# Laser-Induced Plasmas and Applications

edited by

#### Leon J. Radziemski

Department of Physics New Mexico State University Las Cruces, New Mexico

#### **David A. Cremers**

Chemical and Laser Sciences Division Los Alamos National Laboratory Los Alamos, New Mexico

MARCEL DEKKER, INC.

New York and Basel

**ASML 1217** 



Library of Congress Cataloging-in-Publication Data

Laser-induced plasmas: physical, chemical, and biological applications / edited by Leon J. Radziemski, David A. Cremers.

p. cm.

Includes bibliographies.

ISBN 0-8247-8078-7 (alk. paper)

Plasma engineering.
 High power lasers.
 Radziemski, Leon J.,
 Cremers, David A.
 TA2020.L37 1989
 620.044--dc20
 89-7883

CIP

This book is printed on acid-free paper.

Copyright © 1989 MARCEL DEKKER. INC. All Rights Reserved

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 and retrieval system, without permission in writing from the publisher.

MARCEL DEKKER, INC. 270 Madison Avenue, New York, New York 10016

Current printing (last digit): 10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA



# Contents

Preface		iii
Contributors		xi
1 P	hysics of Laser-Induced Breakdown: An Update	1
G	uy M. Weyl	
	T . 1	
1.1	Introduction	1
1.2	Creation of Initial Electrons	3
1.3	Electron Growth in Gases	8
1.4	Laser-Induced Breakdown of Solids and Liquids	36
1.5	Concluding Remarks	58
	References	59
2 N	Iodeling of Post-Breakdown Phenomena	69
R	obert G. Root	
2.1	Introduction	69
2.2	Creation of a Propagating Plasma	70
2.3	Absorption Characteristics of Heated Gases	72
2.4	Features of Propagating Plasmas	75
2.5	One-Dimensional Laser-Supported Combustion Waves	77
2.6	One-Dimensional Laser-Supported Detonation Wave	88
2.7	One-Dimensional Laser-Supported Radiation Wave	92
2.8	Transition Regions	93
2.9	Radial Expansion	95
2.10	Thermal Coupling	99
2.11	Other Factors	100
2.12	Summary	101
	References	101
3 I	ntroduction to Laser Plasma Diagnostics	105
A	Allan A. Hauer and Hector A. Baldis	
3.1	Introduction	105
3.2	Introduction to Optical Diagnostics	110

ix



х		Contents
3.3	Introduction to X-ray Diagnostics	131
	References	161
	Alam War	
	aser-Sustained Plasmas Dennis R. Keefer	169
4.1	Introduction	169
4.2	Principles of Operation	172
4.3	Analytical Models	1.82
4.4	Experimental Studies	189
4.5	Applications of the Laser-Sustained Plasma	196
	References	203
	nertially Confined Fusion Robert L. McCrory and John M. Soures	207
5.1	Historical Overview	207
5.2	Laser-Fusion Scaling Laws	211
5.3	Coronal Physics	217
5.4	X-ray Generation by Laser-Produced Plasmas	224
5.5	Laser-Driven Ablation	227
5.6	Hydrodynamic Stability of Ablatively Driven Shells	239
5.7	Irradiation Uniformity Requirements	243
5.8		251
5.0	Implosion Experiments References	260
	References	200
	aser-Based Semiconductor Fabrication oseph R. Wachter	269
6.1	Aspects of Semiconductor Fabrication	269
6.2	Applications of Lasers in the Semiconductor Industry	276
6.3	Research Areas	283
6.4	Outlook	290
	References	291
	Spectrochemical Analysis Using Laser Plasma Excitation Leon J. Radziemski and David A. Cremers	295
7.1	Review	295
7.2	Methods and Properties of Analysis Using Laser Plasmas	296
7.3	Analysis of Gases	302
7.4	Analysis of Bulk Liquids	306
7.5	Analysis of Particles	309
7.6	Analysis of Solids	313
77	Advances in Instrumentation	318



Cont	ents	хi
7.8	Prognosis	321
	References	323
	state 196	
100 P	fundamentals of Analysis of Solids by Laser-Produced	327
	Yong W. Kim	321
8.1	Chapter Organization	327
8.2	Introduction	327
8.3	Phenomenology of Laser Heating of Condensed-Phase	
	Targets	330
8.4	Quantitative Spectroscopy	336
8.5	Intensity Measurements and Elemental Analysis	341
8.6	Summary	344
	References	345
N	Asser Vaporization for Sample Introduction in Atomic and Ass Spectroscopy oseph Sneddon, Peter G. Mitchell, and Nicholas S. Nogar	347
9.1	Conventional Solid Sample Introduction for Atomic	
	Spectroscopy	347
9.2	Laser Ablation of Solid Samples	350
9.3	Laser Ablation for Sample Introduction in Atomic	
	Spectroscopy	353
9.4	Relative Merits of Laser Ablation for Sample Introduction	
	in Atomic Spectroscopy	363
9.5	Laser Sources for Mass Spectrometry	365
9.6	Applications of Laser Microprobe	369
9.7	Applications of Laser Desorption and Postionization	372
9.8	Conclusion	376
	References	376
	Current New Applications of Laser Plasmas Allan A. Hauer, David W. Forslund, Colin J. McKinstrie, Justin S. Wark, Philip J. Hargis, Jr., Roy A. Hamil, and Joseph M. Kindel	385
10.1	Introduction	385
10.2		
3400000	Particles	386
10.3		413



# DOCKET

# 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.

