INVESTIGATION OF THE STRUCTURE OF MANGANESE-DOPED SILICON-CARBON FILMS OBTAINED BY ELECTROCHEMICAL METHOD

T. Mikhailova, T. Myasoedova
Southern Federal University, Taganrog, Russia

tmihaylova@sfedu.ru

I. INTRODUCTION

Silicon-carbon films are derived from diamond-like carbon materials that have numerous useful properties:

- high coating hardness value,
- low coefficient of friction,
- high corrosion and wear resistance [1-4],
- high electrical resistance (up to 10^{16} Ohm·cm) [5],
- optical bandgap width up to 3.6 eV [6],
- high thermal conductivity (up to 10 W/(m·K)),
- low-temperature coefficient of expansion,
- chemical stability [7-8].

Due to their properties, diamond-like carbon films have multifunctional applications in optical, electrical, and biomedical systems.

But this material also has disadvantages. The main problems are limited adhesion and low thermal stability. These factors greatly limit their practical application. Silicon-carbon films are devoid of these disadvantages while maintaining the advantages of diamond-like carbon films. However, they are very difficult to obtain. This fact makes relevant research in the search for new methods for producing silicon-carbon films.

II. EXPERIMENTAL

In this work, silicon-carbon films were obtained by electrochemical deposition from an electrolyte solution. The ease of implementation and the ability to control the thickness of the films during their growth are the advantages of this method [9]. The choice of a dielectric with a thin copper sublayer as a substrate was justified in [10]. The deposition was carried out in two stages. At the first stage, a "pure" silicon-carbon film was obtained from a solution of methanol (CH_3OH) with hexamethyldisilazane (HMDS) taken in a ratio of 9:1. The deposition time was 8 hours. Then manganese sulfate ($MnSO_4 \cdot 5H_2O$) was added to the solution and precipitation was carried out for another 10 minutes. The embedding of manganese atoms into the structure of a silicon-carbon film was proved by X-ray phase diffractometry [11]. The thickness of the obtained films was about 100 μm.

The structure of silicon-carbon films was studied using the *inVia Raman Microscope* Raman scattering spectrometer (Renishaw, UK). The results of the study are shown in Figure 1.

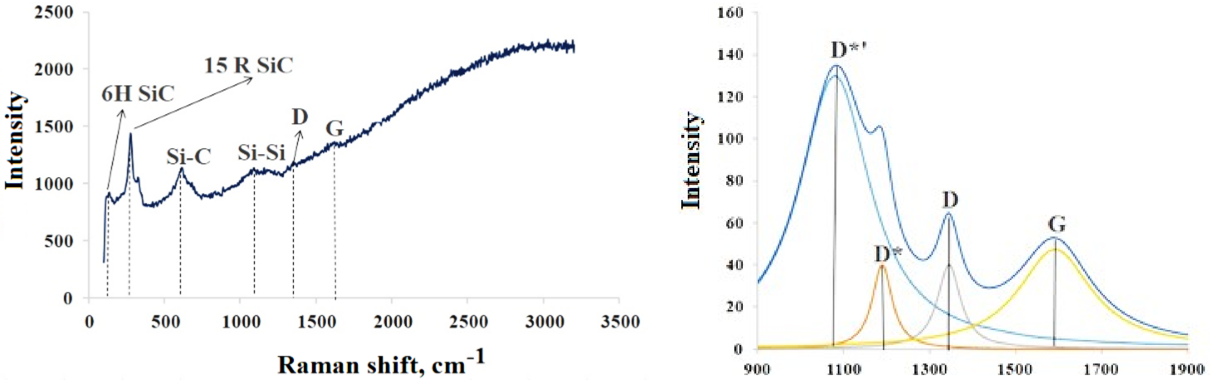

Figure 1. Raman spectrum and decomposition spectrum of peaks D and G of manganese-doped silicon-carbon films (peaks D* and D’ characterize disordered carbon)

The structure of the silicon-carbon film is multiphase and is characterized by the presence of a predominantly hexagonal phase of the 6H SiC polytype with inclusions of the rhombohedral phase of 15R SiC [12]. The presence of the Si-C bond responsible for the presence of the amorphous phase of silicon carbide was also found. The sample is characterized by the presence of D and G peaks. The G peak characterizes carbon in the plane of the vibrational mode sp^2. This parameter displays the degree of crystallization of the material. The D-band displays the degree of structural disorder (disorderliness) near the edge of the microcrystalline structure, which reduces the symmetry of the structure [13, 14]. The D and G peaks are positioned at 1346 cm^{-1} and 1593 cm^{-1}, respectively.

