POTENTIALITY OF THE COMPOSITE FULLEREN BASED CARBON FILMS AS THE STRIPPER FOILS FOR TANDEM ACCELERATORS

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The problem of the radiation resistance of the carbon stripper foils is considered. The short review of the experimental data available in literature and original experimental results of the authors are presented. In the paper discussed is the possibility of composite fulleren based carbon films to be used for preparation of the stripper foils. Some technological methods for preparation of composite fulleren based carbon films are proposed. Raman scattering and atom force microscopy were used for investigation of the fulleren and composite films deposited by evaporation of the C_{60} fulleren powder.
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1 INTRODUCTION

Solid state stripper foils (SSSF) for the tandem accelerators have some advantages in comparison with gas targets. For instance the use of the SSSF provides the higher average charge state of ions and hence higher output energy or, often more impotent, allow the higher beam intensity at a given energy. Carbon stripper foils are normally used as stripper foils because they are stable at a high temperature in vacuum, and have the good electrical and thermal conductivity. To keep the multiple scattering small, low Z materials must be used and carbon is one of the lowest-Z materials that can be fabricated as a thin film suitable for this purpose.

But there is one very impotent disadvantage. Carbon foils have a limited lifetime due to radiation damage. The rate of damage is proportional to ion beam intensity and ion mass. The factors that limit the lifetime of the foil are: (i) increasing of the film thickness and (ii) tightening of the films in the irradiation area [1] that leads to rupturing of the stripper. As will be shown below all these factors are the consequence of irradiation stimulated structure reconstruction in carbon films.

2 EXPERIMENT

Till end of the 70-th of the last century the main technologies for preparation of free-standing carbon films were arc and electron beam evaporation of graphite. But in 1979 the collaboration of the groups from The Daresbury Laboratory and Atom Energy Agency had resulted in development of the chemical vapour deposition (CVD) technology for preparation of hydrogenated carbon stripper foils. [1-3]. The lifetime of those foils was improved by the factor of order. At the same time the first systematic investigation of the irradiation effect on the structure reconstruction in such hydrogenated amorphous carbon films was performed [4, 5]. The conclusion was made that under ion bombardment the thermally activated graphitization process (ordering of the graphite-like structure) takes place. The authors have explained improved radiation resistance of such films by modification of the short-range order with ion bombardment during the deposition process.

Within the 80-th in the Munich technical university researchers made a very comprehensive and complex study of the influence of the short-range order peculiarities (such as distribution of the orientation of the graphite-like nanocrystallites, GLN) on the carbon stripper foil radiation resistance [6, 7]. The crystalline structure of graphite is extremely anisotropic. Carbon atoms are very closely packed in basic planes (graphen sheets) by strong covalent bonds. But graphen sheets are bonded together by weak Van-der-Vaals forces. Interatomic distance in graphen sheets is about 0.14 nm while the distance between graphen sheet is more than 0.3 nm. The level of anisotropy was estimated by the ratio of the intensity of the electron diffraction reflections I_{002}/I_{100}. They had proposed and substantiated the following mechanism of the stripper foils destruction under heavy ions bombardment. Usual deposition methods such as arc and electron beam evaporation results in formation of films with structure having preferable orientation of the graphen sheets in GLN parallel to the film plane. Under ion bombardment the dissipation of the ion energy due to the stopping power leads to heating the carbon material in the irradiated region and hence to the graphitization process. Due to existence of the initial texture the graphitized regions also have a preferable orientation. The accumulation of interstitials between graphene sheets and diffusion of vacancies to the boundary of the nanocrystallits lead to the well-known effect of expansion along the c-axis and compression in the base plane.[8]. It is obvious that carbon films having the texture of the c-axis of the GLN perpendicular to the film plain will be compressed and eventually crack. When the orientation of the GLN is isotropic then the effect of the anisotropic changes of the volume of the GLN is compensated.

They had developed the laser ablation technology

for deposition carbon films and showed that these films have a nearly isotropic structure and improved radiation resistance in comparison with CVD films [6].

In our previous paper it was showed that the level of the isotropy of the amorphous carbon structure could be successively varied by intensity of the ion bombardment during the deposition process [9].

But the nature has given us an almost entirely isotropic carbon material. This is fulleren. Fulleren is a general name of the wide family of the carbon closed molecules that had been revealed about ten years ago [10]. The most stable are C_{60} and C_{70} molecules having 60 and 70 carbon atoms respectively (Fig. 1). In solid state this molecules exist in the form of cubic molecular crystals (fullerits). This structure is very isotropic in comparison with graphite-like structure of the usual amorphous carbon films. It is very attractive idea to estimate potentiality of a such material for stripper foils. But on the first steps one runs into some hard problems.

1. Fullerens have a low sublimation temperature (about 500^{O}C). It makes very simple the evaporation process but it is known that the temperature of the irradiated zone of the stripper foil could reach 1000^{O}C and so pure fullerene films could not operate at such temperature.
2. Despite a great progress in the technology of fullerene production in large quantities the price of the commercially available fullerens is still very high (about 35-45 dollars per gram for pure C_{60} powder).

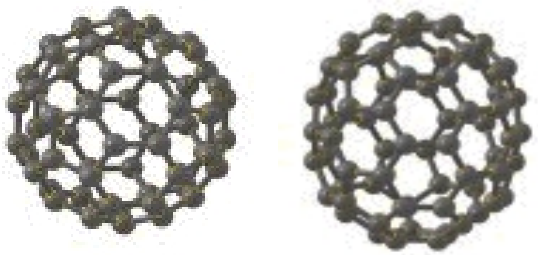

Fig. 1. Fulleren molecules C_{60} and C_{70}.

