The Effect of the Substrate Spatial Orientation on the Properties of Tetrahedral Amorphous Carbon Coatings Deposited from Pulse Plasma Flows

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Introduction

Coatings based on tetrahedral amorphous carbon (ta-C) are characterized by a variety of structures, which determines a complex of unique mechanical, chemical and optical properties. Due to these properties, ta-C coatings are used in the automotive industry, medicine, optics and other fields.

The structure, morphology, and properties of ta-C coatings depend not only on the energy and density of ions in the plasma flow, on the temperature of the substrate, but also on the direction of the flow of particles arriving on the substrate.

In an articles on the deposition of ta-C coatings by a pulsed vacuum-arc method on a substrate with different spatial orientations, insufficient attention was paid to the study of the optical properties and surface morphology. The combination of scanning electron microscopy (SEM) and atomic force microscopy (AFM) techniques make it possible to better characterize the surface.

The aim of this work is to study the effect of the substrate orientation relative to the propagation direction of the pulsed carbon plasma flow on the structure, morphology, mechanical and optical properties of ta-C coatings.

Experimental

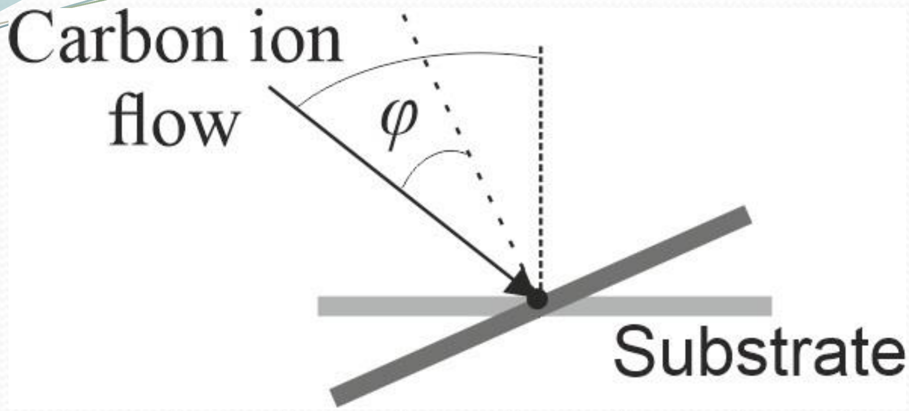


Fig. 1. Schematic of substrate position and incidence angle of carbon ion flow.

Deposition conditions:

Working pressure	4×10^{-3} Pa
Pulsed voltage	300 V
Pulse frequency	5 Hz
Pulse number:	1000
Deposition time	200 sec
Distance	300 mm
Incidence angles	0°, 15°, 45°, 75°

Silicon (111) substrates have been cleaned for 20 minutes by argon ions from End-Hall ion source

Techniques and methods:

Raman spectroscopy (T64000, Horiba-Jobin Yvone)
514.5 nm, 3 mW, 1050 to 1900 cm^{-1}

