Langmuir Probe In Theory And Practice

Published by the American Geophysical Union as part of the Geophysical Monograph Series, Volume 103. Space plasma measurements are conducted in a hostile, remote environment. The art and science of measurements gathered in space depend therefore on unique instrument designs and fabrication methods to an extent perhaps unprecedented in experimental physics. In-situ measurement of space plasmas constitutes an expensive, unforgiving, and highly visible form of scientific endeavor.

Low-temperature radio frequency plasmas are essential in various sectors of advanced technology, from micro-engineering to spacecraft propulsion systems and efficient sources of light. The subject lies at the complex interfaces between physics, chemistry and engineering. Focusing mostly on physics, this book will interest graduate students and researchers in applied physics and electrical engineering. The book incorporates a cutting-edge perspective on RF plasmas. It also covers basic plasma physics including transport in bounded plasmas and electrical diagnostics. Its pedagogic style engages readers, helping them to develop physical arguments and mathematical analyses. Worked examples apply the theories covered to realistic scenarios, and over 100 in-text questions let readers put their newly acquired knowledge to use and gain confidence in applying physics to real laboratory

situations.

From flat-panel televisions to thermonuclear fusion for energy production, plasmas currently have numerous and wide applications in sciences and industry. A diversity of plasma diagnostics is available to physicists and engineers to measure and control plasma parameters. Among them, the Langmuir probe is the most inexpensive and most popular instrument and method. The Langmuir probe is a small electrode which is submerged in plasma in order to measure the probe current-voltage characteristic. The same characteristic is processed further to derive the electron and ion concentration, the electron distribution function, and the plasma potential at the probe location. Langmuir probe diagnostics afford rapid measurements of the electron distribution function and plasma potential at a good time resolution, 10-8 seconds in a wide range of plasma densities 10+3 - 10+14 cm-3, and the electron energy from the room temperature to hundreds of electron-volts - qualities which are essential for researchers. In view of these facts, Langmuir probe diagnostics are applied very frequently to measuring plasma parameters. This book will be useful in teaching plasma diagnostics to undergraduate and graduate students in plasma physics courses. And it will also serve as a practical reference manual for physicists and engineers working in the growing area of plasma physics. The reader of this book will learn what kind of plasma parameters the Langmuir probe can measure, how to develop the probe diagnostics for specific cases, and how the probe data obtained should be processed to deduce reliable plasma

parameters. In this book, the reader can find not only the basic physics information important to understanding the principles of probe operation, but also how the "real" probe disturbs plasma, and how it is possible to reconstruct undisturbed plasma parameters with available probe data.

The Earth's Electric Field provides you with an integrated and comprehensive picture of the generation of the terrestrial electric fields, their dynamics and how they couple/propagate through the medium. The Earth's Electric Field provides basic principles of terrestrial electric field related topics, but also a critical summary of electric field related observations and their significance to the various related phenomena in the atmosphere. For the first time, Kelley brings together information on this topic in a coherent way, making it easy to gain a broad overview of the critical processes in an efficient way. If you conduct research in atmospheric science, physics, atmospheric chemistry, space plasma physics, and solar terrestrial physics, you will find this book to be essential reading. The only book on the physics of terrestrial electric fields and their generation mechanisms, propagation and dynamics–making it essential reading for scientists conducting research in upper atmospheric, ionospheric, magnetospheric and space weather Covers the processes related to electric field generation and electric field coupling in the upper atmosphere along with providing new insights about electric fields generated by sources from sun to mud Focuses on real-world implications—covering topics such as space weather, earthquakes, the effect on power grids, and the effect on

GPS and communication devices

An understanding of the processes involved in the basic and applied physics and chemistry of the interaction of plasmas with materials is vital to the evolution of technologies such as those relevant to microelectronics, fusion and space. The subjects dealt with in the book include: the physics and chemistry of plasmas, plasma diagnostics, physical sputtering and chemical etching, plasma assisted deposition of thin films, ion and electron bombardment, and plasma processing of inorganic and polymeric materials. The book represents a concentration of a substantial amount of knowledge acquired in this area - knowledge which was hitherto widely scattered throughout the literature - and thus establishes a baseline reference work for both established and tyro research workers.

