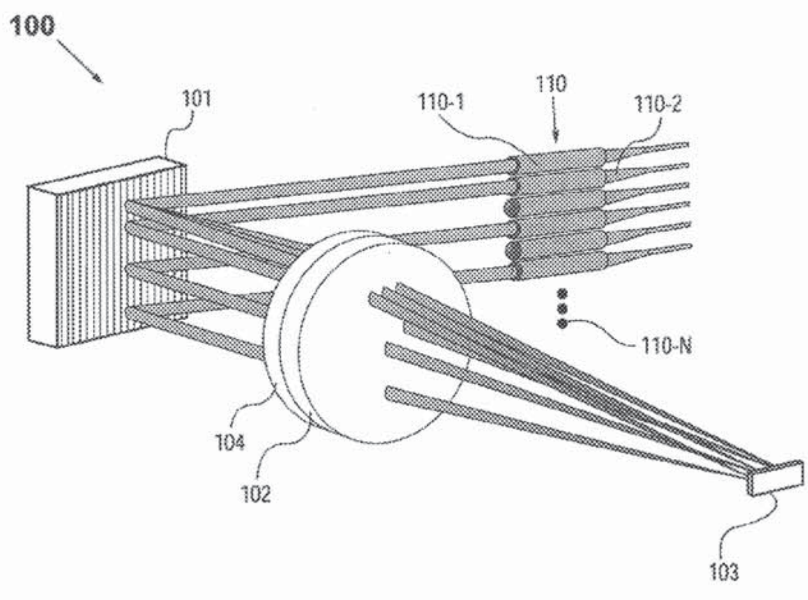
(57) **ABSTRACT**

This invention provides a novel wavelength-separating-routing (WSR) apparatus that uses a diffraction grating to separate a multi-wavelength optical signal by wavelength into multiple spectral channels, which are then focused onto an array of corresponding channel micromirrors. The channel micromirrors are individually controllable and continuously pivotable to reflect the spectral channels into selected output ports. As such, the inventive WSR apparatus is capable of routing the spectral channels on a channel-by-channel basis and coupling any spectral channel into any one of the output ports. The WSR apparatus of the present invention may be further equipped with servo-control and spectral power-management capabilities, thereby maintaining the coupling efficiencies of the spectral channels into the output ports at desired values. The WSR apparatus of the present invention can be used to construct a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for WDM optical networking applications.

67 Claims, 12 Drawing Sheets



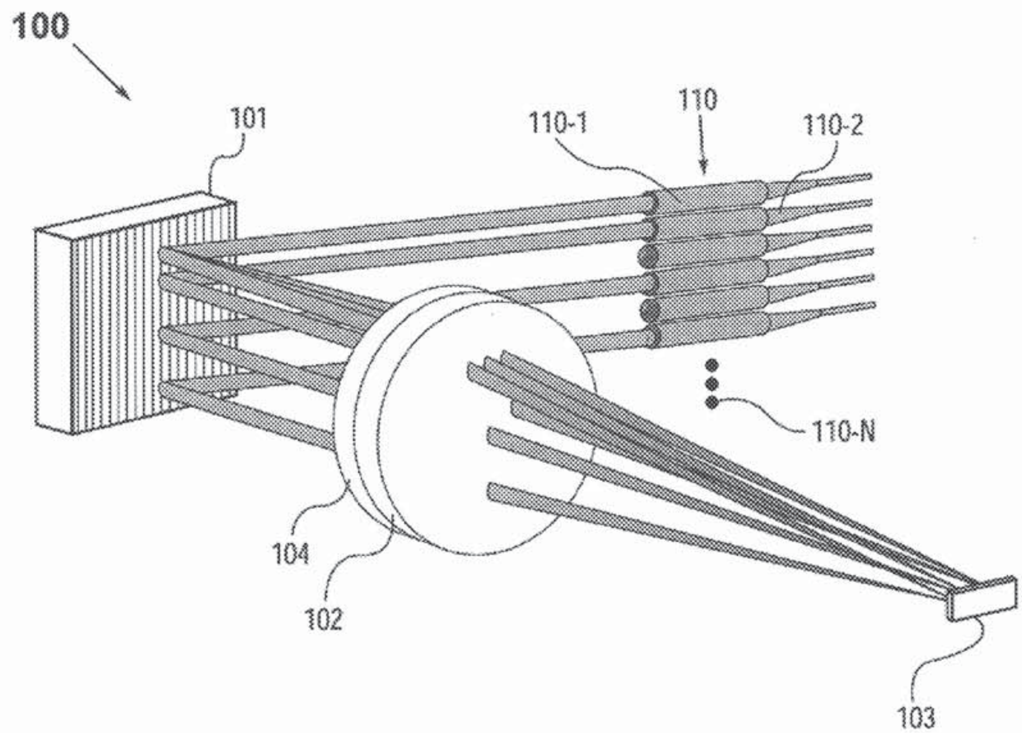


Fig. 1A

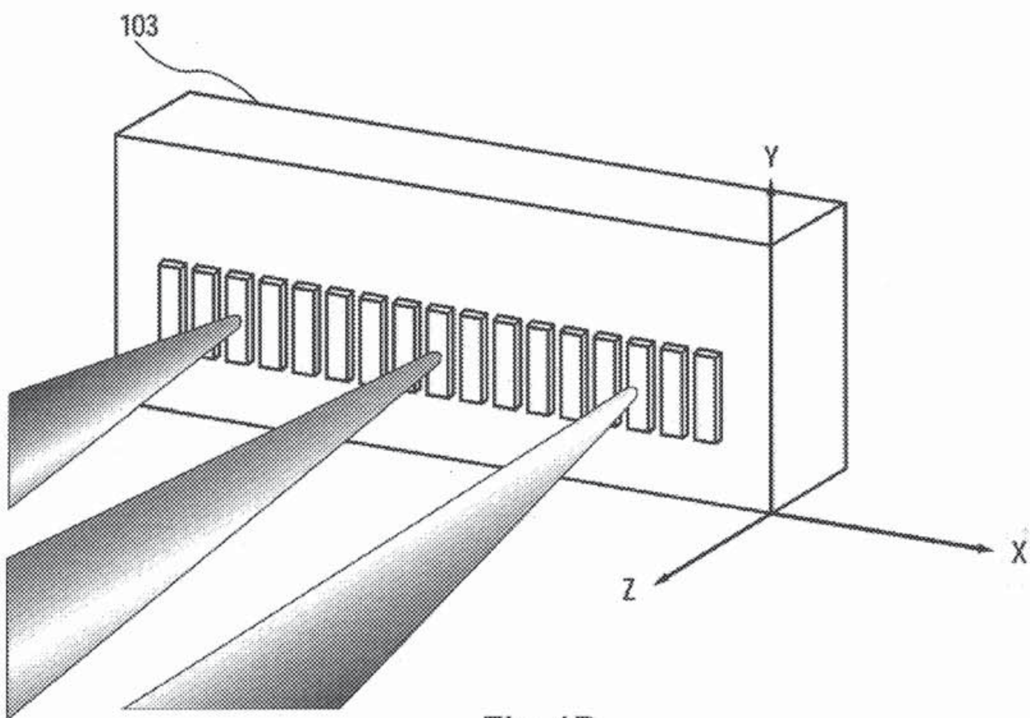


Fig. 1B

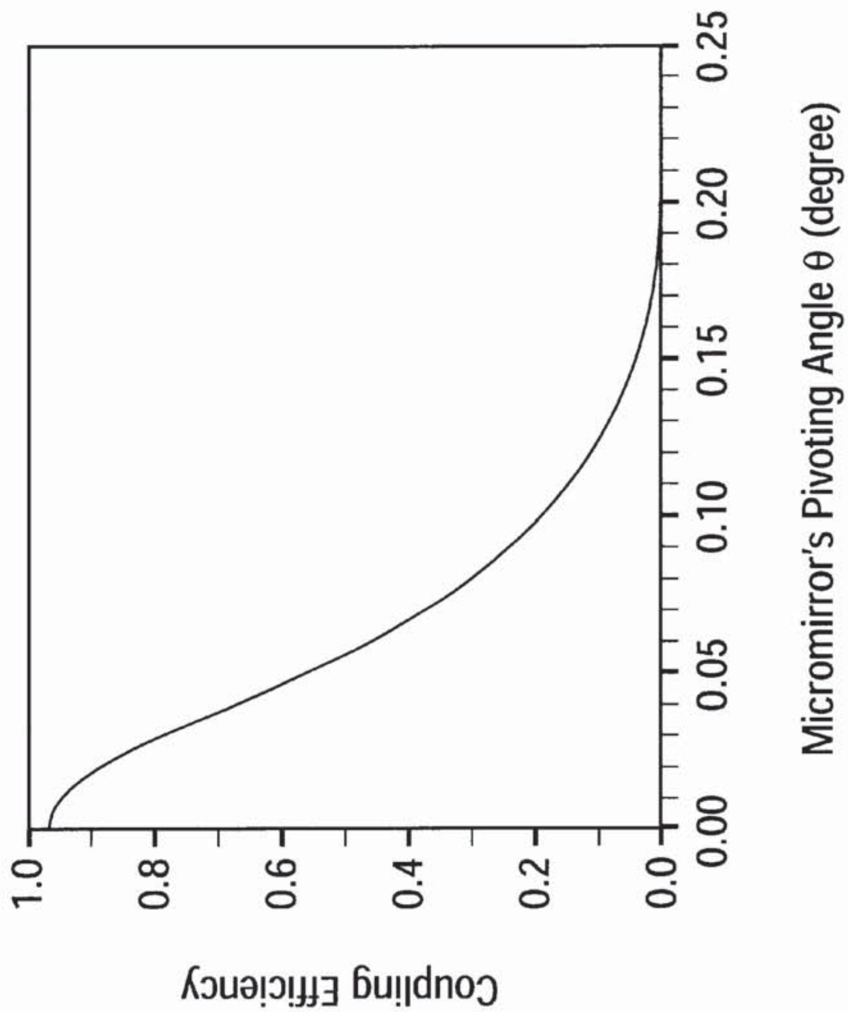

Coupling Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
Micromirror's Pivoting Angle θ (degree)

