Synthesis of nanodiamonds and carbon nanotubes in silicon-argon arc

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Abstract. This paper presents the results of the synthesis of nanodiamonds and carbon nanotubes in silicon-argon plasma. At a pressure of 500 Torr in the plasma reactor, carbon atoms evaporated from the surface of the graphite anode of the electric arc. The peculiarity of the graphite anode was that small pieces of silicon were embedded on the surface of the anode. As a result of the experiment, nanodiamonds and carbon nanotubes were formed on the surface of the graphite cathode. The linear dimensions of nanodiamonds range from 10 to 50 nm. The diameters of carbon nanotubes range from 4 nm to 20 nm, and their length is from 100 to 2 microns.

1. It is known that germanium is a catalyst for accelerating the reactions of diamond formation from graphite [1,2]. In [1], microdiamonds were synthesized with the catalytic participation of germanium by the CVD method. The experiment lasted more than 60 hours. In work [2] the synthesis of such diamonds with the catalytic participation of germanium was carried out in an argon arc. The experiment lasted several tens of seconds. The efficiency of plasma methods in the synthesis of carbon and semiconductor nanostructures was shown. In the presence of a powerful plasma jet, independent nanostructures made of germanium and silicon can also be synthesized.

2. This paper presents the results of the synthesis of carbon nanostructures with the catalytic participation of silicon in the argon arc.

The anode of the electric arc installation was a graphite rod with a diameter of 14 mm and a height of 30 mm. A hole with a diameter of 3 mm and a depth of 10 mm was drilled on the surface of the anode. Before the experiment, this hole was filled with silicon powder. The cathode of the electric arc was a graphite rod with a diameter of 6 mm and a height of 40 mm. The experiment was conducted in an argon medium with a pressure of 500 Torr. To implement the arc, the upper electrode was lowered to create contact with the lower electrode-anode and the contact was broken. At the same time, the arc was lit. The distance between the electrodes was maintained at 2 mm. The voltage between the electrodes was 22 V at a current of 60 A. In the experiment, the evaporation of atoms of carbon and silicon. Pairs of carbon and silicon atoms were raised by the Archimedean force and deposited on the cathode surface, mainly on the side surface. Here the growths were formed, which were analyzed on optical and electron microscopes. The hardness of nanostructures was determined by grinding between two glasses. The powder placed between two glasses after grinding left traces on the surface of the glasses.

3. Figure 1-6 shows images of experimental samples obtained with the Carl zeiss Auriga Crossbeam electron microscope.
Figure 1. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A. The magnification of 15000 times.

Figure 2. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A. Magnification 50000 times.

Figure 3. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A. An increase of 100 000 times.

Figure 4. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A. Magnification 500,000 times.

Figure 5. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A.

Figure 6. Images of samples obtained in an argon atmosphere at a pressure of 500 Torus, a voltage of 22 V and a current of 60 A. Magnification 150,000 times.
There are two types of nanostructures in the field of view: nanotubes and nanodiamonds. Moreover, nanodiamonds have a greater degree of location closer to the end of the cylindrical anode, nanotubes are more localized away from the end of the anode. The images show samples that contain both nanotubes and nanodiamonds. The linear dimensions of nanodiamonds range from 10 nm to 50 nm. Figure 6 shows nanodiamonds of a pyramidal structure with dimensions of about 50 nm. All diamonds have complete surfaces, although the external structure is not always similar to natural diamonds. This is most likely due to either the completion of the process (the arc was turned off), or the temperature regime (the temperature increased). And in both cases, the synthesis is terminated. The diameters of carbon nanotubes range from 4 nm to 20 nm, and their length is from 100 to 2 microns.

4. Very interesting results were obtained by elemental analysis of the obtained samples. Despite the fact that silicon vapor, carbon vapor, and iron vapor were involved in the synthesis process, the final product turned out to be only 100% pure carbon. They lack both silicon and iron. This phenomenon can be explained as follows. As shown by theoretical calculations of the temperature distribution in the interelectrode gap, on the surfaces of the electrodes (cathode and anode), performed in [3], the arc discharge electrodes can be in a state of surface boiling. At the same time, the electrodes themselves retain a solid state. Since in our case graphite rods served as electrodes, carbon and boiling silicon atoms simply evaporated from the surface of the anode and then deposited on the surface of the cathode.

For each electrode material, the current value should be selected according to its physical characteristics, such as electrical conductivity, thermal conductivity, melting point and boiling point. It is by manipulating the magnitude of the electric current that the desired synthesis of a particular nanostructure can be achieved.

The role of silicon in the formation of carbon nanostructures is that silicon acts as a catalyst for the synthesis of carbon nanostructures. It is in the region of the cathode where the synthesis of the obtained samples takes place, most likely, such a temperature that neither silicon nanotubes nor silicon carbide are formed. Due to high temperature, they fly higher, taking away the energy that is released during the synthesis of carbon nanostructures.

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References

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