Production of silicon coatings by plasma-arc method

Kaleeva A.A., Timerkaev B.A., Petrova O.A., Shamsutdinov R.S., Dautov I.G, Mastygin A.V.

1 KNRTU–KAI, Kazan, Russia
andreeva.anzhelika.a@yandex.ru

Abstract. Silicon coatings consisting of micro and nanopores were obtained by plasma-arc method. An experimental setup was assembled for the synthesis of nanostructures. A number of experiments on the synthesis of silicon nanostructures with changes in parameters such as current, voltage, and pressure in a vacuum chamber were carried out. In the experiments, a molybdenum cathode was used as a substrate for the deposition of silicon nanostructures. Atomic silicon evaporated from the anode. The experiments were carried out in an argon medium at a pressure of about 500 Torus. The current in the experiments is about 8 A, and the voltage is within 80 V. The resulting coatings with silicon nanostructures will increase the active surface area by several tens of times.

1. Introduction
Silicon and its derivatives are important materials for industrial applications, such as in semiconductors, optoelectronics, and telecommunications. Despite the fact that there are many methods for obtaining silicon coatings of various forms, the field of research remains relevant for the search for more efficient methods of synthesis and new applications of nanostructured coatings [1]. Nanostructured silicon coatings allow for a surprisingly large contact surface area, which is porous and useful, for example, for sensing technology. The studies show that the physicochemical properties, namely, porosity, nanofiber morphology, and oxidation level, play an important role in the optical properties of the resulting coatings. There are studies that report the production of silicon or silicon oxide nanostructures by various methods: electron-beam evaporation [2], radio-frequency sputtering [3], molecular-beam deposition [4], chemical vapor deposition [5]. For example, in a study by Canadian scientists Abeda M. M. et al. To obtain Si/SiO2 thin films, the plasma laser deposition method is used [6]. The paper [6] deals with the direct influence of the arc discharge plasma parameters, such as plasma density, pressure and temperature, as well as the complete interaction of particles during the cavitation phenomena, mainly on the size of the formed particles, from a few nm to microns, and on the rate of their formation [6].

The paper describes a method of arc evaporation of a material for the production of silicon coatings, where it is also possible to predict the relationship of pressure and temperature with the size of the formed micro and nanopores.

2. Experimental Setup
The experimental setup for producing nanostructured coatings includes a sealed chamber, a vacuum system, an inert gas supply system, measuring instruments, and a system of electrodes fixed in the
The positive electrode is silicon, and the negative one is a molybdenum rod. After the air is pumped out of the vacuum chamber and then filled with an inert gas to a pressure of about 500 Tor, a voltage of 80 V is applied to the electrodes. At the same time, the ballast resistance was connected to the arc discharge circuit. In order to ignite an electric arc, the electrodes should be closed and opened for a short time. In this case, a discharge with a current of about 8 A lights up. In the interelectrode space, an arc discharge burns in a mixture of inert gas and vapors released from the silicon surface.

The rate of evaporation of silicon atoms from the anode surface depends on the current I, voltage U, gas pressure p, and the interelectrode distance d. In different experiments, the above-mentioned parameters varied quite widely. The most satisfactory results were obtained for the values p = 500 Tor, I = 8 A, U = 50 V, d = 3 mm. The duration of the experiment varied from 10 to 30 seconds.

During the experiments, the growth of deposits was observed on the surface of the cathode. These deposits were examined with a scanning electron microscope. Figures 1-4 show photographs of these studies.

![Figure 1](image.png)

**Figure 1.** The surface of the sample after the experiment. Magnification of 5,000 times. (p = 500 Tor, I = 8 A, U = 50 V, d = 3 mm.)
Figure 2. An increase of 15,000 times. As can be seen from the figure, the pore diameter is about 1 micron. (p = 500 Tor, I = 8 A, U = 50 V, d = 3 mm).

In the above images, the surface of the sample is porous and heterogeneous, we can say that it is multi-layered, since in some micropores you can see another porous surface. The shape of micropores and nanopores is different and they are formed in a chaotic order. One square meter can contain hundreds of nanopores. The surface of the obtained samples is subject to oxidation, with the formation of silicon dioxide bonds.

The same microscope was used for elemental analysis of the obtained nanostructures (Table 1).

| Element | Weight. % | At.% |
|---------|-----------|------|
| C K     | 1.61      | 2.76 |
| O K     | 47.98     | 61.60|
| Si K    | 47.68     | 34.87|
| Ge L    | 2.73      | 0.77 |

The elemental analysis of the sample presented in Table 1 indicates the presence of silicon and oxygen on the sample surface. Carbon and germanium elements were also found on the surface, which is explained by the presence of these elements in the experimental chamber.

The images of the electron microscope with a magnification of 30,000 times show a lot of nanopores, which in the photo we can see as a kind of white coating.
Figure 3. Silicon coating with a 15 000-fold magnification of the image.

Figure 4. The increase of the sample surface 30 000 times

The application of the obtained silicon nanostructures can be different, for example, this coating can be used in the anode elements of lithium-ion batteries. Due to its porous structure, the silicon coating can store tens of times more lithium ions than a graphite anode element.
3. Conclusions
Thus, the plasma-arc method for the synthesis of nanostructures allows us to obtain a developed silicon surface of various morphologies. Such structures can be useful in the creation of anode cells of lithium-ion batteries, as they allow you to increase the active surface area of the material due to porosity.

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