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Impulse Plasma Deposition of Carbon Nanoparticles

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In this paper the results of carbon nanoparticle deposition on metal surface by impulse plasma deposition method (IPD) are presented. Graphite plates were used as sources of dust particles and copper substrates for their deposition. During the experimental work spherical nanocarbon particles with dimensions of 20–180 nm were obtained on the copper substrate and copper particles forming dendritic nanostructures on the substrate surface where their average size was 400 nm.

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1. Introduction

Nanomaterials and nanoparticles are the subject of intensive research due to their unique physiochemical properties and applications in electronics, photonics, chemical catalysis, and biomedicine [1]. Therefore, methods for obtaining nanoparticles are actively developed. One of the promising methods is the nanoparticles synthesis in the pulsed plasma where particles are obtained by electric erosion of an electrode material or a substrate which are placed in the path of the plasma flow [2, 3]. The advantages of this method are small size of synthesized nanoparticles, less than 10 nm, high chemical purity, versatility, and a wide choice of materials for synthesis.

2. Experimental

The experiments were conducted on a pulsed plasma accelerator IPU-30 [4]. The principle scheme of the experimental setup is shown in Fig. 1 (top view). The arc discharge plasma is ignited in the inter-electrode space after discharging the previously charged capacitor banks and accelerated along the cylindrical chamber due to the Ampere force of its own magnetic field.

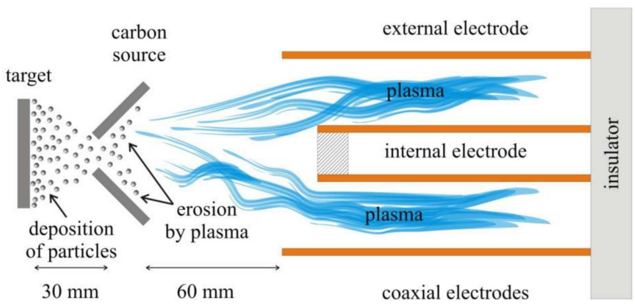

Fig. 1. Principle scheme (top view) of experimental setup and plasma processes.

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Two identical, mirror graphite plates are placed in the path of the plasma flow at a distance of 60 mm from the electrode system, at an angle of 45 degrees to the axis of the chamber (as shown in Fig. 1). The length of the two plates covers the diameter of the outer electrode, so the plasma flow igniting and accelerating from any sector of the inter electrode space passes through the graphite plates fully. These plates are the sources of carbon dust particles. The emission of dust particles occurs on the surface of the plates as a result of the plasma flow interactions with graphite plates, and these particles are also attracted to the plasma flow in the direction of its motion.

The copper substrates are placed at a distance of 30 mm from the graphite plates perpendicular to the chamber axis. These substrates are used for the dust particles that appear to settle on them.

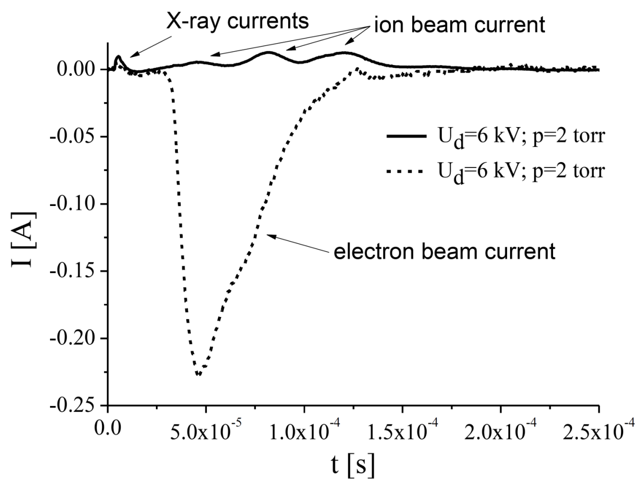

Fig. 2. Time distribution of currents of plasma particles.

In Fig. 2 the graphs of time distribution of currents of plasma particles obtained using a Faraday cup are shown. The first peak, which appears at the initial moment of time, corresponds to the current of the X-ray radiation. This is caused by a sharp braking of the plasma flow on the electrodes during a discharge in the inter-electrode space. The moment of time corresponding to the appearance of current of the X-ray radiation is used as the zero-time reference. Thus, this time corresponds to the discharge time.

As can be seen in Fig. 2 the ion current consists of several peaks (linear plot). Consequently, the plasma is interrupted several times during combustion. The distribution of the electron current corresponds to an intermittent linear plot. The rapidly moving electrons propagate continuously during the plasma combustion and several times exceed the ion current.

The distribution of the discharge current obtained by the Rogowski Belt is shown in Fig. 3. The value of the current amplitude is ~ 5 kA and varies in direct proportion to the discharge voltage. The graph of discharge current shown in Fig. 3 corresponds to a voltage of 10 kV. The pressure of the residual gas (air) in the chamber is 2×10^{-2} torr. Experiments on obtaining nanoparticles were conducted in the residual gas at the same pressure.

