Plasma-chemical synthesis of zinc oxide nanotubes

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Abstract. This research presents the results of the synthesis of zinc oxide nanotubes in electric arc plasma. The diameters of these nanotubes are about 120-150 nm, and the length is about several micrometers. Individual nanotubes can reach up to 1 mm. As electron microscopic studies have shown, zinc oxide nanotubes are a “matryoshka”: they are strung on a carbon nanotube. Firstly, a broken carbon nanotube with a diameter of about 30 nm is formed, and then a zinc oxide nanotube grows on it. Moreover, there is no contact between these nanotubes.

1. The structural features and unique properties of zinc oxide nanostructured elements are of great interest to both scientists and manufacturers. Some are interested in the efficiency of zinc-oxide light-emitting diodes, while others are interested in creating transistors based on p- and n-type zinc-oxide semiconductor nanotubes [1]. Laser ultraviolet generation in zinc oxide nanorods under optical excitation is no less interesting, since recombination of interacting free excitons prevails in them at high pump energy [2]. Filamentous ZnO nanocrystals also have piezoelectric properties [3]. This list could be continued.

At present, this interest is not only not subsiding, but is even more increasing. In last years, there have been works on hybrid nanotubes. In this regard, the greatest resonance was caused by the work of Albert Nasibullin with co-authors from different countries on the creation of single-layer carbon nanotubes coated with zinc oxide [1]. This team, by treating the surface of single-layer carbon nanotubes (SLCNT) with ozone and using atomic layer deposition technology, managed to achieve uniform deposition of ZnO on the surface of SLCNT.

In this research, we were able to combine these two operations into one and obtain carbon nanotubes coated with zinc oxide.

2. The experimental setup for the synthesis of carbon nanotubes coated with zinc oxide consisted of a vacuum chamber with water-cooled walls, an electric power source, a vacuum and gas supply system, and measuring instruments. The vacuum chamber had an observation window for observing the course of the experiment, and a special device made it possible to change the distance between the electrodes.

We used graphite rods as electrodes. A small depression with a diameter of 3 mm and a depth of 10 mm was made in the anode rod, which was filled with graphite dust mixed with iron filings. As a source of zinc, we used a tube of galvanized iron with a diameter of 25.2 mm, inside which, in the future, we organized an arc discharge.
Before the experiment, the vacuum chamber was pumped to a pressure of 10 Torr and filled with argon to a pressure of 500 Torr. During arc discharge evaporation of carbon atoms as graphite dust from the iron and from the surface of the anode. Evaporation of zinc atoms due to washing the inner walls of the galvanized pipe with a plasma stream began approximately 4-6 seconds after the arc was ignited. Zinc oxide nanotubes were deposited on the surface of the copper substrate, on the end surface of the galvanized pipe, and on the side surface of the cathode. Also, in the form of a veil, they stretched to the surface of the negative electrode at a distance of about 2-3 cm (Fig. 1, Fig. 2).

3. Figures 1 and 2 show in which areas of the interelectrode space and substrates the synthesis of new nanostructures is recorded. No formation of zinc oxide on the cathode surface closer to the discharge end is observed. From figure 1, you can determine the approximate temperature of the cathode surface and the inner surface of the galvanized pipe. These temperatures are clearly higher than the synthesis temperature of zinc oxide nanostructures. But there the synthesis of carbon nanostructures is possible. The synthesis of carbon nanostructures is also possible above the side surface of the cathode, as well as on substrates. In the first seconds after the discharge is ignited, while all surfaces are still relatively cold, there is no zinc in the plasma flow. Therefore, carbon nanostructures are synthesized on the cathode surface and on the substrates. As the inner surfaces of the galvanized pipe heat up, along with carbon atoms, zinc atoms begin to evaporate, which combine with oxygen atoms and are deposited on various surfaces, forming nanostructures.

The obtained samples were studied using an electron microscope.

Figure 3-4 shows zinc oxide nanotubes synthesized on a substrate. As you can see from the above figures, the diameters of these nanotubes are about 120-150 nm, and the length is about several micrometers. Individual nanotubes can reach up to 1 mm. The most interesting result of the work was the fact that zinc oxide nanotubes are "matryoshka", they are strung on a carbon nanotube. Figure 2 clearly shows the formation of zinc oxide nanotubes. From the figure, we can see that initially a
broken carbon nanotube with a diameter of about 30 nm was formed, and then a zinc oxide nanotube grew on it. Moreover, there is no contact between these nanotubes.

4. As shown by elemental analysis, the composition of these nanotubes is 70% Zn, 23% O and 5.6% C in weight percentages.

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