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Laser-induced Formation of Conductive Structures on Diamond-like Carbon Films

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Modification of diamond-like carbon (DLC) films by laser radiation with a wavelength of 532 nm and pulse duration of 18 ns was investigated. The treatment of DLC films with laser fluence over 0.4 J/cm2 was accompanied by the formation of conductive structures with a surface resistance from a few to hundreds kΩ/sq. Dependence of films conductivity from the laser fluence was established. Relationship between energy density of laser radiation and the structural changes in the films, its heating and evaporation is discussed.

Keywords: Diamond-like carbon films, Laser modification, Surface resistance, Nanocrystalline graphite.

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1. INTRODUCTION

Laser modification of diamond-like carbon (DLC) films can be used to create any configuration of resistive structure [1]. Information about the relationship between laser-induced conductivity parameters of DLC films and structural transformations occurring in the modified films is required for the development of laser modification technology of DLC films and expansion of their use in electronics. Method of Raman scattering (RS) is a traditional [2] to estimate the phase composition of carbon materials and it can be used to study the processes occurring in the films during modification.

Purpose of this work is obtaining laser-induced conductive structures in DLC films, definition of relation between films conductivity and parameters of laser irradiation and studying of structural-phase transformations in laser-modified films as well.

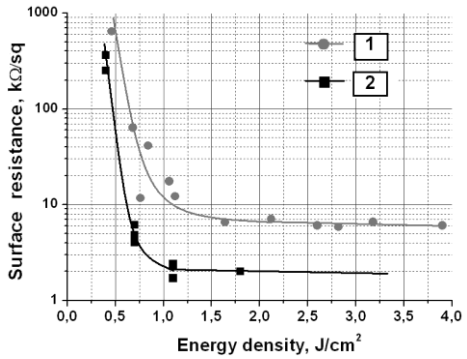
2. EXPERIMENTAL DETAILS

Modification of 0.7÷1.2 μm thickness DLC films deposited on the aluminum substrates performed by focusing a laser beam (wavelength of 532 nm, pulse duration of 18 ns, frequency of 10 Hz) to a round spot 0.4 mm in diameter. Laser fluence was in the range 0.4÷7.1 J/cm^2. The samples were moving with a velocity of 0.2 cm/s.

Measurement of surface resistance of the modified films was performed by standard four-probe technique. The spectral analytic complex "Nanofinder" based on scanning confocal microscope (Lotis TII, Ltd, Belarus) was used to study laser-induced structural phase transformations in the DLC films by Raman method.

3. RESULTS AND ANALYSIS

The initial DLC films had electrical resistivity ≥ 10^8 Ω·cm. Resistance of the films decreased as a result of laser treatment. Figure 1 shows the dependence of the surface resistance of the DLC film on the energy density of radiation exposure (immediately after processing and one year later). Increase of films conductivity was accompanied by reduction of their reflectivity in a wide spectral range (Fig. 2).



1 - one year after treatment,
2 - immediately after processing

Fig. 1 – Dependence of the surface resistance on laser fluence

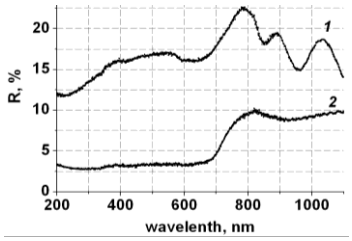
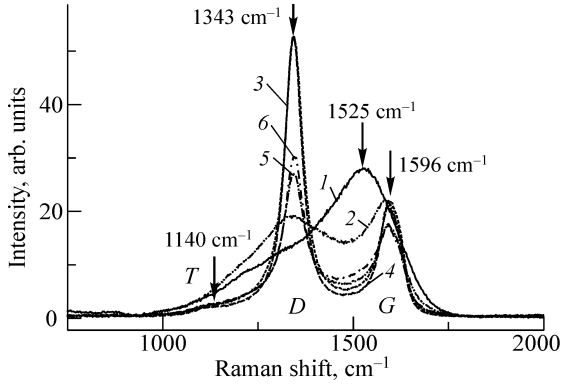


Fig. 2 – Reflectance spectra of initial (1) and modified film (2)

Resistance of the film decreases nonlinear with energy density increasing. Maximum decrease is observed with fluence increasing from 0.4 to 1.1 J/cm^2. Further growth of irradiance to value of 3.7 J/cm^2 causes only 3 times decrease of surface resistance. This feature may be associated with the threshold nature of the restructuring of interatomic bonds in which result the DLC film becomes conducting, or with percolation nature of conductive phase cluster formation. Slowdown of the film re-

sistance decline with growth of irradiance may be caused by reduction of its thickness due to partial evaporation. Study of initial and modified DLC films Raman scattering was carried out to determine the composition of highly conductive phase (Fig. 3).