Scanning electron microscopy (JSM-6700F, JEOL)
15 kV, working distance of 6 mm

AFM (Solver-PRO P47, NT-MDT)
4×4 μm^2

Ellipsometry (LEF-752, ISP SB RAS)
632 nm, 45 to 70º with a step of 5º

Nanoindentation method (NanoScan-3D, FSBI TISNCM)
1 - 50 mN

Results and discussion

Raman spectroscopy

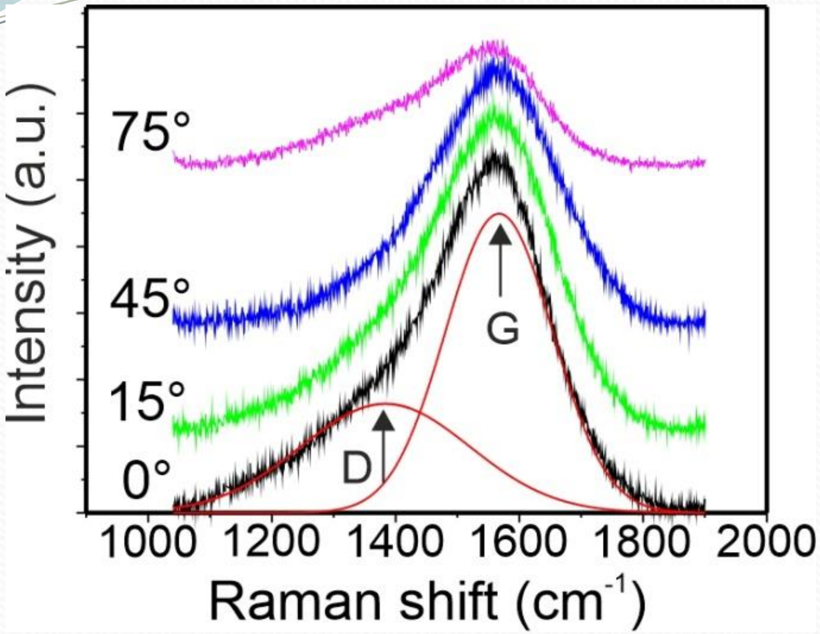
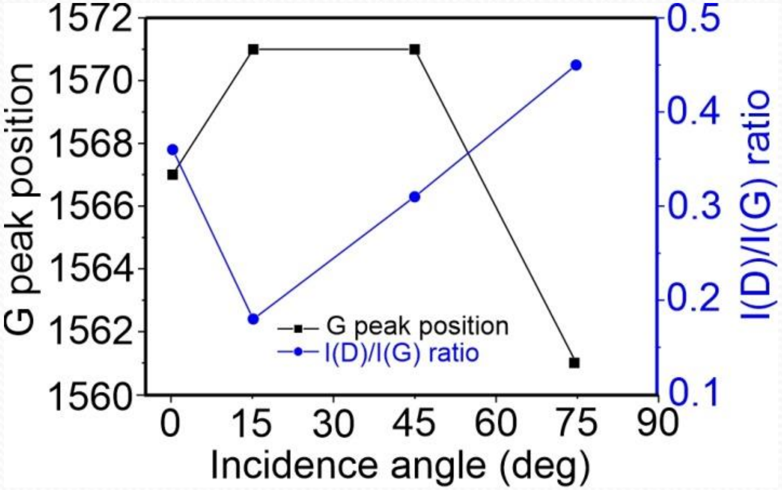


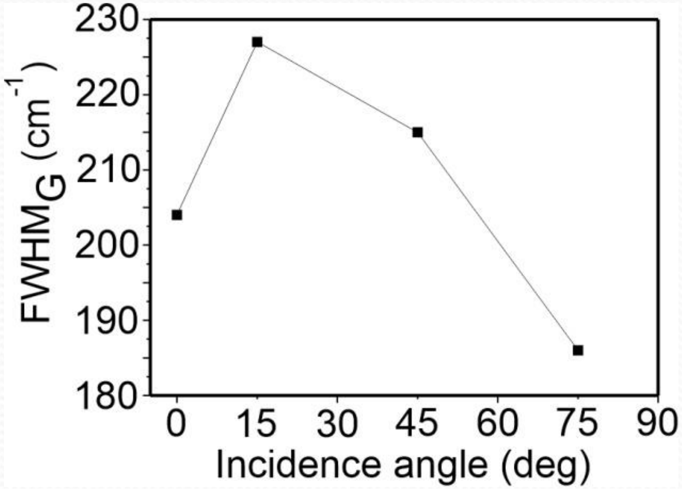
Fig. 2. Raman spectra of ta-C coatings deposited at different incidence angles of carbon ion flow.

The structural features of carbon materials are related to such parameters of Raman spectra as the G peak position, the intensity ratio I(D)/I(G) and the full width at half maximum (FWHM) of G-peak.

These parameters are widely used to determine the disorder degree in carbon materials.



