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Short Communication

Influence of the Angle of Inclination of the Plasma Flow of Carbon to the Substrate on the Electrical Capacitance and Morphology of the Surface of Carbon Coatings

I.V. Sudzhanskaya[1], A.I. Poplavsky[1], I.Yu Goncharov[1], O.V. Glukhov[2]

[1] *Belgorod State University, 85, Pobedy Str., 308015 Belgorod, Russia*
[2] *National University of Radioelectronics, 14, Science Boulevard, 61166 Kharkov, Ukraine*

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Carbon film was obtained by pulsed vacuum-arc method on the silicon wafers. Method of impedance spectroscopy was obtained results change of electrical capacitance of parameters obtained carbon films. Morphology of surface produce by scanning probe microscopy methods was investigated. Determine correlation dependence between electrical capacity of carbon films and morphology surface against condition theirs obtainment. The explanation of the obtained results was proposed.

Ключевые слова: Carbon films, Electrical capacity, Conductivity, Morphology surface.

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1. INTRODUCTION

Diamond-like carbon coatings are used as superhard wear-resistant coatings in microelectronics and nanotechnology for the production of cantilevers, sensors, sensors [1-2].

The properties of coatings depend on the method and conditions for their production.

The pulsed vacuum-arc method has a number of advantages over the steady-state method of obtaining superhard carbon coatings, since it makes it possible to obtain plasma densities two orders of magnitude higher than stationary methods and to regulate the ion energy without applying an accelerating potential to the substrate [3].

Varying the parameters of the formation of the carbon coating allows changing the properties of the coatings obtained in a wide range, which is related to the percentage ratio of the phases with sp^3 and sp^2- hybridization of valence electrons in the coating.

Plasmon energy makes it possible to estimate the ratio of the phases in the coating. With an increase in the fraction of the phase with sp^3-hybridization of the valence electrons, the plasmon energy increases. An increase in the fraction of the phase with sp^2-hybridization of the valence electrons leads to the formation of coatings with a lower density, which may affect the electrical properties and changes in the morphology of the coating surface [4].

The purpose of this work was to determine the influence of the angle of inclination of the plasma flux of carbon on the substrate on the microstructure and the electrical capacitance of carbon coatings.

2. DESCRIPTION OF THE OBJECT AND METHODS OF THE STUDY

Carbon coatings, up to 100 nm thick, were obtained by a pulsed vacuum-arc method on a single-crystal silicon substrate with a (100) plane orientation [5]. The vacuum chamber was previously evacuated to a pressure of 10^{-3} Pa, and the silicon surface was cleaned before ion deposition by ion bombardment with argon ions. Three series of samples were obtained: 1 – in the direct stream; 2 – in the sliding stream; 3 – in a sliding flow with nitrogen in the vacuum chamber to a pressure of 0.01 Pa.

The electrical properties of the coatings were investigated using the Novocontrol concept 43 impedance, equipped with the WinFit software package, which allows for mathematical processing of the results. The change in surface morphology was monitored by the NTEGRA AURA scanning probe microscope NT-MDT Company in atomic force microscopy.

Using the Tecnai G2 F20 S-TWIN transmission electron microscope equipped with a sector-type post-column filter Gatan 860 GIF 2001, the plasmon energy of the nanosized carbon coating was determined.

3. DESCRIPTION AND ANALYSIS OF THE RESULTS

The carried out studies of the influence of the parameters of the process of formation of the carbon coating on the electrical capacity of the obtained samples (Fig.1) showed that carbon coatings obtained in the direct flow possess the lowest capacity.

Almost the same capacity is possessed by carbon coatings obtained in a sliding flow and with nitrogen in the vacuum chamber, which may be due to an increase in the fraction of the phase with sp^2-hybridization of valence electrons in the carbon coating as compared to sp^3 and is confirmed by the results of measurements of plasmon energy, which for the carbon The coating obtained in the direct stream was 31 eV, for a coating obtained in a sliding stream of 28 eV, for a coating obtained in a sliding stream with a nitrogen flow of 25.5 eV.

