Plasma with carbon nanoparticles and their application

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Abstract: This work is devoted to the investigation of the carbon nanoparticles synthesis in RF discharge with a mixture of gases (Ar/CH_4 and Ar/C_2H_2) and the influence of plasma parameters on the formation and growth of nanoparticles and nanomaterials. A method for determining the diameter of nanoparticles based on the measurement of self-bias voltage and electron density was considered. The study showed a significant influence of the diameters of synthesized nanoparticles on the optical properties of the plasma, in particular, on the emission intensity. This phenomenon can be applied to increase the efficiency of illumination devices. The results of a complex study of superhydrophobic surfaces obtained by plasma deposition of synthesized nanoparticles are also presented. The experimental results showed that the contact wetting angle ranged from 140° to 165°.

Keywords: nanoparticle growth, dusty plasma, application of dusty plasma.

1. Intoduction

Nanoworld is the part of space in which matter, whether alive or not, is formed from atoms by self-organisation. The great interest shows the nanoparticles which have the diameter less than 100 nm. Nanoparticles (biological, organic, organometallic) are individual substances with a specific structure. Atomic associates containing a small number of atoms are called molecules or clusters. As it is known, the quantum properties can be manifested by the reductions of particle size and temperature. Nanoclusters at the molecular level of matter structure in the range of 1–100 nm are fundamentally different from atoms and microparticles in their properties. It is nanoclusters that are the basic ‘elements’ from which various nano-objects exist in the nanoworld. Nanomaterials, including nanoparticles, can be produced by several methods. One of them is plasma synthesis. Plasma is essential for the synthesis of nanoparticles, because in this case it plays the role of a tool while at the same time being a favourable medium for the growth of nanoparticles. The synthesis output of nanomaterials, including nanoparticles of different sizes, various nanomaterials with certain structural characteristics can be controlled by plasma parameters (nanofilms, nanotubes, nanoparticles, etc) [1-4]. The main tool for the synthesis of nanoparticles is gas discharge plasma. The most widely available type for nanoparticles synthesis is radiofrequency discharge plasma. It is notable that when nanoparticles are formed in such a plasma system, for instance in the case of the plasma enhanced chemical vapor deposition (PECVD) method, the plasma is assumed to be a dusty plasma or a complex plasma.

2. Experimental setup

The emission intensity of radio-frequency capacitive discharge (RF) plasma with nanoparticles was studied in an experimental setup the scheme of which is shown in figure 1.

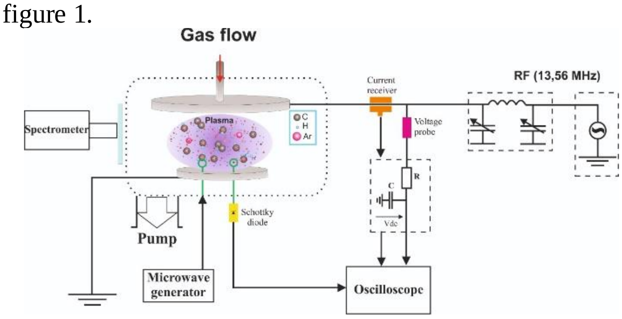


Fig. 1. Scheme of the experimental setup for generation of RF discharge plasma with nanoparticles

The experimental setup consists of a working chamber, a system for pumping and inlet of working gases, two horizontally located plane-parallel electrodes with diameters 8 and 12 cm. The top electrode is connected to a high-frequency voltage source (f = 13.56 MHz, Seren R301), the bottom is grounded. First, a high vacuum is released in the working chamber (up to 10–5 mbar), and then a mixture of argon and methane Ar/CH4 is introduced (percentage of methane 1.5%), due to which the pressure ranges in 0.1–0.8 mbar. At the following step, a high-frequency voltage (power 5–35 W) is supplied to the upper electrodes. Finally, plasma of high-frequency capacitive discharge is ignited between the two electrodes [5, 6]. The electron density of the plasma during the synthesis of nanoparticles was estimated by measuring plasma-induced shift of the microwave resonance mode [7]. As shown in figure 1, the two antennas, transmitter, which was connected to the microwave generator (Rhode & Schwarz signal generator with a bandwidth of 100–4320 MHz) and receiver connected with oscilloscope via Schottky diode, were placed into the chamber. The electron density values were measured by comparing the resonant frequency (TM110 mode, 2723 MHz in methane) of without plasma and with plasma cases

3. Results and discussion

It has been experimentally shown that nanoparticles synthesized and located in plasma, depending on their size, contribute to a significant increase in luminescence intensity. As the experimental results show, the intensity is many times greater than argon gas plasma glow. Subsequently, the optimum particle size for producing high light intensity and increasing the light intensity of a fluorescent discharge lamp was investigated using this method. We therefore offer this effect as one method of altering the intensity of light. In connection with the above mentioned, this work is devoted to experimental investigations of the carbon nanoparticles growth process in RF discharge of argon-methane gas mixture and the effect of the nanoparticles on optical properties of plasmas. The dependence of nanoparticles nucleation time on gas discharge parameters was investigated by observing the self-bias voltage. Furthermore, a detailed analysis of the synthesized nanoparticles was carried out to determine the size by SEM for each time point from 0 to 35 s at different discharge parameters, i.e., power and pressure. The discharge was found to change the emission property depending on the size of the nanoparticles. In order to understand this phenomenon in more detail, experiments were carried out to study the dependence of plasma volume glow intensity on various gas discharge parameters and nanoparticles sizes (percentage of plasma-forming gas mixture, pressure in the working volume and discharge power). Furthermore, we consider the discharge lamp with nanoparticles. The dependence of the emission intensity on the diameter of nanoparticles in the plasma of the discharge lamp was obtained (see figure 2). As can be seen from the graph, the highest intensity of plasma glow is observed at particle sizes of 60–70 nm. This phenomenon can be visually observed in figure 3, which shows images of the emission intensity of a laboratory sample of a gas discharge lamp depending on the diameter of the nanoparticles. From the figure it can be clearly seen that when the diameter of nanoparticles is 60–70 nm, the intensity of glow increases up to a certain value, which is considered to be the optimal value for obtaining the maximum light intensity. The absorption of plasma particles on the surface of dust particles leads to the increase of the plasma bulk resistance and of the plasma sheath capacitance. Consequently, the increase of the electron temperature up to two times lead to increasing of the light emission [8].

