Reconfigurable 16-Channel WDM DROP Module Using Silicon MEMS Optical Switches

C. R. Giles, B. Barber, V. Aksyuk, R. Ruel, Larry Stulz, and D. Bishop

***Abstract*—A reconfigurable 16-channel 100-GHz spacing wavelength-division-multiplexed DROP module for use at 1550 nm was demonstrated using silicon microelectromechanical system (MEMS) optical switches and arrayed waveguide grating routers. Thru-channel extinction was greater than 40 dB and average insertion loss was 21 dB. Both drop-and-retransmit of multiple channels (11–18 dB contrast, 14–19-dB insertion loss) and drop-and-detect of single channels (>20-dB adjacent channel rejection, 10–14-dB insertion loss) were implemented.**

***Index Terms*— Fiber-optic communications, MEMS devices, micromachines, optical networks.**

I. Introduction

ADVANCED LIGHTWAVE systems utilizing wavelength-division-multiplexed (WDM) channels are capable of supporting functions acting in the optical layer to enhance provisioning and protection of the network. Optical wavlength add/drop multiplexers (ADM) selectively remove one or more WDM channels and replace them with new channels at the same wavelengths. Residual leakage of the dropped channels must be very small to minimize their interference to the added channels. This requires low-channel crosstalk through the wavelength multiplexers and demultiplexers and high-contrast optical switches in a reconfigurable ADM. Integrated reconfigurable ADM's have been demonstrated using silica on silicon [1] and InP [2], but their utility is compromised by marginal optical performance relative to that needed in real applications. A free-space optics ADM having a bulk-grating and micromachine mirror array has also been reported, with promising performance [3] In this letter, we describe a reconfigurable drop module (RDM) implemented as a hybrid optical circuit comprised of two 16-channel arrayed waveguide grating routers (AWGR) [4], sixteen MEMS optical switches, and ancillary optical components. The RDM was designed with drop-and-transmit (DT) capability for eight channels such that when dropped, they remained combined in a single optical fiber, suitable for WDM transport away from the RDM node. Eight other channels were configured for drop-and-detect (DD) where dropped channels exit on separate fibers, suitable for local reception. Channel-add for full ADM functionality may be trivially obtained using a final-stage coupler.

II. Results

Fig. 1 shows the layout of the 16-channel 100-GHz channel spaced RDM configured with DT capability for half of the channels and DD capability for the remaining channels. An input optical circulator (0.6-dB port-to-port insertion loss) redirected DT-channels to a transmission fiber and the first AWGR demultiplexed the input channels and recombined any DT-channels. DT was controlled by reflective MEMS optical switches [5]; channels reached the thru-port when switches were in the transmit-state and dropped when the switches were activated into their reflection state. Channels configured for drop-and-detect were divided after the first silica-waveguide AWGR using 3-dB passive couplers, resulting in fixed drop-ports and ports that were connected to the output AWGR through nonreflective MEMS switches. The nonreflective switches were the same as the reflective types only their shutter angles were set to reduce reflected light coupling back into the fiber. A channel reached the thru-port when the corresponding MEMS switch was in the transmit state, otherwise it was blocked.

As seen in the AWGR transmission spectra of Fig. 2, the first AWGR had 40-GHz BW gaussian passbands with transmission loss varying from 7.1 to 12.4 dB, *including* the 3-dB coupler loss of channels 1–4 and 13–16, whereas the second AWGR (this router was a "non-wrap-around" design, transmitting only one band of 16 channels) with flattened 50-GHz passbands had losses ranging from 7.45 to 10.61 dB. This combination of two router types was chosen to simplify their channel registration while achieving good crosstalk performance and minimal bandwidth narrowing. Insertion loss of

