

High-performance fibres

High-performance fibres

THIRD EDITION

INTRODUCTION to FIBER OPTICS

JOHN CRISP AND BARRY ELLIOTT



Other titles in the Woodhead Publishing Limited series on fibres, published in association with The Textile Institute

Series Editor: Professor J E McIntyre

Regenerated cellulose fibres

Wool science and technology

Silk, mohair, cashmere and other luxury fibres

Synthetic fibres

Cotton science and technology

Bast and other leaf fibres

Introduction to Fiber Optics

High-performance fibres

Edited by
J W S Hearle



The Textile Institute



CRC Press
Boca Raton Boston New York Washington, DC

WOODHEAD PUBLISHING LIMITED

Cambridge England

Published by Woodhead Publishing Limited in association with The Textile Institute

Woodhead Publishing Ltd
Abington Hall, Abington
Cambridge CB1 6AH, England
www.woodhead-publishing.com

Published in North and South America by CRC Press LLC
2000 Corporate Blvd, NW
Boca Raton FL 33431, USA

First published 2001, Woodhead Publishing Ltd and CRC Press LLC

© 2001, Woodhead Publishing Ltd

The authors have asserted their moral rights.

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. Reasonable efforts have been made to publish reliable data and information, but the authors and the publishers cannot assume responsibility for the validity of all materials. Neither the authors nor the publishers, nor anyone else associated with this publication, shall be liable for any loss, damage or liability directly or indirectly caused or alleged to be caused by this book.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming and recording, or by any information storage or retrieval system, without permission in writing from the publishers.

The consent of Woodhead Publishing and CRC Press does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from Woodhead Publishing or CRC Press for such copying.

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

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library.

Library of Congress Cataloging in Publication Data

A catalog record for this book is available from the Library of Congress.

Woodhead Publishing ISBN 1 85573 539 3

CRC Press ISBN 0-8493-1304-X

CRC Press order number: WP1304

Cover design by The ColourStudio

Typeset by Best-set Typesetter Ltd., Hong Kong

Printed by T J International, Cornwall, England

Introduction to Fiber Optics

3rd Edition

**John Crisp
Barry Elliott**



AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK • OXFORD
PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO

Newnes is an imprint of Elsevier



Contents

List of contributors	ix
1 Introduction	1
J W S HEARLE	
1.1 A new generation of fibres	1
1.2 Molecular dimensionality	4
1.3 Contrasting mechanical properties	9
1.4 Economics	16
References	21
2 Aramids	23
S REBOUILLAT	
2.1 Introduction	23
2.2 Polymer preparation	24
2.3 Spinning	29
2.4 Structure and properties	36
2.5 Applications	48
2.6 Acknowledgements	58
References	58
3 Gel-spun high-performance polyethylene fibres	62
J L J VAN DINGENEN	
3.1 Introduction	62
3.2 Manufacture	62
3.3 Fibre characteristics	68
3.4 Properties	69
3.5 Yarn and fabric processing	80
3.6 Applications	85
References	92

Newnes
An imprint of Elsevier
Linacre House, Jordan Hill, Oxford OX2 8DP
30 Corporate Drive, Burlington, MA 01803

First published 1996
Second edition 2001
Third edition 2005

Copyright © 1996, 2001, John Crisp; 2005, John Crisp and Barry Elliott.
All rights reserved

The right of John Crisp and Barry Elliott to be identified as the authors of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988

No part of this publication may be reproduced in any material form (including photocopying or storing in any medium by electronic means and whether or not transiently or incidentally to some other use of this publication) without the written permission of the copyright holder except in accordance with the provisions of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd, 90 Tottenham Court Road, London, England W1T 4LP. Applications for the copyright holder's written permission to reproduce any part of this publication should be addressed to the publisher.

Permissions may be sought directly from Elsevier's Science and Technology Rights Department in Oxford, UK; phone: (+44) (0) 1865 843830; fax: (+44) (0) 1865 853333; e-mail: permissions@elsevier.co.uk. You may also complete your request on-line via the Elsevier Science homepage (<http://www.elsevier.com>), by selecting 'Customer Support' and then 'Obtaining Permissions'.

