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Production of stripper foils by laser ablation of carbon–boron sputter targets

Stefan K. Zeisler [a,*], Vinder Jaggi [a,b]

[a] TRIUMF, Applied Technology Group, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 2A3
[b] Advanced Applied Physics Solutions, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 2A3

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ABSTRACT

The TRIUMF Applied Technology Group operates several high-power industrial cyclotrons for commercial radioisotope production. Two of these accelerators, TR30-1 and TR30-2, can deliver H^- beams of 30 MeV and beam currents in excess of 1000 μA. For many years, in-house produced diamond-like carbon (DLC) foils of approximately 2.0–3.0 μm thickness have been utilized to extract proton beams from these accelerators.

The TRIUMF Carbon Foil Laboratory uses pulsed laser deposition to manufacture DLC films in a wide thickness range (10 nm to ~10 μm). It is known that the quality and the composition of the graphite sputter target used in the laser ablation process has a significant effect on the mechanical properties of the deposited film as well as its durability in ion beams. Encouraged by the findings of Sugai et al. [1], we investigated the production of stripper foils by laser ablation of graphite/boron composites as well as multilayer foils using pure graphite and boron targets.

1. Introduction

Carbon stripper foils are widely used in research accelerators as well as industrial applications. Many commercial cyclotron facilities for the large-scale production of medical radioisotopes accelerate H^- ions to 12–30 MeV and beam currents up to ~1.6 mA. High-power accelerators in an industrial environment require stripper foils of the highest quality and durability.

The lifetime of carbon stripper foils in an accelerator depends on several parameters, such as type of foil material (amorphous, microcrystalline or nanocrystalline carbon structures), mounting method, handling of the foil before and during the mounting process, and eventually ion beam density, beam distribution and beam stability. Special attention should be given to the careful handling and mounting of stripper foils to ensure that they do not suffer mechanical damage (microcracks) before they are irradiated. Additionally, the foils should be mounted in a way that allows shrinkage or expansion when exposed to high temperatures by beam heating [2].

We previously presented our experiences with multilayer stripper foils containing one layer of diamond-like carbon (DLC) sandwiched between two layers of amorphous carbon [3]. Further developments were since conducted to produce pure DLC foils, which have become the standard beam strippers used in the TRIUMF isotope production facilities. In order to further improve the mechanical properties of foils and their lifetime in intense ion beams, we investigated the manufacture of foils by laser ablation of sputter targets containing boron.

2. Materials and methods

The laser deposition system used in experiments has been described previously [3]. All cylindrical sputter targets were of 10 cm diameter and 12 mm thickness. Depositions were performed on standard microscope slides (25 mm × 75 mm; Fisher Scientific Canada, Ottawa ON) coated with betain sugar solution [4] or detergent. After deposition, the films were annealed in air at 200 °C for 1.5–2 h and separated by dipping the substrate into hot water. Foils were removed from the water surface and dried at ambient temperature.

Target	Supplier	Method/application
Graphite type SFG-2	Poco Graphite, Inc. Decatur TX, USA	Standard foil (2.5 μm)
Graphite, 15% (w) B composite target	Plasmaterials, Inc. Livermore CA, USA	Regular deposition to desired thickness (2.5 μm)
Graphite, 5% (w) B composite target	Plasmaterials, Inc.	Regular deposition to desired thickness (2.5 μm)
Boron carbide (99.9%)	Plasmaterials, Inc.	Thin films only (< 150 nm)

* Corresponding author. Tel.: +1 604 222 7364; fax: +1 604 221 0436.
E-mail address: Zeisler@triumf.ca (S.K. Zeisler).

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Boron nitride (99.9%)	Plasmaterials, Inc.	Regular deposition
1. Graphite type SFG-2	Poco Graphite, Inc.	Double layer foils: 10% B, 90% DLC
2. Boron (99.9%)	Plasmaterials, Inc.	
1. Graphite type SFG-2	Poco Graphite, Inc.	Triple layer foils: 45% DLC, 10% B, 45% DLC
2. Boron (99.9%)	Plasmaterials, Inc.	

