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Nuclear Instruments and Methods in Physics Research A 561 (2006) 120–123
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

# Preparation and investigation of ultra-thin diamond-like carbon (DLC) foils reinforced with collodion

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Available online 11 January 2006

**Abstract**

Ultra-thin ($\leqslant 1\,\mu g/cm^2$) diamond-like carbon (DLC) foils prepared by sputtering and supported by high-transmission meshes, have proven advantageous over standard carbon foils for timing and stripping of low-energy ions in many accelerator experiments. Specifically manufacture support mesh permits the use of much thinner, smoother and larger foils that can be accomplished without it. The main limitation of fine mesh as a mechanical support appears to be interaction of transmitting ions with the mesh that might affect both energy and angle distributions of primary ion beams under some irradiation conditions. As an alternative, collodion coatings can be used to support a foil during the mounting and handling, but later such coatings must be removed completely.

In this work, process of removal of collodion coating from ultra-thin DLC foils by using ion beam bombardment in the energy range 6–15 MeV was investigated with the main emphasis given to determination of the minimal beam intensity sufficient to remove collodion, and to the measurement of the thickness of possible residual deposits. Removing of collodion was monitored online by measuring the energy of ions penetrating the foils. This was performed with high-resolution magnetic and electrostatic analyzers available at the beam lines of the Heidelberg MP-Tandem, and VERA-Tandem, respectively.

In addition, preliminary results are presented of lifetime measurements for the collodion-reinforced very thin DLC foils in the thickness range of $0.6–5\,\mu g/cm^2$. The results were obtained for a 20 MeV, $^{63}Cu$ ion beam.


*PACS:* 81.05.Tp; 81.15.Cd; 29.27.Fh; 29.25.−t

*Keywords:* DLC foils; Collodion; Tandem accelerator; Stripper lifetime

## 1. Introduction

Ultra-thin ($\leqslant 1\,\mu g/cm^2$) diamond-like carbon foils, so called DLC foils, which are being produced in Kurchatov Institute by sputter deposition, have proven advantageous over conventional carbon foils for timing and stripping of low-energy ions in many accelerator experiments [1–9]. Usually, ultra-thin DLC foils are supported with high-transmission (up to 90%) meshes. Mesh support permits the fabrication of extremely flat and smooth ultra-thin target foils as large as 70 mm diameter with very high mechanical stability. However, some applications of mesh-supported foils, i.e., accelerator mass spectrometry (AMS) might suffer from energy and angle scattering of transmitting ions due to their interaction with crosspieces of supporting mesh. In particular, this can result in low-energy "tails" in energy distributions of transmitting ions, with the relative population of the "tails" being dependent on the irradiation conditions and mesh parameters.

Collodion-reinforcement of carbon target foils during the mounting is a well-known alternative to mesh as mechanical support, but later collodion must be removed completely. A variety of methods for removal of collodion support by different methods is described by Stoner [10]. However, little is known about relevant treatment of

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0168-9002/$ - see front matter 
doi:10.1016/j.nima.2005.12.178

ultra-thin DLC foils. In this work, we investigate removal of the collodion from the ultra-thin DLC foils by using ion-beam bombardment with the aim to determine the minimal beam intensity sufficient to clean the foil safely and to verify the thickness of possible residual deposits. Thickness of the foils during the ion beam treatment was monitored by means of energy loss measurements for ions traversing the foils by high-resolution scanning magnetic and electrostatic analyzers available at the beam lines of the Heidelberg MP-tandem and VERA-Accelerator mass spectrometry (AMS) tandem [11,12], respectively.

Very thin collodion-reinforced DLC stripper foils with long lifetimes can be of considerable value in improvement of ion transmission high-intensity heavy-ion accelerators. Comparative lifetime measurements for DLC stripper foils 5 μg/cm$^2$ thick are reported in Ref. [3]. In this paper, we present lifetimes of much thinner DLC foils as a function of their thickness down to 0.6 μg/cm$^2$ for $^{63}$Cu ion beams of 20 MeV.