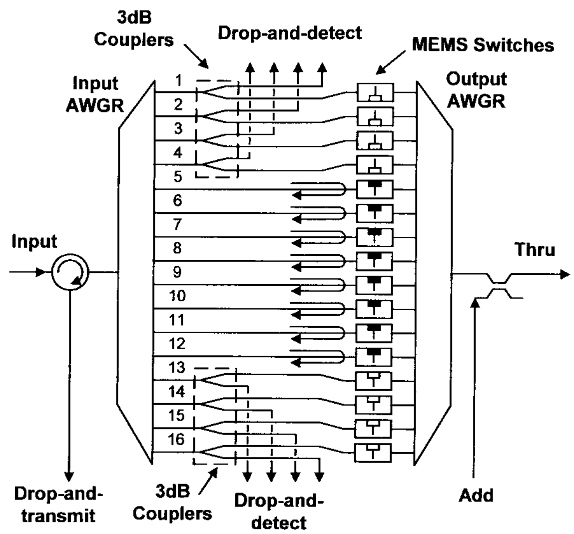
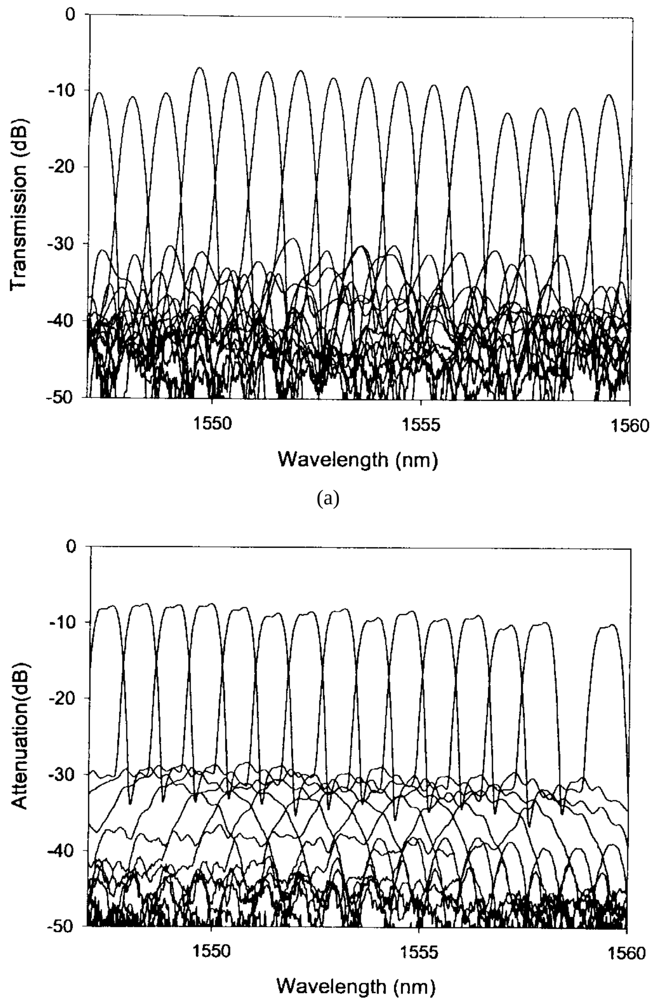


Fig. 1. Reconfigurable drop module with channels 1–4 and 13–16 arranged for DD and channels 5–12 arranged for DT. Arbitrary reconfiguration of all 16 channels is obtained using voltage-actuated silicon MEM's optical switches.

Manuscript received September 24, 1998.
The authors are with the Lucent Technologies, Holmdel, NJ 07733 USA.
Publisher Item Identifier S 1041-1135(99)00355-9.



(a)

(b)

Fig. 2. Transmission spectra of (a) Gaussian passband input AWGR and (b) flattened passband output AWGR.

the DD channels from the input of the RDM to their respective drop-port ranged from 10.8 to 13.8 dB. The MEMS optical switches consisted of a thin, gold-coated silicon shutter that was raised in a pivoting action by a voltage applied to a moveable capacitor plate on the opposite side of a fulcrum. An array of dimples on the underside of the capacitor plate ensured that it never fully contacted the lower electrode thereby preventing the occurrence of stiction. Applying the voltage interposed the shutter between two anitreflection-coated fibers that were epoxy-bonded to the switches' silicon substrate. Switch losses in the transmit state ranged from 0.8 to 3.3 dB, varying because of small alignment errors between the optical fibers present during the passive assembly of the switches. The return loss of the switches in the reflective state ranged from 2.2 to 4.8 dB for those switches having the shutter angle aligned for normal incidence. As seen in Fig. 3, most switches exhibited high extinction ratios, >40 dB, achievable with a moderate control voltage (20–40 V). Switching time with a step drive voltage was approximately 95 μs.