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0 7506 67567

For information on all Newnes publications visit our web site
at www.newnespress.com

Typeset by Charon Tec Pvt. Ltd, Chennai, India
www.charontec.com
Printed and bound in Great Britain

Working together to grow
libraries in developing countries

www.elsevier.com | www.bookaid.org | www.sabre.org

ELSEVIER

BOOK AID
International

Sabre Foundation

4	Other high modulus-high tenacity (HM-HT) fibres from linear polymers	93
	D BEERS, R J YOUNG, C L SO, D J SIKKEMA, K E PEREPELKIN AND G WEEDON	
4.1	Melt-spun wholly aromatic polyester	93
4.2	PBO and related polymers	101
4.3	PIPD or 'M5' rigid-rod polymer	108
4.4	Russian aromatic fibres	115
4.5	Solid-state extrusion high-molecular weight polyethylene fibres	132
	References	144
5	Carbon fibres	156
	J G LAVIN	
5.1	Introduction	156
5.2	Physical properties	157
5.3	PAN-based carbon fibres	162
5.4	Pitch-based carbon fibres	165
5.5	Vapour-grown carbon fibres	183
5.6	Carbon nanotubes	185
5.7	Applications	187
	References	188
6	Glass fibres	191
	F R JONES	
6.1	Introduction	191
6.2	Glass for fibres	196
6.3	Fibre manufacture	201
6.4	Fibre finish	204
6.5	Glass fibre properties	213
6.6	Fibre assemblies	219
6.7	Composites	224
6.8	Design of fibre glass composites	233
6.9	Conclusions	234
6.10	Acknowledgements	235
	References	235
7	Ceramic fibres	239
	A R BUNSELL AND M-H BERGER	
7.1	Introduction	239
7.2	Silicon carbide-based fibres	240

Contents

Preface	vii
1 Optic fiber and light – a brilliant combination	1
2 What makes the light stay in the fiber?	10
3 The choice of frequency	18
4 Propagation of light along the fiber	23
5 Decibels	40
6 Losses in optic fibers	52
7 Dispersion and our attempts to prevent it	61
8 Real cables	71
9 Connecting optic fibers – the problems	87
10 Fusion splicing	97
11 Mechanical splices	108
12 Connectors	113
13 Couplers	133
14 Light sources and detectors	147
15 Testing a system	156
16 System design – or, will it work?	175
17 The transmission of signals	192
18 Designing an optical system and selecting components	201
19 LANs and topology	212
20 Some final thoughts	220

7.3	Other non-oxide fibres	247
7.4	Alumina-based fibres	248
7.5	Other polycrystalline oxide fibres	255
7.6	Single-crystal oxide fibres	255
7.7	Conclusions	255
	References	256
8	Chemically resistant fibres	259
	A R HORROCKS AND B MCINTOSH	
8.1	Introduction	259
8.2	Chlorinated fibres: PVDC	260
8.3	Fluorinated fibres: PTFE, PVF, PVDF and FEP	261
8.4	Poly(etheretherketones): PEEK	267
8.5	Poly(phenylene sulphide), PPS	274
8.6	Poly(ether imide), PEI	277
8.7	Others	278
	References	279
9	Thermally resistant fibres	281
	A R HORROCKS, H EICHHORN, H SCHWAENKE, N SAVILLE AND C THOMAS	
9.1	Introduction	281
9.2	Thermosets	282
9.3	Aromatic polyamides and polyarimids	292
9.4	Semi-carbon fibres: oxidised acrylics	301
9.5	Polybenzimidazole, PBI	310
9.6	Polybenzoxazoles, PBO	318
9.7	Final comments	319
	References	322
	Appendix: Quantities and units	325
	Index	327

Contents

Bibliography	224
Glossary	225
Quiz time answers	232
Index	243

Preface

An increasing proportion of the world's communications are carried by fiber optic cables. It has spread quietly, almost without being noticed into every situation in which information is being transmitted whether it is within the home hi-fi system, cable television or telecommunication cables under the oceans.

The purpose of this book is to provide a worry-free introduction to the subject. It starts at the beginning and does not assume any previous knowledge of the subject and, in gentle steps, it introduces the theory and practical knowledge that is necessary to use and understand this new technology.

In learning any new subject jargon is a real problem. When the words are understood by all parties they make an efficient shorthand form of communication. Herein lies the snag. If not understood, jargon can create an almost impenetrable barrier to keep us out. In this book jargon is introduced only when required and in easily digested snacks.

This third edition does little to change the basic physics presented in the first two editions but gives much more information on the latest optical connectors available, e.g. the LC and MT-RJ, plus information on the pervasive international standards that are now available to guide users in the design of a fiber optic system and of course on the progress in the field of gigabit Local Area Networks such as ten gigabit Ethernet.

