Application of plasma methods for the synthesis of nanostructures

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Abstract. There are many plasma methods for the synthesis of nanostructures, for example, the plasma-chemical vapor deposition method, the cathode-arc deposition method, the plasma jet method, the ion sputtering method, etc. Each of the listed methods can be organized in various ways, and each method is suitable for creating certain nanostructure.

1. Introduction

Gas-discharge plasma is widely used in various applications \cite{1–29}, including those used for the synthesis of nanostructures. Nanostructures can be synthesized by various methods and methods, however, plasma methods for the synthesis of nanostructures play a special role. Different methods for synthesizing nanostructures use different approaches, some methods use a top-down approach, while others use a bottom-up approach. The top-down approach involves the production of nanostructures by grinding large bodies to nanoscale values. And the “bottom-up” approach involves the assembly of nanostructures from atoms and molecules, i.e. there is an enlargement of objects to nanoscale values. Plasma methods involve the use of gas-discharge plasma to transform a substance into an atomic state. Further, the substance in the atomic form, under certain conditions, participates in the formation of nanostructures.

2. Plasma methods for the synthesis of nanostructures

There are many plasma methods for the synthesis of nanostructures, for example, the plasma-chemical vapor deposition method, the cathode-arc deposition method, the plasma jet method, the ion sputtering method, etc. Each of the listed methods can be organized in various ways, and each method is suitable for creating certain nanostructures.

2.1. Plasma chemical vapor deposition

Plasma chemical vapor deposition can be used to synthesize thin nanosized films. In this case, films are formed from a material in a gaseous state, which passes into a solid state on a substrate. As a rule, these processes take place in sealed chambers at low pressures. The electric discharges used in this process can be direct current, alternating current, and also the HF range. In addition to electrical discharges, microwave plasma can be used. The process can be supplemented with laser radiation. The substrate on which the films are deposited may have a heating element to maintain a certain temperature. There are computerized systems that are capable of applying films with a given composition, respectively, and properties in an automated mode by plasma-chemical vapor deposition,
as well as performing experiments and saving operating modes, all this ensures high repeatability of results.

2.2. Cathode-arc deposition
The basis of cathode-arc deposition is the vapor deposition process, in which the evaporation of the cathode material occurs as a result of the action of an electric arc. The process proceeds as follows: first, electrodes and a substrate are installed in a sealed chamber, on which it is planned to deposit the cathode material. Further, air is pumped out of the chamber, the volume of the chamber is ventilated with inert gases, then an inert gas, for example, helium, argon, etc., is pumped into the chamber to the required pressure and an arc discharge is initiated. The sprayed material is deposited in the form of a powder, which, depending on the material and conditions, can be nanoparticles, nanotubes, fullerenes.

2.3. Plasma jet method
As in the case of cathode-arc deposition, the plasma jet method is based on the process of deposition by condensation from the vapor phase. However, depending on the material being deposited, chemical vapor deposition processes can also be involved in the deposition of coatings by this method. This method is also called plasma spraying, its essence lies in the fact that a sprayed material is fed into the plasma jet, which melts when it enters the area of the plasma jet and is directed to the substrate in the form of drops, nanoclusters, individual atoms and molecules.

2.4. Ion sputtering
The method of ion sputtering is based on the sputtering of a material as a result of the collision of heavy particles such as ions with it. The target can be bombarded not only with ions, but also with atoms and molecules. Not all incident heavy particles are able to cause the emission of atoms and molecules from the target surface, for this they must have sufficient (threshold) kinetic energy equal to 20-50 eV.

Before the start of the process, air is pumped out of the chamber for the purpose, then an inert gas is pumped into the chamber space to the required pressure. As a rule, with a two-electrode system at a pressure below 0.5 Pa, the glow discharge cannot be ignited, therefore, in this case, this is the lower limit of the pressure value in this process. A voltage of the order of several kilovolts is applied to the electrodes, which exceeds the ionization potential and the breakdown voltage, this leads to the fact that electrons begin to be emitted from the cathode, that is, secondary electron emission occurs. These electrons escaping from the cathode are directed towards the anode, while on their way they experience inelastic collisions with gas atoms and thereby ionize them. The inert gas ions formed in this way hit the target surface (which is also the cathode) and knock out atoms from its surface. The use of a more complex four-electrode (triode) system makes it possible to carry out the ion sputtering process at much lower pressures compared to the two-electrode system.

The highest productivity can be achieved using a magnetron sputtering system. A magnetic system consisting of permanent magnets is installed on the reverse side of the cathode. Thus, a closed magnetic field is formed perpendicular to the electric field created between the electrodes on the front side of the cathode. In crossed electric and magnetic fields, electrons are efficiently captured near the surface of the sputtered target. Thus, an electron that has fallen into such a “trap” can only get out of it by colliding with another particle, but even then, it will only switch to a new trajectory, located a little further. Such transitions will continue until the fields are weakened. Those: each electron will make more collisions. Thus, to increase the efficiency of ionization, which will lead to an increase in the density of the ion current, and, consequently, to an increase in the rate of sputtering of the target material. In this case, the pressure at which the spraying process will take place can be less than 0.1 Pa. The ion sputtering process can also be supplemented with laser radiation. The ion sputtering method mainly produces films from a few nanometers to hundreds of micrometers. In addition to films, it is also possible to obtain nanoparticles using a transverse gas flow.
3. Conclusion
Various plasma methods were considered in the work. It can be concluded that for the creation of certain nanostructures, it is worth choosing the appropriate methods.

I would like to express my gratitude to A. O. Sofronitskiy for his consultation while writing this paper.

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