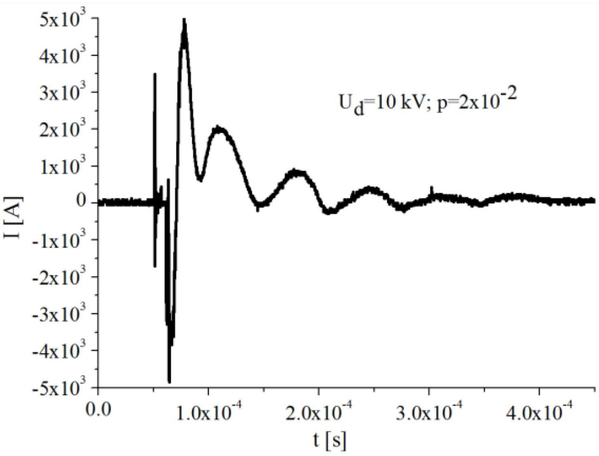

Fig. 3. Oscillogram of discharge current.

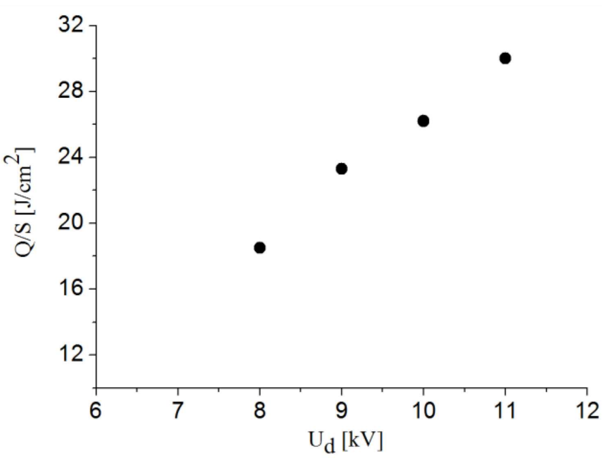

Fig. 4. Dependence of energy density of pulsed plasma on voltage value at electrodes.

Figure 4 shows the dependence of the energy density of pulsed plasma obtained with a wire calorimeter on the discharge voltage. In this experiment the maximum value of the energy density of the pulsed plasma was determined and it was 30 J/cm^2. The main part of this energy are ion fluxes.

3. Results

The interaction of the pulsed plasma with the surface and the evolution of the appearance of particles at this moment are shown in Fig. 5. The video frames of this process were captured by the high-speed camera "Phantom VEO710S". The capture speed was 78000 frames per second. Thus the distance between the adjacent frames is 12.82 μs. Nanocarbon particles are the products of erosion that appear when plasma flow moves through the graphite plates. The interactions of the pulsed plasma with the surface of the carbon plates are accompanied by instantaneous heating (Fig. 5a and b, the time range 0–51.2 μs) and ejection (Fig. 5c and d, 89.6–128 μs) with subsequent scattering of particles from the surface of the plates (Fig. 5e and f, 192–268.8 μs).

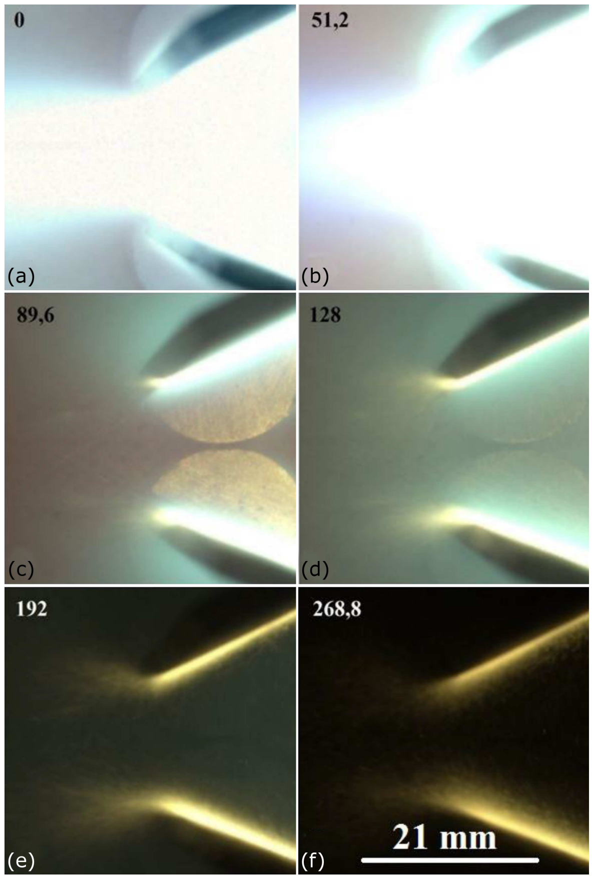

Fig. 5. Time evolution of erosion of surfaces of graphite plates after interacting with pulsed plasma (the numbers on figures a-f indicate moment of time in μs).