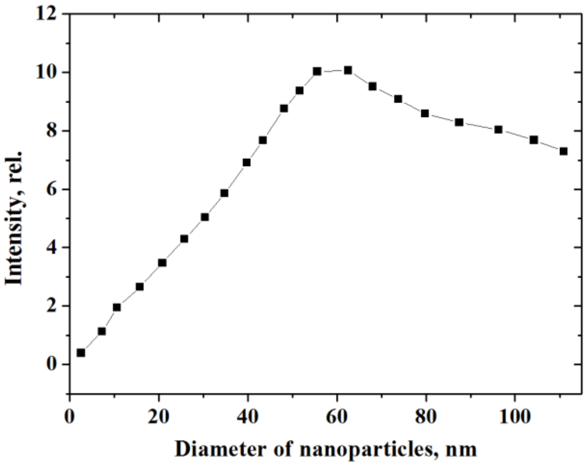
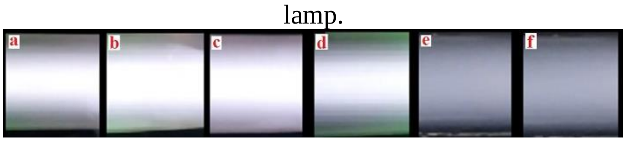


Fig. 2. The dependence of plasma emission intensity on diameter of nanoparticles in plasma of gas-discharge lamp.



(a) ~ 20 nm, (b) ~ 40 nm, (c) ~ 60 nm, (d) ~ 80 nm, (e) ~ 120 nm, (f) ~ 150 nm;

Fig. 3. Images of emission intensity from the diameter of nanoparticles in the plasma of a laboratory sample of gas discharge lamp.

Also, work was carried out on a complex study of superhydrophobic surfaces obtained by PECVD methods in RF-discharge plasma with gas mixtures (Ar/CH_4 and Ar/C_2H_2). The synthesized particles were deposited on the surface of silicon and glass substrates. The results of the experimental study showed that the contact angle varies in a range 140°-165° and highly depends on the plasma parameters. It was determined that with an increase in the number of cycles of particle deposition, the contact angle also increases. Moreover, it was observed that at 1-3% of methane or acetylene only nanoparticles are synthesized and hydrophobicity can be easily damaged by a water droplet. As the methane concentration increases up to 7%, nanoclusters with a diameter of 4-10 nm form a nanofilm. The SEM images and experiments with a water droplet also show that at 7% of methane content the interaction between nanoparticles produced on the surface becomes strong due to the 68 nm nanofilm formed on the surface. Finally, the changes in the contact angle on the obtained superhydrophobic surfaces as a function of the storage time under normal temperature and pressure conditions were studied. The experimental results showed that the films obtained in Ar/C_2H_2 plasma begin to lose their hydrophobic properties 2 months after deposition, and after 6 months the contact angle drops to 80°. The samples obtained in Ar/CH_4 plasma showed much higher resistance to change. The contact angle of these samples decreased from 160° to 135° after 14 months (Fig. 4).

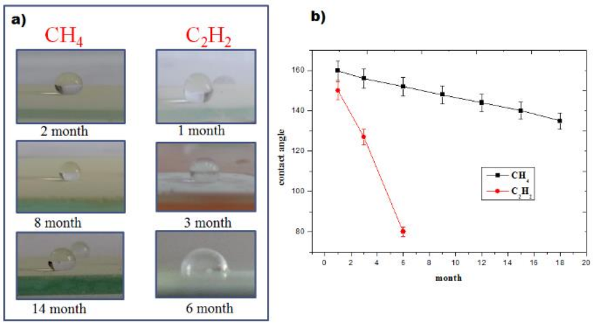


Fig. 4. Dependence of the contact angle on storage period of samples

4. Conclusion

We investigated the influence of the carbon nanoparticles synthesized in the RF discharge on the emission intensity of the discharge plasma. During the investigation of the plasma intensity, it was revealed that the nanoparticles with diameter of 60 nm led to the strongest glow intensity enhancement. It should be noted that up to this value of diameter the intensity increases steadily, and after that with further increase in the diameter of nanoparticles a decline in the glow intensity takes place. Eventually, taking into account this fact, we developed an experimental illumination lamp with nanoparticles of diameter 60–70 nm inside. The presence of nanoparticles results in twice as much light emission as conventional fluorescent lamps.

Also, a complex study of superhydrophobic surfaces obtained by PECVD methods in RF discharge plasma with gas mixtures (Ar/CH_4 and Ar/C_2H_2) was carried out. The results of the experimental study showed that the contact angle varies in a range 140°-165° and highly depends on the plasma parameters. The contact angles of coatings obtained by the PECVD method in Ar/CH_4 plasma change from 160° to 135° over 18 months storage, whereas for Ar/C_2H_2 plasma the contact angle decreases sharply, from 150° to 80° in over 6 months.

5. References

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