The procedure for decomposing Raman peaks allows you to see the "hidden" peaks. A detailed analysis of the spectral parameters was obtained by fitting the curve profile using the Lorentz function. A band of D*- D*' peaks was detected on the spectra of the sample in the region of ~1200 cm^{-1}. The appearance of D*- D*' peaks may be associated with the presence of a phase of an unordered graphite layer with inclusions of ionic impurities [15].

III. CONCLUSIONS

Thus, the electrochemical deposition method makes it possible to obtain silicon-carbon complex structures. The influence of the structure of the obtained films on their properties requires further study.

REFERENCES

[1] F.M. Kimock, “Commercial applications of ion beam deposited diamond-like carbon (DLC) coatings”, Surf. and Coatings Techn., Vol. 56, № 3, pp. 273-279, 1993.

[2] G. Fanchini [et al.], “Effect of isotopic substitution on IR and ESR properties of mass se-lected ion beam deposited ta-C films”, Diamond and Related Mater., Vol. 12, № 3, pp. 900-904, 2003.

[3] A.H. Lettington, C. Smith, “Optical properties and applications of diamond-like carbon coatings”, Diamond and Related Mater., Vol. 1, № 7, pp. 805-809, 1992.

[4] C.H. Su [et al.], “Mechanical and optical properties of diamond-like carbon thin films deposited by low temperature process”, Thin Solid Films, Vol. 498, № 1, pp. 220-223, 2006.

[5] A. Grill, “Electrical and optical properties of diamond-like carbon”, Thin Solid Films, Vol. 355, pp. 189-193, 1999.

[6] K.B.K. Teo [et al.], “Highest optical gap tetrahedral amorphous carbon”, Diamond and Related Mater., Vol. 11, № 3, pp. 1086-1090, 2002.

[7] M. Shamsa [et al.], “Thermal conductivity of diamond-like carbon films”, Appl. Phys. Lett., Vol. 89, № 16, pp. 1619-2113, 2006.

[8] A.A. Balandin, “Thermal properties of graphene and nanostructured carbon materials”, Nature Mater., Vol. 10, № 8, pp. 569-581, 2011.

[9] N. Basman, R. Uzun, E. Gocer, “Electrodeposition of Si-DLC nanocomposite film and its electronic application”, Mtcrosist. Technol., Vol. 24, pp. 2287-2294, 2018.

[10] M.N. Grigoryev, T.S. Mikhailova, T.N. Myasoedova, “Resistive structures based on silicon-carbon films for gas sensors”, News of the SFU. Tech. Sci., Vol. 6, pp. 85-93, 2019.

[11] T.S. Mikhailova, M.N. Grigoryev, T.N. Myasoedova, “The two-stage electrochemical deposition of a manganese-doped silicon-carbon film onto the silicon (100) substrate”, https://iopscience.iop.org/article/10.1088/1742-6596/1410/1/012027, doi:10.1088/1742-6596/1410/1/012027, access mode, free.

[12] N.K. Plugotarenko [et al.], “Electrochemical deposition of silicon-carbon films: a study on the nucleation and growth mechanism”, Nanomaterials, Vol. 9., P. 1754, 2019.

[13] Andrea C. Ferrari, “Raman spectroscopy of grapheme and graphite: Disorder, electron-phonon coupling, doping and nonadiabatic effects”, Solid State Commun, Vol. 143, № 1-2, pp. 47-57, 2007.

[14] E.I. Bîru, H. Iovu, “Graphene nanocomposites studied by raman spectroscopy”, Raman Spectroscopy, pp. 178-201, 2018.

[15] V. Sharma [et al.], “Structure and chemistry of crankcase and exhaust soot extracted from diesel engines”, Carbon, Vol. 103, pp. 327-338, 2016.