Fig. 1C

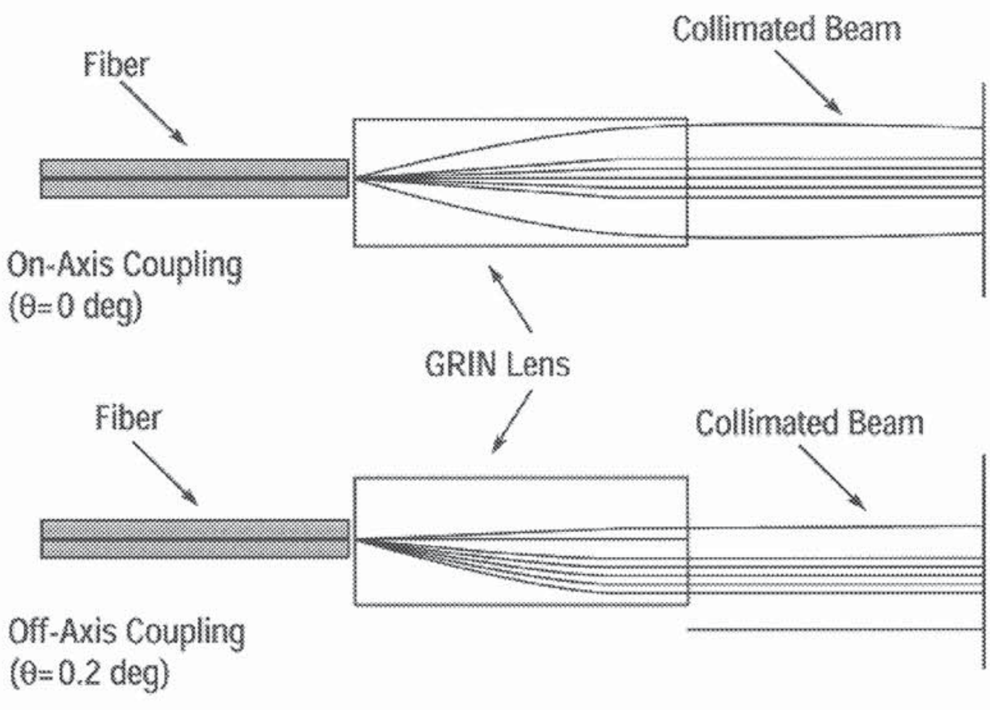

Collimated Beam
Fiber
On-Axis Coupling
(θ=0 deg)
GRIN Lens
Fiber
Collimated Beam
Off-Axis Coupling
(θ=0.2 deg)

