Technology of growing silicon nanotubes

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Abstract. The paper presents the results of studies on silicon nanotubes production in an arc discharge. The features of the experiments, the description of the experimental setup are given. A description of the obtained nanostructures studied on an electron microscope is presented. It is unequivocal to assert that the obtained silicon nanotubes are single-walled, it is not yet possible. But the fact of obtaining silicon nanotubes is indisputable.

Keywords: vacuum, silicon, nanotubes, arc discharge

1. Introduction
Nanostructured semiconductors are key materials of modern electronics. Silicon nanostructures are considered promising candidates in nanoelectronics, optoelectronics, sensors, biology, medicine and other fields of science and technology in connection with their unique physical properties, simple and economical methods of their obtaining [1-4].

The available technological methods for depositing silicon-based coatings are subdivided into chemical and physical methods [5-6]. In the described work, a physical method of coating deposition was used, namely, the growth of silicon nanostructures in an electric arc discharge. Vacuum arc evaporation of silicon is considered to be one of the promising methods of deposition of coatings due to low energy capacities of processes (50 eV / atom), high coating characteristics and the ability to flexibly manipulate coating parameters [7]. High adhesion (up to 250 MPa), high film growth rate (up to 1.5 μm / min) and high productivity are also provided.

During the recent years, reports where an arc is described on polycrystalline silicon were published [8]. However, a large concentration of power at cathode leads to its cracking and destruction. In the research paper [9], the arc burned on a polycrystalline cathode no more than 30 s. In Ref. [10] after work more than 2 minutes, melting of the working surface and destruction of a part of the cathode were observed.

2. Experiment
In this paper, an attempt is made to create silicon nanomaterials in a low-current argon arc. To obtain silicon nanostructures in an arc discharge, an experimental setup was assembled. Silicon and tungsten were used as electrodes. The arc discharge between the electrodes was ignited in argon at a pressure of 500 Torr. The experimental setup consists of a water-cooled vacuum chamber of a cylindrical shape...
(figure 1), a vacuum and gas supply system, a source of electrical power, and also measuring instruments.

During the preparation of the experiment, air is evacuated from the vacuum chamber and then the chamber is filled with argon up to 500 Torr.

![Vacuum chamber diagram](image)

**Figure 1.** Vacuum chamber. 1 - cylindrical chamber; 2, 3 - the door; 4, 5, 6 - pipes for supplying the cooled liquid; 7 - a branch pipe for drainage of a liquid; 8, 9 - regulators of the distance between the electrodes; 10 - electrode retainer; 11 - stand for the substrate; 12 - current leads; 13, 14 - inspection windows; 15 - a branch pipe for gas supply; 16 - a branch pipe for gas extraction; 17 - support for the camera.

The pressure in the vacuum chamber was measured with a U-shaped manometer, the current was fixed with an ammeter. In order to ignite the arc discharge into the chamber between the electrodes, the RNO-250-5 transformer used for smooth regulation of the AC voltage with a frequency of 50 Hz was used, the maximum current of the regulator at the output was 12 A / 20 A; power - up to 5 kW. The ballast was connected in series to the transformer to ensure a stable discharge. The surface of the electrodes before the experiment is thoroughly polished to a mirror finish, in order to reduce the amount of oxides. The materials of the electrodes were tungsten and silicon, the interelectrode distance was 1 cm (figure 2), the voltage is applied to the electrodes on the order of 80 V. Since the resistance of silicon at room temperatures is large enough, preheating of silicon is required to ignite the microarc. For this purpose, the electrodes are closed for a short time. When the current flows, silicon is heated, its conductivity increases, and when the contacts are opened, a micro-arc with a current of the order of 8 A is formed. In the process of burning the arc, a built-up edge is formed on the surface of the tungsten. This build-up was examined using a scanning electron microscope AURIGA CARL ZEISS with an allowable magnification of 300 to 500 000 times and a resolution of about 2.5 nm.
Figure 2. Fixation of the silicon anode (from above) and tungsten cathode in the working unit (bottom).

Figure 3 shows photographs of the build-up from the cathode, obtained with an electron microscope. A large number of formless tubular formations of various sizes, intertwining with each other and curling along the entire length.

3. Results
Figure 3a shows that the winding tubes have approximately the same diameters, of the order of 30-37 nm. In addition to these tubes of other, clearly distinguishable formations, this increase is not observed. In the photographs, 3 b, we can see the same structures of climbing tubes, intertwined with each other, but already having the form of cylinders, with a diameter of 15-19 nm. It is unequivocal to assert that the obtained silicon nanotubes are single-walled, it is not yet possible. But the fact of obtaining silicon nanotubes is indisputable.
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