
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

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)

1. Plasma engineering. 2. High power lasers. I. Radziemski, Leon J.,
II. 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 per-
mission 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 Physics of Laser-Induced Breakdown: An Update	1
Guy M. Weyl	
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 Modeling of Post-Breakdown Phenomena	69
Robert 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 Introduction to Laser Plasma Diagnostics	105
Allan A. Hauer and Hector A. Baldis	
3.1 Introduction	105
3.2 Introduction to Optical Diagnostics	110

3.3	Introduction to X-ray Diagnostics	131
	References	161
4	Laser-Sustained Plasmas	169
	Dennis R. Keefer	
4.1	Introduction	169
4.2	Principles of Operation	172
4.3	Analytical Models	182
4.4	Experimental Studies	189
4.5	Applications of the Laser-Sustained Plasma	196
	References	203
5	Inertially Confined Fusion	207
	Robert L. McCrory and John M. Soures	
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 Ablastively Driven Shells	239
5.7	Irradiation Uniformity Requirements	243
5.8	Implosion Experiments	251
	References	260
6	Laser-Based Semiconductor Fabrication	269
	Joseph R. Wachter	
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
7	Spectrochemical Analysis Using Laser Plasma Excitation	295
	Leon J. Radziemski and David A. Cremers	
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
7.7	Advances in Instrumentation	318

Contents

xi

7.8	Prognosis	321
	References	323
8	Fundamentals of Analysis of Solids by Laser-Produced Plasmas	327
	Yong W. Kim	
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
9	Laser Vaporization for Sample Introduction in Atomic and Mass Spectroscopy	347
	Joseph Sneddon, Peter G. Mitchell, and Nicholas S. Nogar	
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
10	Current New Applications of Laser Plasmas	385
	Allan A. Hauer, David W. Forslund, Colin J. McKinstry, Justin S. Wark, Philip J. Hargis, Jr., Roy A. Hamil, and Joseph M. Kindel	
10.1	Introduction	385
10.2	Applications of Laser-Plasma-Generated X-rays and Particles	386
10.3	Laser-Plasma Acceleration of Particles	413

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.