The influence of the slope angle of the plasma current on the morphology of the surface of a nano-sized carbon coating was studied. The results are presented in Table 1.

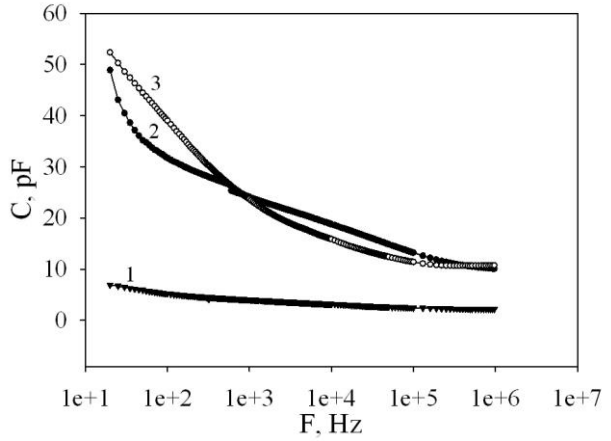

Fig. 1 – Dependence of the electrical capacitance of the samples of the carbon coating obtained in the direct flow (1), in the sliding flow (2), when nitrogen pressure is pumped into the vacuum chamber (3)

Table 1 – Characteristics of the surface of carbon coatings obtained with different parameters of the process of their formation

№	type of coating	max. height of the nano-projections, nm	degree of coating roughness, nm
1	C in the direct stream	2.8	0.25
2	C in a sliding stream	5	0.64
3	C:N in a sliding stream	13.8	0.56

Surface morphology studies have shown that the lowest degree of roughness (0.25 nm) and the maximum height of the nano-projections have carbon coatings obtained in the direct flow. The degree of roughness of the samples obtained in a sliding flow and with nitrogen in the vacuum chamber is practically the same. The scans of the surface of the carbon coating obtained with different parameters of the process of their formation are shown in Fig. 2.

Thus, the obtained results of surface morphology changes depending on the angle of inclination of the plasma flow to the substrate and the nitrogen admittance are consistent with the results of electrical measurements, on the basis of which it can be concluded that the change in the morphology of the surface of carbon coatings is related to the ratio sp^2 and sp^3 in the coating.

On the other hand, changes in the roughness of carbon coatings deposited on silicon, observed in experiments, depending on the conditions of their formation are due to the tendency of the film-substrate system to a minimum of free energy.

The driving force of the processes is the relaxation of mechanical stresses that occur when nonequilibrium condensation of carbon occurs on relatively cold silicon substrates.

The dynamics and kinetics of the transition to a new equilibrium state is due to the statistical process of redistribution of atoms on the surface and a change in their relative position due to surface migration with the activation energy Edif characteristic for each case.