(a)

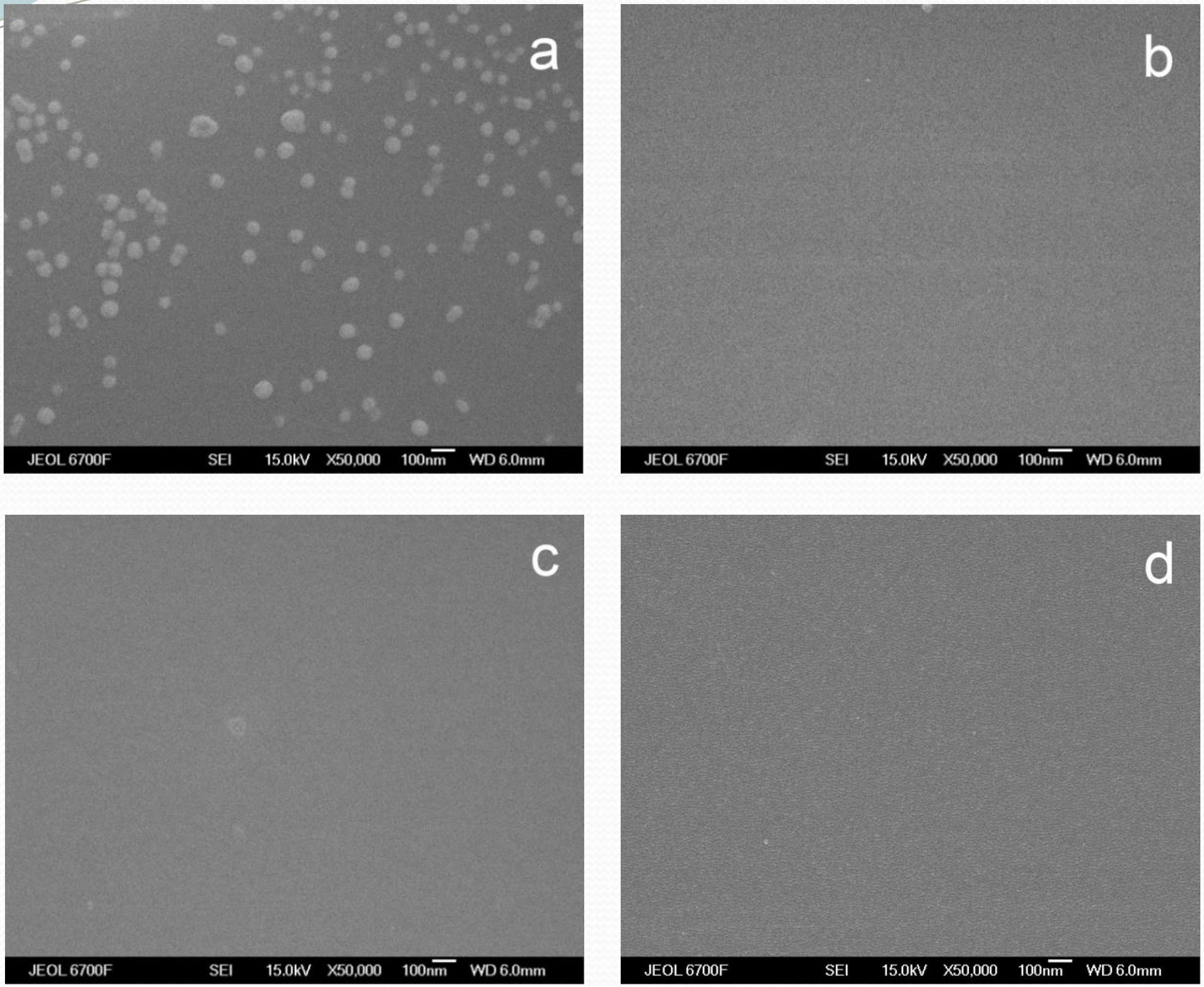


(b)

Fig. 3. a) G peak position, I(D)/I(G) ratio and (b) $FWHM_G$ as a function of incident angle of carbon ion flow.

