ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD)
Specialty 6D060400 – Physics

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DIAGNOSTICS OF LOW TEMPERATURE COMPLEX PLASMA AT LOW AND ATMOSPHERIC PRESSURES

The PhD thesis is devoted to the experimental research and diagnosis of various properties of the complex low-temperature plasma gas discharge in a low and at atmospheric pressure.

Relevance of the dissertation theme:

Plasma is a partially or fully ionized gas, with the densities of positive and negative charges are almost the same, and the linear dimensions of the occupied region significantly exceed the distance (the so-called Debye radius) at which the electric field of a single charged particle disappears due to screening by other particles.

Plasma diagnostics is a set of research methods whose purpose is to determine the local, instantaneous or general and average values of its main parameters: the form and structure, the concentrations of electrons, atoms and molecules that make up the plasma-forming medium in the main and various excited states, the average kinetic energy and temperature of charged particles, the presence and density of chemical active substances, radicals, etc.

Traditionally, the term "complex plasma" is used as a definition for a normal plasma of low pressure gases containing highly dispersed charged particles of a condensed matter with a size of from several hundred nanometers to several tens of micrometers. Also in the literature, the term "dusty plasma" is widespread. However, over the past decades, the scope of the definition of "complex plasma" has expanded significantly. This fact is due to the development of generation methods and new research in the field of low-temperature atmospheric discharge plasmas. The development of new sources of non-equilibrium, "cold" plasma as plasma jets of a dielectric barrier discharge, surface discharges, microdischarges and the study of their properties in relation to medicine, agro-industry, technology of new materials show that plasma in these types of gas discharges has a complex composition.

Complex plasma differs from ordinary plasma by the presence of additional components such as nano and microparticles, chemically active radicals and ions, metastables and etc. They can be introduced in- vitro or can be generated spontaneously. Plasma can also be considered as a complex if it's in interaction with surfaces of solids or liquids. In this thesis, methods for diagnosing and properties of complex low-temperature plasma are investigated both at low pressures and at atmospheric pressure.

The presence of dust particles in the low pressure gas discharge plasma leads to appearance of a new plasma parameter — the charge of the dust particle, which

in turns depends on the size of the dust particle and the local parameters of the surrounding plasma. The charge of a dust particle can be very large. For example, in a low-pressure gas-discharge plasma, the negative charge of a dust particle reaches 10^3– 10^5 electron charges for particles of few microns in size. Due to the large mass of dust particles and the big amount of the charge, the presence of a dust component greatly changes the characteristic spatial and temporal properties in the plasma. Therefore, determination of the basic parameters and diagnostics of complex dusty plasma is the very important task for understanding physical processes in this type of plasmas.

The complex atmospheric pressure plasma, including the dielectric barrier discharge DBD, is still not fully understood and does not lose interest from the world scientific community. Due to the presence of various metastable atoms, active ions and radicals of oxygen and nitrogen, water vapor, and due to the continuous interaction with the surface of materials and living cells, low-temperature atmospheric plasma is a complex medium with a complex composition. Therefore, today, for a deep understanding of physicochemical processes and for optimization of technological processes, one of the most important tasks is the study and diagnostics of plasma of complex plasmas at atmospheric pressure.

The main goal of work: diagnostics and study the properties of low-temperature complex plasma at low and atmospheric pressure by different methods.

The object of the research: low-temperature buffer and complex plasma of high-frequency discharge, glow discharge, plasma - coulomb crystal structures in microgravity conditions and complex gas-discharge plasma of dielectric barrier discharge and atmospheric pressure plasma jet.

The subject of the study is the temperature and concentration of charged particles in a complex plasma, plasma potential, self-bias voltage of a radio frequency (RF) discharge, dimensions of a dust-free region around the probe, dust particles, static and dynamic current-voltage characteristics, emission spectra of the discharges, structure of DBD.

In order to achieve the above stated goal, it is necessary to do the following tasks:

– to study the processes in the near-probe region in the presence of dust particles in the low-temperature complex glow discharge plasma and to determine the parameters of the background plasma based on the measurement of the radius of the dust free region.