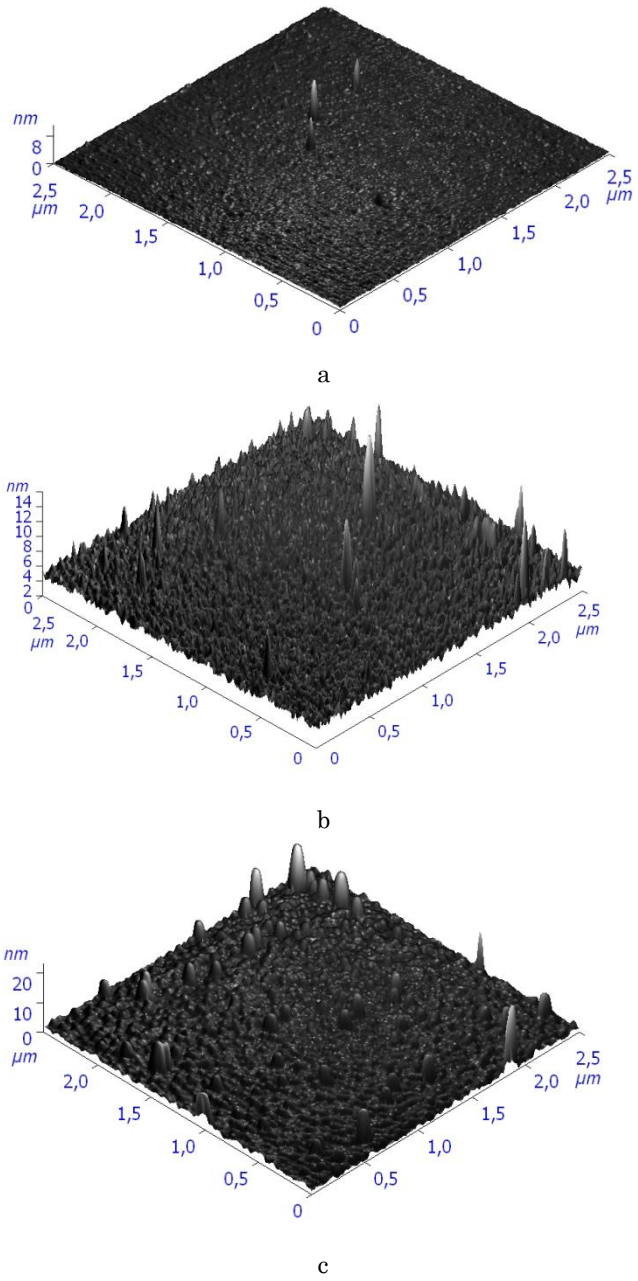

Fig. 2 – Scans of the surface of the carbon coating obtained a) in the direct stream; b) in the sliding stream; c) in a sliding flow with nitrogen up to 0.02 Pa, obtained in atomic force microscopy

The conversion kinetics determined by the characteristic time of atomic jumps depends on the coefficient of surface diffusion (D_{dif}):

$$D_{dif} = D_0\left(-\frac{E_{dif}}{kT}\right) \quad (1)$$

where D_0 – the pre-exponential factor; k – the constant Boltzmann; T – temperature. As a result of this phase transformation, a solid but elastically strained film

covering the substrate can undergo a process of relaxation formation up to complete (coalescing) decomposition into isolated islands [5, 7].

4. CONCLUSION

It is obtained that the samples obtained in the direct flow possess the lowest capacity. Almost the same capacity is possessed by samples obtained in a sliding flow and by nitrogen injection into a vacuum chamber, which may be due to an increase in the fraction of the phase with sp^2-hybridization of valence electrons in the carbon coating compared to sp^3, which is confirmed by the results of measurements of the plasmon energy of carbon coatings.

The correlation dependence between the results of measuring the electrical capacity of carbon coatings and the morphology of the surface, depending on the conditions of their formation, is established.

The work was carried out using the equipment of the Joint Research Center "Technologies and Materials of the “Belgorod National Research University”.

Влияние угла наклона плазменного потока углерода к подложке на электрическую емкость и морфологию поверхности углеродных покрытий

И.В. Суджанская[1], А.И. Поплавский[1], И.Ю. Гончаров[1], О.В. Глухов[2]

[1] *Белгородский государственный национальный исследовательский университет, ул. Победы, 85, 308015 Белгород, Россия*

[2] *Национальный университет радиоэлектроники, пр. Науки, 14, 61166 Харьков, Украина*

Углеродные покрытий были получены импульсным вакуумно-дуговым методом на подложках монокристаллического кремния. Методом импедансной спектроскопии получены результаты изменений электрической емкости в зависимости от параметров формирования углеродных покрытий. Исследование морфологии поверхности производили методом сканирующей зондовой микроскопии. Установлена корреляционная зависимость между электрической емкостью углеродных покрытий и изменением морфологии поверхности в зависимости от условий их формирования. Предложены объяснения полученных результатов.

Ключевые слова: Углеродные покрытия, Электрическая емкость, Электропроводность, Морфология поверхности.

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