Fig. 1D

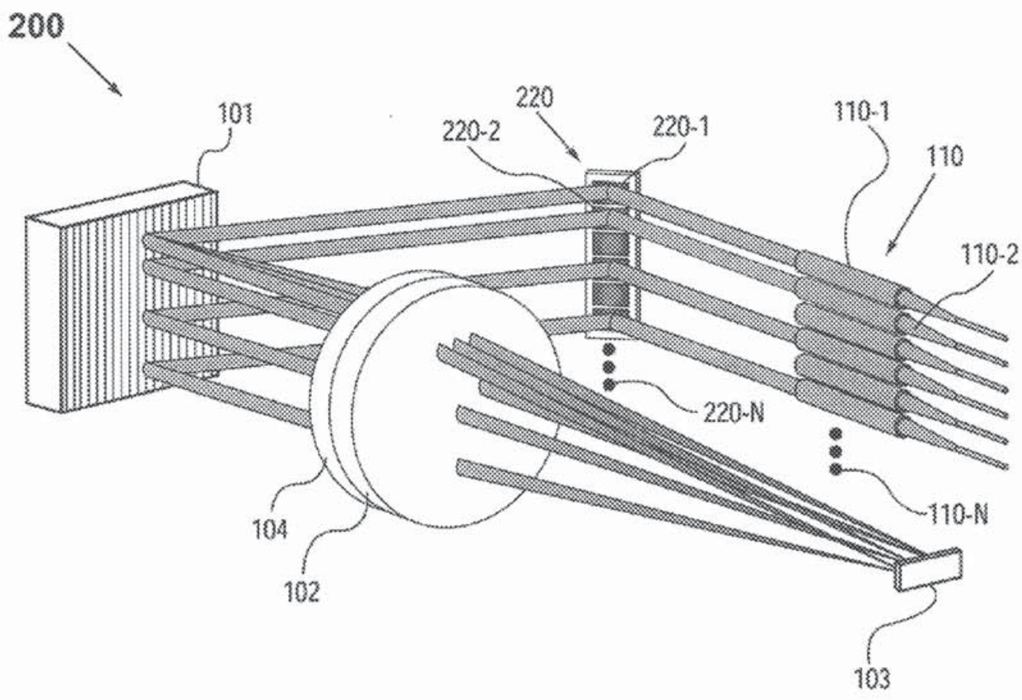


Fig. 2A

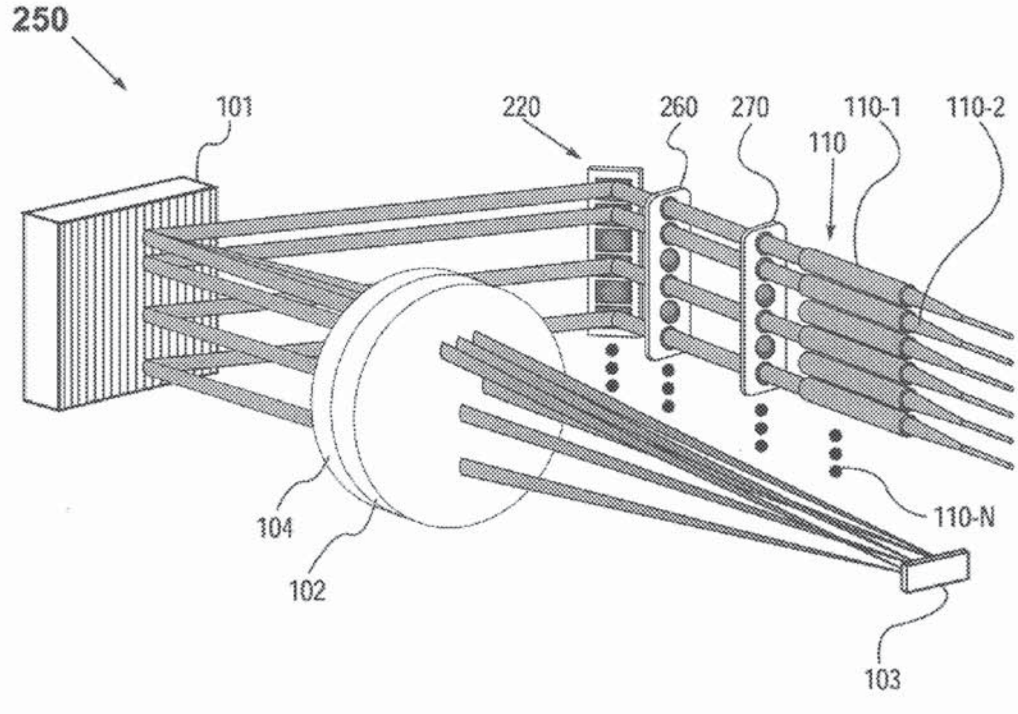


Fig. 2B

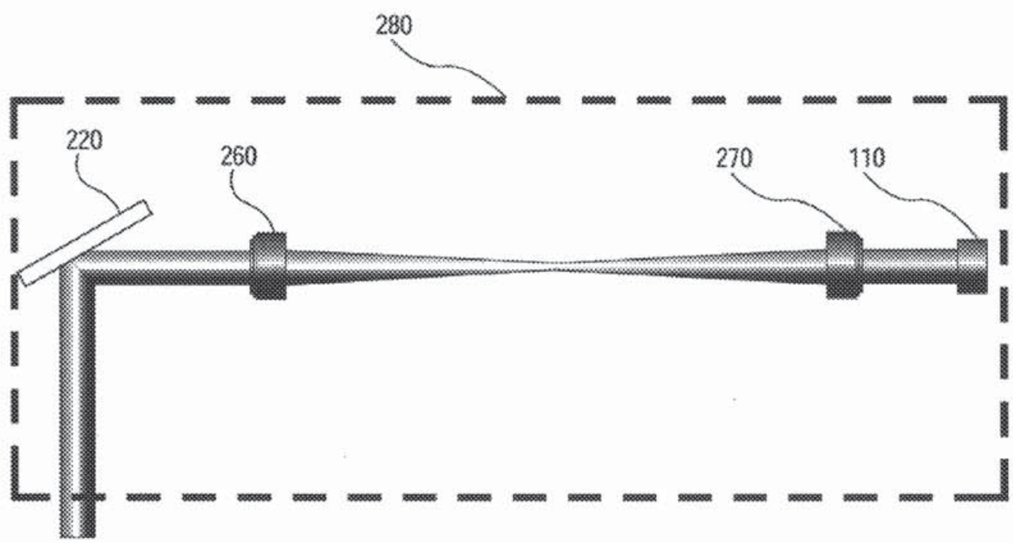


Fig. 2C

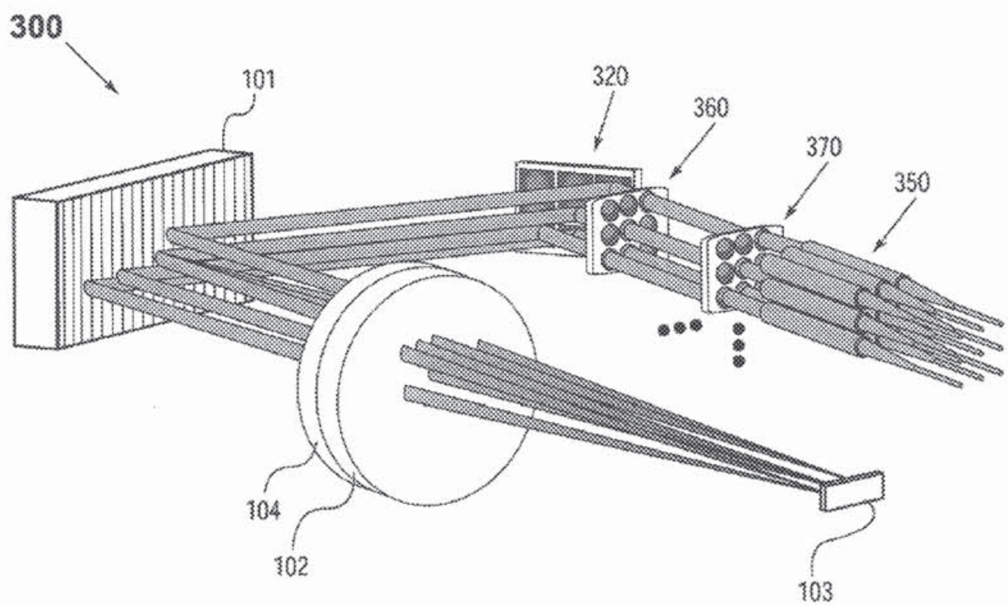


Fig. 3

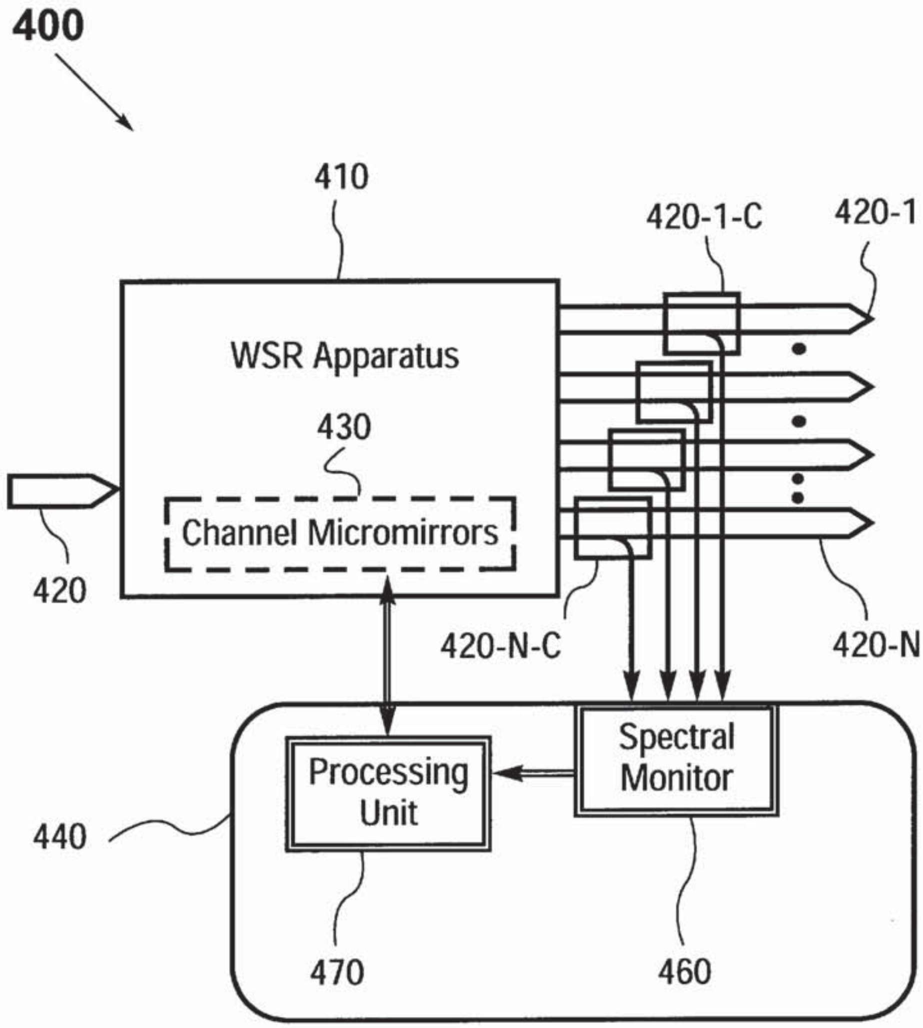

400
410
420-1-C
420-1
WSR Apparatus
430
Channel Micromirrors
420
420-N-C
420-N
Processing Unit
Spectral Monitor
440
470
460

Fig. 4A

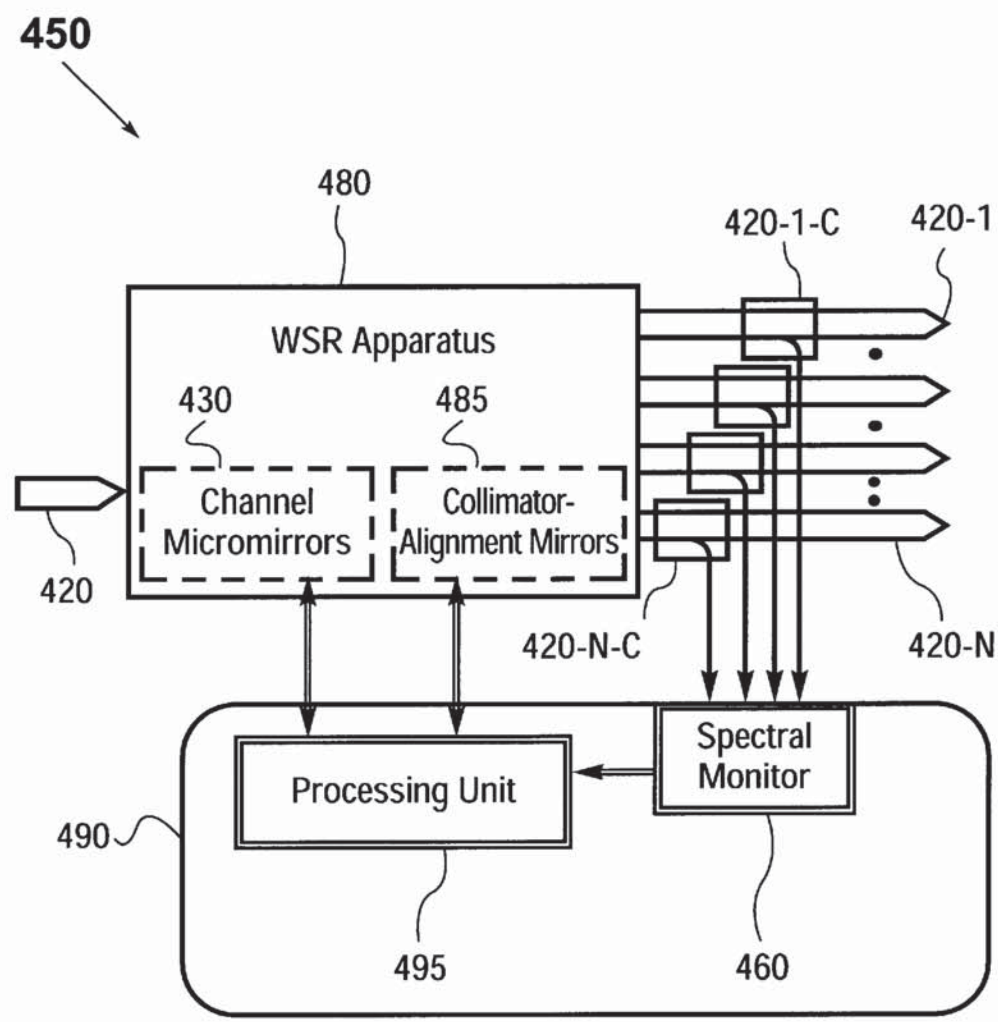

450
480
420-1-C
420-1
WSR Apparatus
430
485
Channel Micromirrors
Collimator-Alignment Mirrors
420
420-N-C
420-N
Spectral Monitor
Processing Unit
490
495
460

