

Cambridge University Press

0521020069 - UV Lasers: Effects and Applications in Materials Science

W. W. Duley

Frontmatter

[More information](#)

---

This volume provides a comprehensive overview of the use of ultraviolet laser radiation in the processing of materials. It is the first book to cover all the major up-to-date applications of UV lasers in a unified approach.

The development of lasers operating at ultraviolet wavelengths has provided materials scientists and engineers with a new set of tools. These combine the ability to vaporize the most refractory of materials with the precision to ablate micrometer-sized holes in polymers and the ability to remove thin layers from the cornea for correction of refractive errors in the human eye. This book outlines these applications and explores the use of UV laser radiation for the ablation and deposition of metals, insulating solids, polymers, semiconductors and superconductors. Emphasis has been placed on understanding the physical mechanisms accompanying these processes and the conversion of intense UV radiation to photo-thermal and photochemical energy in irradiated materials. An extensive bibliography has been included.

*UV Lasers: effects and applications in materials science* will be an invaluable source of current information in the rapidly developing field of laser applications for engineers, scientists, researchers and students in universities, government laboratories and the private sector. This book will also be valuable as a supplementary text for graduate courses in materials science.

Cambridge University Press  
0521020069 - UV Lasers: Effects and Applications in Materials Science  
W. W. Duley  
Frontmatter  
[More information](#)

---

UV Lasers: effects and applications in materials science

Cambridge University Press  
0521020069 - UV Lasers: Effects and Applications in Materials Science  
W. W. Duley  
Frontmatter  
[More information](#)

---

*UV Lasers:  
effects and applications in  
materials science*

W. W. DULEY  
*University of Waterloo, Ontario*



Cambridge University Press  
 0521020069 - UV Lasers: Effects and Applications in Materials Science  
 W. W. Duley  
 Frontmatter  
[More information](#)

CAMBRIDGE UNIVERSITY PRESS  
 Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press  
 The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

[www.cambridge.org](http://www.cambridge.org)  
 Information on this title: [www.cambridge.org/9780521464987](http://www.cambridge.org/9780521464987)

© Cambridge University Press 1996

This publication is in copyright. Subject to statutory exception  
 and to the provisions of relevant collective licensing agreements,  
 no reproduction of any part may take place without  
 the written permission of Cambridge University Press.

First published 1996  
 This digitally printed first paperback version 2005

*A catalogue record for this publication is available from the British Library*

*Library of Congress Cataloguing in Publication data*

Duley, W. W.  
 UV lasers: effects and applications in materials science / W.W. Duley.

p. cm.  
 Includes bibliographical references.

ISBN 0 521 46498 6

1. Gas lasers – Industrial applications. 2. Ultraviolet radiation –  
 Industrial applications. 3. Materials – Effects of radiation on.  
 I. Title.

TA1695.D845 1996  
 620.1'1228 – dc20 96-13553 CIP

ISBN-13 978-0-521-46498-7 hardback  
 ISBN-10 0-521-46498-6 hardback

ISBN-13 978-0-521-02006-0 paperback  
 ISBN-10 0-521-02006-9 paperback

# Contents

<i>Preface</i>	<i>page</i>	x
<i>Acknowledgments</i>		xii
1 Short wavelength lasers		1
1.1 Ultraviolet lasers		4
1.2 Rare gas halide lasers		6
1.3 Optical components		19
1.4 Optics for microstructure generation		25
1.5 Beam profile monitors		32
1.6 References		33
2 Optical properties of materials at UV wavelengths		36
2.1 Optical constants		36
2.2 Metals		39
2.3 Semiconductors		42
2.4 Insulators		49
2.5 Organic media		56
2.6 Multiphoton and non-linear effects		60
2.7 Small particles and thin films		64
2.8 Composites		70
2.9 Liquids		72
2.10 References		74
3 Photochemical and photothermal effects		78
3.1 Introduction		78
3.2 Fundamental limitations in laser materials processing		78
3.3 Photochemical or photothermal material removal		90
3.4 Radiation resistance		95
3.5 Some rules for laser processing		96
3.6 References		97