Fig.5a and b (in the alphabetical order) show the moments of time when the plasma interacts with the surface, and the interaction duration is up to 100 μs. When plasma interacts with the surfaces of the graphite plates, it destroys them and focuses itself (Fig. 5b). The dust particles that appear as a result of erosion by the plasma flow follow the trajectory of the plasma (Fig. 5c and f). Thus, the plasma flux, focused by the graphite plates, acts and heats the surface of the copper substrates dispersed at 30 mm from the graphite plates and arranged coaxially to the plasma flow. The velocity of the plasma flow is relatively high (usually 25–30 km/s) so that the plasma stream will be the first to influence the copper plate. Thus first, a jet of plasma dust (Fig. 5c and d) comes at a preheated surface, and then a stream of exclusively dust particles (Fig. 5e and f) comes to the surface.

As a result of the experiments aimed at this process, the nanoparticles shown in Figs. 6 and 7 were obtained on the surface of copper plates. Figure 6 shows the electron microscope image of copper nanoparticles that form dendritic structures. Copper particles are fabricated during the erosion of electrodes. The dendritic structure does not exceed 15 μm. The average particle size in the structure is $\sim$ 400 nm.

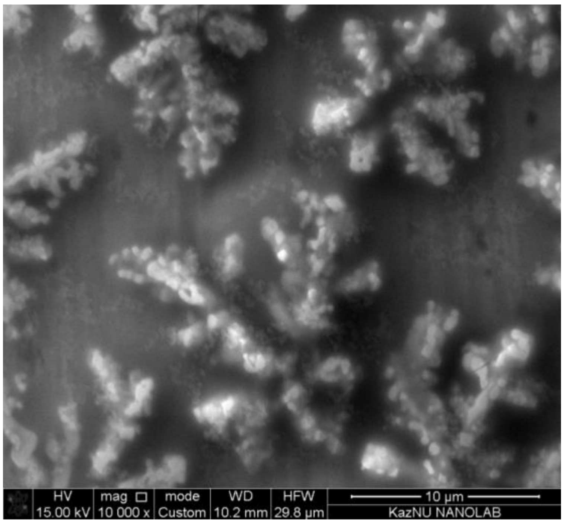

Fig. 6. Dendritic structured copper particles on substrate surface.

Images of nanoparticles, which appeared during the erosion of graphite plates obtained by the electron microscope are shown in Fig. 7. As can be seen from this figure, the shape of the particles is not spherical which is characteristic of carbon particles. The dimensions vary from 20 to 180 nm. Trajectories, flight directions, and concentrations of nanoparticles formed during their emission depend on the magnitude of the voltage applied to the electrodes and the angular position of the plates. When the voltage was 6–7 kV, the motion of the nanoparticle was turned against the plasma flow.

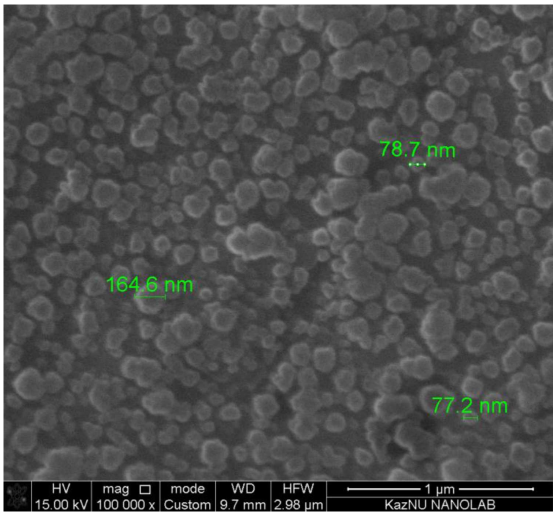

Fig. 7. Carbon nanoparticles on substrate surface.

At high (10–12 kV) voltages, the trajectory of the motion of nanoparticles coincides with the direction of motion of the plasma stream. By adjusting the angle of the arrangement of the graphite plates relative to the axis of movement of the plasma flow, it is possible to control the direction of the flow of the formed nanoparticles to focus and change the emission intensity of the nanoparticles.

4. Conclusion

The process of interaction of pulsed plasma with the surface of graphite plates was studied. Trajectories of the scattered dust particles at the plasma erosion of plate surface were obtained. The dependence of the concentration, velocity, and trajectory of motion of dust particles on the geometric parameters of the plates (the source of carbon particles) and on the discharge voltage was obtained. The size of deposited carbon nanoparticles varies within the range of 20–180 nm. In addition, nanoparticles of the electrode material were obtained.

Acknowledgments

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