Results and discussion

Scanning electron microscopy

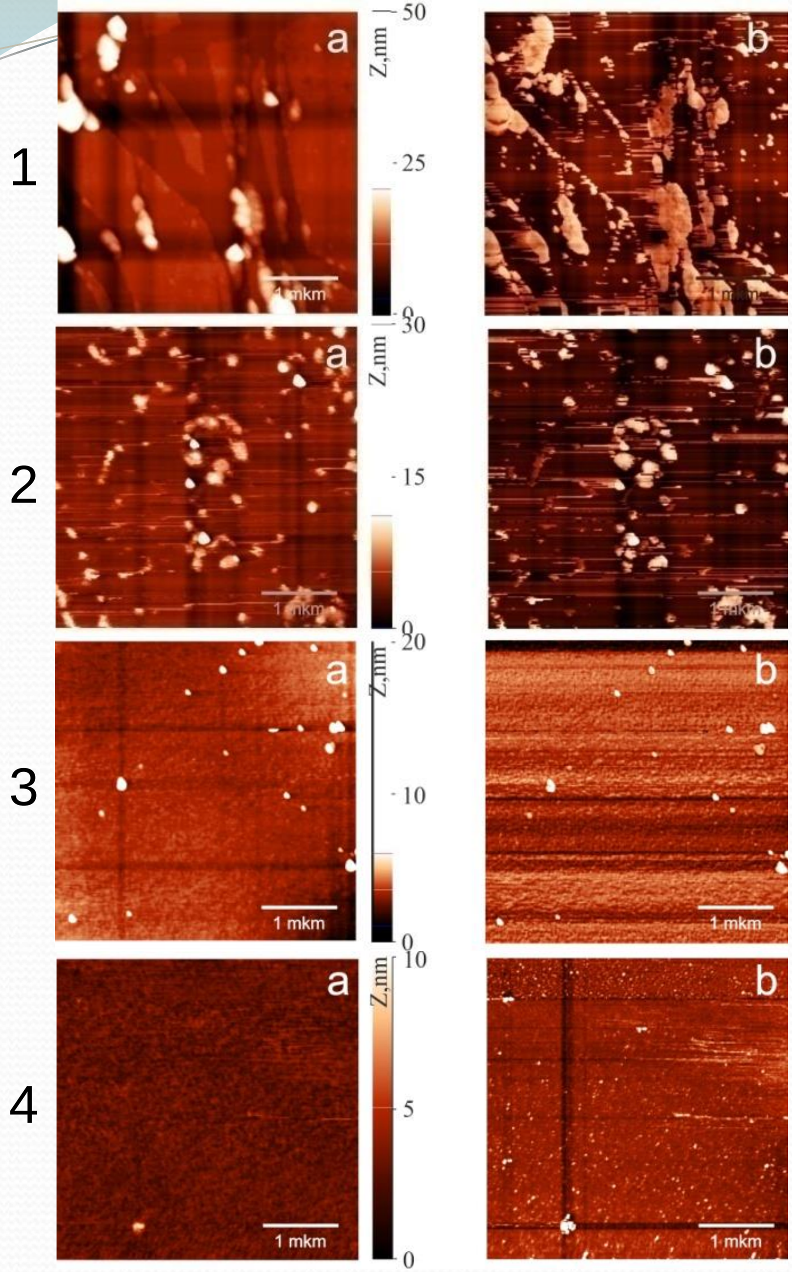


Nanoparticles with diameter from 50 to 100 nm

Fig. 4. SEM images of ta-C coatings deposited at different incidence angles of carbon ion flow: (a) 0°; (b) 15°; (c) 45°; (d) 75

