

Electron Kinetics and Applications of Glow Discharges

NATO ASI Series

Advanced Science Institutes Series

A series presenting the results of activities sponsored by the NATO Science Committee, which aims at the dissemination of advanced scientific and technological knowledge, with a view to strengthening links between scientific communities.

The series is published by an international board of publishers in conjunction with the NATO Scientific Affairs Division

A	Life Sciences	Plenum Publishing Corporation
B	Physics	New York and London
C	Mathematical and Physical Sciences	Kluwer Academic Publishers
D	Behavioral and Social Sciences	Dordrecht, Boston, and London
E	Applied Sciences	
F	Computer and Systems Sciences	Springer-Verlag
G	Ecological Sciences	Berlin, Heidelberg, New York, London,
H	Cell Biology	Paris, Tokyo, Hong Kong, and Barcelona
I	Global Environmental Change	

PARTNERSHIP SUB-SERIES

1. Disarmament Technologies	Kluwer Academic Publishers
2. Environment	Springer-Verlag
3. High Technology	Kluwer Academic Publishers
4. Science and Technology Policy	Kluwer Academic Publishers
5. Computer Networking	Kluwer Academic Publishers

The Partnership Sub-Series incorporates activities undertaken in collaboration with NATO's Cooperation Partners, the countries of the C/S and Central and Eastern Europe, in Priority Areas of concern to those countries.

Recent Volumes in this Series:

- Volume 365* — Techniques and Concepts of High-Energy Physics IX
edited by Thomas Ferbel
- Volume 366* — New Developments in Quantum Field Theory
edited by Poul Henrik Damgaard and Jerzy Jurkiewicz
- Volume 367* — Electron Kinetics and Applications of Glow Discharges
edited by Uwe Kortshagen and Lev D. Tsendin
- Volume 368* — Confinement, Duality, and Nonperturbative Aspects of QCD
edited by Pierre van Baal



Series 5: Physics

Electron Kinetics and Applications of Glow Discharges

Edited by

Uwe Kortshagen

University of Minnesota
Minneapolis, Minnesota

and

Lev D. Tsendin

St. Petersburg State Technical University
St. Petersburg, Russia

Kluwer Academic Publishers

NEW YORK, BOSTON, DORDRECHT, LONDON, MOSCOW

eBook ISBN 0-306-47076-4

Print ISBN 0-306-45822-5

©2002 Kluwer Academic Publishers
New York, Boston, Dordrecht, London, Moscow

Print ©1998 Kluwer Academic / Plenum Publishers, New York

All rights reserved

No part of this eBook may be reproduced or transmitted in any form or by any means, electronic, mechanical, recording, or otherwise, without written consent from the Publisher

Created in the United States of America

Visit Kluwer Online at: <http://www.kluweronline.com>
and Kluwer's eBookstore at: <http://www.ebooks.kluweronline.com>

PREFACE

This book resulted from the NATO Advanced Research Workshop on “Electron Kinetics and Applications of Glow Discharges,” held in St. Petersburg, Russia, on May 19-23, 1997. Glow discharges have found widespread applications in many technological processes from the manufacture of semiconductors, to recent developments in nanotechnology, to the traditional fields of gas lasers, and discharge lamps. Consequently, the interest in the physics of glow discharges has experienced yet another resurgence of interest.

While the non-equilibrium character of glow discharges is widely accepted, the opinion still prevails that the main features can be captured by fluid models, and that kinetic treatments are only required for the understanding of subtle details. The erroneousness of this belief is demonstrated by the failure of fluid models to describe many basic features of glow discharges such as, for instance, electrode phenomena, striations, and collisionless heating effects. An adequate description of glow discharges thus has to be of kinetic nature.

The organizers and participants of the workshop were united in the belief that a critical assessment of the state-of-the-art of kinetic methods for the description of glow discharges was overdue. In particular, two different “schools” have developed over the past decades: analytical and semi-analytical approaches are favored by researchers mostly from Eastern countries while strongly computer-based methods are mostly used in the Western countries. The objectives of the workshop were: a) to bring together representatives of these different schools to propel research of glow discharge kinetics by creating synergistic effects between these different approaches, and b) to assess a broad spectrum of theoretical and experimental studies of glow discharge kinetics.

The authors of this book are well-known experts in the field of glow discharge research. The book presents a state-of-the-art review of our understanding of the kinetic nature of glow discharges.*

The workshop organizers want to thank all speakers and participants of the workshop for their scientific contributions and their support, which was invaluable in making this workshop a successful event. We are particularly thankful to

NATO Division of Scientific and Environmental Affairs

for its generous support of the workshop. In particular, we thank Dr. L. Veiga da Cunha and his staff for the excellent cooperation. We gratefully acknowledge co-sponsoring of the workshop by

*Articles resulting from poster presentations given during the workshop are published in *Plasma Physics Reports*, Volume 24, No. 7 (1998).

The Russian Foundation of Basic Research,
Applied Materials, Inc., and
OSRAM Sylvania, Inc.

We also wish to thank Drs. Anatoliy Kudryavtsev and Alexander Smirnov and Mrs. Karon Mooney for their support in organizing this workshop, and Dr. C. Eggs for the technical assistance provided in editing this book.

