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Production of carbon stripper foils for high-power cyclotrons

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Abstract

TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics operates three industrial negative ion cyclotrons for commercial radioisotope production. Two of these cyclotrons (TR30 and TR30-2) can deliver 30 MeV protons at beam currents in excess of 1000 μA and are designed for optional dual beam extraction and continuous operation.

High-power negative ion accelerators use stripper foils as thick as 500 μg/cm^2. It has been found that very smooth films with nanocrystalline microstructure perform the best in high-current applications. However, high-quality thick foils with good uniformity are difficult to manufacture. To meet our specific requirements, we have developed a carbon arc deposition system capable of producing durable, homogeneous carbon stripper foils. In this paper, we report on the fabrication of carbon foils with a thickness of 100–200 μg/cm^2. The manufacturing equipment capable of producing ~600 cm^2 of foil in a single run and the process details are described. Properties of these foils and their performance in the cyclotron are discussed.

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Keywords: Carbon foils; Carbon arc deposition; Stripper

1. Introduction

Carbon foils have many applications in industry and science. Thin carbon foils are often used in negative ion accelerators to strip the electrons off the ions in the accelerated beam, which changes its polarity. In the case of high-power industrial cyclotrons, one of the prime concerns to the user is the lifetime of the foils. Durable foils reduce cyclotron downtime and maintenance and thereby reduce personnel radiation exposure. For example, in our radioisotope production facility, changing the extraction foils in the cyclotron results in about 5 h of downtime and 100 μSv of personnel dose.

Imperfect foils or foils that are too thin may lead to a catastrophic failure during irradiation that occasionally results in damage to the machine or to the beamline and in turn, may result in significant downtime and substantial loss of revenue.

Many standard techniques for producing thin carbon films with thicknesses from 4 μg/cm^2 to 1 mg/cm^2 have been described in Refs. [1–8]. In our laboratory, we used the carbon arc deposition method with great success.

2. Materials and methods

A customized evaporation system with a water-cooled steel bell jar of 50 cm diameter was purchased from PTB Sales, Azusa CA, USA. Ultra high vacuum in the deposition chamber is established with a CTI-8 cryogenic pump.

The circular substrate holder, designed and fabricated by TRIUMF, was manufactured from aluminum and anodized for electrical insulation. It has a diameter of 40 cm and can accept 35 standard microscope slides or similar substrates.

Spectroscopically pure graphite rods were purchased from Pelco International, Redding CA, USA. Betaine monohydrate was obtained from Fisher Scientific Canada (Acros Organics Catalogue), Nepean ON, Canada. Customized sapphire and molybdenum substrates were purchased from UHV Technologies, Ft. Worth TX, USA.

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3. Deposition process

Molybdenum or sapphire slides are thoroughly cleaned and then coated with the betaine/sugar (7:1) release agent described by Maier-Komor et al. [9]. Two drops of solution are placed on one side of each slide and then wiped off with paper tissue until a shiny surface becomes visible. The slides are mounted onto the substrate holder with the coated side facing the carbon rods. The median distance to the center of the discharge is 20 cm.

The carbon films are produced by arc discharge at 20 V and a current of 160–200 A. During the process, the chamber is water-cooled and evacuated with a cryo pump. In our system, the optimum deposition is achieved by flashing the carbon arc for just a few seconds at a time. It takes about 30 cycles to achieve the required area density of approximately 200 $\mu g/cm^2$, while the thickness of the films is monitored using a quartz crystal.

After completion, the chamber is vented and the substrates are transferred to a vacuum oven in which they are baked at 100 °C for 1 h, and finally left to cool overnight. The films can then be detached in a hot water bath and dried on a sheet of plastic. The foils so obtained are mechanically stable and can be handled easily. They may be stored for extended periods. When needed, they are installed on the foil holders and mounted on the extractors in the cyclotron.

One or two samples are usually removed from the batch before the baking step to measure the absolute thickness and homogeneity using a calibrated Dektak-IIA stylus. This gives an absolute value of the foil thickness from which the area density can be calculated.

