Synthesis of silicon nanowires in electric arc argon plasma

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Abstract. This paper presents a method of synthesis of silicon nanowires in microarc argon plasma. During the experiment, an adjustable direct current source with a ballast resistor was used. The cathode was a molybdenum rod, and the anode was silicon. The silicon was located in a small deepening in a graphite rod. During the experiment, synthesis of silicon nanowires was observed on the surface of molybdenum rod. The obtained silicon nanowires are straight and non-hollow inside, nanowires have a smooth surface and have a hexagonal cross-section. The resulting nanowires will be able to find further application in light emitting diodes, lithium-ion batteries, supercapacitors, photovoltaics.

1. Introduction

In modern world, nanostructures with certain unique properties are of great interest. In some cases, their dimensions are fundamental, in other cases, electrical, thermal and magnetic properties are measurable. Sometimes strength and structural properties are important. The materials of nanoformations and their structure are also important. Most chemical elements can combine into various nanostructures under specific conditions. Nowadays, no one is surprised by such phrases as germanium nanostructures, silicon nanostructures [1-5] and carbon nanostructures or nanodiamonds and nanowires [6]. Carbon nanostructures can be created by evaporation of graphite rods in the arc discharge, during decomposition of hydrocarbon raw materials in the sliding glow discharge [7], during hydrocarbon combustion with the imposition of external electric field [8] and etc. Various methods can be used to maintain the discharge stability for these, for example [9-11].

Silicon nanowires are intensive explored and used in various fields of science and technology, for example, in photonics, photovoltaics and biomedicine. Nanowires are nanostructures that are stretched along one direction and have a cross-section from one to tens and hundreds of nanometers, depending on the synthesis conditions. Unlike nanotubes, nanowires are not hollow inside, they are completely filled. Silicon nanowires in crystalline form have the features of semiconductor materials, due to this nanowires can be widely used in electronics, light-emitting diodes, lithium-ion batteries.

Today, the synthesis of silicon nanostructures is carried out in several ways: the chemical vapor deposition method, thermal evaporation method, reactive ion etching method and etc [4]. Each of these methods has certain advantages over others, but at the same time, they also have disadvantages. Silicon nanostructure consumers are interested in their most diverse properties. Some consumers are interested in electrical characteristics, others consumers are invested in thermal and strength properties, for another consumers dimensions are important. Now scientists are interested in obtaining samples that meet the requirements for practical use in a variety of fields. Recently, methods have
began to appear in which the synthesis of silicon nanostructures is carried out in an electric arc discharge. Scientists share the results of research on the synthesis of silicon nanotubes in argon plasma [1–3, 5]. The resulting nanotubes were obtained in the form of complex and regular structures with an average diameter of about 50 nm. It is reported in publications that the structure of silicon nanotubes is determined by the gas medium, current and discharge voltage, as well as the temperature field in the region of synthesis of nanostructures.

2. Synthesis of silicon nanowires

In this paper propose a method for synthesis silicon nanowires in microarc argon plasma. The experimental setup consisted of a vacuum chamber, a gas-supply system, electric power sources, water supply and measuring instruments. Silicon, which was located in a small deepening in graphite rod, and molybdenum rod with a ground smooth flat end were used as electrodes.

As is well known, at room temperatures silicon has a very large electrical resistance, and sudden heating leads to cracking of silicon and structural destruction. Thanks to the results achieved in previous research [1-3, 5], it was found that if silicon is preheated to high temperatures (using low current and high voltage), then silicon can be the anode of an electric arc discharge. If use only one power source, it should provide a voltage in the range from 20 to 150 V. For this experiment a special power source that meets these requirements was created, which consisted of a transformer, a ballast resistance and a rectifier unit.

The discharge device was placed in a vacuum chamber. The distance between the electrodes could be controlled using the adjustment screws of the vacuum chamber. Figure 1 shows the schematic representation of a vacuum chamber.

![Figure 1. The schematic representation of a vacuum chamber: 1 – adjustment screw for anode; 2 – anode; 3 – graphite rod; 4 – silicon rod; 5 – molybdenum rod; 6 – cathode; 7 – adjustment screw for cathode; 8 – fixation electrodes; 9 – gas supply tube; 10 – tube of gas out; 11 – water supply tube; 12 – tube of water out; 13 – stand of vacuum chamber.](image-url)
During the experiment, the vacuum chamber was filled with argon to a pressure of 500 Torr. A voltage of about 80 V was applied to the electrodes. Using the adjustment screws of the vacuum chamber, the position of the electrodes was changed: for a short time electrodes were brought closer for contact, and then they were disconnected. This was necessary to initiation of an electric arc. In the course of the experiments, growths on graphite and deposition on molybdenum were formed.

3. Analysis results
These resulting growths were studied on a scanning electron microscope. The results are presented in figure 2 and figure 3.

![Figure 2](image)

**Figure 2.** The result obtained in the process of growing silicone nanowires.

The figure 2 and figure 3 shows a large number of formations. They do not have a specific character of location. The resulting nanowires are straight and non-hollow inside. Their length reaches about 1400 nm and a diameter of more than 100 nm.

These structures are thicker in diameter and have a strict hexagonal cross-section, unlike silicon nanowires grown by other methods. But we cannot draw an analogy with carbon nanotubes or with germanium nanotubes obtained under similar conditions. As is known, carbon nanotubes always end with a dome, which representing half of the fullerene sphere, and germanium nanotubes are closed with a knob [12]. Regarding the formation of carbon nanotubes, there are also two views. Either they grow from any base or are formed as a result of wrapping graphene sheets. Silicon nanowires have an even end, as if they were chopped off. They can not be represented as a wrapper of silicene. Apparently, they grew from a certain base and on the surface all chemical bonds of silicon atoms were involved. This is also indicated by the smooth surface of the grown nanowires; threadlike structures do not have pores and branches on the walls.
Figure 3. The nanowires are straight and non-hollow inside. Diameter of nanowires over 100 nm.

As a result, due to the optimal selection of the discharge voltage and current, the distance between the electrodes, the type and pressure of the buffer gas, it was possible to synthesize silicon nanowires, which differ from previously synthesized both in size and structure.

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