# Preface

Presently, low-temperature plasma is widely used in science and engineering. Many technological problems such as cutting and welding, melting of metals, welding and spraying of refractory, wear-resistant, corrosion-resistant coatings, obtaining of spherical and dispersion of powders, thermal surface treatment of refractory materials, plasma polishing of optical glass and metals, recycling of heat-resistant plasma chemical waste and others may be successfully solved using low-temperature plasma. Different types of devices for obtaining of plasma flows are developed—plasma torches, where the high-frequency induction (RF), the high-frequency capacitance, ultrahigh-frequency (UHF) and optical discharges are used as the plasma sources.

Effective use of these types of plasma torches requires extensive studies of plasma processes in order to: identify their laws; receive the plasma stream with the desired properties; determine the optimal operating conditions and the development of new structures of plasma torches; direct control of the plasma; and others. These problems can be solved on the basis of experimental studies and mathematical modeling of processes in the plasma.

Field experiments (with the ability to implement them) give detailed information about the plasma. Many phenomena in plasma have been predicted by theoretical calculations, and discovered and confirmed experimentally, in particular, the results of field experiments can be used for comparison with the experimental data in order to analyze the physical processes and the direct control of the plasma.

Unfortunately, many experiments are expensive and experimental methods are still far from perfect. The errors of the experimental methods are often large enough, and often the experimental data of different authors have large discrepancies and contradictory. Some experiments are difficult to carry out in conditions of low-temperature plasma, and their data provide only its integral characteristics.

An important problem of determining the spatial distributions of quantities such as temperature and composition of the plasma, gas flow rate, the electromagnetic field inside the plasma flow and others, their relationships with the external parameters of the plasma torch is a difficult experimental problem. The solution of this problem becomes more difficult when you study the properties of multivariate,

nonequilibrium, transient, nonsymmetric plasma flows that is determined solely by a wide variety of physical processes in the plasma and by the complex nature of its components interaction.

Such difficulties in obtaining experimental data for a wide range of plasma flows parameters make actual the development of theoretical modeling techniques.

Theoretical studies of the plasma by mathematical simulation methods allow to eliminate many of the natural experiment limitations, complement and extend the possibilities in the study of plasma, as well as replace complex, expensive, and sometimes impracticable principal experiment. Based on the developed mathematical models you can study the physical processes occurring in the plasma, set optimal modes of plasma sources, to determine changes of the external adjustable parameters, measuring point and the minimum number of measured physical quantities needed for solving the problem of plasma control. In particular, progress in the study of plasma and use cannot be without an in-depth theoretical studies.

One of the main tasks of theoretical studies of plasma processes is to obtain local physical parameters of the plasma and the establishment of their links with external power and the geometric parameters of the plasma torch. Typically, in engineering design it is required to make some form of temperature distribution and plasma flows, corresponding to the special conditions of practical use. This is typically achieved by altering the current, plasma gas flow rate, the operating mode of the generator, and the geometric characteristics of the plasma torch, i.e., only control the external parameters of the plasma torch.

Significant progress in the use of the plasma can be achieved by providing direct control of plasma flows. This requires a structural parametric identification of the plasma. In this case, you first need to examine and define the properties and parameters of the plasma, to find the place of measurement, to build functional relationships, etc. This problem can be solved with the help of mathematical modeling as a real object for study using different mathematical models describing physical processes in the plasma. However, the theoretical description of the plasma is often carried out with the help of highly nonlinear differential equations in partial derivatives. The solution of these equations belongs to the class of rigid and ill-conditioned problems, and is a serious mathematical and information problem.

The obtained results allow us to establish the flow pattern and gas heating, of energy in the plasma, to determine the area of cold channel, thermal and ionic imbalance in the plasma region preference models, create the necessary conditions for solving the problem of structural parametric identification and on the basis of the decision to make the transition to the system automatic control of plasma parameters. You can also use the results as the necessary material for the study and design of plasma torches, optimization of various plasma processes and the creation of simulation models of plasma, which have been free from stability problems of computational procedures.

To learn the basics of theory of low-temperature plasma readers are invited to first familiarize themselves with the contents of the first five chapters. In Chap. 1 the general approach to the description of plasma processes, the basic model of the plasma, their assumptions and applicability are outlined. Models and cross sections

for the interaction of particles in the plasma are considered using the classical model of elastic collisions in Chap. 2, and with the help of quantum-mechanical theory of scattering particles in Chap. 3.

Determinations of the composition, thermodynamic functions, transport coefficients of the plasma on the basis of model and the mean free path are given in Chap. 4. In Chap. 5 the solution of the Boltzmann kinetic equation by the Chapman–Enskog approach and calculation of the transport coefficients of the plasma are provided.

In Chap. 6 the main method of control volume for solving the problems of heat transfer and plasma dynamics is presented along with the various numerical schemes (methods) of solutions, their analysis in terms of accuracy, and the ease of implementation. Stability analysis and determining the cause and the remedy of the instability are also discussed in this chapter. We introduce the discrete analogues of various equations of plasma mathematical models. The structural organization of the computational procedures for the simulation of plasma processes is also given.

In Chap. 7 the methodology and the main results of the simulation of the RF plasma torches is set out. As an addition to those obtained in Chap. 6 algorithms, there are the method of calculating the two-dimensional electromagnetic field in the RF plasma torches and simulation of the RF plasma torches based equilibrium and nonequilibrium models.

Similarly, in Chap. 8 the methodology and the main results of the simulation of Arc plasma torches, different design and technological applications (Arc in the channel for cutting and spraying, free Arc welding and melting of metals, etc.) are presented.

In Chap. 9 the modern models and algorithms for the calculation of the near-electrode processes taking into account the working conditions of the majority of electric Arcs are described. The calculations for thermionic cathodes based on pure and thoriated tungsten in a wide range of parameters of the cathode and plasma, as well as algorithms for calculating the heating of the cathode and anode processes are provided.

In Chap. 10 the issues of heat transfer and dynamics of solid particles in plasma, model of heat and motion of particles in the plasma and the main results of the calculations with respect to the jet of the RF plasma torches are described. The results of the interaction model and the dispersed flow with the plasma are given.

Description of the experimental stand, the main methods of diagnosis, and the results of measurements of plasma parameters in the induction and Arc plasma torches are described in Chap. 11.

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This book was written after my many years of working in the field of low-temperature plasma physics. However, this would not have been possible if it were not for many years of creative collaborations with Prof. S. Dresvin. He was who introduced me to the world of low-temperature plasma physics, when I was still a student of the Electromechanical Faculty of St. Petersburg State Polytechnic University.

I would like to emphasize the special contribution to my creative extension of the work of the Prof. O. Sokolov. During the many sleepless «White nights» in St. Petersburg, we had a conversation with him about a systematic approach to solve a multidimensional system of nonlinear differential equations. It is a great idea that the internal feedback about physical processes found their realization in the simulation model for a sustainable solution of a system of differential equations for plasma.

I have many excellent professors, colleagues, friends, my talent graduate students in colleges and universities of St. Petersburg and Moscow, and I would like to emphasize their help and support in the process of working on the material of this book.

I am infinitely grateful to my parent, my wife, and my sons for their help and support. Their daily smiles are the driving motor of the writing of this book.

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