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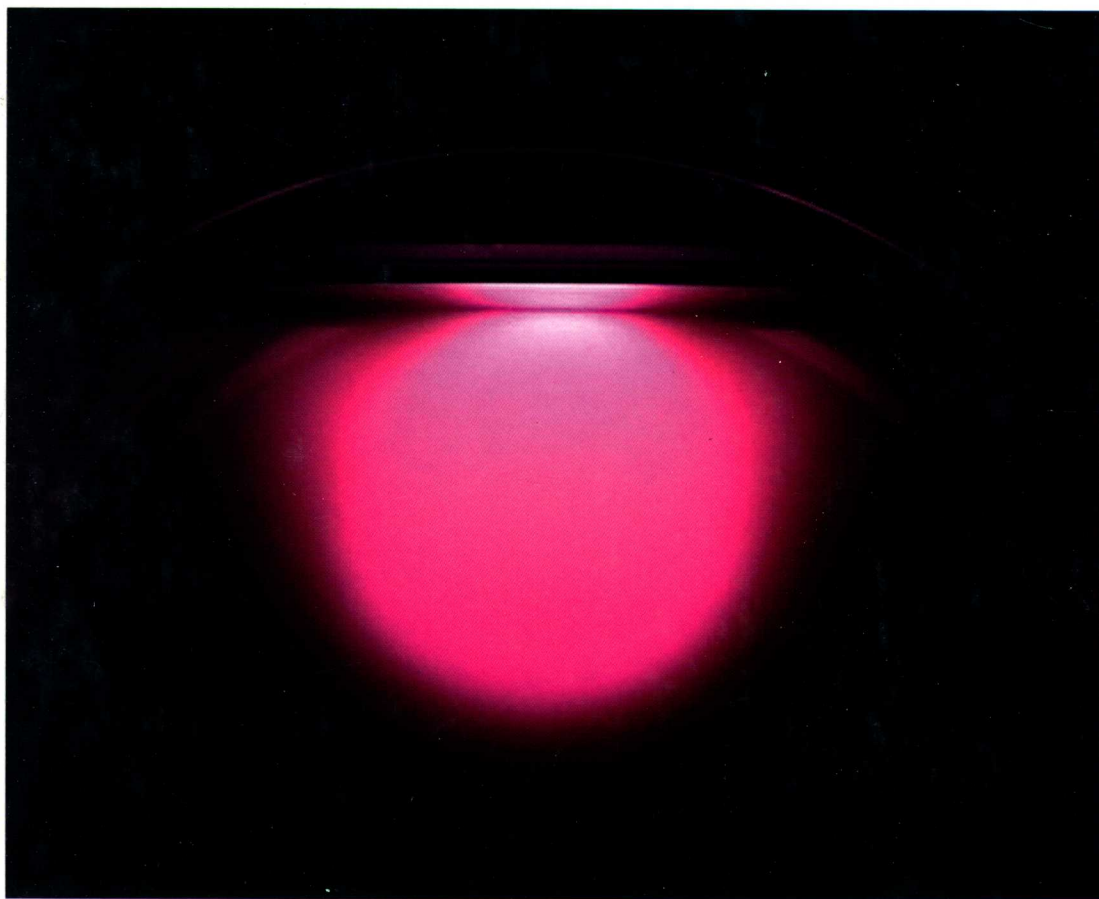
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Low Temperature Plasmas

Fundamentals, Technologies, and Techniques

Volume 1

Second, Revised and Enlarged Edition



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Fundamentals, Technologies and Techniques

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Edited by

*Rainer Hippler, Holger Kersten, Martin Schmidt,
and Karl H. Schoenbach*

2nd, Revised and Enlarged Edition



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Micro wave excited argon hydrogen plasma
(with kind permission of A. A. Meyer-Plath,
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Preface

The first edition of the book on Low-Temperature Plasma, published in 2000, has been well received by physicists, scientist, and engineers dealing with plasma physics and plasma physical applications, particularly plasma processing. This positive response of practicing plasma scientists and engineers to this book, as well as the rapid development in the area of low-temperature plasma applications, has encouraged the publishing house and the editors to publish a second edition.