Fig. 4B

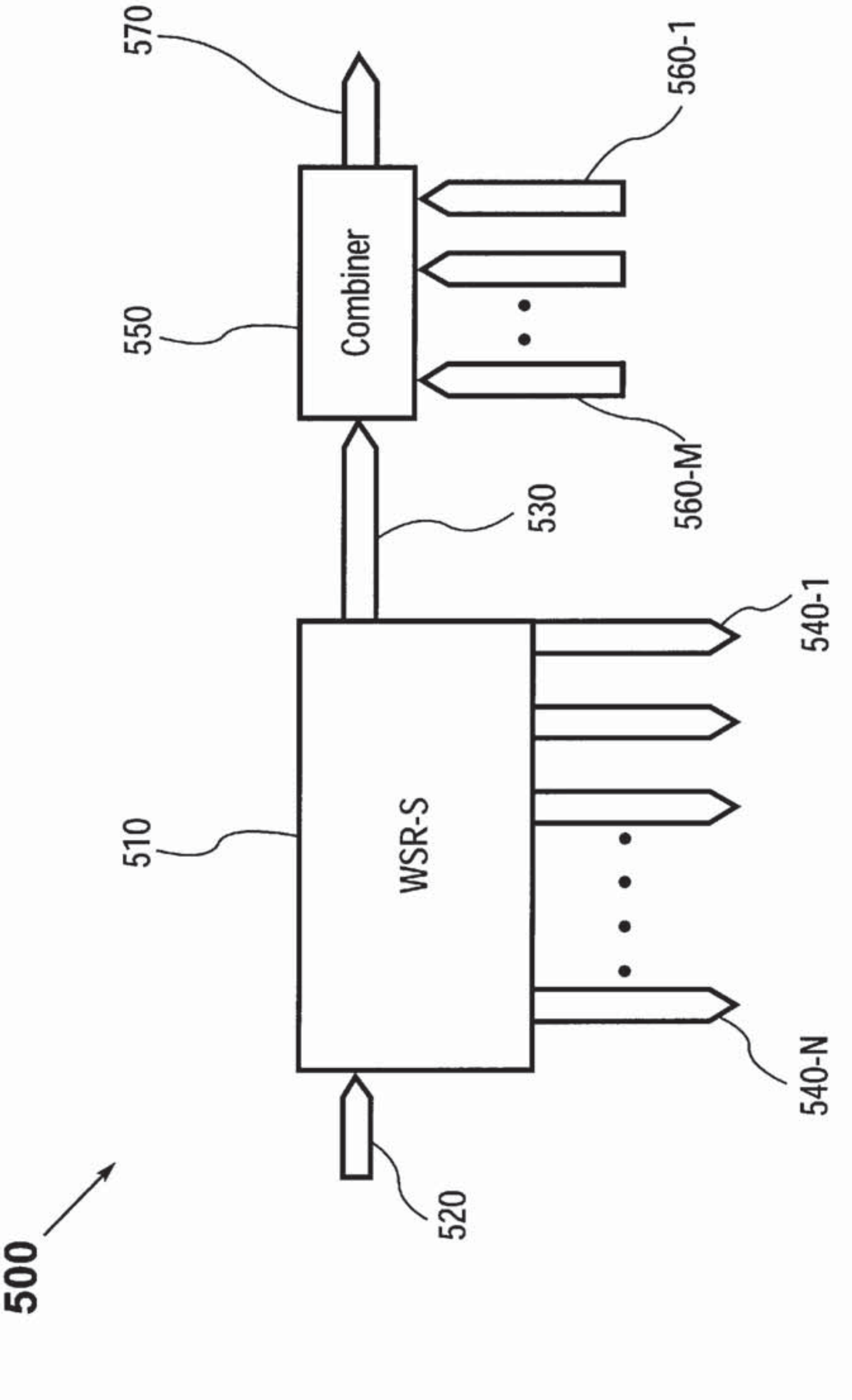
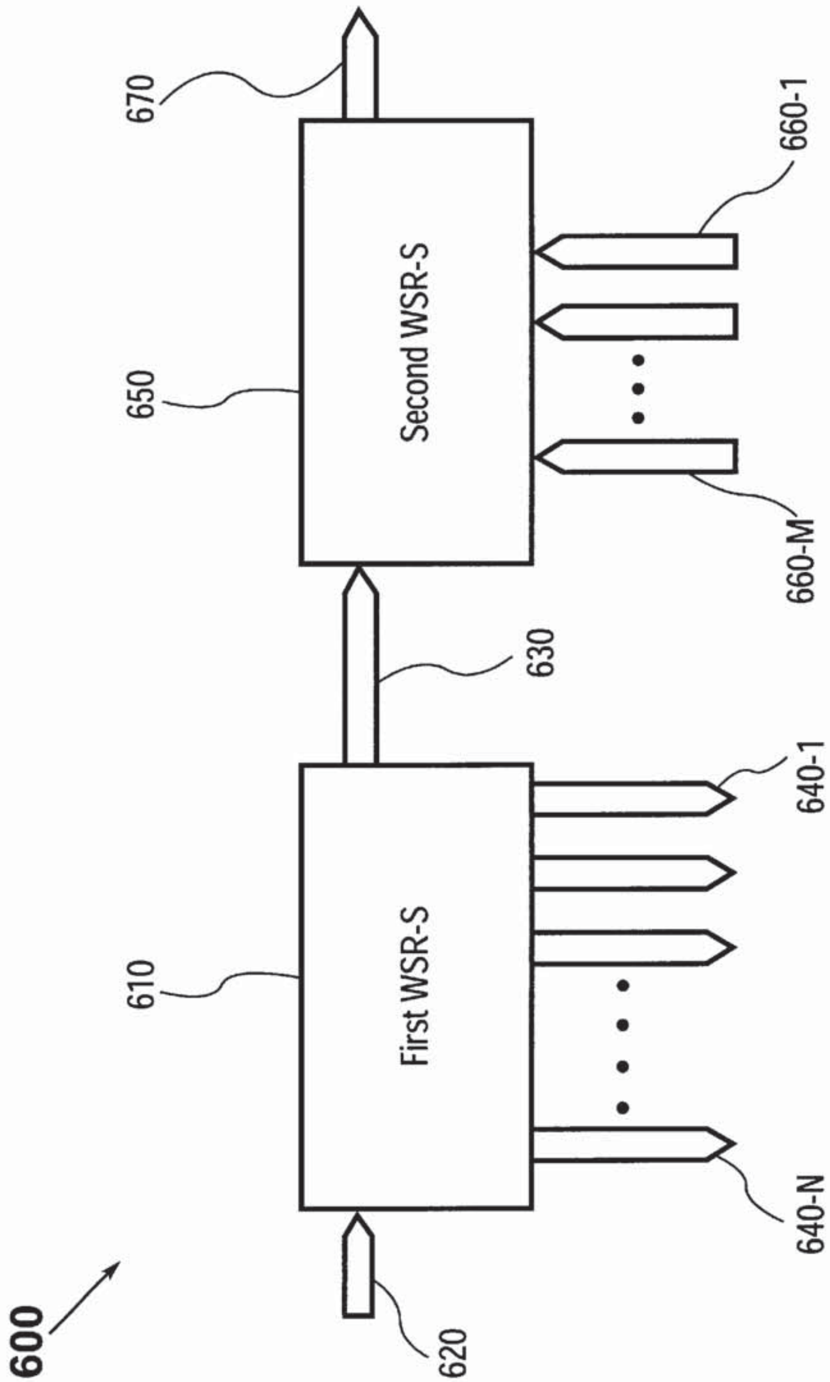


Fig. 5



670
650
Second WSR-S
660-1
660-M
630
610
First WSR-S
640-1
640-N
600
620

Fig. 6

RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXERS WITH SERVO CONTROL AND DYNAMIC SPECTRAL POWER MANAGEMENT CAPABILITIES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of U.S. Provisional Patent Application No. 60/277,217, filed Mar. 19, 2001 which is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates generally to optical communication systems. More specifically, it relates to a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs) for wavelength division multiplexed optical networking applications.

BACKGROUND

As fiber-optic communication networks rapidly spread into every walk of modern life, there is a growing demand for optical components and subsystems that enable the fiber-optic communications networks to be increasingly scalable, versatile, robust, and cost-effective.

Contemporary fiber-optic communications networks commonly employ wavelength division multiplexing (WDM), for it allows multiple information (or data) channels to be simultaneously transmitted on a single optical fiber by using different wavelengths and thereby significantly enhances the information bandwidth of the fiber. The prevalence of WDM technology has made optical add-drop multiplexers indispensable building blocks of modern fiber-optic communication networks. An optical add-drop multiplexer (OADM) serves to selectively remove (or drop) one or more wavelengths from a multiplicity of wavelengths on an optical fiber, hence taking away one or more data channels from the traffic stream on the fiber. It further adds one or more wavelengths back onto the fiber, thereby inserting new data channels in the same stream of traffic. As such, an OADM makes it possible to launch and retrieve multiple data channels (each characterized by a distinct wavelength) onto and from an optical fiber respectively, without disrupting the overall traffic flow along the fiber. Indeed, careful placement of the OADMs can dramatically improve an optical communication network's flexibility and robustness, while providing significant cost advantages.

Conventional OADMs in the art typically employ multiplexers/demultiplexers (e.g, waveguide grating routers or arrayed-waveguide gratings), tunable filters, optical switches, and optical circulators in a parallel or serial architecture to accomplish the add and drop functions. In the parallel architecture, as exemplified in U.S. Pat. No. 5,974,207, a demultiplexer (e.g., a waveguide grating router) first separates a multi-wavelength signal into its constituent spectral components. A wavelength switching/routing means (e.g., a combination of optical switches and optical circulators) then serves to drop selective wavelengths and add others. Finally, a multiplexer combines the remaining (i.e., the pass-through) wavelengths into an output multi-wavelength optical signal. In the serial architecture, as exemplified in U.S. Pat. No. 6,205,269, tunable filters (e.g., Bragg fiber gratings) in combination with optical circulators are used to separate the drop wavelengths from the pass-through wavelengths and subsequently launch the add channels into the pass-through path. And if multiple wavelengths

are to be added and dropped, additional multiplexers and demultiplexers are required to demultiplex the drop wavelengths and multiplex the add wavelengths, respectively. Irrespective of the underlying architecture, the OADMs currently in the art are characteristically high in cost, and prone to significant optical loss accumulation. Moreover, the designs of these OADMs are such that it is inherently difficult to reconfigure them in a dynamic fashion.

U.S. Pat. No. 6,204,946 to Askyuk et al. discloses an OADM that makes use of free-space optics in a parallel construction. In this case, a multi-wavelength optical signal emerging from an input port is incident onto a ruled diffraction grating. The constituent spectral channels thus separated are then focused by a focusing lens onto a linear array of binary micromachined mirrors. Each micromirror is configured to operate between two discrete states, such that it either retroreflects its corresponding spectral channel back into the input port as a pass-through channel, or directs its spectral channel to an output port as a drop channel. As such, the pass-through signal (i.e., the combined pass-through channels) shares the same input port as the input signal. An optical circulator is therefore coupled to the input port, to provide necessary routing of these two signals. Likewise, the drop channels share the output port with the add channels. An additional optical circulator is thereby coupled to the output port, from which the drop channels exit and the add channels are introduced into the output port. The add channels are subsequently combined with the pass-through signal by way of the diffraction grating and the binary micromirrors.

Although the aforementioned OADM disclosed by Askyuk et al. has the advantage of performing wavelength separating and routing in free space and thereby incurring less optical loss, it suffers a number of limitations. First, it requires that the pass-through signal share the same port/fiber as the input signal. An optical circulator therefore has to be implemented, to provide necessary routing of these two signals. Likewise, all the add and drop channels enter and leave the OADM through the same output port, hence the need for another optical circulator. Moreover, additional means must be provided to multiplex the add channels before entering the system and to demultiplex the drop channels after exiting the system. This additional multiplexing/demultiplexing requirement adds more cost and complexity that can restrict the versatility of the OADM thus-constructed. Second, the optical circulators implemented in this OADM for various routing purposes introduce additional optical losses, which can accumulate to a substantial amount. Third, the constituent optical components must be in a precise alignment, in order for the system to achieve its intended purpose. There are, however, no provisions provided for maintaining the requisite alignment; and no mechanisms implemented for overcoming degradation in the alignment owing to environmental effects such as thermal and mechanical disturbances over the course of operation.