On the spectrum of the original film (1) there is a signal, which is a superposition of D and G bands. G band dominates with a maximum at 1525 $см^{-1}$. The similar Raman spectrum is typical for tetrahedral amorphous carbon with a predominance of sp^3-hybridized bonds [3]. Laser modification of DLC film causes the reduction of the D and G bandwidth. The amplitude of D band signal grows with increasing of laser fluence from 0.4 J/cm² to 2.3 J/cm². Amplitude of Raman signal decreases due to the erosion of the film with increasing energy density up to 7.1 J/cm². At the Raman spectra of the film modified with laser fluence of 1 J/cm², clearly resolved D band with a maximum at 1343 cm^{-1} and G band with a maximum at 1596 cm^{-1}. Spectral feature which can be interpreted as a known T peak, whose origin is associated either with curved graphene layers [4] or with the sp^3-hybridized carbon [3] is observed in the range of 1130÷1150 cm^{-1}.

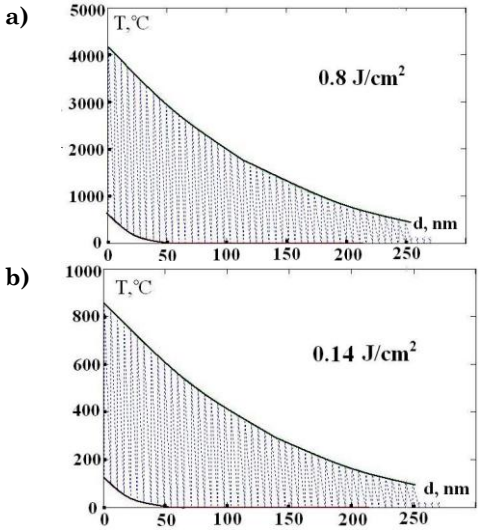


1 – initial DLC film; 2-6 – treated DLC films: 2 – laser fluence 0.4 J/cm², 3 – 1 J/cm², 4 – 2.3 J/cm², 5 – 3.5 J/cm², 6 – 7.1 J/cm²

Fig. 3 – Raman spectra of DLC films

Raman spectra with the intensity ratio of D and G bands about equal 2 and G band maximum near 1600 cm^{-1} are characteristic of nanocrystalline graphite [3]. Comparison of obtained results and the data [3] allows assuming that laser irradiation DLC film lead to formation of sp^2-hybridized carbon nanoscale inclusions.

To establish the connection between the change in conductivity of the film and its heating by laser radiation was calculated temperature distribution into the target by solving the heat conduction problem in the investigated range of laser fluence (Fig. 4). Calculations showed that the graphitization threshold reaching at temperatures up to 800°C for stationary heating [5], correlates with the threshold of pulsed laser forming of conductive structures (Fig. 4a), and evaporation threshold reaching at temperatures up to 4000°C for stationary heating [6] almost matches with the experimentally observed slowdown of conductivity (Fig. 4b). According to the calculations, the heat affected zone of single laser pulse is in the range of 270 nm. The calculated thresholds of energy density required to achieve the temperature of surface graphitization and the temperature of evaporation graphitic layer are respectively equal to 0.14 J/cm² and 0.8 J/cm².



a) threshold of graphitization (laser fluence 0.8 J/cm²), b) start of evaporation (0.14 J/cm²)

Fig. 4 – The temperature distribution in depth of target

Laser fluence used for modification the DLC films, was ranged from 0.4 to 7.1 J/cm². Consequently, a partial evaporation of the film also contributes to the change in its conductivity, when the surface is irradiated with the laser fluence greater than a threshold value required to initiate evaporation of graphitic layer.

CONCLUSIONS

Thus, under pulsed laser irradiation with the fluence of 0.4-7.1 J/cm² at DLC films are formed conductive structure with a surface resistance from a few to hundreds kΩ/sq. Increase of the DLC films conductivity associated with the formation and growth of sp^2-hybridized areas of carbon. At a certain value of laser fluence observes the formation of clusters of nanocrystalline graphite. Evaporation of graphitic layer at the thresholds laser fluence also affects to decrease surface resistance of the DLC films.

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