In the area of low-temperature plasma physics, the last decade may be characterized by progress in the development of plasma sources, new types of excitation, and the rise in interest (again) in plasmas at atmospheric pressure with their various new applications. Dusty plasmas became a recognized field of plasma research and not merely a concern for contamination in semiconductor chip production. Plasma processing on an industrial scale is now well established and considered as a key technology, cutting across disciplines. The progress in the developments of plasma sources and applications is accompanied by advances of the kinetic theory and improvements in diagnostics, especially related to optical spectroscopy.

These developments have led to a critical review and, where necessary, additions to chapters which were included in the first edition. The progress in the area of low-temperature plasma physics, in plasma sources, novel plasma scientific applications, and improvements in diagnostics has been taken into account by introducing a series of new chapters, written by distinguished plasma scientists from Europe, the United States, and Asia. These new contributions are related to dusty plasmas and its applications, and to new diagnostic methods. Atmospheric pressure plasmas, with emphasis on microdischarges, and their applications have been covered in several chapters. One of those is the emerging field of medical applications using atmospheric pressure plasmas, including cold-plasma-based sterilization. Additional chapters relate to transient plasma ignition, EUV light sources, magnetron-, hollow-cathode-discharges, plasma-assisted surface modification of biointerfaces, and plasma jets for thin film deposition.

We would like to thank all the contributors to this book. It was a pleasure working with them. We acknowledge gratefully the help of Mrs. H. Boldt in the technical preparation of the manuscript, and would like to express our special appreciation to Mrs. V. Palmer and Mrs. C. Wanka, both of Wiley-VCH, for their valuable advice and their patience during the process of editing this book.

R. Hippler, H. Kersten, M. Schmidt, K.H. Schoenbach
Greifswald, Kiel, and Norfolk, June 2007



Johannes Conrads

* 28 September 1934

† 23 September 2005

On 23 September 2005, Professor Dr. Johannes Peter Franziskus Conrads passed away in his hometown of Jülich, Germany. Throughout his life and because of his outstanding work, he was one of the most important promoters of plasma physics. After completing his studies and the conferral of a doctorate in physics at the RWTH in Aachen, Germany, he developed standard radiators and spectrometers for the vacuum-ultra-violet at the KFA Jülich in the 1960s. As a post-doctoral researcher with the National Academy of Science, Washington, DC, he produced the first visible spectral lines of the sun corona in a laboratory plasma at the NASA-Langley Research Center, Virginia. In a rocket experiment in 1991 he flew a new spectroheliograph, which he developed himself, to observe the sun for allowed and forbidden spectral lines of fivefold-ionized oxygen. From 1969 to 1992, he worked in the area of plasma physics and controlled fusion of lighter nuclei at the research center Jülich. He developed the facilities DPF-Jül-I and DPF-Jül-II as well as an 80-meter flying-time-spectrometer, with which the neutron spectra of the fusion of deuterium and of deuterium and lithium could be identified. He assumed the leadership of Textor, an experiment conducted by the Institute for Plasma Physics (IPP) to research the interaction between plasma and wall of a Tokamak under near thermonuclear conditions, beginning in 1974. In 1984 and 1985 he taught plasma physics in Princeton, USA, and was the head of the nucleonics department of the Tokamak-Fusion-Test-Reactor (TFTR). In 1986, he resumed the leadership of the technical department of the IPP in Jülich and participated in research of the heating of Textor, resulting in reaching 60 million degrees Celsius with outstanding energy and particle confinement.

Johannes Conrads was appointed as professor at the Bergische Universität Wuppertal in 1991, and taught there in the Department of Electrical Engineering as professor of plasma physics. A year later he was appointed professor at the Ernst-Moritz-Arndt-Universität in Greifswald.

Here, he held the chair of experimental physics. He was also director and head of the board of the Institute of Low Temperature Plasma Physics in Greifswald, the only institute of its kind in Germany.

Based on the first analysis of the status and perspectives of plasma physics by Prof. Ecker (Bochum), Professor Conrads conducted the second analysis between 1993 and 1995. With the second analysis, more than 200 scientists from three continents identified prospects for the development of plasma-supported products and processes, for which a world market of several hundred billion Euro is expected between 2005 and 2010.