U.S. Pat. No. 5,906,133 to Tomlinson discloses an OADM that makes use of a design similar to that of Aksyuk et al. There are input, output, drop and add ports implemented in this case. By positioning the four ports in a specific arrangement, each micromirror, notwithstanding switchable between two discrete positions, either reflects its corresponding channel (coming from the input port) to the output port, or concomitantly reflects its channel to the drop port and an incident add channel to the output port. As such, this OADM is able to perform both the add and drop functions without involving additional optical components (such as optical circulators used in the system of Aksyuk et al.). However, because a single drop port is designated for all the drop channels and a single add port is designated for all the add channels, the add channels would have to be multiplexed before entering the add port and the drop channels likewise need to be demutiplxed upon exiting from the drop port. Moreover, as in the case of Askyuk et al., there are no provisions provided for maintaining requisite optical alignment in the system, and no mechanisms implemented for combating degradation in the alignment due to environmental effects over the course of operation.

As such, the prevailing drawbacks suffered by the OADMs currently in the art are summarized as follows:

1) The wavelength routing is intrinsically static, rendering it difficult to dynamically reconfigure these OADMs.
2) Add and/or drop channels often need to be multiplexed and/or demultiplexed, thereby imposing additional complexity and cost.
3) Stringent fabrication tolerance and painstaking optical alignment are required. Moreover, the optical alignment is not actively maintained, rendering it susceptible to environmental effects such as thermal and mechanical disturbances over the course of operation.
4) In an optical communication network, OADMs are typically in a ring or cascaded configuration. In order to mitigate the interference amongst OADMs, which often adversely affects the overall performance of the network, it is essential that the power levels of spectral channels entering and exiting each OADM be managed in a systematic way, for instance, by introducing power (or gain) equalization at each stage. Such a power equalization capability is also needed for compensating for nonuniform gain caused by optical amplifiers (e.g., erbium doped fiber amplifiers) in the network. There lacks, however, a systematic and dynamic management of the power levels of various spectral channels in these OADMs.
5) The inherent high cost and heavy optical loss further impede the wide application of these OADMs.

In view of the foregoing, there is an urgent need in the art for optical add-drop multiplexers that overcome the aforementioned shortcomings in a simple, effective, and economical construction.

SUMMARY

The present invention provides a wavelength-separating-routing (WSR) apparatus and method which employ an array of fiber collimators serving as an input port and a plurality of output ports; a wavelength-separator; a beam-focuser; and an array of channel micromirrors.

In operation, a multi-wavelength optical signal emerges from the input port. The wavelength-separator separates the multi-wavelength optical signal into multiple spectral channels, each characterized by a distinct center wavelength and associated bandwidth. The beam-focuser focuses the spectral channels into corresponding spectral spots. The channel micromirrors are positioned such that each channel micromirror receives one of the spectral channels. The channel micromirrors are individually controllable and movable, e.g., continuously pivotable (or rotatable), so as to reflect the spectral channels into selected ones of the output ports. As such, each channel micromirror is assigned to a specific spectral channel, hence the name "channel micromirror". And each output port may receive any number of the reflected spectral channels.

A distinct feature of the channel micromirrors in the present invention, in contrast to those used in the prior art, is that the motion, e.g., pivoting (or rotation), of each channel micromirror is under analog control such that its pivoting angle can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port.

In the WSR apparatus of the present invention, the wavelength-separator may be provided by a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a curved diffraction grating, a dispersing prism, or other wavelength-separating means known in the art. The beam-focuser may be a single lens, an assembly of lenses, or other beam-focusing means known in the art. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting means known in the art. And each channel micromirror may be pivotable about one or two axes. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional or two-dimensional array. In the latter case, the channel micromirrors must be pivotable biaxially.

The WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, in optical communication with the wavelength-separator and the fiber collimators, for adjusting the alignment of the input multi-wavelength signal and directing the spectral channels into the selected output ports by way of angular control of the collimated beams. Each collimator-alignment mirror may be rotatable about one or two axes. The collimator-alignment mirrors may be arranged in a one-dimensional or two-dimensional array. First and second arrays of imaging lenses may additionally be optically interposed between the collimator-alignment mirrors and the fiber collimators in a telecentric arrangement, thereby "imaging" the collimator-alignment mirrors onto the corresponding fiber collimators to ensure an optimal alignment.

The WSR apparatus of the present invention may further include a servo-control assembly, in communication with the channel micromirrors and the output ports. The servo-control assembly serves to monitor the power levels of the spectral channels coupled into the output ports and further provide control of the channel micromirrors on an individual basis, so as to maintain a predetermined coupling efficiency of each spectral channel in one of the output ports. As such, the servo-control assembly provides dynamic control of the coupling of the spectral channels into the respective output ports and actively manages the power levels of the spectral channels coupled into the output ports. (If the WSR apparatus includes an array of collimator-alignment mirrors as described above, the servo-control assembly may additionally provide dynamic control of the collimator-alignment mirrors.) Moreover, the utilization of such a servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during assembly of a WSR apparatus of the present invention, and further enables the system to correct for shift in optical alignment over the course of operation. A WSR apparatus incorporating a servo-control assembly thus described is termed a WSR-S apparatus, thereinafter in the present invention.

Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices, including a novel class of dynamically reconfigurable optical add-drop multiplexers (OADMs), as exemplified in the following embodiments.

One embodiment of an OADM of the present invention comprises an aforementioned WSR-S (or WSR) apparatus and an optical combiner. The output ports of the WSR-S apparatus include a pass-through port and one or more drop ports, each carrying any number of the spectral channels. The optical combiner is coupled to the pass-through port, serving to combine the pass-through channels with one or more add spectral channels. The combined optical signal constitutes an output signal of the system. The optical combiner may be an N×1 (N≧2) broadband fiber-optic coupler, for instance, which also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the system.

In another embodiment of an OADM of the present invention, a first WSR-S (or WSR) apparatus is cascaded with a second WSR-S (or WSR) apparatus. The output ports of the first WSR-S (or WSR) apparatus include a pass-through port and one or more drop ports. The second WSR-S (or WSR) apparatus includes a plurality of input ports and an exiting port. The configuration is such that the pass-through channels from the first WSR-S apparatus and one or more add channels are directed into the input ports of the second WSR-S apparatus, and consequently multiplexed into an output multi-wavelength optical signal directed into the exiting port of the second WSR-S apparatus. That is to say that in this embodiment, one WSR-S apparatus (e.g., the first one) effectively performs a dynamic drop function, whereas the other WSR-S apparatus (e.g., the second one) carries out a dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped, other than those imposed by the overall communication system. Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of the WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions in a network environment.

Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Various changes, substitutions, and alternations can be made herein, without departing from the principles and the scope of the invention. Accordingly, a skilled artisan can design an OADM in accordance with the present invention, to best suit a given application.

All in all, the OADMs of the present invention provide many advantages over the prior art devices, notably:

1) By advantageously employing an array of channel micromirrors that are individually and continuously controllable, an OADM of the present invention is capable of routing the spectral channels on a channel-by-channel basis and directing any spectral channel into any one of the output ports. As such, its underlying operation is dynamically reconfigurable, and its underlying architecture is intrinsically scalable to a large number of channel counts.
2) The add and drop spectral channels need not be multiplexed and demultiplexed before entering and after leaving the OADM respectively. And there are not fundamental restrictions on the wavelengths to be added or dropped.
3) The coupling of the spectral channels into the output ports is dynamically controlled by a servo-control assembly, rendering the OADM less susceptible to environmental effects (such as thermal and mechanical disturbances) and therefore more robust in performance. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced.
4) The power levels of the spectral channels coupled into the output ports can be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) by way of the servo-control assembly. This spectral power-management capability as an integral part of the OADM will be particularly desirable in WDM optical networking applications.
5) The use of free-space optics provides a simple, low loss, and cost-effective construction. Moreover, the utilization of the servo-control assembly effectively relaxes the requisite fabrication tolerances and the precision of optical alignment during initial assembly, enabling the OADM to be simpler and more adaptable in structure, lower in cost and optical loss.
6) The underlying OADM architecture allows a multiplicity of the OADMs according to the present invention to be readily assembled (e.g., cascaded) for WDM optical networking applications.

The novel features of this invention, as well as the invention itself, will be best understood from the following drawings and detailed description.

BRIEF DESCRIPTION OF THE FIGURES

FIGS. **1A–1D** show a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention, and the modeling results demonstrating the performance of the WSR apparatus;

FIGS. **2A–2C** depict second and third embodiments of a WSR apparatus according to the present invention;

FIG. **3** shows a fourth embodiment of a WSR apparatus according to the present invention;

FIGS. **4A–4B** show schematic illustrations of two embodiments of a WSR-S apparatus comprising a WSR apparatus and a servo-control assembly, according to the present invention;

FIG. **5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention; and

FIG. **6** shows an alternative embodiment of an OADM according to the present invention.

DETAILED DESCRIPTION

In this specification and appending claims, a "spectral channel" is characterized by a distinct center wavelength and associated bandwidth. Each spectral channel may carry a unique information signal, as in WDM optical networking applications.

FIG. **1A** depicts a first embodiment of a wavelength-separating-routing (WSR) apparatus according to the present invention. By way of example to illustrate the general principles and the topological structure of a wavelength-separating-routing (WSR) apparatus of the present invention, the WSR apparatus **100** comprises multiple input/output ports which may be in the form of an array of fiber collimators **110**, providing an input port **110-1** and a plurality of output ports **110-2** through **110-N** (N≧3); a wavelength-separator which in one form may be a diffraction grating **101**; a beam-focuser in the form of a focusing lens **102**; and an array of channel micromirrors **103**.