4. Results and discussion

Initially, it was difficult to deposit homogeneous and light-tight carbon films, mostly due to sparking and pinhole formation. Experiments with 3.18 mm carbon rods failed entirely, so the system was reconfigured to fit 6.35 mm carbon rods to permit a higher deposition rate. We were able to obtain suitable carbon foils on standard microscope slides, however, the custom-made sapphire and molybdenum substrates were more inert and increased the reproducibility of the production process.

Using the carbon arc method, it was possible to successfully manufacture self-supporting, light-tight, robust carbon foils with thicknesses from 100 to 600 $\mu g/cm^2$ in large quantities. It appeared that maintaining a high vacuum and permitting the slides to cool between deposition periods was essential for a successful production.

Performing the post-deposition baking process at elevated temperature (160–170 °C) yielded foils of somewhat grainier appearance, which performed as well or slightly better in the cyclotron beam than the ones conditioned at 100 °C.

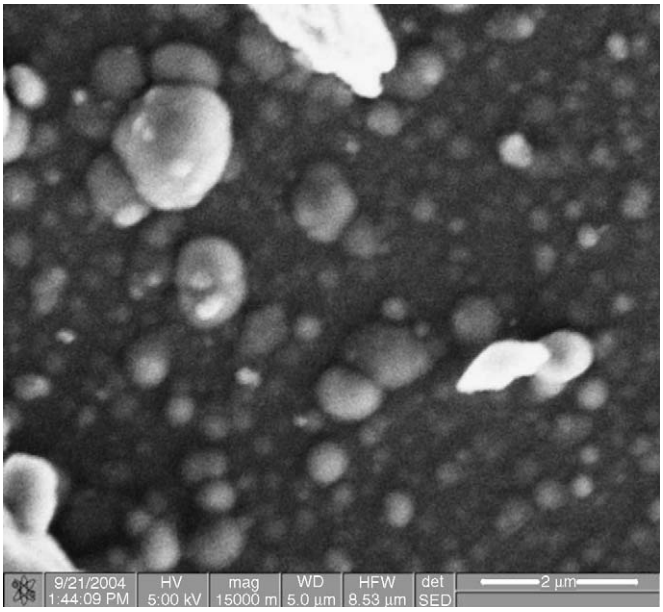

Fig. 1. SEM picture of a carbon foil produced by carbon arc deposition.

Under the microscope, our carbon foils show a very fine structure, good uniformity and virtually no defects. Fig. 1 shows a SEM micrograph of a typical foil sample, Fig. 2 a thickness profile recorded with the Dektak-IIA stylus.

We tested both smooth and shiny foils as well as foils with uneven surfaces in day-to-day operation on the TR30 cyclotrons. Extracted beam currents were in the order of 500–700 μA at 30 MeV. The smooth and shiny foils were found to have a ~50% greater lifetime than similar foils with rougher surfaces. We also confirmed that at our peak beam currents, thicker foils lasted longer than thinner ones. On the other hand, thicker foils disperse the beam much more, requiring very careful tuning of a beamline. Naturally, the optimum thickness depends on the particular application and can only be found empirically. For the TR30 type cyclotrons, their beamline configuration and target stations, extraction foils of 200 $\mu g/cm^2$ provided both excellent beam shape and durability.

The beam performance of our foils was compared to those commercially available from ACF Metals (Tucson AZ, USA) and Yissum Research Development Company (Hebrew University of Jerusalem, Israel—now defunct). Extracted beam currents were again in the 500–700 μA range (at 30 MeV).

Foils obtained from ACF Metals usually deteriorated rapidly and had to be changed after approximately 36 h of continuous operation, whereas foils from Yissum typically failed after 4–5 days. The carbon foils produced as described above, under the same beam conditions, usually lasted 4–5 days (glass substrate) and 7–10 days (Mo substrate). The maximum lifetime observed for one of our foils was 4.5 months. Most of the foils produced under optimum conditions survived 7–9 days of continuous beam.