Results and discussion

Atomic force microscopy



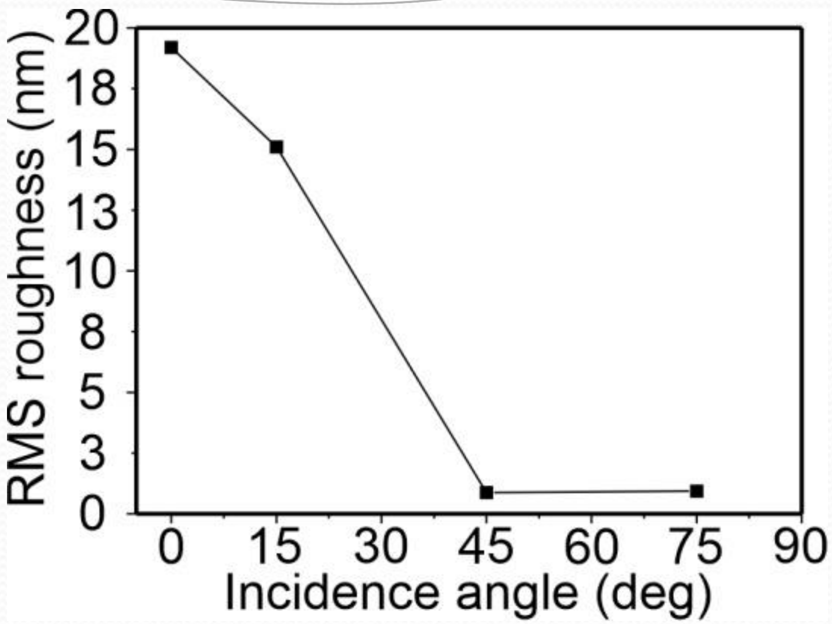


Fig.6. RMS roughness of ta-C coatings as a function of incident angle of carbon ion flow.

0° ⟶ 45°

↓

RMS 19.2 nm ⟶ 0.88 nm

Fig.5. AFM images (a - topology, b - phase contrast) of ta-C coatings deposited at different incidence angles of carbon ion flow: (1) 0°; (2) 15°; (3) 45°; (4) 75°

Results and discussion

Ellipsometry

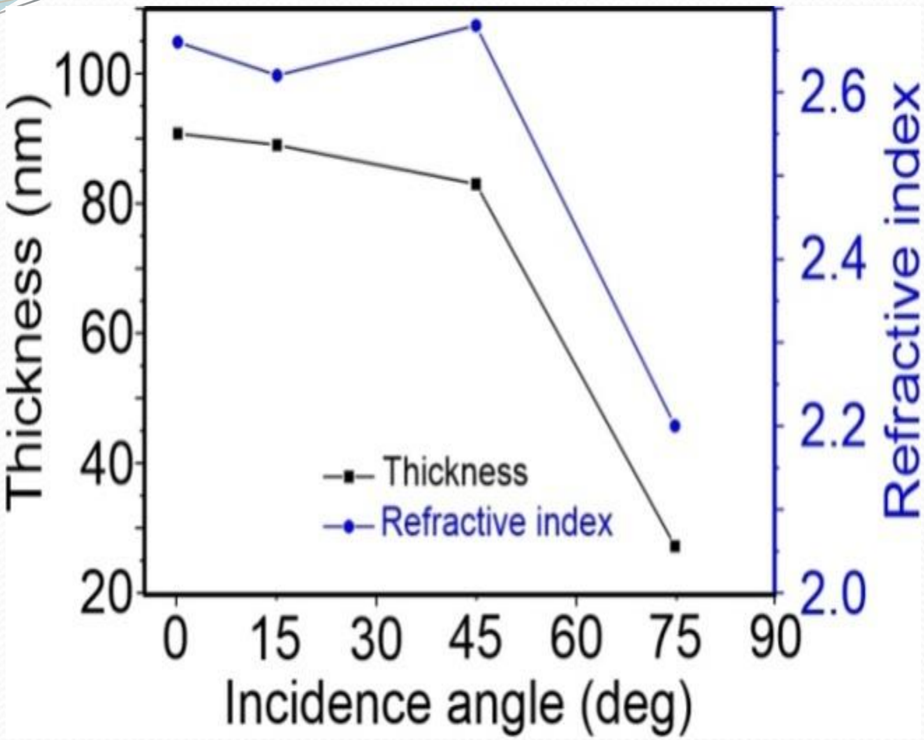


Fig.7. Thickness and refractive index of ta-C coatings as a function of incident angle of carbon ion flow.