## 2. Experimental

### 2.1. Preparation of the DLC foil samples

The development for the preparation and characterization of thin DLC foils is described in details in our previous papers [1,7]. The applied method is DC glow discharge sputtering of graphite in a low-density krypton plasma. In this research, DLC films in a thickness range of 0.6–2 μg/cm$^2$ were deposited on standard glass slides, with betaine-sucrose solution as release agent [13]. The deposited DLC films, still on their substrates were coated with collodion by gentle dipping into 10% or 20% solutions. This resulted in collodion supports with thicknesses of about 180 and 400 nm, respectively, as measured with a Alpha-Step 200 (Tencor Instruments) profilometer. Some amount of deposited DLC foils were not coated with collodion to serve as references during monitoring of the collodion removal. After floating off in distilled water, collodion-reinforced foils were mounted on target frames with 18 mm diameter apertures, while uncoated reference foils were picked up on fine copper meshes with distances between crosspieces of 250 μm. The required meshes were stretched over frames with similar apertures.

### 2.2. Removal of collodion coatings from the ultra-thin DLC foils by using ion beams

The first experimental run on removal of collodion coatings from the ultra-thin DLC foils has been carried out at the beam line of the MP-tandem at the Max-Planck-Institut für Kernphysik (MPIK), Heidelberg. The main purpose of this was the thickness determination of possible residual layers. The set of collodion-coated foils was installed together with those uncoated, in front of the high resolution ($\Delta E/E \sim 8 \times 10^{-4}$) magnetic analyzer which enabled us to determine an effective thickness of the foils by measuring the energy of transmitting ions. The foils were irradiated with a 6 MeV, $O^{2+}$ ion beam of 50–100 nA with a beam spot area of about 16 mm$^2$. Such beam currents remove the collodion coating immediately from the foil surface. In this setup, an uncertainty in determination of the foil thickness by the energy loss measurements was estimated to be about 0.2 μg/cm$^2$.

In Fig. 1 a scheme of the irradiation setup is shown together with data for magnetic field of the analyzer corresponding to the energy of transmitting ions versus thickness of the foil. Thus ten different DLC foils were investigated. Thinner foils require higher magnetic field. In the frame of measuring uncertainty the collodion support has been fully removed from the foils by ion bombardment because the uncoated foils are not thinner than the former coated ones.

Further investigations to remove collodion from reinforced DLC foils was conducted at VERA AMS facility with use of higher resolution ($5 \times 10^{-4}$) electrostatic analyzer (ESA) to monitor thickness of the foils by measuring the energy of transmitting ions. The experimental setup for online determination of thickness of residual collodion was the same as shown in Fig. 2 of Ref. [9]. The set of collodion-coated (10% solution) and uncoated (mesh supported) foils was installed in front of ESA and the foils were irradiated with a 12 MeV, $C^+$ ion beam ranging from 0.1 pA to 100 nA with a beam spot area changing from 0.2 to 6.0 mm$^2$. The ions penetrating the foils were analyzed by the ESA in a scanning mode and detected by a Si-detector. Resulting energy plots for ions transmitted by 1 μg/cm$^2$ foils are shown in Fig. 2. One foil without collodion required mounting on a mesh, the other one was collodion coated and the collodion removed by the ion beam during measurement. For comparison the energy plot of the primary beam is plotted. The shift between energy plots of the primary beam and that of ions penetrating the foils, as shown in Fig. 2, is due to the ion energy loss in the 1 μg/cm$^2$ carbon foil thus providing both

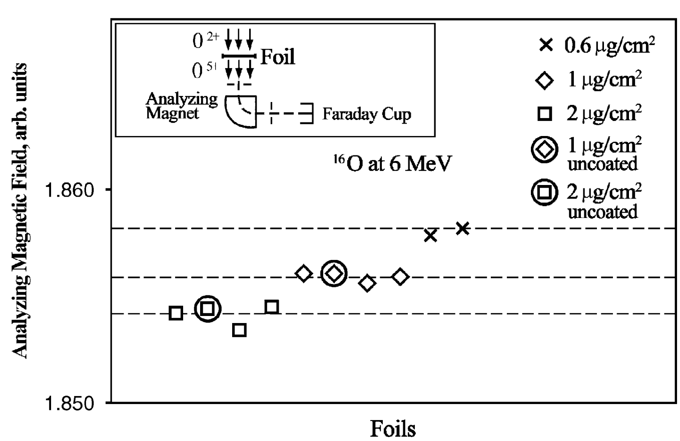


Fig. 1. Thickness measurement for different DLC foils with the high-resolution magnetic analyzer. Each point represents a magnetic field corresponding to the peak of the energy plot for one foil of specific thickness.