First problem could be avoided in two ways. It is possible to fabricate the "sandwich" structure: amorphous carbon/fulleren/amorphous carbon (Fig. 2). Due to their large size (diameter about 0.7 nm) fulleren molecules could not diffuse to the surface of the film through amorphous carbon and sublimate. To reduce the prices of the films it is possible to use fulleren enriched carbon soot as an evaporated fulleren material.

Fig. 2. "Sandwich" structure a-C/C_{60}/a-C.

Another possible structure is the composite films composed of fulleren agglomerates embeded in an amorphous carbon matrix. Such structure could be prepared by code position of amorphous carbon (arc or electron evaporation) and fullerens (sublimation). But as things turned out the more simple method is available.

We have investigated the structure of the films deposited by thermal evaporation of the pure C_{60} powder in dependence of the deposition rate. Pure C_{60} powder was sublimated from the tantalum effusion cell at the temperature of about 600^{O}C. One silicon substrate was located at a distance of 4 cm from the tantalum cell. Another substrate was located at a distance of 10 cm from the evaporator. Such a deposition configuration allows us to produce samples deposited under the same conditions but other deposition rate. Deposition rates were about 0.5 μm/min and 0.1 μm/min for the different substrates.

Raman scattering (RS) spectroscopy was used for characterisation of the nanostructure of the films. Morphology of the surface of the films was analysed by means of atom force microscopy.

RS spectra of the films are presented in Fig. 3. The RS spectrum of the film deposited at a lower rate is typical for pure C_{60} films and consists of three lines at 1426 cm^{-1}, 1470 cm^{-1} and 1578 cm^{-1} (Fig. 3, spectrum 1) that could be unambiguously ascribed to the "intramolecular" vibration modes with symmetry H_g, A_g and H_g [11, 12].

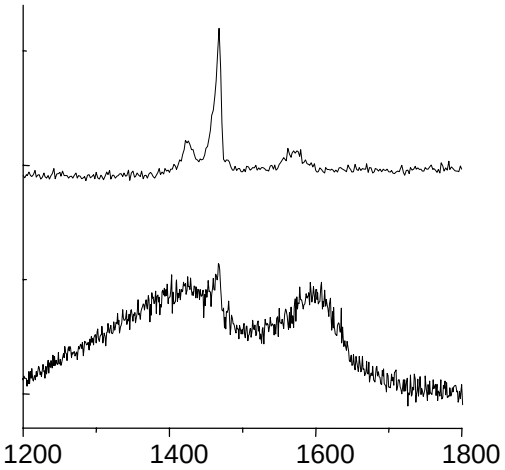

Fig. 3. Raman spectra of the films deposited at lower (1) and higher (2) diposition rate.

RS spectra of the film deposited at higher deposition rate is more complicated (Fig. 3, spectrum 2). The broad bands with the centres of about 1400 cm^{-1} and 1600 cm^{-1} are associated with D ("disordered") and G ("graphitic") bands respectively of the amorphous carbon with graphite-like short-range order. The narrow line at the 1470 cm^{-1} is an evidence that the film contains C_{60} molecules (A_g mode).

In Fig. 4 the atom force microscopy image of the surface morphology of the two different carbon films are presented. One could see that the morphology of the surface of the films is quite different as well as the Raman spectra. Surface of the pure fulleren films is composed of agglomerates of the fulleren molecules that is typical for the nanocrystalline fulleren films. Surface morphology of the composite a-C/C_{60} film is rougher and something similar to the morphology of the amor-

phous carbon films deposited by dc-magnetron sputtering [9].

This results allow to conclude that 1) at the high deposition rate fulleren molecules could be collapsed into graphite-like nanocrystallites; 2) composite structure a-C/C_{60} with different phase composition could be successively prepared by varying the deposition rate during fulleren sublimation.

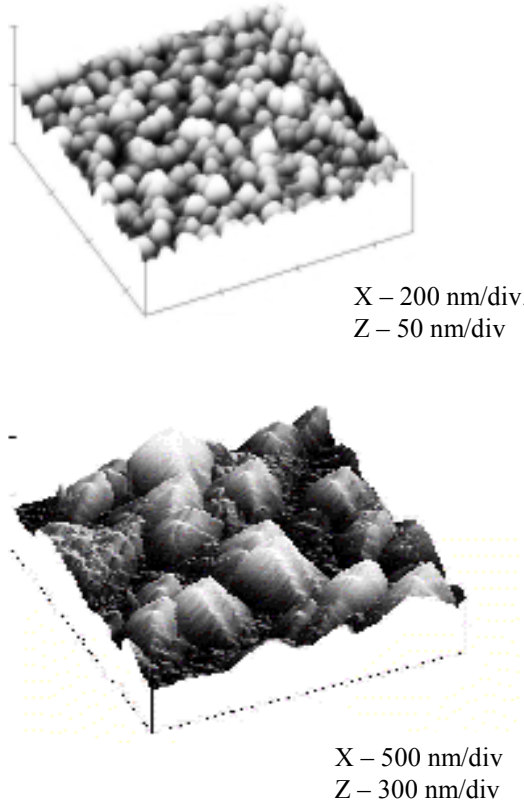

Fig. 4. AFM image of the surface morphology of the films deposited at low (a) a high (b) deposition rate.

It is obvious that further research is necessary to examine real operation properties of these films including radiation resistance against heavy ion bombardment. Radiation damage most likely will leads to collapse of C_{60} molecules into graphite-like clusters. But one may expect that graphen sheets in new carbon clusters will be preferably oriented along the incident ion beam [6, 7]. Radiation damage in such a structure does not results in compression and rupture of the film.

3 CONCLUSION

The first estimation of the potentiality of the fulleren based composite carbon films as stripper foils for tandem accelerators was made. Some technological methods for preparation of fulleren based composite carbon films are proposed.

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