John Crisp
Barry Elliott
2005: Credo ut intelligam

- Chapter 1: Introduction
Professor John Hearle, The Old Vicarage, Church Road,
Mellor, Stockport SK6 5LX, UK
Tel: 0161 427 1149 Fax: 0161 427 8527
e-mail: *johnhearle@compuserve.com*
- Chapter 2: Aramids
Dr Serge Rebouillat, DuPont de Nemours Int. SA, 2,
Chemin du Pavillon, PO Box 50, CH-1218 Le Grand-
Saconnex, Geneva, Switzerland
e-mail: *serge.rebouillat@che.dupont.com*
- Chapter 3: Gel-spun high-performance polyethylene fibres
Dr Jan L J van Dingenen, DSM High Performance Fibres,
Eisterweg 3, 6422, PN Heerlen, The Netherlands
Tel: +31 45 54 36 856 Fax: +31 45 54 36 778
e-mail: *jan.dingenen-van@dsm-group.com*
- Chapter 4: Other high modulus-high tenacity (HM-HT) polymer
fibres
Dr David Beers, 8115 Prince George Road, Charlotte,
NC 28210, USA
Tel: 001 704 552 2201
e-mail: *dbeers22@bellsouth.net*
Professor Robert Young and C L So, Materials Science
Centre, UMIST, Manchester M60 1QD, UK
e-mail: *robert.young@UMIST.ac.uk*
Professor Dr Doetze Sikkema, Magellan Systems
International
PO Box 9300, 6800 SB Arnhem, The Netherlands
Tel: +31 26 366 3459 Fax: +31 26 366 5175
e-mail: *Doetze.Sikkema@msfiber.com*

Professor Kirill Perepelkin, Materials Science Department,
St Petersburg State University of Technology and Design,
Bkl'shaya Morskaya Str., 18, Saint-Petersburg 191186,
Russia

Fax: +7(812) 31512-10 and 315 1456

e-mail: *msd@sutd.ru*

Mr Gene Weedon, 4919 Waycrest Terrace, Richmond,
Virginia 23234, USA

Tel. and Fax: 804 271 0259

e-mail: *Gweedon@erols.com*

Chapter 5: Carbon fibres

Dr J G Lavin, Carbon Nanotechnologies Inc,
16200 Park Row, Houston, TX 77084, USA

e-mail: *lavin@cnanotech.com*

Chapter 6: Glass fibres

Professor F R Jones, Department of Engineering
Materials, University of Sheffield, Sir Robert Hadfield
Building, Mappin Street, Sheffield S1 3JD, UK

e-mail: *F.R.Jones@shef.ac.uk*

Chapter 7: Ceramic fibres

Professor Anthony Bunsell and **Dr M-H Berger**, Ecole des
Mines de Paris, Centre des Materiaux, BP 87, Evry, Cedex
91003, France

Fax: 01-60-76-31-50

e-mail: *Anthony.Bunsell@mat.ensmp.fr*

Chapter 8: Chemically resistant fibres

Professor A R Horrocks, Director of Research, Bolton
Institute, Deane Road, Bolton BL3 5AB, UK

e-mail: *arh1@bolton.ac.uk*

Mr Bruce McIntosh, Zyex Ltd., Stonedale Road, Oldend
Lane Industrial Estate, Stonehouse, Gloucestershire
GL10 3RQ, UK

e-mail: *bmm@zyex.com*

Chapter 9: Thermally resistant fibres

Professor A R Horrocks, Director of Research, Bolton
Institute, Deane Road, Bolton BL3 5AB, UK

Dr H Eichhorn, BASF Aktiengesellschaft, KF – E100,
67056 Ludswighafen, Germany

Tel: +49 621 60 47160 Fax: +49 621 60 20275

e-mail: *hans-dieter.eichhorn@basf-ag.de*

Mr Hasso Schwaenke, Kynol Europa GmbH, Hochallee 11,
20149 Hamburg, Germany

Tel: +49-40-458403 Fax: +49-40-459602

e-mail: *Schwaenke@kynol.de*

Mr Neil Saville, N and M A Saville Associates, 40, Penn
Drive, Liversedge, West Yorks WF15 8DB, UK

Tel: 01274 853220 Fax: 01924 401099

Mr Charles Thomas, Celanese Acetate, PO Box 32414,
Charlotte, NC 28232-4500, USA

e-mail: *Charles.Thomas@CelaneseAcetate.com*