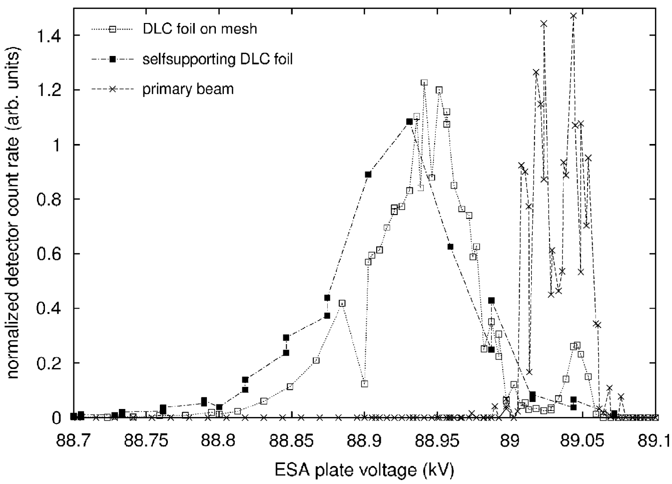


Fig. 2. Energy plots of the electrostatic analyzer for the mesh-supported and the self-supporting (collodion is removed nearly completely) DLC foils 1 μg/cm$^2$ thick together with that for primary beam.

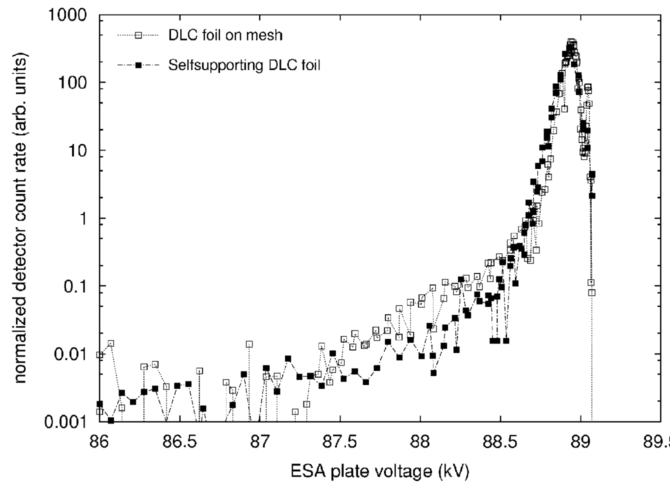


Fig. 3. Energy plots of the electrostatic analyzer for a collodion-coated DLC foil 1 μg/cm$^2$ thick after gradually increasing ion irradiation dose.

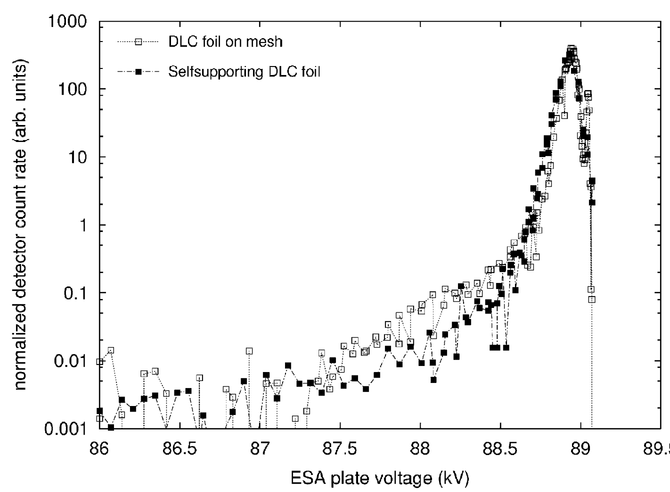


Fig. 4. Energy plots of the electrostatic analyzer for the mesh-supported and the self-supporting (collodion is removed nearly completely) DLC foils 1 μg/cm$^2$ thick. Please notice a logarithmic scale.

thickness calibration and sensitivity of this technique. The results of Fig. 2 are in good agreement with those in Fig. 1, confirming, in spite of the minor statistics, that the thickness of residual collodion might be less than 0.2 μg/cm$^2$ after the proper cleaning with an ion beam. This result demonstrates the suitability of collodion-reinforcement even for ultra-thin DLC foils and enables us to take advantage of large-size self-supporting DLC foils of this type.