In operation, a multi-wavelength optical signal emerges from the input port **110-1**. The diffraction grating **101** angularly separates the multi-wavelength optical signal into multiple spectral channels, which are in turn focused by the focusing lens **102** into a spatial array of distinct spectral spots (not shown in FIG. **1A**) in a one-to-one correspondence. The channel micromirrors **103** are positioned in accordance with the spatial array formed by the spectral spots, such that each channel micromirror receives one of the spectral channels. The channel micromirrors **103** are individually controllable and movable, e.g., pivotable (or rotatable) under analog (or continuous) control, such that, upon reflection, the spectral channels are directed into selected ones of the output ports **110-2** through **110**-N by way of the focusing lens **102** and the diffraction grating **101**. As such, each channel micromirror is assigned to a specific spectral channel, hence the name "channel micromirror". Each output port may receive any number of the reflected spectral channels.

For purposes of illustration and clarity, only a selective few (e.g., three) of the spectral channels, along with the input multi-wavelength optical signal, are graphically illustrated in FIG. **1**A and the following figures. It should be noted, however, that there can be any number of the spectral channels in a WSR apparatus of the present invention (so long as the number of spectral channels does not exceed the number of channel mirrors employed in the system). It should also be noted that the optical beams representing the spectral channels shown in FIG. **1**A and the following figures are provided for illustrative purpose only. That is, their sizes and shapes may not be drawn according to scale. For instance, the input beam and the corresponding diffracted beams generally have different cross-sectional shapes, so long as the angle of incidence upon the diffraction grating is not equal to the angle of diffraction, as is known to those skilled in the art.

In the embodiment of FIG. **1**A, it is preferable that the diffraction grating **101** and the channel micromirrors **103** are placed respectively at the first and second (i.e., the front and back) focal points (on the opposing sides) of the focusing lens **102**. Such a telecentric arrangement allows the chief rays of the focused beams to be parallel to each other and generally parallel to the optical axis. In this application, the telecentric configuration further allows the reflected spectral channels to be efficiently coupled into the respective output ports, thereby minimizing various translational walk-off effects that may otherwise arise. Moreover, the input multi-wavelength optical signal is preferably collimated and circular in cross-section. The corresponding spectral channels diffracted from the diffraction grating **101** are generally elliptical in cross-section; they may be of the same size as the input beam in one dimension and elongated in the other dimension.

It is known that the diffraction efficiency of a diffraction grating is generally polarization-dependent. That is, the diffraction efficiency of a grating in a standard mounting configuration may be considerably higher for P-polarization that is perpendicular to the groove lines on the grating than for S-polarization that is orthogonal to P-polarization, especially as the number of groove lines (per unit length) increases. To mitigate such polarization-sensitive effects, a quarter-wave plate **104** may be optically interposed between the diffraction grating **101** and the channel micromirrors **103**, and preferably placed between the diffraction grating **101** and the focusing lens **102** as is shown in FIG. **1**A. In this way, each spectral channel experiences a total of approximately 90-degree rotation in polarization upon traversing the quarter-wave plate **104** twice. (That is, if a beam of light has P-polarization when first encountering the diffraction grating, it would have predominantly (if not all) S-polarization upon the second encountering, and vice versa.) This ensures that all the spectral channels incur nearly the same amount of round-trip polarization dependent loss.

In the WSR apparatus **100** of FIG. **1**A, the diffraction grating **101**, by way of example, is oriented such that the focused spots of the spectral channels fall onto the channel micromirrors **103** in a horizontal array, as illustrated in FIG. **1**B.

Depicted in FIG. **1**B is a close-up view of the channel micromirrors **103** shown in the embodiment of FIG. **1**A. By way of example, the channel micromirrors **103** are arranged in a one-dimensional array along the x-axis (i.e., the horizontal direction in the figure), so as to receive the focused spots of the spatially separated spectral channels in a one-to-one correspondence. (As in the case of FIG. **1**A, only three spectral channels are illustrated, each represented by a converging beam.) Let the reflective surface of each channel micromirror lie in the x-y plane as defined in the figure and be movable, e.g., pivotable (or deflectable) about the x-axis in an analog (or continuous) manner. Each spectral channel, upon reflection, is deflected in the y-direction (e.g., downward) relative to its incident direction, so to be directed into one of the output ports **110-2** through **110**-N shown in FIG. **1**A.

As described above, a unique feature of the present invention is that the motion of each channel micromirror is individually and continuously controllable, such that its position, e.g., pivoting angle, can be continuously adjusted. This enables each channel micromirror to scan its corresponding spectral channel across all possible output ports and thereby direct the spectral channel to any desired output port. To illustrate this capability, FIG. **1**C shows a plot of coupling efficiency as a function of a channel micromirror's pivoting angle θ, provided by a ray-tracing model of a WSR apparatus in the embodiment of FIG. **1**A. As used herein, the coupling efficiency for a spectral channel is defined as the ratio of the amount of optical power coupled into the fiber core in an output port to the total amount of optical power incident upon the entrance surface of the fiber (associated with the fiber collimator serving as the output port). In the ray-tracing model, the input optical signal is incident upon a diffraction grating with 700 lines per millimeter at a grazing angle of 85 degrees, where the grating is blazed to optimize the diffraction efficiency for the "−1" order. The focusing lens has a focal length of 100 mm. Each output port is provided by a quarter-pitch GRIN lens (2 mm in diameter) coupled to an optical fiber (see FIG. **1**D). As displayed in FIG. **1**C, the coupling efficiency varies with the pivoting angle θ, and it requires about a 0.2-degree change in θ for the coupling efficiency to become practically negligible in this exemplary case. As such, each spectral channel may practically acquire any coupling efficiency value by way of controlling the pivoting angle of its corresponding channel micromirror. This is also to say that variable optical attenuation at the granularity of a single wavelength can be obtained in a WSR apparatus of the present invention. FIG. **1**D provides ray-tracing illustrations of two extreme points on the coupling efficiency vs. θ curve of FIG. **1**C: on-axis coupling corresponding to θ=0, where the coupling efficiency is maximum; and off-axis coupling corresponding to θ=0.2 degrees, where the representative collimated beam (representing an exemplary spectral channel) undergoes a significant translational walk-off and renders the coupling efficiency practically negligible. All in all, the exemplary modeling results thus described demonstrate the unique capabilities of the WSR apparatus of the present invention.

FIG. **1**A provides one of many embodiments of a WSR apparatus according to the present invention. In general, the wavelength-separator is a wavelength-separating means that may be a ruled diffraction grating, a holographic diffraction grating, an echelle grating, a dispersing prism, or other types of spectral-separating means known in the art. The beam-focuser may be a focusing lens, an assembly of lenses, or other beam-focusing means known in the art. The focusing function may also be accomplished by using a curved diffraction grating as the wavelength-separator. The channel micromirrors may be provided by silicon micromachined mirrors, reflective ribbons (or membranes), or other types of beam-deflecting elements known in the art. And each micromirror may be pivoted about one or two axes. What is important is that the pivoting (or rotational) motion of each channel micromirror be individually controllable in an analog manner, whereby the pivoting angle can be continuously adjusted so as to enable the channel micromirror to scan a spectral channel across all possible output ports. The underlying fabrication techniques for micromachined mirrors and associated actuation mechanisms are well documented in the art, see U.S. Pat. No. 5,629,790 for example. Moreover, a fiber collimator is typically in the form of a collimating lens (such as a GRIN lens) and a ferrule-mounted fiber packaged together in a mechanically rigid stainless steel (or glass) tube. The fiber collimators serving as the input and output ports may be arranged in a one-dimensional array, a two-dimensional array, or other desired spatial pattern. For instance, they may be conveniently mounted in a linear array along a V-groove fabricated on a substrate made of silicon, plastic, or ceramic, as commonly practiced in the art. It should be noted, however, that the input port and the output ports need not necessarily be in close spatial proximity with each other, such as in an array configuration (although a close packing would reduce the rotational range required for each channel micromirror). Those skilled in the art will know how to design a WSR apparatus according to the present invention, to best suit a given application.

A WSR apparatus of the present invention may further comprise an array of collimator-alignment mirrors, for adjusting the alignment of the input multi-wavelength optical signal and facilitating the coupling of the spectral channels into the respective output ports, as shown in FIGS. **2A–2B** and **3**.

Depicted in FIG. **2A** is a second embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **200** is built upon and hence shares a number of the elements used in the embodiment of FIG. **1A**, as identified by those labeled with identical numerals. Moreover, a one-dimensional array **220** of collimator-alignment mirrors **220-1** through **220**-N is optically interposed between the diffraction grating **101** and the fiber collimator array **110**. The collimator-alignment mirror **220-1** is designated to correspond with the input port **110-1**, for adjusting the alignment of the input multi-wavelength optical signal and therefore ensuring that the spectral channels impinge onto the corresponding channel micromirrors. The collimator-alignment mirrors **220-2** through **220**-N are designated to the output ports **110-2** through **110**-N in a one-to-one correspondence, serving to provide angular control of the collimated beams of the reflected spectral channels and thereby facilitating the coupling of the spectral channels into the respective output ports according to desired coupling efficiencies. Each collimator-alignment mirror may be rotatable about one axis, or two axes.

The embodiment of FIG. **2A** is attractive in applications where the fiber collimators (serving as the input and output ports) are desired to be placed in close proximity to the collimator-alignment mirror array **220**. To best facilitate the coupling of the spectral channels into the output ports, arrays of imaging lenses may be implemented between the collimator-alignment mirror array **220** and the fiber collimator array **110**, as depicted in FIG. **2B**. By way of example, WSR apparatus **250** of FIG. **2B** is built upon and hence shares many of the elements used in the embodiment of FIG. **2A**, as identified by those labeled with identical numerals. Additionally, first and second arrays **260, 270** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the collimator-alignment mirror array **220** and the fiber collimator array **110**. The dashed box **280** shown in FIG. **2C** provides a top view of such a telecentric arrangement. In this case, the imaging lenses in the first and second arrays **260, 270** all have the same focal length f. The collimator-alignment mirrors **220-1** through **220**-N are placed at the respective first (or front) focal points of the imaging lenses in the first array **260**. Likewise, the fiber collimators **110-1** through **110**-N are placed at the respective second (or back) focal points of the imaging lenses in the second array **270**. And the separation between the first and second arrays **260, 270** of imaging lenses is 2f. In this way, the collimator-alignment mirrors **220-1** through **220**-N are effectively imaged onto the respective entrance surfaces (i.e., the front focal planes) of the GRIN lenses in the corresponding fiber collimators **110-1** through **110**-N. Such a telecentric imaging system substantially eliminates translational walk-off of the collimated beams at the output ports that may otherwise occur as the mirror angles change.

