

# *Fibre Optics*

## Principles and Practices



***Abdul Al-Azzawi***



# *Fibre Optics*

Principles and Practices

*Abdul Al-Azzawi*



CRC Press

Taylor & Francis Group

Boca Raton London New York

---

CRC Press is an imprint of the  
Taylor & Francis Group, an informa business

This material was previously published in *Photonics: Principles and Practices* © 2007 by Taylor & Francis Group, LLC.

CRC Press  
Taylor & Francis Group  
6000 Broken Sound Parkway NW, Suite 300  
Boca Raton, FL 33487-2742

© 2007 by Taylor & Francis Group, LLC  
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works  
Printed in the United States of America on acid-free paper  
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-8295-5 (Hardcover)  
International Standard Book Number-13: 978-0-8493-8295-6 (Hardcover)

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

No part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access [www.copyright.com](http://www.copyright.com) (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

**Trademark Notice:** Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at  
<http://www.taylorandfrancis.com>

and the CRC Press Web site at  
<http://www.crcpress.com>

# Table of Contents

## Chapter 1

Fibre Optic Cables.....	1
1.1 Introduction.....	1
1.2 The Evolution of Fibre Optic Cables.....	1
1.3 Fibre Optic Cables.....	5
1.4 Plastic Fibre Cables.....	6
1.5 Light Propagation in Fibre Optic Cables .....	7
1.6 Refractive-Index Profile .....	8
1.7 Types of Fibre Optic Cables .....	8
1.7.1 Single-Mode Step-Index Fibre Cable .....	9
1.7.2 Multimode Step-Index Fibre Cable (Multimode Fibre Cable) .....	9
1.7.3 Multimode Graded-Index Fibre (Graded-Index Fibre Cable) .....	10
1.8 Polarization Maintaining Fibre Cables.....	10
1.9 Specialty Fibre Cables.....	11
1.10 Fibre Cable Fabrication Techniques .....	11
1.10.1 Double Crucible Method .....	12
1.10.2 Chemical Vapour Deposition Processes .....	13
1.10.3 Outside Vapour Deposition .....	14
1.10.4 Vapour Axial Deposition .....	14
1.10.5 Modified Chemical Vapour Deposition .....	15
1.10.6 Plasma Chemical Vapour Deposition .....	16
1.11 Fibre Drawing .....	17
1.12 Numerical Aperture .....	17
1.13 Modes in a Fibre Optic Cable .....	19
1.14 Light Source Coupling to a Fibre Cable.....	20
1.15 Launching Light Conditions into Fibre Cables .....	22
1.16 Fibre Tube Assembly .....	23
1.17 Fibre Optic Cables versus Copper Cables .....	23
1.18 Applications of Fibre Optic Cables.....	25
1.19 Experimental Work.....	26
1.19.1 Case (a): Fibre Cable Inspection and Handling.....	26
1.19.2 Case (b): Fibre Cable Ends Preparation.....	26
1.19.3 Case (c): NA and Acceptance Angles Calculation .....	26
1.19.4 Case (d): Fibre Cable Power Output Intensity.....	27
1.19.5 Technique And Apparatus .....	27
1.19.6 Procedure .....	29
1.19.7 Safety Procedure .....	29
1.19.8 Apparatus Set-Up .....	29
1.19.8.1 Case (a): Fibre Cable Inspection and Handling .....	29
1.19.8.2 Case (b): Fibre Cable Ends Preparation .....	31
1.19.8.3 Case (c): NA and Acceptance Angles Calculation .....	34
1.19.8.4 Case (d) Fibre Cable Power Output Intensity.....	35
1.19.9 Data Collection .....	37
1.19.9.1 Case (a): Fibre Cable Inspection and Handling .....	37
1.19.9.2 Case (b): Fibre Cable Ends Preparation .....	37
1.19.9.3 Case (c): NA and Acceptance Angles Calculation.....	37
1.19.9.4 Case (d): Fibre Cable Power Output Intensity .....	37

1.19.10	Calculations and Analysis .....
1.19.10.1	Case (a): Fibre Cable Inspection and Handling .....
1.19.10.2	Case (b): Fibre Cable Ends Preparation .....
1.19.10.3	Case (c): NA and Acceptance Angles Calculation.....
1.19.10.4	Case (d): Fibre Cable Power Output Intensity .....
1.19.11	Results and Discussions .....
1.19.11.1	Case (a): Fibre Cable Inspection and Handling .....
1.19.11.2	Case (b): Fibre Cable Ends Preparation .....
1.19.11.3	Case (c): NA and Acceptance Angles Calculation.....
1.19.11.4	Case (d): Fibre Cable Power Output Intensity .....
1.19.12	Conclusion .....
1.19.13	Suggestions for Future Lab Work .....
1.20	List of References.....
1.21	Appendix.....
	Further Reading .....

## Chapter 2

	Advanced Fibre Optic Cables .....
2.1	Introduction.....
2.2	Advanced Types of Fibre Optic Cables.....
2.2.1	Dual-Core Fibre for High-Power Laser .....
2.2.2	Fibre Bragg Gratings .....
2.2.2.1	Manufacturing Method .....
2.2.3	Chirped Fibre Bragg Gratings .....
2.2.3.1	Manufacturing Method .....
2.2.4	Blazed Fibre Bragg Gratings .....
2.2.5	Nonzero-Dispersion Fibre-Optic Cables .....
2.2.6	Photonic Crystal Fibre Cables .....
2.2.7	Microstructure Fibre Cables .....
2.2.8	Polymer Holey-Fibre Cables .....
2.2.9	Image Fibre Cables.....
2.2.10	Liquid Crystal Photonic Bandgap Fibre Cables .....
2.2.11	Lensed and Tapered Fibre Cables .....
2.2.11.1	Advantages of Lensing Technology .....
2.2.11.2	Manufacturing Technologies .....
2.2.12	Bend-Insensitive Fibre Cables .....
2.2.13	Nanoribbon Fibre Optic Cables .....
2.3	Applications of Advanced Fibre Cables .....
2.4	Experimental Work.....
2.4.1	Conclusion .....
2.4.2	Suggestions for Future Lab Work .....
2.5	List of References.....
2.6	Appendix.....
	Further Reading .....

## Chapter 3

	Light Attenuation in Optical Components .....
3.1	Introduction.....
3.2	Light Losses in an Optical Material.....
3.2.1	Absorption.....
3.2.2	Dispersion .....

# Explore Litigation Insights



Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

### API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

### LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

### FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

### E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.