Uwe Kortshagen
University of Minnesota
Minneapolis

Lev D. Tsandin
St. Petersburg State Technical University
St. Petersburg, Russia
March 1998

CONTENTS

ANALYTICAL AND SEMI-ANALYTICAL MODELING APPROACHES

Principles of the Electron Kinetics in Glow Discharges	1
L. D. Tsendin	
Spherical Symmetrical Approach to the Theory of Runaway Breakdown	19
A. V. Gurevich, A. V. Lukyanov, K. P. Zybin, and R. A. Roussel-Duprè	
Nonlocal Effects in Stationary and Non-Stationary Discharges	37
V. V. Ivanov, K. S. Klopovsky, D. V. Lopaev, Yu. A. Mankelevich, A. T. Rakhimov, and T. V Rakhimova	

BASICS OF NUMERICAL PLASMA MODELING

Particle Simulation Methods for Glow Discharges: Past, Present and Future, With Applications	59
C. K. Birdsall, E. Kawamura, and V. Vahedi	
Convected Scheme Simulations of Glow Discharges	75
G. J Parker and W. N. G. Hitchon	
Modeling of a Magnetized Plasma: The Stationary Plasma Thruster	85
J. P. Boeuf, L. Garrigues, and L. C. Pitchford	

DC DISCHARGES I

DC Positive Column in the Nonlocal Regime	101
J. Ingold	
On the Radial Structure of the Electron Velocity Distribution and Related Macroscopic Properties in DC Column Plasmas	119
R. Winkler and D. Uhrlandt	

DC DISCHARGES II

Electron Kinetics in Homogeneous and Stratified Positive Column and Anode Region	137
Y. B. Golubovskii and V. O. Nekuchaev and I. A. Porokhova	

Electron Kinetics in Cathode Region of Glow Discharges. Plane and Hollow Cathodes	161
R. Arslanbekov and A. Kudryavtsev	
A Hydrodynamic Description of Electrons in a Space-Time Varying Electric Field . . .	179
N. L. Aleksandrov	
Glow-Like Discharges with Runaway Electrons	199
L. P. Babich	

STOCHASTIC ELECTRON HEATING I

The Dynamics of Fermi Acceleration	215
M. A. Lieberman	
Application of Mapping Dynamics to Analysis of a Capacitive RF Discharge	227
A. J. Lichtenberg, R. Cohen, and Z. Wang	
Electron Kinetic and Electrodynamic Characteristics of ICP in Stochastic Heating Regime	241
V. Godyak	
Collisionless Electron Heating in RF Gas Discharges: I. Quasilinear Theory	257
Y. M. Aliev, I. D. Kaganovich, and H. Schlüter	
Collisionless Electron Heating in RF Gas Discharges: II. The Role of Collisions and Non-Linear Effects	283
U. Buddemeier and I. D. Kaganovich	
The Anomalous Skin Effect in Bonded Systems	293
V. Kolobov	
Collisionless Heating in Capacitively-Coupled Radio Frequency Discharges	313
M. M. Turner	

INDUCTIVELY COUPLED PLASMAS

Modeling and Diagnostics of Low Pressure Inductively Coupled Plasmas	329
U. Kortshagen	
Fluid, Kinetic and Hybrid Simulation Strategies for Modeling Chemically Complex Inductively Coupled Plasmas	349
M. Li, H. Date, and D. B. Graves	
Transport and Reaction in Inductively Coupled Plasmas for Microelectronics	367
D. J. Economou, J. Feldsien, and R. S. Wise	

DISCHARGE KINETICS IN MOLECULAR MASS

New Trends in the Kinetic Modeling of Discharges in Low Pressure Molecular Gases	391
C. M. Ferreira and B. F. Gordiets	

Electron Kinetics in Low-Voltage Cesium-Hydrogen Discharges	409
F. G. Baksht and V. G. Ivanov	

MAGNETIZED DISCHARGES, SURFACE WAVE DISCHARGES

Surface Wave Sustained Discharges	423
S. Grosse, H. Schlüter, and M. Schlüter	
Momentum Transfer Theory of Electron Transport in $E \times B$ Field	441
Z. Petrovic and S. B. Vrhovac	
Hot Electrons in an Expanding Magnetized Hydrogen Plasma	459
D. K. Otorbaev, Z. Quig, G. J. H. Brussaard, M. C. M. van de Sanden, and D. C. Schram	

ADVANCED DIAGNOSTICS I

Resonance Radiation Transport in Glow Discharge Plasmas	471
J. E. Lawler and J. J. Curry	
Optical Characterization of RF Inductively Coupled Plasmas	489
A. E. Wendt, D. F. Beale, W. N. G. Hitchon, E. Keiter, V. Kolobov, L. Mahoney, A. A. Pierre and J. Stittsworth	
Experimental Studies of RF Sheaths	503
W. G. Graham and C. M. O. Mahoney	
Time Resolved Measurements of Pulsed Discharges: The Role of Metastable Atoms in the Afterglow	511
L. J. Overzet and J. Kleber	

ADVANCED DIAGNOSTICS II

Radio Frequency Capacitive Sheath Diagnostics by Time Resolved Measurements of Fast Electrons	525
A. S. Smirnov and K. E. Orlov	
Probe Methods for Investigation of Anisotropic Plasma	531
A. P. Mezentsev and A. S. Mustafaev	
Workshop Participants	547
Index	549