FIG. **3** shows a fourth embodiment of a WSR apparatus according to the present invention. By way of example, WSR apparatus **300** is built upon and hence shares a number of the elements used in the embodiment of FIG. **2B**, as identified by those labeled with identical numerals. In this case, the one-dimensional fiber collimator array **110** of FIG. **2B** is replaced by a two-dimensional array **350** of fiber collimators, providing for an input-port and a plurality of output ports. Accordingly, the one-dimensional collimator-alignment mirror array **220** of FIG. **2B** is replaced by a two-dimensional array **320** of collimator-alignment mirrors, and first and second one-dimensional arrays **260, 270** of imaging lenses of FIG. **2B** are likewise replaced by first and second two-dimensional arrays **360, 370** of imagining lenses respectively. As in the case of the embodiment of FIG. **2B**, the first and second two-dimensional arrays **360, 370** of imaging lenses are placed in a 4-f telecentric arrangement with respect to the two-dimensional collimator-alignment mirror array **320** and the two-dimensional fiber collimator array **350**. The channel micromirrors **103** must be pivotable biaxially in this case (in order to direct its corresponding spectral channel to any one of the output ports). As such, the WSR apparatus **300** is equipped to support a greater number of the output ports.

In addition to facilitating the coupling of the spectral channels into the respective output ports as described above, the collimator-alignment mirrors in the above embodiments also serve to compensate for misalignment (e.g., due to fabrication and assembly errors) in the fiber collimators that provide for the input and output ports. For instance, relative misalignment between the fiber cores and their respective collimating lenses in the fiber collimators can lead to pointing errors in the collimated beams, which may be corrected for by the collimator-alignment mirrors. For these reasons, the collimator-alignment mirrors are preferably rotatable about two axes. They may be silicon micromachined mirrors, for fast rotational speeds. They may also be other types of mirrors or beam-deflecting elements known in the art.

To optimize the coupling of the spectral channels into the output ports and further maintain the optimal optical alignment against environmental effects such as temperature variations and mechanical instabilities over the course of operation, a WSR apparatus of the present invention may incorporate a servo-control assembly, for providing dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis. A WSR apparatus incorporating a servo-control assembly is termed a WSR-S apparatus, thereinafter in this specification.

FIG. **4A** depicts a schematic illustration of a first embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **400** comprises a WSR apparatus **410** and a servo-control assembly **440**. The WSR **410** may be in the embodiment of FIG. **1A**, or any other embodiment in accordance with the present invention. The servo-control assembly **440** includes a spectral monitor **460**, for monitoring the power levels of the spectral channels coupled into the output ports **420-1** through **420**-N of the WSR apparatus **410**. By way of example, the spectral monitor **460** is coupled to the output ports **420-1** through **420**-N by way of fiber-optic couplers **420-1**-C through **420**-N-C, wherein each fiber-optic coupler serves to tap off a predetermined fraction of the optical signal in the corresponding output port. The servo-control assembly **440** further includes a processing unit **470**, in communication with the spectral monitor **460** and the channel micromirrors **430** of the WSR apparatus **410**. The processing unit **470** uses the power measurements from the spectral monitor **460** to provide feedback control of the channel micromirrors **430** on an individual basis, so as to maintain a desired coupling efficiency for each spectral channel into a selected output port. As such, the servo-control assembly **440** provides dynamic control of the coupling of the spectral channels into the respective output ports on a channel-by-channel basis and thereby manages the power levels of the spectral channels coupled into the output ports. The power levels of the spectral channels in the output ports may be dynamically managed according to demand, or maintained at desired values (e.g., equalized at a predetermined value) in the present invention. Such a spectral power-management capability is essential in WDM optical networking applications, as discussed above.

FIG. **4B** depicts a schematic illustration of a second embodiment of a WSR-S apparatus according to the present invention. The WSR-S apparatus **450** comprises a WSR apparatus **480** and a servo-control assembly **490**. In addition to the channel micromirrors **430** (and other elements identified by the same numerals as those used in FIG. **4A**), the WSR apparatus **480** further includes a plurality of collimator-alignment mirrors **485**, and may be configured according to the embodiment of FIGS. **2A**, **2B**, **3**, or any other embodiment in accordance with the present invention. By way of example, the servo-control assembly **490** includes the spectral monitor **460** as described in the embodiment of FIG. **4A**, and a processing unit **495**. In this case, the processing unit **495** is in communication with the channel micromirrors **430** and the collimator-alignment mirrors **485** of the WSR apparatus **480**, as well as the spectral monitor **460**. The processing unit **495** uses the power measurements from the spectral monitor **460** to provide dynamic control of the channel micromirrors **430** along with the collimator-alignment mirrors **485**, so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values.

In the embodiment of FIG. **4A** or **4B**, the spectral monitor **460** may be one of spectral power monitoring devices known in the art that is capable of detecting the power levels of spectral components in a multi-wavelength optical signal. Such devices are typically in the form of a wavelength-separating means (e.g., a diffraction grating) that spatially separates a multi-wavelength optical signal by wavelength into constituent spectral components, and one or more optical sensors (e.g., an array of photodiodes) that are configured such to detect the power levels of these spectral components. The processing unit **470** in FIG. **4A** (or the processing unit **495** in FIG. **4B**) typically includes electrical circuits and signal processing programs for processing the power measurements received from the spectral monitor **460** and generating appropriate control signals to be applied to the channel micromirrors **430** (and the collimator-alignment mirrors **485** in the case of FIG. **4B**), so to maintain the coupling efficiencies of the spectral channels into the output ports at desired values. The electronic circuitry and the associated signal processing algorithm/software for such processing unit in a servo-control system are known in the art. A skilled artisan will know how to implement a suitable spectral monitor along with an appropriate processing unit to provide a servo-control assembly in a WSP-S apparatus according to the present invention, for a given application.

The incorporation of a servo-control assembly provides additional advantages of effectively relaxing the requisite fabrication tolerances and the precision of optical alignment during initial assembly of a WSR apparatus of the present invention, and further enabling the system to correct for shift in the alignment over the course of operation. By maintaining an optimal optical alignment, the optical losses incurred by the spectral channels are also significantly reduced. As such, the WSR-S apparatus thus constructed is simpler and more adaptable in structure, more robust in performance, and lower in cost and optical loss. Accordingly, the WSR-S (or WSR) apparatus of the present invention may be used to construct a variety of optical devices and utilized in many applications.

For instance, by directing the spectral channels into the output ports in a one-channel-per-port fashion and coupling the output ports of a WSR-S (or WSR) apparatus to an array of optical sensors (e.g., photodiodes), or a single optical sensor that is capable of scanning across the output ports, a dynamic and versatile spectral power monitor (or channel analyzer) is provided, which would be highly desired in WDM optical networking applications. Moreover, a novel class of optical add-drop multiplexers (OADMs) may be built upon the WSR-S (or WSR) apparatus of the present invention, as exemplified in the following embodiments.

FIG. **5** depicts an exemplary embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **500** comprises a WSR-S (or WSR) apparatus **510** and an optical combiner **550**. An input port **520** of the WSR-S apparatus **510** transmits a multi-wavelength optical signal. The constituent spectral channels are subsequently separated and routed into a plurality of output ports, including a pass-through port **530** and one or more drop ports **540-1** through **540**-N ($N \geqq 1$). The pass-through port **530** may receive any number of the spectral channels (i.e., the pass-through spectral channels). Each drop port may also receive any number of the spectral channels (i.e., the drop spectral channels). The pass-through port **530** is optically coupled to the optical combiner **550**, which serves to combine the pass-through spectral channels with one or more add spectral channels provided by one or more add ports **560-1** through **560**-M ($M \geqq 1$). The combined optical signal is then routed into an existing port **570**, providing an output multi-wavelength optical signal.

In the above embodiment, the optical combiner **550** may be a $K \times 1$ ($K \geqq 2$) broadband fiber-optic coupler, wherein there are K input-ends and one output-end. The pass-through spectral channels and the add spectral channels are fed into the K input-ends (e.g., in a one-to-one correspondence) and the combined optical signal exits from the output-end of the K×1 fiber-optic coupler as the output multi-wavelength optical signal of the system. Such a multiple-input coupler also serves the purpose of multiplexing a multiplicity of add spectral channels to be coupled into the OADM **500**. If the power levels of the spectral channels in the output multi-wavelength optical signal are desired to be actively managed, such as being equalized at a predetermined value, two spectral monitors may be utilized. As a way of example, the first spectral monitor may receive optical signals tapped off from the pass-through port **530** and the drop ports **540-1** through **540**-N (e.g., by way of fiber-optic couplers as depicted in FIG. **4**A or **4**B). The second spectral monitor receives optical signals tapped off from the exiting port **570**. A servo-control system may be constructed accordingly for monitoring and controlling the pass-through, drop and add spectral channels. As such, the embodiment of FIG. **5** provides a versatile optical add-drop multiplexer in a simple and low-cost assembly, while providing multiple physically separate drop/add ports in a dynamically reconfigurable fashion.

FIG. **6** depicts an alternative embodiment of an optical add-drop multiplexer (OADM) according to the present invention. By way of example, OADM **600** comprises a first WSR-S apparatus **610** optically coupled to a second WSR-S apparatus **650**. Each WSR-S apparatus may be in the embodiment of FIG. **4**A or **4**B. (A WSR apparatus of the embodiment of FIG. **1**A, **2**A, **2**B, or **3** may be alternatively implemented.) The first WSR-S apparatus **610** includes an input port **620**, a pass-through port **630**, and one or more drop ports **640-1** through **640**-N (N≧1). The pass-through spectral channels from the pass-through port **630** are further coupled to the second WSR-S apparatus **650**, along with one or more add spectral channels emerging from add ports **660-1** through **660**-M (M≧1). In this exemplary case, the pass-through port **630** and the add ports **660-1** through **660**-M constitute the input ports for the second WSR-S apparatus **650**. By way of its constituent wavelength-separator (e.g., a diffraction grating) and channel micromirrors (not shown in FIG. **6**), the second WSR-S apparatus **650** serves to multiplex the pass-through spectral channels and the add spectral channels, and route the multiplexed optical signal into an exiting port **770** to provide an output signal of the system.