– to study the electron temperature of the complex plasma in an RF discharge in noble gas mixtures and to study the effect of the dust component on the parameters of the background plasma, to study evolution of the dust particle structures in plasma Coulomb crystals in microgravity conditions.

– to adapt the method of conventional probe diagnostics in order to determine the parameters of a complex plasma with nano dust particles and to study the dependence of these parameters on the cyclic growth of nanoparticles in an asymmetric RF discharge.

– to study the electrical, optical and structural properties of low-temperature DBD plasma, atmospheric pressure plasma jet (APP jet) and determination of discharge modes and plasma chemical composition.

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The main provisions for the defense:

– experimental measurement of the size of the dust-free region around the probe during the decreasing (in absolute value) the applied negative probe potential relative to the potential of the surrounding plasma allows us to determine the temperature and concentration of electrons fn the complex plasma in the glow discharge positive column;

– the addition of a small amount of argon to the main gas helium in the ratio of 97% He + 3% Ar leads to a decrease in the electron temperature of the background plasma, while the presence of the dust component contributes to an increase in the electron temperature;

– the cyclic growth of nanoparticles in the complex plasma of an RF discharge leads to a decrease in the electron concentration and to a significant increase in the plasma potential and temperature of the electrons;

– with a uniform increase in the volume flow rate of plasma-forming inert gases such as argon and helium in the range of 1–20 l / min, the length of the plasma jet is reduced after reaching a certain maximum, an increase in the applied voltage on the electrodes contributes to an increase in the length of the jet, while the change in the frequency of the voltage does not have a significant influence.

Scientific novelty of the dissertation results.

For the first time in this work:

– an alternative method for determining the basic parameters of a glow discharge background plasma based on the measurement of the size of a dust-free region as has been developed;

– the method of "complex" sweep of the applied voltage was used to carry out probe diagnostics and to determine the electron temperature and potential of the nanoparticle containing complex plasma of an asymmetric RF discharge;

– the charge of scattering particles in a plasma Coulomb crystal under microgravity conditions was estimated.

– the dependence of the structural properties on the experimental conditions of the plasma jet and the volume dielectric barrier discharge at atmospheric pressure has been studied in more detail.

Practical and theoretical importance of the dissertation.

The results obtained in the thesis are valuable for the development of complex plasma physics and the physics of low-temperature plasma as a whole.

They might be very useful for in-depth understanding of the mechanisms of formation of self-organizing structures from dust particles in low-temperature plasma, for studying the charging process of particles, for detailed research of plasma properties interacting with the surface of materials, for developing scientific and technological bases for processing low-temperature plasma of various materials, biological objects and living tissues. Developed method for diagnosing complex plasma at low pressures may be useful for determining the parameters of background plasma in laboratory setups of various gas discharges, in PE - CVD and etching, in vacuum-plasma equipments for cleaning and activating the surfaces of substrates in microelectronics and in installations for the synthesis of various nanostructured materials in a plasma environment.

Validity and reliability of the results. The dissertation results obtained by using well-known and approved experimental methods as a Langmuir probe, methods for studying the electrical properties of plasma (oscillography of current and voltage, measuring self-displacement voltage), and optical diagnostic methods (optical emission spectroscopy, high-speed photography). The results obtained by applying the proposed new method for diagnosing buffer plasma parameters based on a study of the dust free region around the probe are in good agreement with the results of the classical probe method. Also, a theoretical calculation of the size of the dust-free region shows good agreement with the experiment. The results of studying the behavior of plasma parameters during the growth of nanoparticles obtained by the method of "complex sweep" of the probe voltage correlate with the results of measuring the self-bias voltage. Also, the reliability and validity of the results are confirmed by publications in foreign journals with a high impact factor and in publications recommended by the Committee on the Control of Education and Science of the MES RK, and in the works of international scientific conferences in the near and far abroad.