Nanoindentation

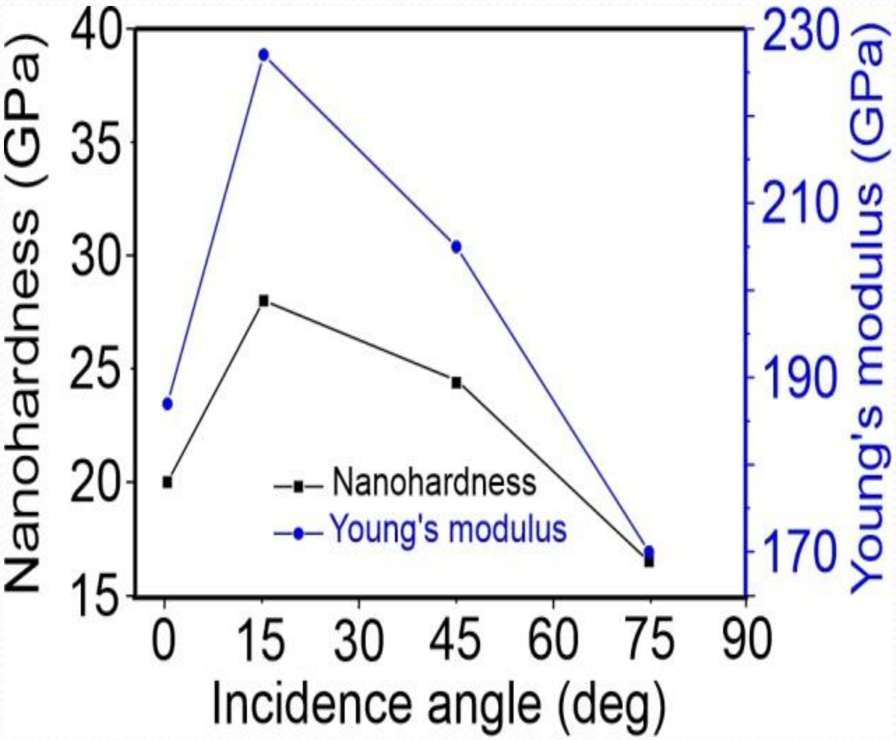


Fig.8. Nanohardnes and Young's modulus of ta-C coatings as a function of incident angle of carbon ion flow.

Conclusions:

A significant decrease in the number of nano- and macroparticles with an increase in the incidence angle of the flow was found by SEM and AFM. The surface of the coatings becomes smooth, without defects and pores, and the RMS roughness decreases, probably due to the elastic reflection of nano- and macroparticles from the sample surface.

It is shown that the thickness and refractive index of ta-C coatings decrease with the increase in the incidence angle of the flow (ellipsometry method). The decrease in thickness is explained by a decrease in the intensity of the incident ions flow on tilted substrate. The refractive index decreases due to a reduction of the thickness, density, and hardness of the coatings.

As the angle of incidence of the carbon ion flow increases, the nanohardness and Young's modulus decrease (nanoindentation method), which is explained by a decrease in the density and, possibly, sp^3 content.

With an increase in the incidence angle to 15°, the size and number of sp^2 clusters decreases, while the number of chain groups and the sp^3 content increase. A further increase in the angle leads to ordering of the sp^2 clusters, an increase in the number of rings in the sp^2 clusters, and a possible decrease in the sp^3 content (Raman spectroscopy technique).

Studies have shown that the optimal position of the substrate relative to the incident flow is 15°. The ta-C coating deposited at this angle is characterized by the high hardness (28 GPa) and Young's modulus (227 GPa), while the coating thickness is almost equal to the thickness of the coating deposited at the incident angle of 0°.

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THANK YOU FOR YOUR ATTENTION!