In the embodiment of FIG. **6**, one WSR-S apparatus (e.g., the first WSR-S apparatus **610**) effectively performs dynamic drop function, whereas the other WSR-S apparatus (e.g., the second WSR-S apparatus **650**) carries out dynamic add function. And there are essentially no fundamental restrictions on the wavelengths that can be added or dropped (other than those imposed by the overall communication system). Moreover, the underlying OADM architecture thus presented is intrinsically scalable and can be readily extended to any number of cascaded WSR-S (or WSR) systems, if so desired for performing intricate add and drop functions. Additionally, the OADM of FIG. **6** may be operated in reverse direction, by using the input ports as the output ports, the drop ports as the add ports, and vice versa.

Those skilled in the art will recognize that the aforementioned embodiments provide only two of many embodiments of a dynamically reconfigurable OADM according to the present invention. Those skilled in the art will also appreciate that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention as defined in the appended claims. Accordingly, a skilled artisan can design an OADM in accordance with the principles of the present invention, to best suit a given application.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions, and alternations can be made herein without departing from the principles and the scope of the invention. Accordingly, the scope of the present invention should be determined by the following claims and their legal equivalents.

What is claimed is:

1. A wavelength-separating-routing apparatus, comprising:

a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports.

2. The wavelength-separating-routing apparatus of claim **1** further comprising a servo-control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

3. The wavelength-separating-routing apparatus of claim **2** wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

4. The wavelength-separating-routing apparatus of claim **3** wherein said servo-control assembly maintains said power levels at a predetermined value.

5. The wavelength-separating-routing apparatus of claim **1** further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

6. The wavelength-separating-routing apparatus of claim **5** wherein each collimator-alignment mirror is rotatable about one axis.

7. The wavelength-separating-routing apparatus of claim **5** wherein each collimator-alignment mirror is rotatable about two axes.

8. The wavelength-separating-routing apparatus of claim **5** further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

9. The wavelength-separating-routing apparatus of claim **1** wherein each channel micromirror is continuously pivotable about one axis.

10. The wavelength-separating-routing apparatus of claim **1** wherein each channel micromirror is pivotable about two axes.

11. The wavelength-separating-routing apparatus of claim **10** wherein said fiber collimators are arranged in a two-dimensional array.

12. The wavelength-separating-routing apparatus of claim 1 wherein each channel micromirror is a silicon micromachined mirror.

13. The wavelength-separating-routing apparatus of claim 1 wherein said fiber collimators are arranged in a one-dimensional array.

14. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises a focusing lens having first and second focal points.

15. The wavelength-separating-routing apparatus of claim 14 wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points of said focusing lens.

16. The wavelength-separating-routing apparatus of claim 1 wherein said beam-focuser comprises an assembly of lenses.

17. The wavelength-separating-routing apparatus of claim 1 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

18. The wavelength-separating-routing apparatus of claim 1 further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

19. The wavelength-separating-routing apparatus of claim 1 wherein each output port carries a single one of said spectral channels.

20. The wavelength-separating-routing apparatus of claim 19 further comprising one or more optical sensors, optically coupled to said output ports.

21. A servo-based optical apparatus comprising:

a) multiple fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually controllable to reflect said spectral channels into selected ones of said output ports; and

e) a servo-control assembly, in communication with said channel micromirrors and said output ports, for maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

22. The servo-based optical apparatus of claim 21 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

23. The servo-based optical apparatus of claim 22 wherein said servo-control assembly maintains said power levels at a predetermined value.

24. The servo-based optical apparatus of claim 21 further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

25. The servo-based optical apparatus of claim 24 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

26. The servo-based optical apparatus of claim 24 wherein each collimator-alignment mirror is rotatable about at least one axis.

27. The servo-based optical apparatus of claim 21 wherein each channel micromirror is continuously pivotable about at least one axis.

28. The servo-based optical apparatus of claim 21 wherein each channel micromirror is a silicon micromachined mirror.

29. The servo-based optical apparatus of claim 21 wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

30. The servo-based optical apparatus of claim 21 wherein said beam-focuser comprises one or more lenses.

31. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

e) a one-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

32. The optical apparatus of claim 31 further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

33. The optical apparatus of claim 32 wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

34. The optical apparatus of claim 31 wherein each channel micromirror is continuously pivotable about at least one axis.

35. The optical apparatus of claim 31 wherein each collimator-alignment mirror is rotatable about at least one axis.

36. The optical apparatus of claim 31 further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

37. An optical apparatus comprising:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots;

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously controllable to reflect said spectral channels into selected ones of said output ports; and

e) a two-dimensional array of collimator-alignment mirrors, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

38. The optical apparatus of claim **37** further comprising a servo-control assembly, in communication with said channel micromirrors, said collimator-alignment mirrors, and said output ports, for providing control of said channel micromirrors along with said collimator-alignment mirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

39. The optical apparatus of claim **38** wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors and said collimator-alignment mirrors.

40. The optical apparatus of claim **37** wherein each collimator-alignment mirror is rotatable about at least one axis.

41. The optical apparatus of claim **37** wherein each channel micromirror is continuously pivotable about at least one axis.

42. The optical apparatus of claim **41** wherein each channel micromirrors is pivotable about two axes, and wherein said fiber collimators are arranged in a two-dimensional array.

43. The optical apparatus of claim **37** further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

44. An optical system comprising a wavelength-separating-routing apparatus, wherein said wavelength-separating-routing apparatus includes:

a) an array of fiber collimators, providing an input port for a multi-wavelength optical signal and a plurality of output ports including a pass-through port and one or more drop ports;

b) a wavelength-separator, for separating said multi-wavelength optical signal from said input port into multiple spectral channels;

c) a beam-focuser, for focusing said spectral channels into corresponding spectral spots; and

d) a spatial array of channel micromirrors positioned such that each channel micromirror receives one of said spectral channels, said channel micromirrors being individually and continuously pivotable to reflect said spectral channels into selected ones of said output ports, whereby said pass-through port receives a subset of said spectral channels.

45. The optical system of claim **44** further comprising a servo-control assembly, in communication with said channel micromirrors and said output ports, for providing control of said channel micromirrors and thereby maintaining a predetermined coupling of each reflected spectral channel into one of said output ports.

46. The optical system of claim **45** wherein said servo-control assembly comprises a spectral monitor for monitoring power levels of said spectral channels coupled into said output ports, and a processing unit responsive to said power levels for providing control of said channel micromirrors.

47. The optical system of claim **44** further comprising an array of collimator-alignment mirrors, in optical communication with said wavelength-separator and said fiber collimators, for adjusting an alignment of said multi-wavelength optical signal from said input port and directing said reflected spectral channels into said output ports.

48. The optical system of claim **47** further comprising first and second arrays of imaging lenses, in a telecentric arrangement with said collimator-alignment mirrors and said fiber collimators.

49. The optical system of claim **47** wherein each collimator-alignment mirror is rotatable about at least one axis.

50. The optical system of claim **44** wherein each channel micromirror is pivotable about at least one axis.

51. The optical system of claim **44** wherein each channel micromirror is a silicon micromachined mirror.

52. The optical system of claim **44** wherein said beam-focuser comprises a focusing lens having first and second focal points, and wherein said wavelength-separator and said channel micromirrors are placed respectively at said first and second focal points.

53. The optical system of claim **44** wherein said wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

54. The optical system of claim **44** further comprising a quarter-wave plate optically interposed between said wavelength-separator and said channel micromirrors.

55. The optical system of claim **44** further comprising an auxiliary wavelength-separating-routing apparatus, including:

a) multiple auxiliary fiber collimators, providing a plurality of auxiliary input ports and an exiting port;

b) an auxiliary wavelength-separator;

c) an auxiliary beam-focuser; and

d) a spatial array of auxiliary channel micromirrors;

wherein said subset of said spectral channels in said pass-through port and one or more add spectral channels are directed into said auxiliary input ports, and multiplexed into an output optical signal directed into said exiting port by way of said auxiliary wavelength-separator, said auxiliary beam-focuser and said auxiliary channel micromirrors.

56. The optical system of claim **55** wherein said auxiliary channel micromirrors are individually pivotable.

57. The optical system of claim **55** wherein each auxiliary channel micromirror is pivotable continuously about at least one axis.

58. The optical system of claim **55** wherein each auxiliary channel micromirror is a silicon micromachined mirror.

59. The optical system of claim **55** wherein said auxiliary wavelength-separator comprises an element selected from the group consisting of ruled diffraction gratings, holographic diffraction gratings, echelle gratings, curved diffraction gratings, and dispersing prisms.

60. The optical system of claim **55** wherein said pass-through port constitutes one of said auxiliary input ports.

61. A method of performing dynamic wavelength separating and routing, comprising:

a) receiving a multi-wavelength optical signal from an input port;

b) separating said multi-wavelength optical signal into multiple spectral channels;

c) focusing said spectral channels onto a spatial array of corresponding beam-deflecting elements, whereby each beam-deflecting element receives one of said spectral channels; and

d) dynamically and continuously controlling said beam-deflecting elements, thereby directing said spectral channels into a plurality of output ports.

62. The method of claim **61** further comprising the step of providing feedback control of said beam-deflecting elements, thereby maintaining a predetermining coupling of each spectral channel directed into one of said output ports.

63. The method of claim **62** further comprising the step of maintaining power levels of said spectral channels directed into said output ports at a predetermining value.

64. The method of claim **61** wherein each spectral channel is directed into a separate output port.

65. The method of claim **61** wherein a subset of said spectral channels is directed into one of said output ports, thereby providing one or more pass-through spectral channels.

66. The method of claim **65** further comprising the step of multiplexing said pass-through spectral channels with one or more add spectral channels, so as to provide an output optical signal.

67. The method of claim **61** wherein said beam-deflecting elements comprise an array of silicon micromachined mirrors.

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