The personal contribution of the author lies in the fact that the entire volume of the thesis, the choice of the research method, the assembly, the adjustment and the modernization of the experimental facilities, the conducting of experiments and the analysis of the obtained data were carried out by the author independently. The setting of tasks and discussion of the results were carried out jointly with the scientific supervisors.

Publications. According to the materials of the dissertation, 24 publications were published: 5 in journals from the List of KKSON MES RK for publication of the main results of the thesis for the PhD degree and 3 articles in foreign journals with impact factor included in the international information resource Web of Science (Clarivate Analytics , USA) and Scopus (Elsevier, the Netherlands); 15 papers in the materials of the International Scientific Conferences and 1 innovative patent of the Republic of Kazakhstan.

Approbation of the dissertation. The results obtained in the dissertation were presented and discussed:

– at the 7th International Conference on Dusty Plasma Physics ICPDP-2014 (2014, New Delhi, India);

– at the 22nd Europhysics conference on atomic and molecular physics of ionized gases "ESCAMPIG-XXII" (2014, Greifswald, Germany);

– at the international conference on the physics of strongly-coupled Coulomb systems “SCCS-2014” (2014, New Mexico, USA);

– at the international conference "Frontiers in low-temperature plasma diagnostics" FLTPD-2015 (2015, Porquerol, France);

– at the 14th International Workshop on Dusty Plasma Physics (2015, Auburn, Alabama, USA);

– at the 8th International Conference on Plasma Physics and Plasma Applications "PPPT-8" (2015, Minsk, Belarus);

– at the 23rd International Conference on Phenomena in Ionized Gases “ICPIG” (2015, Iasi, Romania);

– at the 15th International Conference on Physics of Non-ideal Plasmas "PNP-15" (2015, Almaty);

– at the international conference of students and young scientists "FARABI ALEMI" (2015, KazNU named after Al-Farabi, Almaty);

– at the 42nd Conference of the European Physical Society for Plasma Physics "EPS-XXXXII" (2015, Lisbon, Portugal);

– at the 9th international scientific conference "Modern achievements of physics and fundamental physical education" (2016, Almaty);

– at the 23rd Europhysical Conference on Atomic and Molecular Physics of Ionized Gases "ESCAMPIG-XXIII" (2016, Bratislava, Slovakia)

– at the 24th International Conference on Phenomena in Ionized Gases “ICPIG” (2017, Estoril, Portugal);

– at the 8th international conference on dust plasma physics "ICPDP-2017" (2017, Prague, Czech Republic);

– at the international conference on the physics of strongly-coupled Coulomb systems “SCCS-2017” (2017, Kiel, Germany);

– at the 44th conference of the European Physical Society for Plasma Physics "EPS-XXXXIV" (2017, Belfast, Ireland);

– at the 24th Europhysical Conference on Atomic and Molecular Physics of Ionized Gases "ESCAMPIG-XXIV" (2018, Glasgow, Scotland, United Kingdom).

– at the 15th International Workshop on Dusty Plasma Physics (2015, Baltimore, Maryland, USA);

– at the International Symposium on Plasma Physics and Plasma Technologies (2018, Prague, Czech Republic);

Relation of the dissertation theme to the plans of scientific research. The dissertation was fulfilled in accordance with the plans of the following

fundamental scientific research works (SRW) SC RK MES «Grant funding of scientific research» on the themes:

- “The influence of dust formation processes and the properties of near - wall plasma with dust particles on the operating modes of fusion reactors” (2015-2017, 3112 / GF4);
- “Investigation of the properties and effects of atmospheric pressure cold plasmas on the surface of materials” (2015-2017, 3220 / GF4);
- “Development of scientific and technological bases for increasing plant growth and grain yield using atmospheric pressure treatment with cold plasma” (2018–2020, IRN AP05134280);

The scope and structure of the thesis. The thesis consists of an introduction, 3 sections, conclusion and list of references from 136 titles, contains 124 pages of basic computer text, including 78 figures and 1 table.