A computational study is presented of the properties of a guardring-type circular planar Langmuir probe, commonly flush-mounted in the skin of a satellite. This geometry results in a three-dimensional potential distribution which cannot be treated analytically, even in axially symmetric problems. Given arbitrary particle velocity distributions at infinity, the current-voltage characteristics of the external aperture grid potentials) may be determined by detailed particle trajectory calculations. The electric field and charge density distributions in the vicinity of the probe are defined at the nodes of a grid. The charge density in the Poisson equation is evaluated by summing trajectory contributions. The collected currents are similarly evaluated. The Poisson field is computed self-

consistently by an iterative technique. Two kinds of particle velocity distribution are considered, e.g., a streaming Maxwellian at infinity, and photoelectric (or secondary) emission at the satellite surface. An infinite-satellite model is assumed for the Poisson case (Debye length = 1 cm). For the Laplace case (Debye length infinite), the effects of finite satellite dimensions, of Mach streaming at an angle, and of photoelectrons are investigated.

TO THE SECOND EDITION In the nine years since this book was first written, rapid progress has been made scientifically in nuclear fusion, space physics, and nonlinear plasma theory. At the same time, the energy shortage on the one hand and the exploration of Jupiter and Saturn on the other have increased the national awareness of the important applications of plasma physics to energy production and to the understanding of our space environment. In magnetic confinement fusion, this period has seen the attainment 13 of a Lawson number nTE of 2 x 10 cm -3 sec in the Alcator tokamaks at MIT; neutral-beam heating of the PL T tokamak at Princeton to KTi = 6. 5 keV; increase of average ß to 3%-5% in tokamaks at Oak Ridge and General Atomic; and the stabilization of mirror-confined plasmas at Livermore, together with injection of ion current to near field-reversal conditions in the 2XIIß device. Invention of the tandem mirror has given magnetic confinement a new and exciting dimension. New ideas have

emerged, such as the compact torus, surface-field devices, and the EßT mirror-torus hybrid, and some old ideas, such as the stellarator and the reversed-field pinch, have been revived. Radiofrequency heat ing has become a new star with its promise of dc current drive. Perhaps most importantly, great progress has been made in the understanding of the MHD behavior of toroidal plasmas: tearing modes, magnetic VII VIII islands, and disruptions. Cylindrical Langmuir probes were used to determine quiescent plasma conditions and instability thresholds in a mirror geometry magnetoplasma experiment (ELMAX). Radial profiles of electron temperature, density, and velocity distribution were measured in an argon plasma maintained by two magnetic annular arc sources. A digital data recording system was devised which facilitated reduction of the probe curves with a computer program using collisionless probe theory. For magnetic fields below 400 gauss the peak values of electron temperature and density were 40,000 degrees K and 10 to the 13th power/cc respectively, and observed density oscillations were less than 5%. (Author).

This book provides a systematic introduction to the physics of plasma diagnostics measurements. It develops from first principles the concepts needed to plan, execute and interpret plasma measurements, making it a suitable book for graduate students and

professionals with little plasma physics background. The book will also be a valuable reference for seasoned plasma physicists, both experimental and theoretical, as well as those with an interest in space and astrophysical applications. This second edition is thoroughly revised and updated, with new sections and chapters covering recent developments in the field.

The objective of these proceedings was to provide a platform for the exchange of information on the design, construction and operation of fusion experiments. The technology which is being developed for the next step devices and fusion reactors was also covered.

The Langmuir probe theories of Self and Shih, Waymouth, and Kiel for collisional plasmas are examined theoretically. A probe theory for a collision dominated plasma with a collision dominated probe sheath is presented. Spherical probe measurements were made in a hot cathode helium discharge at 0.3 and 0.4 Torr. Good agreement on the ion densities between the Self and Shih method and a method suggested by Medicus was obtained. The Medicus method gave better agreement with second derivative techniques on the determination of plasma potential than the Self and Shih method. (Author).