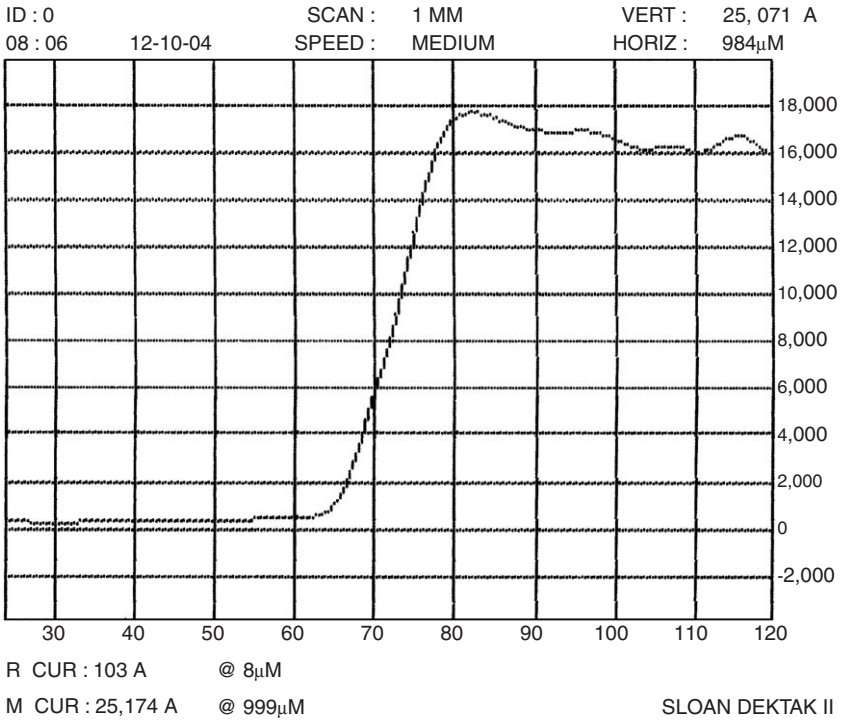

Fig. 2. Profile of a standard carbon foil measured with a Dektak-IIA stylus; X, scanning length, 1 unit = 10 μm; Y, thickness in Ångström units.

5. Conclusions

Mechanically stable, homogeneous carbon stripper foils are essential for reliable commercial radioisotope production with negative ion cyclotrons. We have demonstrated that it is possible to reproducibly fabricate carbon foils of excellent quality using a simple carbon arc deposition system. Developments are in progress to improve the production equipment and to make customized foils available to other research institutions.

Acknowledgments

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References

[1] G. Dollinger, P. Maier-Komor, Nucl. Instr. and Meth. B 53 (1991) 352.
[2] P. Maier-Komor, A. Bergmaier, G. Dollinger, C.M. Frey, H.J. Körner, Nucl. Inst. and Meth. A 397 (1997) 131.
[3] R.L. Auble, J.K. Baier, D.M. Galbraight, C.M. Jones, P.H. Stelson, D.C. Weiser, Nucl. Instr. and Meth. 177 (1980) 289.
[4] I. Sugai, T. Hattori, H. Suzuki, H. Kinoshita, H. Kato, K. Yamazaki, Nucl. Instr. and Meth. A 265 (1988) 376.
[5] I. Sugai, T. Hattori, H. Kato, Y. Takahashi, H. Muto, K. Yamazaki, Nucl. Instr. and Meth. A 282 (1989) 164.
[6] H. Muto, M. Oyaizu, K. Kawasaki, Y. Takahashi, K. Takeuchi, I. Sugai, T. Hattori, Nucl. Instr. and Meth. B 103 (1995) 249.
[7] V.Kh. Liechtenstein, T.M. Ivkova, E.D. Olshanski, A.M. Baranov, R. Repnov, R. Hellborg, R.A. Weller, H.L. Wirth, Nucl. Instr. and Meth. A 438 (1999) 79.
[8] P. Maier-Komor, G. Dollinger, R. Krücken, Nucl. Instr. and Meth. A 521 (2004) 176.
[9] P. Maier-Komor, Nucl. Instr. and Meth. 102 (1972) 485.