3. Results and discussion

3.1. Composite targets

The production process using composite targets with 15% and 5% boron, yielded films of acceptable quality. The deposition rate was comparable to the standard SFG-2 graphite target (0.08–0.13 nm/s). At 15% boron content, the foils were rather brittle and not as easy to handle as the standard DLC foils or those containing only 5% boron. Foils produced from either composite targets had pinholes. Only foils with 5% boron were used for testing in the TR30 cyclotrons. On average, they lasted approximately 20–50% longer than a standard DLC foil of equal thickness.

3.2. Boron carbide target

The deposition of films using a boron carbide target required very high laser beam power. Even at maximum beam output of the laser, the deposition proceeded very slowly (0.02–0.04 nm/s), therefore this method was only explored for films <150 nm thickness. The resulting thin foils had good mechanical properties, were nearly transparent and extremely robust. However, after a small number of production cycles the results could not be reproduced. Efforts to machine the target face in order to recover the original surface structure failed due to the hardness of boron carbide.

3.3. Boron nitride target

Boron nitride, being isoelectronic to carbon, exists in amorphous, graphitic and diamond-like structures. Several attempts were made to deposit boron nitride films similar to DLC under varying conditions, but it was impossible to produce a cohesive layer. Therefore, this process was abandoned.

3.4. SFG-2 and boron targets

Two kinds of multilayer depositions were investigated. The first method involved the deposition of 250 nm of pure boron into the prepared substrate, followed by 2250 nm of diamond-like carbon (10% B, 90% DLC), for a total thickness of 2.5 μm. The resulting foils were free of pinholes and slightly more mechanically stable than the standard DLC foils. Their performance in the TR30 cyclotrons was superior to the standard foil (narrower beam profile, 10% longer lifetime).

In the second process, the boron layer was sandwiched between two equal layers of diamond-like carbon (45% DLC–10% B–45% DLC), again to a total thickness of 2.5 μm. These triple layer foils were pinhole free and showed outstanding mechanical strength and the highest flexibility of any foils ever produced in our laboratory. They can be rolled repeatedly to a small radius and return to their original flat geometry without breakage (Fig. 1).

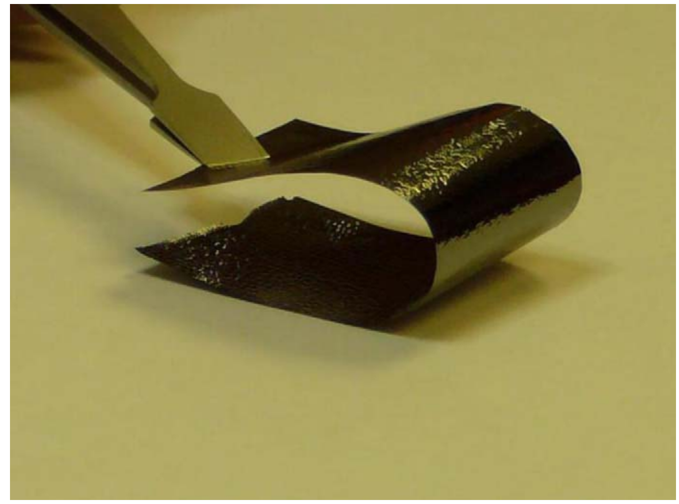

Fig. 1. Triple layer foil, 25 mm × 60 mm, 1.7 μm total thickness (45% DLC–10% B–45% DLC).

We explored this process for different thicknesses, namely 2.5, 2.0, 1.7, 1.0 and 0.5 μm. All foils had the same extraordinary properties. Foils of 1.7–2.5 μm thickness are currently being evaluated in the TRIUMF cyclotrons. Preliminary results indicate an increase in the lifetime of about 10–15% compared to the standard DLC foil.

4. Conclusions

Our experiments indicate that two kinds of boron containing films may be of particular interest as stripper foils. The foils deposited from a graphite/5% boron composite target appear to have superior stability in H^- beams and are preferable if longer lifetime in the accelerator is the main objective.

In cases where highest mechanical strength and flexibility of the stripper are required, preference may be given to the triple layer foil with a pure boron layer sandwiched between two DLC layers.

Experiments are continuing to combine both methods in order to produce a foil of high mechanical strength and excellent durability in ion beams.

Acknowledgments

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