High Power Impulse Magnetron Sputtering: Fundamentals, Technologies, Challenges and Applications is an in-depth introduction to HiPIMS

that emphasizes how this novel sputtering technique differs from conventional magnetron processes in terms of both discharge physics and the resulting thin film characteristics. Ionization of sputtered atoms is discussed in detail for various target materials. In addition, the role of self-sputtering, secondary electron emission and the importance of controlling the process gas dynamics, both inert and reactive gases, are examined in detail with an aim to generate stable HiPIMS processes. Lastly, the book also looks at how to characterize the HiPIMS discharge, including essential diagnostic equipment. Experimental results and simulations based on industrially relevant material systems are used to illustrate mechanisms controlling nucleation kinetics, column formation and microstructure evolution. Includes a comprehensive description of the HiPIMS process from fundamental physics to applications Provides a distinctive link between the process plasma and thin film communities Discusses the industrialization of HiPIMS and its real world applications

This unified introduction provides the tools and techniques needed to analyze plasmas and connects plasma phenomena to other fields of study. Combining mathematical rigor with qualitative explanations, and linking theory to practice with example problems, this is a perfect textbook for senior undergraduate and graduate students taking

one-semester introductory plasma physics courses. For the first time, material is presented in the context of unifying principles, illustrated using organizational charts, and structured in a successive progression from single particle motion, to kinetic theory and average values, through to collective phenomena of waves in plasma. This provides students with a stronger understanding of the topics covered, their interconnections, and when different types of plasma models are applicable. Furthermore, mathematical derivations are rigorous, yet concise, so physical understanding is not lost in lengthy mathematical treatments. Worked examples illustrate practical applications of theory and students can test their new knowledge with 90 end-of-chapter problems. A kinetic theory approach is employed to develop a unified theoretical representation of the spherical Langmuir probe. Two-stream, Maxwellian distribution functions are employed for the charged particles, and the densities and temperatures associated with the distribution functions are determined by satisfying the first several moments of the corresponding Boltzmann equations. Numerical techniques for computing probe characteristics on a digital computer are described. Computed characteristics are obtained, compared with previous results and evaluated for a broad range of plasma conditions; including both the collisonless and collision dominated extremes. The theoretical

approach is concluded to be sound. Areas for future improvement in the model are identified. The utility of the Waymouth model as a Langmuir probe data analysis tool is explored. It is shown that this approximate analytical model provides an accurate representation of the probe characteristic over a broad range of conditions. (Author).

Waves and Oscillations in Plasmas addresses central issues in modern plasma sciences, within the context of general classical physics. The book is working gradually from an introductory to an advanced level. Addressing central issues in modern plasma sciences, including linear and nonlinear wave phenomena, this second edition has been fully updated and includes the latest developments in relevant fluid models as well as kinetic plasma models, including a detailed discussion of, for instance, collisionless Landau damping, linear as well as non-linear. The book is the result of many years of lecturing plasma sciences in Norway, Denmark, Germany, and also at the Unites States of America. Offering a clear separation of linear and nonlinear models, the book can be tailored for students of varying levels of expertise in plasma physics, in addition to areas as diverse as the space sciences, laboratory experiments, plasma processing, and more. Features: Presents a simple physical interpretation of basic problems is presented where possible Supplies a complete

summary of classical papers and textbooks placed in the proper context Includes worked examples, exercises, and problems with general applicability Thermionic Phenomena is the third volume of the series entitled The Collected Works of Irving Langmuir. This volume compiles articles written during the 1920's and early 1930's, the period when the science of thermionics is beginning to be of importance. This text is divided into two parts. The first part discusses vacuum pumps, specifically examining the effect of space charge and residual gases on thermionic currents in high vacuum. This part also explains fundamental phenomena in electron tubes having tungsten cathodes and the use of high-power vacuum tubes. The second part of this text looks into the electron emission and adsorbed films, specifically studying the relation between contact potentials and electrochemical action and other related topics on electron emission. This publication will be invaluable to those interested in the works of Langmuir, particularly on thermionic phenomena.