Johannes Conrads was a consultant to the European Commission, Directorate XII, in the field of plasma physics for more than 30 years. For 20 years he coordinated the international "Symposium on Fusion Technology," since 1992 the conference "Plasma Surface Engineering" and in 1997 the international conferences "Gas Discharges and their Applications" and "Science and Technology of Light Sources." He was a member of the Editorial Advisory Board of "Fusion Technology" since 1978 and publisher of the magazine "Contributions to Plasma Physics" since 1998.

For his excellence, Professor Conrads, long-time director of the Institute of Low Temperature Plasma Physics (Greifswald), received the order of the Federal Republic of Germany. Professor Conrads was an example for collaborators and colleagues worldwide with his commitment to the sciences, especially to plasma physics. His friends and colleagues have lost an excellent researcher, teacher, and a person characterized by depth and care.

Klaus-Dieter Weltmann, Greifswald



Alfred Rutscher

* 19 December 1931

† 28 November 2005

On 28 November 2005, Prof. Dr. Alfred Rutscher passed away in Greifswald. Alfred Rutscher completed his study of physics in 1955 at the Ernst-Moritz-Arndt-University Greifswald when Rudolf Seeliger, the founder of the Greifswald school of gaseous electronics, retired. His scientific life for the next 40 years was devoted to low-temperature plasma physics. His PhD Thesis about *Ionization Waves in Electrical Gas Discharges* and his second thesis (habilitation), *Plasma of the Positive Column*, have marked his primary research field on the dynamics and kinetics of nonthermal plasmas at low and medium pressures and the interaction with walls. One of his important contributions (together with S. Pfau and K. Wojacek) was the development and detailed test of the so-called B-invariant similarity laws (published 1969 in *Beiträge zur Plasmaphysik*). In 1970, Alfred Rutscher was appointed as Full Professor for experimental physics. He was an academic teacher with heart and soul. Generations of students listened to his excellent physics lectures, and many of them were guided to a doctoral degree, some to the habilitation. More than 130 publications in scientific journals and conference proceedings, as well as four patents, can be attributed to him. The latter, as well as the book *Wissensspeicher Plasmatechnik*, indicate his second scientific activity, namely: plasma technology. With his contributions to *Macroscopic Kinetics*, he has developed an important heuristic method for a description of plasma chemical systems. His third scientific interest was devoted to physics history.

Alfred Rutscher made contributions to physics books such as the physics textbook series by Grimsehl, the handbook *Effekte der Physik und ihre Anwendungen*, and the book *Low Temperature Plasma Physics – Fundamental Aspects and Applications*.

From 1968 until his retirement in 1997, Alfred Rutscher was active in a variety of leading positions, in particular as Dean of the Faculty for Mathematics and Natural Sciences from 1973 to 1975. From 1974 to 1979 and from 1987 to 1996 he was head of the Institute of Physics of the

University of Greifswald. It was a proof of his outstanding scientific qualification, as well as his personal integrity, that he continued to be the head of the institute after the German reunification. The Deutsche Forschungsgemeinschaft (DFG) named him as permanent referee for the field of atomic and plasma physics. Alfred Rutscher contributed significantly to the establishment of the first collaborative research center, *Kinetics of Partially Ionized Plasmas* (SFB 198) in 1993, and he was its first spokesperson.

The close cooperation with and loyalty to the Leibniz Institute for Low Temperature Plasma Physics (INP), founded in 1991, had high priority throughout his life. Alfred Rutscher was a founding member of the INP and member of its board of trustees for over 8 years.

From 1977 to 1988 he was the East German representative in the International Scientific Committee of the International Conference on Phenomena in Ionized Gases and he served as conference chairman when this conference was held in East Germany (XIIIth ICPIG, Berlin 1977). Furthermore, Alfred Rutscher acted as local chairman of the VIIIth European Conference on Atomic and Molecular Physics of Ionized Gases (VIIIth ESCAMPIG) in Greifswald in 1986. For many years he was a member of the editorial board of the journal *Contributions to Plasma Physics* formerly *Beiträge zur Plasmaphysik*.

In 2001 Alfred Rutscher was honored by the awarding of the *Rudolf-Seeliger-Prize* of the German Society for Plasma Technology (DGPT), and he was an honorary member of the Czech Society for Physics and Mathematics.

The low-temperature plasma physics community, his friends, and colleagues lost an excellent academic teacher, researcher and a modest and generous person.

Jürgen Meichsner, Greifswald

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