ABSRACT

of the dissertation for the degree of Doctor of Philosophy (PhD) specialty 6D074000- Nanomaterials and nanotechnologies

UTEGENOV ALMASBEK ULUBEKOVICH

THE SYNTHESIS AND PROPERTIES OF CARBON NANOMATERIALS OBTAINED IN COMPLEX GAS-DISCHARGE PLASMA

The thesis presents the results of experimental work on the synthesis of carbon nanomaterials and the study of their properties in the dust plasma of electric discharges of a mixture of different gases. The paper uses modern experimental methods of synthesis, including synthesis in gas discharges, as well as studies of the properties of nanoparticles, in particular, the optical method for determining the size of nanoparticles, electron microscopy and Raman spectroscopy.

Relevance of the dissertation theme

Research on the synthesis of nanomaterials, have a high tendency of development among the world scientific community. This is due to the fact that leading experts in the creation of new, technologically important materials in the field of industry and medicine, resort to the use of nanomaterials. Nanomaterials have a very wide range of applications.Such materials are used in the area of energy conversion and storage, which in turn is vital to overcome crises related to global warming and the scarcity of fossil fuels. Nanotechnology is playing an increasingly important role in many of the key technologies of the new Millennium. The application of nanoscale materials and structures is a new area of application of nanoscience and nanotechnology. In recent years, there has been an extraordinary increase in nanoscience and technology, mainly due to the development of new technologies for the synthesis of nanomaterials and the availability of tools for the classification and manipulation of nanoparticles. Nanoparticle production requires an understanding of the fundamentals of nanoscale chemistry and physics for their commercialization.

In many experimental works for the synthesis of nanoparticles, gas discharge plasma is used as a universal medium, where a number of possibilities for controlling the synthesis process arise by means of different manipulations of the discharge parameters.

It is known that after the synthesis of particles in the gas discharge, the plasma becomes complex (containing a dust component). The main difficulties in the synthesis of nanomaterials in the plasma medium is the appearance of a

particle-free space in the plasma, which in turn leads to an uneven growth of nanoparticles in volume.

Also, to date, great interest in the world is a unique international project ITER, aimed at the construction of the first international experimental thermonuclear reactor, the world's largest tokamak. The aim of the ITER project is to demonstrate the technological feasibility of using thermonuclear energy on an industrial scale. In this regard, some progress has been made: ultra-high temperatures and sufficient retention time in principle already provide a positive energy balance of thermonuclear reactions. The high temperature (about 150 million degrees) of the plasma cord in thermonuclear reactors is one of the main conditions for the synthesis of light nuclei. To prevent contact of such high-temperature plasma with the walls of the reactor and the divertor, it is held in the center of the toroidal chamber by a magnetic field. However, during the failure of the plasma cord, the isolated powerful pulse plasma flow interacts with the surface of the in-chamber materials of the reactor.The study of the interaction of hot plasma with the reactor components placed inside the chamber is a complex problem in the physics of thermonuclear reactors. Interaction processes determine the choice of materials of the thermonuclear reactor wall, as well as its proper operation, taking into account the restrictions imposed by the interaction with the wall.

To date, the following main problems can be identified that play a key role in the interaction of plasma with the material of the front wall of the reactors, it is the formation of dust due to the erosion of materials; the accumulation of radioactive tritium in the materials of the vacuum chamber. The accumulation of dust and its deposition, nanostructured films in the reactor volume mainly play a negative role. First, it leads to instability of combustion of high-temperature plasma and the origin of breakdowns, and secondly, the capture and accumulation of tritium that is a problem for the safe operation of the reactor and its efficiency.

Active research in this area, although it has clarified a large number of issues related to the interaction of plasma with solids, still leave many misunderstood points, in particular the question of dust formation in thermonuclear reactors, and to solve it requires careful study.

In connection with the above, we can conclude that the study of the characteristics of nanoparticles synthesized in the plasma environment of electric discharges and related issues are **relevant** for the formation of the foundations of the theory of formation of nanomaterials in plasma of complex composition.

The main goal of work is the synthesis of carbon nanomaterials in dusty plasma of electric gas discharges and investigation of their properties.

The object of the research: the synthesized carbon nanoparticles obtained by plasma-chemical method in plasma of radiofrequency (RF) discharge of a mixture of inert and carbon-containing gases and the properties of the plasma, and the nanostructured carbon products of erosion of the target obtained in the installation of the pulsed plasma accelerator.

The subject of the study: dimensions (diameter) of carbon nanoparticles synthesized in the plasma of RF discharge of argon-acetylene gas mixture, geometric shape of the plasma-dust cloud of carbon nanoparticles, surface properties of erosion products of the candidate material of the first wall of the tokamak.

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

– synthesize carbon nanoparticles in the RF discharge and investigate the dependence of the geometric forms of the plasma-dust cloud of nanoparticles on the parameters of the superimposed additional constant field.

– to develop a system for determining the size of carbon nanoparticles at an early stage of their formation by the plasma chemical method in the HF discharge of the argon-acetylene gas mixture based on the method of dynamic light scattering.

– to investigate the process of interaction of pulsed plasma stream with graphite targets with the aim of obtaining highly developednanostructured surfaces for the installation of the pulsed plasma accelerator (IPU, IETP at Al-Farabi KazNU).

– to analyze the surfaces of erosion products of the candidate material of the first wall of thermonuclear power reactors (TNPR) using SEM and Raman spectroscopy.

