Adhesive coatings based on aligned arrays of carbon nanostructures

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The development of nanotechnologies and the possibility of creating spatially oriented nanoscale structures have generated a wide interest in research in the field of creating artificial bio-like structures [1] in which the reproduction of parameters of biological objects allows solving a number of problems in the field of mechanical contacts of high strength and repair materials with "dry" adhesion working in a vacuum. Among the artificial biomimetic nanostructures, carbon nanostructures based on arrays of vertically aligned carbon nanotubes (VA CNT) possess the best adhesion characteristics, which is associated with an increase in the adhesion force due to an increase in the number of nanostructures contacting the surface [2]. For controlled growth of CNTs with specified characteristics, the most promising method is plasma enhanced chemical vapor deposition (PECVD). However, a large number of parameters of the PECVD method require establishing the relationship between their influence on the growth of carbon nanotubes with controlled parameters.

The purpose of this study is to investigate the influence of patterns of carbon nanotubes growing modes by PECVD on their geometrical dimensions and adhesion properties.

Si/TiN/Ni structure was used for creating experimental samples. Growing VA CNT was performed by PECVD using specialized module cluster complex nanotechnological NANOFAB NTC-9 (NT-MDT, Russia). To provide different CNT parameters during PECVD changed values of the activation time, plasma power, temperature, and growth time. Depending on the type of grown samples, plasma could also be initiated. The initiation of the plasma was carried out using a high-voltage DC source. The samples with 4 types of VA CNT were grown: bundles (Fig. 1a), individual (Fig. 1b), branched (Fig.1c) and disoriented (Fig. 1d).

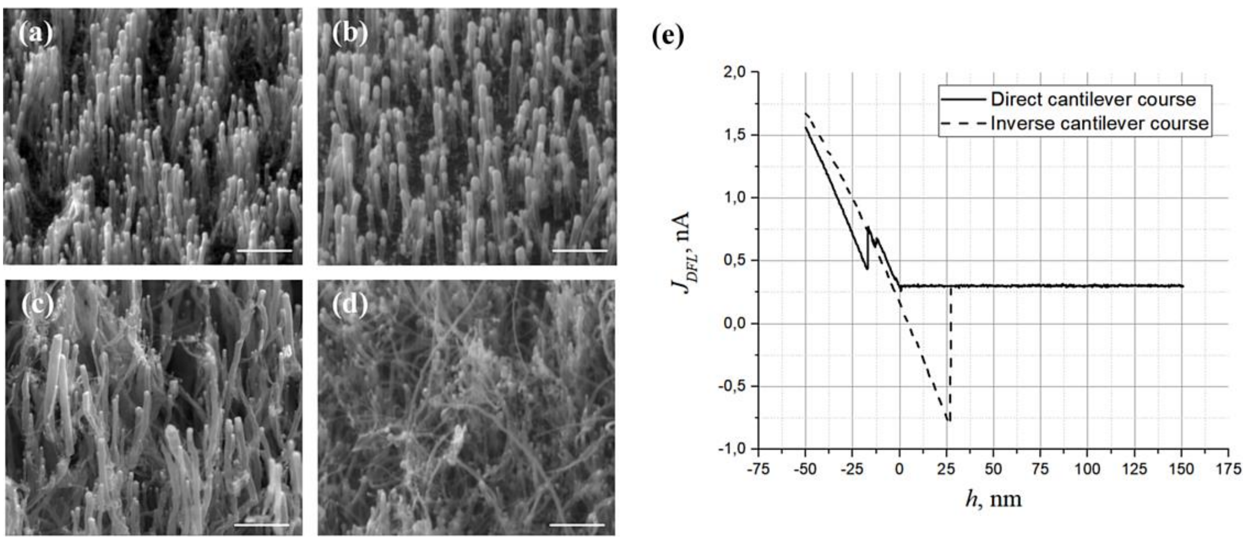

Figure 1. (a) CNTs bundles, (b) individual VA CNTs, (c) branched VA CNTs, (d) disoriented CNTs, (e) experimental dependence ΔJDFL for individual VA CNTs

The estimation of geometrical parameters of CNT arrays was carried out using a scanning electron microscope (SEM) Nova NanoLab 600 (FEI, Netherlands). Investigation of the adhesion strength of the experimental samples was carried out using a probe nanolaboratory Ntegra (NT-MDT, Russia). As a probe of an atomic force microscope (AFM), a colloid probe of the CPC_SiO_2-20/Au series was used with a radius of 20 μm and a stiffness coefficient k = 0,3 N/m. Measurements of the adhesion value were carried out at 10 points of the array of each experimental sample in the AFM force spectroscopy mode. In the process of force spectroscopy was measured the dependence of the cantilever bending value (J_{DFL} signal) on the degree of extension of the z-piezoelectric element of the scanner (signal *h*) in direct (solid line) and the inreverse (dashed line) cantilever cources. The experimental dependence $\Delta J_{DFL}(h)$ for samples with individual VA CNT is shown in Figure 1e. Using the resulting force spectroscopy AFM dependencies evaluated VA CNT array adhesion force F_a to the surface of AFM probe, by the method described in [1].

The analysis of SEM images of experimental samples with CNT bundles (series A) showed that exposure in an ammonia plasma leads to etching of catalytic centers (CC) Ni and a decrease in their diameter. In this case, the CNT growing regimes with the "activation" time of less than 1 min assist to the formation of CNT bundles. In this case, the measured adhesion strength was 5.03, 8.53 and 11.12 μN for samples A1-A3, respectively.

In the samples with individual VA CNTs (series B), the increase of "activation" time was also accompanied by the processes of combining small CC into larger ones with increasing diameter and decreasing density. At the same time, an increase in the plasma power up to 40 W contributed to the complete removal of small CC and a higher electric field strength, which made it possible to obtain arrays of individual VA CNTs. The measured adhesion strength for samples B1-B3 was 2.3, 0.67 and 1.56 μN, respectively. With a change in the growth temperature from 645 to 675°C on SEM images of samples of branched CNTs (C series), it can be seen that a short "activation" time promotes an increase in the adhesion of the CC to the substrate. As a result, growth occurs both along the "top" and "base" mechanisms with the formation of arrays of branched CNTs. The measured adhesion strength for C1-C3 samples was 3.21, 6.41 and 2.24 μN, respectively. To obtain experimental samples of disoriented CNTs (series D), plasma was not initiated during the growth process. The absence of a vector of electric field strength, which determines the direction of CNT growth, led to the formation of a disoriented array of CNTs. The increase in the growth time from 4 to 12 min allowed the production of CNT arrays with a height of 2.11 to 3.07 μm. The measured adhesion strength for samples D1-D3 was 1.09, 7.38 and 2.71 μN, respectively.

Analysis of the results of measurements showed that the largest average value of the adhesion strength (8.23 microns) had experimental samples of the series A. Individual VA CNTs of experimental samples B series showed the lowest adhesion value among all series of samples (1.51 μN), which may be due to the prevalence of transverse deformation of CNTs and their coalescence during measurement. Analysis of the results of measurements of adhesion in samples with branched (series C) and disoriented (series D) CNT showed that the average adhesion strength was 3.96 and 3.72 μN, respectively.

The results of the research can be used to create adhesive coatings and mechanical contacts of high strength for the space industry and robotics, as well as for the creation of elements of carbon nanoelectronics.

This work was financially supported by Russian Foundation for Basic Research (projects 16-29-14023 and 18-32-00652) and Internal grant of the Southern Federal University (project VnGr-07/2017-26).

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