Optical characteristics of the assembled reconfigurable

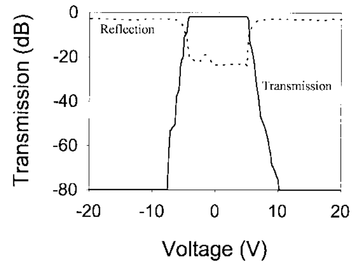
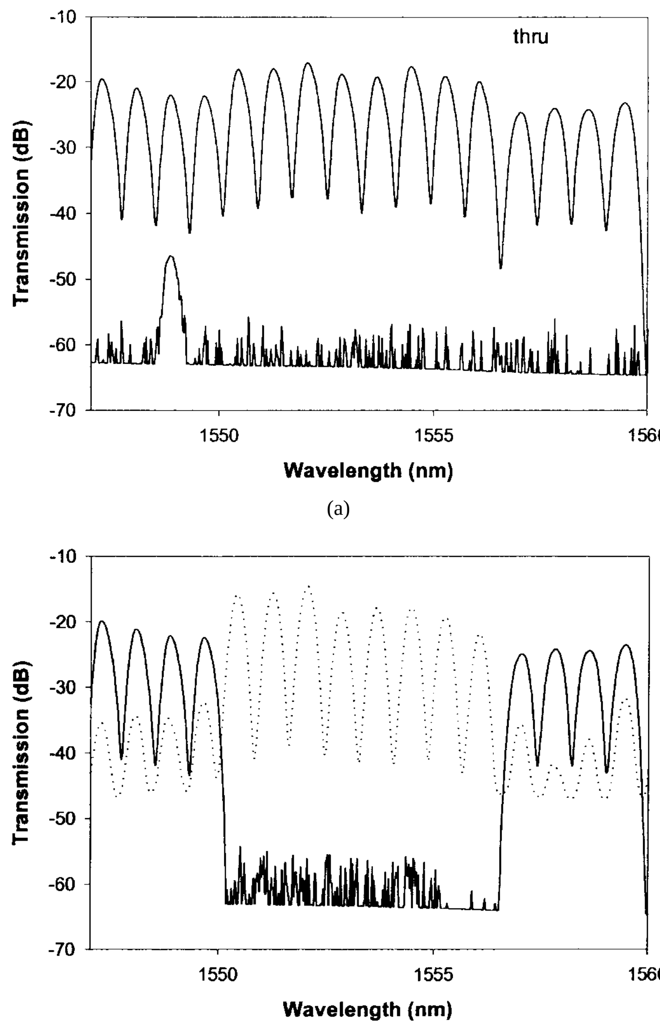


Fig. 3. Transmission (solid line) and reflection (dotted line) characteristics of a typical MEMS optical switch.



(a)

(b)

Fig. 4. (a) Optical spectra at the thru-port with all channels transmitted and all channels blocked by the MEMS switches. (b) Optical spectra at the thru-port (solid line) and the drop-and-transmit port (dotted line) with all DT channels (channels 5–12) in the drop state.

transmitted or dropped. Thru-channel loss of the RDM ranged from 17–24 dB, including loss from the 3-dB splitters of the drop-and-detect channels, and crosstalk through it was below −40 dB (noise-limited measurement). This crosstalk level would cause negligible performance degradation in a digital lightwave transmission system. High extinction at the thruwhile all others exceeded 40 dB. Fig. 4(b) shows spectra at the thru-port and the DT port with the RDM set to drop the 8 drop-and-transmit channels. Losses of the drop-and-transmit channels ranged from 14 to 19 dB and their extinction ratios from transmit to drop state, 11–18 dB, were limited by weak reflections from the fiber gaps in the switches. Low-power reflections of the DD channels also appeared in the drop-and-continue port, but would have little impact as they would be rejected by a demultiplexer before the DT channel receivers. Unwanted reflections from the fiber gaps could be greatly reduced using angle-cleaved fibers and appropriately orienting the MEMS shutter in the gap. These values of extinction, loss and crosstalk through the RDM are sufficient for most network applications where the RDM is used in conjunction with optical amplifiers to compensate the loss. Full channel add/drop capability could be implemented by the inclusion of a passive combiner after the output port of the RDM.

III. Summary

We have demonstrated an arbitrarily reconfigurable 16-channel 100-GHz spacing drop module using MEMS optical switches to achieve excellent channel isolation and crosstalk. These switches may replace large bulk-optic components to make very compact reconfigurable WDM network modules for use in advanced lightwave systems. Ultimately, these switches might be integrated with passive optical structures including WDM routers and cross-connect fabrics, enabling practical large-scale WDM network devices.

References

[1] K. Okamoto, K. Takiguchi, and Y. Ohmori, “16-channel optical add/drop multiplexer using silica based arrayed-waveguide gratings,” *Electron. Lett.*, vol. 31, no. 9, pp. 723–724, 1995.

[2] C. G. M. Vreeburg, T. Uitterdijk, Y. S. Oei, M. K. Smit, F. H. Groen, E. G. Metaal, P. Demeester, and H. J. Frankena, “First InP-based reconfigurable integrated add-drop multiplexer,” *IEEE Photon. Technol. Lett.*, vol. 9, pp. 188–190, Feb. 1997.

[3] J. E. Ford, J. A. Walker, V. Aksyuk, and D. J. Bishop, “Wavelength-selectable add/drop with tilting micromirrors,” presented at the LEOS Annu. Meeting, Nov. 1997, postdeadline paper PD 2.3.

[4] C. Dragone, “An $N \times N$ optical multiplexer using a planar arrangement of two star couplers,” *IEEE Photon. Technol. Lett.*, vol. 3, pp. 812–815, 1991.

[5] V. Aksyuk, B. Barber, C. R. Giles, R. Ruel, L. Stulz, and D. Bishop “Low insertion loss packaged and fiber-connectorized MEMS reflective optical switch,” *Electron. Lett.*, submitted for publication.