The Collected Works of Irving Langmuir, Volume 4: Electrical Discharge is a 12-chapter text that covers the fundamental and theoretical aspects of electrical discharge, with a particular emphasis on discharge in gases. The opening chapters are concerned the negative probes as being due to the random positive-ion current of the plasma and the proper space-

charge with a very simple discharge tube and some miscellaneous experiments on a simple tube in which streamer type discharges were observed, as well as the effects of small amounts of tungsten in the argon discharge. These topics are followed by discussions on the verification of the Langmuir Probe-Theory; the disturbing effects of mercury vapor blast from the cathode spot on the mercury pool; and the phenomena observed in the low pressure discharges. Other chapters explore the Faraday dark space of the glow discharge and how the electrons of a beam in a plasma are given their higher velocity components. The final chapters introduce the concept of plasma oscillation. This book will be of value to electronics engineers and technical workers. Shortly after the demonstration of the first laser, the most intensely studied theoretical topics dealt with laser-matter interactions. Many experiments were undertaken to clarify the major ablation mechanisms. At the same time, numerous theoretical studies, both analytical and numerical, were proposed to describe these interactions. These studies paved the ways toward the development of numerous laser applications, ranging from laser micro- and nanomachining to material analysis, nanoparticle and nanostructure formation, thin-film deposition, etc. Recently, more and more promising novel fields of laser applications have appeared, including biomedicine, catalysis, photovoltaic cells, etc. This

book intends to provide the reader with a comprehensive overview of the current state of the art in laser ablation, from its fundamental mechanisms to novel applications.

Complex plasmas differ from traditional plasmas in many ways: these are low-temperature high pressure systems containing nanometer to micrometer size particles which may be highly charged and strongly interacting. The particles may be chemically reacting or be in contact with solid surfaces, and the electrons may show quantum behaviour. These interesting properties have led to many applications of complex plasmas in technology, medicine and science. Yet complex plasmas are extremely complicated, both experimentally and theoretically, and require a variety of new approaches which go beyond standard plasma physics courses. This book fills this gap presenting an introduction to theory, experiment and computer simulation in this field. Based on tutorial lectures at a very successful recent Summer Institute, the presentation is ideally suited for graduate students, plasma physicists and experienced undergraduates.

The electric probe has long been used as a fundamental diagnostic tool for measuring the local properties of a plasma. Since Langmuir first developed the electric-probe technique in 1924, probes have been used to measure electron

densities and temperatures in a wide variety of gaseous ionized media, such as electric discharges, afterglows, ionizing shock waves, flames, MHD, and plasma-jet flows, reentry vehicle flow fields, and atmospheric and space plasmas. The first systematic account of modern theories of electriC- probe behavior was given by Chen (1965), who also provided practical information on experimental techniques. A subsequent survey by Swift and Schwar (1970), which was representative of results contained in the literature through 1969, included additional information on some of the modern theories and on practical details of probe utilization. The purpose of this volume is to supplement the previously mentioned two works by providing an account of a large body of the up-to-date informa tion available on electric probes, particularly in the areas of transitional and continuum-flow phenomena, and by offering, for all domains of probe appli cation, a critical appraisal of the more significant probe theories and experi mental investigations in the literature.
The enlarged new edition of this textbook provides a comprehensive introduction to the basic processes in plasmas and demonstrates that the same fundamental concepts describe cold gas-discharge plasmas, space plasmas, and hot fusion plasmas. Starting from particle drifts in magnetic fields, the principles of magnetic confinement fusion are

explained and compared with laser fusion. Collective processes are discussed in terms of plasma waves and instabilities. The concepts of plasma description by magnetohydrodynamics, kinetic theory, and particle simulation are stepwise introduced. Space charge effects in sheath regions, double layers and plasma diodes are given the necessary attention. The novel fundamental mechanisms of dusty plasmas are explored and integrated into the framework of conventional plasmas. The book concludes with a concise description of modern plasma discharges. Written by an internationally renowned researcher in experimental plasma physics, the text keeps the mathematical apparatus simple and emphasizes the underlying concepts. The guidelines of plasma physics are illustrated by a host of practical examples, preferentially from plasma diagnostics. There, Langmuir probe methods, laser interferometry, ionospheric sounding, Faraday rotation, and diagnostics of dusty plasmas are discussed. Though primarily addressing students in plasma physics, the book is easily accessible for researchers in neighboring disciplines, such as space science, astrophysics, material science, applied physics, and electrical engineering. This second edition has been thoroughly revised and contains substantially enlarged chapters on plasma diagnostics, dusty plasmas and plasma discharges. Probe techniques have been rearranged into basic