4	Interaction of UV laser radiation with metals	98
4.1	Absorption and lattice heating	98
4.2	Solution of the heat equation	100
4.2.1	$(\kappa t)^{1/2} \gg \alpha^{-1}; I_0(t) = I_0$	101
4.2.2	$(\kappa t)^{1/2} \gg \alpha^{-1}; I_0(t) = I_0, 0 < t < T; I_0(t) = 0, t > T$	102
4.2.3	$I_0(t) = I_0$	102
4.2.4	A general pulse shape	103
4.3	Melting and vaporization	103
4.4	Ablation rates in metals	108
4.5	Surface morphology	114
4.6	Vaporization products	122
4.7	Laser-assisted etching	131
4.8	Properties of irradiated surfaces	133
4.8.1	General	133
4.8.2	Radiative properties	136
4.8.3	Effect on absorption	137
4.8.4	Preparation of metal surfaces for bonding	139
4.8.5	Treatment for corrosion resistance	144
4.9	References	145
5	Interaction of UV radiation with organic polymers	148
5.1	Absorption of UV radiation	148
5.2	Gaseous products of UV laser ablation	153
5.3	Surface measurements during and prior to ablation	160
5.4	Etch depth per pulse	174
5.5	Theory of polymer ablation	180
5.6	Lithography with excimer lasers	199
5.7	Excimer interaction with HDPE surfaces	211
5.8	Ablation of composite materials	211
5.9	Ablation in biogenic systems	215
5.10	References	227
6	Interactions and material removal in inorganic insulators	232
6.1	Introduction	232
6.2	Defect formation	232
6.2.1	Silicon dioxide	232
6.2.2	Magnesium oxide	237
6.2.3	Alumina	243
6.3	Laser sputtering	246
6.3.1	General	246
6.3.2	AlN, BN and Si <sub>3</sub> N <sub>4</sub>	259
6.3.3	Simple oxides	263
6.3.4	Carbides	265
6.3.5	Other oxides	267
6.4	Laser-assisted chemical etching	269

<i>Contents</i>		ix
6.5	Formation of Bragg gratings in optical fibers	270
6.6	References	272
7	UV laser preparation and etching of superconductors	276
7.1	Introduction	276
7.2	Deposition and properties	276
7.3	Vaporization products	286
7.4	Patterning and etching	297
7.5	Device formation	301
7.6	References	303
8	Interactions and effects in semiconductors	308
8.1	Laser sputtering	308
8.2	Laser-induced chemical etching	318
8.3	Photooxidation	333
8.4	Laser-assisted doping	339
8.5	Laser annealing and amorphization	345
8.6	Particle removal	349
8.7	References	352
9	Laser deposition	357
9.1	Introduction	357
9.2	Chemical routes	357
9.3	Laser intensity and wavelength	358
9.4	Substrate effects	359
9.5	Scale of features and optical systems	361
9.6	Deposition rates	363
9.7	Contamination	366
9.8	Deposition by sputtering and ablation	367
9.9	Laser chemical vapor deposition	376
9.10	Laser planarization	391
9.11	References	394
	<i>Index</i>	400

## *Preface*

The development of lasers operating at ultraviolet wavelengths has provided mankind with a new set of unique tools. With characteristics which combine the precision to remove micrometer-thick layers of corneal tissue for the correction of refractive errors in the human eye and the ability to vaporize even the most refractory of materials, UV lasers have immediately developed into indispensable tools in many areas of materials science. The remarkable ability of high power pulsed excimer laser radiation to vaporize complex materials such as high temperature superconductors, while maintaining stoichiometry in thin films deposited from this vaporized material, offers many exciting opportunities in the creation of superconducting thin films and thin film devices. Similar unique capabilities are available in the deposition, doping and modification of semiconductors using UV laser radiation.

As a result of these and other applications, many of which can be immediately adopted by industry, UV lasers have a secure future in the field of materials science. Their implementation is limited only by our creativity in finding new applications and ways to use these new tools.

A fascinating aspect of the development of these applications involves the many fundamental questions that arise concerning the manner in which intense UV laser radiation interacts with matter. This is an area of great scientific interest and is truly interdisciplinary in nature so that answers to these questions will only come from both theoretical and experimental studies extending over a diverse range of disciplines.

In writing this book I have adopted the thesis that new applications, together with the refinement of present applications, of UV lasers will come only as we gain a deeper understanding of the mechanisms involved in the interaction of intense UV laser radiation with matter. My approach has therefore been to focus on these mechanisms and



their relation to applications of UV laser radiation in materials science. Since interaction mechanisms tend to be most closely related in materials with similar properties, my discussion is then organized in this way with chapters on UV laser processing of metals, insulators, semiconductors and superconductors. The important field of laser deposition is discussed in a separate chapter. Sources of UV laser radiation together with ancillary components and systems are discussed in the first chapter. Chapter 2 provides a summary of the properties of materials at UV wavelengths, whereas Chapter 3 discusses the limitations of laser processing in a more general way. A comprehensive, but by no means exhaustive, bibliography is also provided to assist the reader in gaining access to the burgeoning literature on this subject.

## *Acknowledgments*

My thanks go to Teresa Glaves who assisted with the production of the manuscript and who cheerfully met all the deadlines. Thanks also to Dr Hamid Jahani for preparation of a number of the figures and to Monica Kinsman for typing parts of the manuscript. My thanks also go to students, past and present, who contributed their ideas and insight, who took the courses, and who have been the source of constant inspiration. Special thanks in this regard to Drs K. Dunphy, G. Kinsman, S. Mihailov and M. Ogmen and to Y-L. Mao. I am also indebted to all those who freely granted permission to quote and reproduce various parts of their work and to Professor W. Steen who provided the opportunity to visit the University of Liverpool, where a major part of this book was written. Last, but not least, I thank my wife, Irmgardt, for constant support and for the challenging comment: ‘What will you do with all your spare time now that the book is finished?’

Walter W. Duley  
*Waterloo*