In order, to verify the minimum beam intensity which is necessary to remove collodion coating from the foils, several DLC foils were exposed to different beam currents. Fig. 3 presents energy plots for transmitting ions after gradually increasing ion irradiation dose. Low-energy tails in Fig. 3 are obviously caused by ion energy loss and straggling in the collodion coating. Ion bombardment of 1 nA for 1 min seems to be sufficient to remove collodion coating nearly completely. Such beam current corresponds in our irradiation conditions to a beam density of around 5–10 nA/mm$^2$. For some applications of collodion-reinforced foils, i.e. in TOF analyzers for AMS, higher ion beam intensities might be required to clean the foil completely. Thus the "low-energy tails "of emerging ions might be minimized as shown in Fig. 4.

### 2.3. *Lifetime measurements for ultra-thin DLC stripper foils*

Lifetime measurements for DLC foils with thickness ranging from 0.6 to 5 μg/cm$^2$ have been carried out at the beam line of MP tandem of the Heidelberg MPIK. The foils were installed in front of the analyzing magnet and were irradiated by a $^{63}Cu^{3+}$ beam of 20 MeV energy, and 0.7–2.7 μA beam current and a beam spot area of about 20 mm$^2$. The vacuum was in the $10^{-5}$ Pa range during the ion beam bombardment. The foil conditions during lifetime measurements were monitored by a TV camera, while a high-resolution analyzing magnet permitted the verification of possible thickness changes of the foils under ion bombardment. Results of the foil lifetime measurements are presented in Fig. 5. Lifetime of a foil is defined in the usual manner as the time after which the intensity of the analyzed beam drops to half its initial value. No thickening of the DLC foils was observed during the irradiation lifetimes.

Despite the poor statistics plotted in Fig. 5, there seems to be no strong dependence of the DLC foil lifetime on their thickness in the range down to 1 μg/cm$^2$, while the lifetime drops significantly for thinner foils. Assuming that small holes and cracks in the irradiated area together with its thinning by ion beam sputtering are responsible for the foil failure, shorter lifetimes observed for ultra-thin foils can be explained by their reduced mechanical strength as compared to thicker ones. Our test showed, in addition, that thickness of the collodion coating appeared to be very

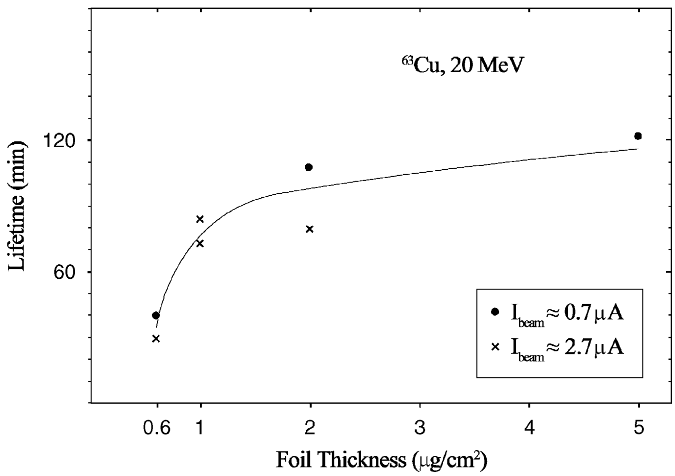


Fig. 5. Lifetimes of the DLC foils of different thickness irradiated in the beam line of the Heidelberg MP-tandem accelerator.

critical to lifetime for very thin foils, i.e. reinforcement of a 1 μg/cm$^2$ foil with a 20% collodion solution instead of 10% one resulted in lifetimes reduced 10–20 times under high-intensity heavy ion beams. This is possibly due to increased energy input to relatively thick collodion support by the ion beam.

More systematic comparative lifetime measurements for differently produced ultra-thin stripper foils are to be conducted in the HV terminal of the Heidelberg MP-tandem accelerator.

## 3. Summary and conclusions

Collodion-reinforcement and ion beam cleaning of self-supporting DLC foils with the minimal thickness of 0.6 μg/cm$^2$ is investigated by using energy analysis of transmitting ions. Lifetime tests of ultra-thin self-supporting DLC stripper foils for high-intensity heavy ion accelerators are in progress. Obtained results offer further improvement and are expected to expand applications of DLC foils in a variety of accelerator applications.


## Acknowledgements

We are grateful to Peter Maier-Komor for his continuing interest to this research, effective support and very fruitful encouragement. Thanks are due to Bernhard Schührer for his help in preparation of the foil samples for the lifetime tests and to all operators of the Heidelberg accelerator facility for their assistance during these tests.


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