Method of research. In solving the problems necessary to achieve this goal, the following methods were used: for the synthesis of carbon nanomaterials, the method of gas-phase deposition in the plasma of RF discharge was used. The method of dynamic light scattering was used to determine the size of nanoparticles at an early stage of their development. To study the surface properties of the nanostructured formations, which are the result of erosion of the candidate material, in experiments on a pulsed plasma accelerator (nanoparticles and nanofilms), the methods of electron, optical microscopy and x-ray diffraction analysis are used. The study of the properties of dusty plasma from nanoparticles in the gas discharge was performed on the basis of video fixation of plasma-dust formation. To control the spatial characteristics of dusty plasma from RF discharge nanoparticles, an additional electrostatic field created by a DC source was used.

The main provisions for the defense:

– An increase in the negative electrostatic field during the synthesis of carbon nanoparticles in the discharge of an argon-methane gas mixture leads to an increase in the dispersion of carbon nanoparticles.

– The developed system for determining the size of carbon nanoparticles in the plasma of an rf discharge of an argon-acetylene gas mixture based on the dynamic light scattering method showed that, in the period of decorrelation of 5.3-20 μs, the diameter of carbon nanoparticles varies from 5.3 to 20 nm.

– The interaction of a pulsed plasma stream with the surface of the candidate material of the first wall of a thermonuclear reactor, in addition to nanoparticles, leads to the appearance of fractal nanostructured materials.

The novelty and originality of the thesis lies in the fact that it is the first time:

– a method for controlling the spatial characteristics of micro - and nano - sized dust particles in the plasma of a gas HF discharge was developed.

– the method of dynamic light scattering was used to determine the size of carbon nanoparticles at the early stage of their synthesis in the plasma of high-frequency gas discharge of the argon-acetylene gas mixture.

– nanostructured materials with fractal surfaces were obtained at the installation of a pulsed plasma accelerator.

Practical and theoretical importance of the dissertation. The results obtained in the thesis are valuable for the development of technology in the development of reactive plasma systems for the synthesis of nanomaterials. The study of the processes of plasma interaction with synthesized nanoparticles allows to determine the structural characteristics of plasma-dust formations, as well as their features. In addition, the study of the properties of nanoparticles at an early stage of their synthesis in the plasma of inert and reactive gases is an urgent task, since in many cases the properties of nanomaterials are determined after experiments by electron microscopy, etc.

The need for such research at the national level is associated with the wide application of the results of work in such areas as controlled thermonuclear energy, nanotechnology and nanomaterials, new structural materials for the needs of the oil and gas and mining industry, instrumentation, ultra-dense integrated circuits, etc., which are priority areas of scientific, technological and industrial-innovative development of Kazakhstan.

Validity and reliability of the resultsconfirmed by publications in journals of foreign countries with high impact factor and in publications recommended by the Committee for control in the field of education and science of the MES of Kazakhstan, in the proceedings of international scientific conferences of near and far abroad, as well as a patent for the invention.

The personal contribution of the author lies in the fact that the whole volume of the dissertation work, the choice of the research method, the problem solving, the modernization of the experimental setup was carried out by the author independently. Setting of tasks and discussion of results were carried out together with scientific consultants.

Publications. According to the materials of the thesis published 35 printed works: 7 in journals from The list of the Committee for control in the field of education and science of the MES of RK for publication of the main results of the thesis for the degree of PhD and 5 articles in journals abroad with impact factor included in the international information resource Web of Knowledge (Thomson Reuters, USA) and Scopus (Elsevier, Netherlands); 21 works in the materials of International scientific conferences and 1 patent of the Republic of Kazakhstan for invention.

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

– at the international conference of students and young scientists "FarabiAlemi" (2014, KazNU. al-Farabi, Almaty);

– at the 7th international conference on dusty plasma physics "ICPDP-2014" (2014, new Delhi, India);

– at the 22nd Europhysical 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 14th international seminar 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 the physics of nonideal plasma "PNP-15" (2015, Almaty);

– at the 42nd conference of the European physical society on plasma physics "EPS-XXXXII" (2015, Lisbon, Portugal);

– at the 21st international Symposium on heavy ion synthesis "HIF-2016" (2016, Astana);

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

– at the 24th international conference on phenomena in ionized gases "ICPIG" (2016, Estoril, Portugal);

– at the 8th international conference on dusty 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 international conference "JSAP-2017" (2017, Japan).

Relation of the dissertation theme to the plans of scientific research. The dissertation work was fulfilled in accordance with the plans of fundamental research works MESRKgrants: «Optimization of operation modes of thermonuclear power reactors on the basis of a comprehensive study of the properties of dust wall plasma» 2012-2014, code 1115/GF4, «Obtaining and modification of nanostructured functional materials in plasma-dust media» 2012-2014, code 0182 PCF-2014-OT, «The influence of the processes of dust formation and properties of the edge plasma with dust particles on modes of operation of fusion power reactors» 2015-2017, code 3112/GF4, «Investigation of the properties of low-temperature complex plasma in order to develop a method for manipulating micro-and nano-sized particles» 2015-2017, code 3097/GF4.

The scope and structure of the thesis. The thesis consists of an introduction, 4 sections, conclusion and list of references from 161 titles, contains 108 pages of basic computer text, including 71 figures and 4 table.