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Carbon–silicon stripper foils

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ABSTRACT

TRIUMF operates several high power industrial cyclotrons for the commercial production of isotopes for radiological diagnostics and therapy. Two of these accelerators, TR30-1 and TR30-2, are capable of delivering 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 various compositions have been utilized to extract proton beams from these cyclotrons (Zeisler and Jaggi, 2008) [1].

The TRIUMF Carbon Foil Laboratory, now incorporated as Micromatter^{TM}, uses pulsed laser deposition to fabricate DLC films in a wide thickness range (from 10 nm to ~10 μm). More recently, we reported the production of DLC foils containing boron (Zeisler and Jaggi, 2010) [2]. Carbon–boron multilayer foils have outstanding mechanical stability and show an extended lifetime in high intensity proton beams. In an attempt to further enhance the quality of our beam strippers, we investigated the production of carbon–silicon multilayer foils.

1. Introduction

Stripper foils are important components of particle accelerators. Many facilities for the commercial production of medical radioisotopes accelerate H^- ions to 12–30 MeV and operate at beam currents of 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, mounting method, handling of the foil before and during the mounting process, as well as beam density, distribution and stability. Careful handling and mounting of the stripper foils are important to ensure that they do not suffer from mechanical damage 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 [3].

We previously published our experiences with pure DLC foils as well as DLC foils containing up to 10% boron as a single layer between two carbon films. Inspired by the extraordinary mechanical and physical durability of these carbon–boron foils, we set out to investigate the suitability of other materials as admixtures to our DLC foils.

A prospective additive or dopant for carbon stripper foils has to fulfill two basic requirements. First, it should be electrically non-conductive. Stripper foils generally erode during ion beam bombardment. The released material is deposited virtually everywhere inside the cyclotron vacuum tank, including the surface of electrical insulators. If the deposit is conductive, such coatings can lead to short-circuits or high voltage sparks inside the accelerator. Second, the additive should not be activated significantly by the particle beam to avoid excessive radiation dose to maintenance personnel.

We chose silicon as additive to our DLC foils for various reasons. Silicon is the second member of the carbon group in the periodic system of the elements. It is mainly tetravalent; its chemical behavior resembles that of carbon in many respects. Silicon is an electrical insulator and does not form considerable quantities of long-lived radioisotopes that emit penetrating radiation if exposed to 30 MeV protons. In addition, high purity silicon sputter targets are relatively inexpensive and readily available from commercial suppliers.

2. Materials and methods

The laser deposition system used in the experiments has been described previously [1]. All cylindrical sputter targets were of 10 cm diameter and 12 mm thickness. The carbon target (Graphite Type SFG-2) was obtained from Poco Graphite, Inc., Decatur, Texas, USA. The silicon sputter target (Si 99.9%) was purchased from Plasmaterials, Inc., Livermore, California, USA.

DLC–Si foils were produced according to the established procedure for carbon–boron multilayer foils. In summary, the

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Fig. 1. Comparison of DLC–B–DLC foil (left, flexible) and DLC–Si–DLC foil (right) of equal thickness.

silicon layer was deposited between two equal layers of DLC. The foils thus produced contained 5%, 10% and 15% Si.

Depositions were performed on standard microscope slides (25 mm × 75 mm; Fisher Scientific Canada, Ottawa ON, Canada) coated with betain-sugar solution [4]. After deposition, the films were annealed in air at 200–240 °C for 1.5 h and separated by dipping the substrate into hot water. Foils were removed from the water surface and dried at ambient temperature.

3. Results and discussion

The deposition of the DLC–silicon multilayer foils followed the same process as for the DLC–boron foils. However, the deposition of silicon proceeded more slowly than that of boron under the same conditions, typically <0.01 nm/s as compared to 0.03–0.04 nm/s for boron (Fig. 1).

The produced foils were light–tight, flat and mechanically stable. Even with only 5% silicon, foils were much more rigid than both pure DLC foils and DLC–boron foils of the same thickness. They entirely lacked the mechanical flexibility and durability of the boron doped foils. Still, they could be mounted into the foil holders for the TR30 cyclotrons without difficulty.

DLC–silicon foils with 10% or 15% Si were found to be rather brittle and were hence not used for beam stripping experiments.

According to the preliminary performance data in our 30 MeV cyclotrons, the silicon containing foils show no noticeable advantage over pure DLC foils. While their exact lifetime under irradiation conditions has not been established in detail as yet, initial observations indicated an inferior performance compared to DLC–boron foils.

4. Conclusions

Multilayer foils comprising DLC–Si–DLC films have been produced successfully by laser plasma ablation. The foils are mechanically stable and rigid but more brittle than pure DLC foils. In view of the rather time consuming manufacturing process, their preliminary performance data from beam extraction experiments do not warrant continuing development work towards a product for routine use in our isotope production facilities.

Acknowledgments

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