theory and a host of practical examples for probe techniques in dc, rf, and space plasmas. New topics in dusty plasmas, such as plasma crystals, Yukawa balls, phase transitions and attractive forces have been adopted. The chapter on plasma discharges now contains a new section on conventional and high-power impulse magnetron sputtering. The recently discovered electrical asymmetry effect in capacitive rf-discharges is described. The text is based on an introductory course to plasma physics and advanced courses in plasma diagnostics, dusty plasmas, and plasma waves, which the author has taught at Kiel University for three decades. The pedagogical approach combines detailed explanations, a large number of illustrative figures, short summaries of the basics at the end of each chapter, and a selection of problems with detailed solutions.

A method was developed and used to obtain theoretical predictions of the current collected from a collisionless, fully Maxwellian plasma at rest by an electrically conducting Langmuir probe having spherical or cylindrical symmetry. The probe characteristic, or functional relation between current and probe potential, was determined for both geometries for probe radii up to 100 times the Debye shielding distance of the hotter species of charged particle, for a complete range of ion-to-electron temperature ratios and for probe potentials from -25

to +25 times the thermal energy of the hotter species. Each current collection result is computed to a relative accuracy of 0.002 or better in an average time of approximately two minutes on the IBM 7094. Explicit comparison is made between the results for a completely Maxwellian plasma and those for a plasma mono-energetic in attracted particles, as treated by Bernstein and Rabinowitz, Lam, and Chen. It is shown that in certain cases, the mono-energetic plasma does not adequately simulate the Maxwellian plasma.

A model of the ion-electron flow in the stagnation region between the detached shock and the wall of a Langmuir-type probe is proposed for ionized air in a shock tube at ion mass fractions less than 1/10,000. Based on the close agreement between numerical calculations and measurements of the probe wall ion current density, the pro posed model gives an accurate description of the ion-electron flow in the stagnation-point boundary layer when negative potentials are applied at the stagnation point of the probe. The procedure is indicated to be applicable also in the region between the detached probe shock and the edge of the boundary layer. The ion and electron densities in the boundary layer are shown to be strongly dependent on the equilibrium conditions for the high-temperature gas behind the shock. Hence, the ion and electron number densities in the undisturbed incident flow ahead of the detached

shock cannot be obtained unless it is possible to calculate the changes in the number densities across the shock. (Author).

TO SOLAR TERRESTRIAL RELATIONS PROCEEDINGS OF THE SUMMER SCHOOL IN SPACE PHYSICS HELD IN ALPBACH, AUSTRIA, JULY 1S-AUGUST 10,1963 AND ORGANIZED BY THE EUROPEAN PREPARATORY COMMISSION FOR SPACE RESEARCH (COPERS) Edited by J. ORTNER European Space Research Organisation. Paris and H. MAS ELAND Sterrewacht ' Sonnenborgh' • Utrecht D. REIDEL PUBLISHING COMPANY DORDRECHT-HOLLAND e-ISBN-13:978-94-010-3590-3 IS8N-13:978-94-0 10-3592-7 00110. 1007/978-94-010-3590-3 '96' Softoover reprint of the hardcover 1st edition 1965 FOREWORD The textbook presented in the following is composed of the proceedings of the Summer School in Space Physics held during the summer months of 1963. This Summer School was organized by the Preparatory Commission (COPERS) of the European Space Research Organisation (ESRO). It was the first time that such a summer course was held in Europe on a subject of space physics. Thanks to an invitation from the Austrian

Government these lectures were given in the College House of Alpbach, Tyrol. Eight outstanding European scientists each presented five two-hour lectures on topics covering the region between the Sun and the Earth. The courses contained the physics of the Sun, the Interplanetary Medium and Trapped Radiation, the Ionosphere and High Latitude Phenomena. Furthermore, a course on space instrumentation was given. Sixty students were selected to attend the courses.

