

Preface

Charged-particle emission is an important fundamental characteristic of plasma. Interest in this phenomenon stems from the feasibility of charged-particle sources spanning a wide range of parameters and functional capabilities. The use of a so-called plasma cathode or plasma electron emitter for electron-beam formation is compelling only when the advantages of this approach for a specific application essentially negate the more commonly employed thermionic cathode approach.

Plasma electron sources can produce greater emission current density, are capable of pulsed beam generation, can operate over a wide range of background gas pressure, and are only weakly dependent on the residual vacuum conditions. The advantages of plasma cathodes are most conspicuous in circumstances where a hot cathode cannot provide the required electron-beam parameters due to limited emissivity, particularly in pulsed mode or when operated at high pressures and in the presence of corrosive media. An important feature of the plasma cathode is that essentially all electrons in the discharge gap can be extracted from the plasma, leading to the high efficiency that is typical of electron-beam sources of this kind.

A shortcoming of plasma electron sources is the relatively high plasma electron temperature, which increases the beam emittance and limits the maximum beam brightness. However, compared to hot cathodes, a plasma-cathode electron source produces a much higher electron-beam current density, allowing, in many cases, considerable reduction or even elimination of the adverse effect of elevated temperature on beam emittance.

The advantageous features of plasma-cathode electron sources make them attractive for various applications such as electron-beam welding and powder cladding, modification of material surface properties, generation of electromagnetic radiation, plasma chemical and radiation technologies, etc.

Research in plasma emission and the development of efficient plasma electron sources constitute an application of the applied physics of low-temperature plasmas – plasma emission electronics. Advances in plasma emission electronics as a new scientific field are intimately linked with the name of its founder – Professor Yuli Efimovich Kreindel, Laureate of the State Prize of the Russian Federation in Physics and Technology. Kreindel pioneered the study of electron emission from the plasma of low-pressure discharges in the former Soviet

Union. Thorough investigations of the emission characteristics of low-temperature plasmas have led to an understanding of the physical mechanisms responsible for plasma electron emission and to the development of efficient methods of stabilizing and controlling the plasma beam characteristics. Following this pioneering work, a wide range of plasma electron sources with unique parameters and various functional capabilities have been made and investigated. Highly efficient plasma cathodes can also be used in plasma ion sources. It should be noted that the parameters of ion or electron beams extracted from plasmas carry information about the physical processes occurring in the plasma, permitting these approaches to be used for studies of fundamental processes occurring in low-pressure discharge plasmas.

In 1977, a remarkable book, *Plasma Electron Sources* by Yu. E. Kreindel, was published [1], presenting a review in this area of plasma emission electronics for the first time. Later, in 1989, *Plasma Processes in Technological Electron Guns* was published [2], with contributions from several authors. The problems and promises of the development of plasma emission electronics have been addressed in various collections of articles [3–5], reviews papers [6–10], and the *Proceedings of the First All-Union Conference on Plasma Emission Electronics* [11]. The formation of large-cross-section electron beams, including those produced in plasma-cathode systems, is discussed in [12]. Research and development of plasma-cathode electron sources has been largely, but not exclusively, a Russian/Soviet Union endeavor. The emphasis on the Russian literature that the reader will notice throughout this book is not due to limited vision but reflects the historical development of the field. Of foreign researchers in this area, we recognize in particular the work of our American colleagues S. Humphries Jr., D. Goebel, and A. Hershcovitch, as well as Professor Ya. Krasik in Israel.

This monograph provides an up-to-date overview of an important subfield of applied plasma physics. It is a review of the current status of plasma emission electronics and its development since the publication of the last monograph on the subject in 1989 [2]. The text concentrates equally on providing physical understanding of the basic processes involved in plasma electron emission and on considering the design and applications of plasma-cathode electron-beam sources. The book will be of interest to designers of electron sources as well as to scientists and engineers who use electron beams in research and industry. The text will also be of benefit to both undergraduate and postgraduate students involved with vacuum and plasma electronics, the generation of charged-particle beams, and their applications.

The book consists of five chapters. The first chapter describes the types of plasma discharges that are most frequently used in plasma-cathode electron sources. These are the hollow-cathode glow discharge, discharges in crossed electric and magnetic fields, such as Penning- and magnetron-type discharges, the constricted low-pressure arc discharge, and the vacuum arc with cathode spots, all of which require no hot electrodes for their operation. The peculiarities of each of these discharge types are discussed, and their characteristics and parameters given.

In the second chapter, emphasis is on the general problems of plasma electron emission, including the principles of stabilization of plasma emission parameters and methods of controlling the electron-beam current. The same chapter reports on the results of studies of electron-beam extraction from plasma at fore-vacuum pressures and considers the characteristics of electron beams formed from nonstationary plasmas.

In the third and fourth chapters, the design of a number of different kinds of plasma electron sources and their characteristics are presented. In particular, the third chapter focuses on sources of axially symmetric (cylindrical and narrow-focused) electron beams, and the fourth chapter is concerned with sources of large-cross-section electron beams, including ribbon beams.

Finally, the fifth chapter considers some of the most typical areas of application of plasma-cathode electron sources.

This book cannot provide a complete coverage of all related work and all relevant source designs known to date, and therefore in a number of cases the reader will find a limited number of references to the appropriate papers. The choice of one or another publication for representation was in many ways dictated by my own preference, and I apologize in advance to colleagues whose work has not been covered in full measure in this book.

After publication of this book in Russian [13], various additions as well as corrections of misprints were made in this English version. For the convenience of the reader, most of the references to articles in the Russian journals have been replaced by their translated sources published in the West, such as *Russian Physics Journal*, *Instruments and Experimental Techniques*, *Technical Physics* and many others.

I am indebted to my Russian-to-English translators, Tatiana Cherkashina and Anna Korovina, as well as to Ekaterina Chudinova, who provided great help in preparing the book for publication. Special thanks go to Ian Brown, my co-author of many years (work related to the investigation of vacuum-arc ion sources) and very good friend, for “forcing” me to write this book, and also for his careful reading of the manuscript and useful advice and comments. This input has provided me with a truly invaluable aid in approaching the subject matter.

It is my great honor to dedicate this work to Professor Yu.E. Kreindel, my first supervisor and scientific father.

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