A technique is given for reducing experimental Langmuir probe traces using the exact theory developed by Laframboise. The method yields charged particle number density and plasma potential taking full account of sheath effects, without the requirement for trial and error iteration. All necessary curves are given and the technique is applied to the reduction of experimental data taken in a DC glow discharge in argon in order to illustrate the method. (Author).

Plasma Diagnostics, Volume 1: Discharge Parameters and Chemistry covers seven chapters on the important diagnostic techniques for plasmas and details their use in particular applications. The book discusses optical diagnostic techniques for low pressure plasmas and plasma processing; plasma diagnostics for electrical discharge light sources; as well as Langmuir probes. The text also describes the mass spectroscopy of plasmas, microwave diagnostics, paramagnetic resonance diagnostics, and diagnostics in thermal plasma processing. Electrical engineers, nuclear engineers,

microwave engineers, chemists, and technical personnel in universities, industry, and national laboratories will find the book invaluable.

Experiments were performed in an RF generated, low density plasma flow to determine the behaviour of small, cylindrical Langmuir probes in high-speed flows. All mean free paths were large compared to the probe diameter except the mean free path for ion-ion collisions. The tests indicated that under simulated static conditions (probe axis parallel to flow velocity), the theory of Laframboise represented the ion current characteristic well when the ratio between radius of probe and Debye length was large, but not when the probe radius was comparable to or smaller than the Debye length. The results indicated clearly that the ion current decreased with increasing normal velocity, reached a minimum, and then increased again for subsequent increases in velocity. Subsequently, the probes were used in a study of the charged particle number density and electron temperature distributions in the stagnation region of a flat-nosed cylinder in supersonic flow. The electron temperature had a constant value throughout the bow shock and the entire shock layer. The charged particle number density distribution measurements provided a graphic demonstration of the merging of the bow shock and the boundary layer at a value of Reynolds number of about 100, and also furnished evidence of the diffusive separation of the ions and atoms in the shock wave. Independent measurements of the ion flux to the stagnation point wall were in good agreement with the Langmuir probe measurements in the shock layer.

Langmuir Probe in Theory and PracticeUniversal-Publishers

This report develops a unified theoretical representation of the spherical Langmuir probe in a collision dominated weakly ionized gas. The analysis is performed by numerically integrating Poisson's equation and a set of moment equations, derived from the Boltzmann equation, that conserve mass, momentum and energy for electrons and ions. The theory provides for the continuous description of Langmuir probes from collisionless through collision dominated conditions. Numerical techniques are developed to carry out the analysis. The numerical results show that the theoretical model satisfies all known theoretical limits for collisionless and collision dominated operating conditions. A new model for Langmuir probe data analysis is developed. The model provides for the description of sheaths of finite thickness and is found to meet all known theoretical limits in the collisionless and collision dominated extremes and provides a continuous description of operating conditions between these extremes. Systematic data analysis procedures employing the new data analysis model are developed. The feasibility of performing a Langmuir probe experiment in a thermodynamic equilibrium cesium plasma for the purpose of validating theoretical probe models under experimental conditions where plasma properties are known from thermodynamic relations is investigated.

A theoretical and experimental investigation of the response of a free molecule Langmuir probe in a

turbulent plasma is made. The effect of arbitrary fluctuations in charged particle density, electron temperature, plasma potential, and ion temperature are considered. The results are applicable for (a) frequencies somewhat less than the ion plasma frequency, (b) moderate ratios of probe radius to Debye length, (c) moderate ratios of applied potential to electron temperature and (d) ratios of ion to electron temperatures less than one. The steady state characteristic is obtained by forming an empirical fit to a numerical analysis describing the collisionless probe current collection. Relations are then derived showing the effect of fluctuations on the average properties, and the connection between the r.m.s. probe current and the various correlations. Electron temperature, charged particle density, floating potential, single probe saturation ion and electron current and double-probe current measurements are studied in detail. It is found that the sensitivity of the probe to the various fluctuating quantities is a function of the ratios of probe radius to Debye length, applied potential to electron temperature, and ion to electron temperature. Subsequently it is shown that many of the correlations and average properties may be determined. Experiments are performed in an unsteady highly expanded low density flowing argon plasma. Both the average and r.m.s. currents are monitored using cylindrical Langmuir probes. (Author).