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Carbon micro-ribbon and strip polarimeter targets for the AGS and RHIC[☆]

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Abstract

Current techniques used to produce carbon micro-ribbon targets 5 μm wide × 3.7–4.5 μg/cm^2 × 25-mm long will be described. Developmental emphasis was to provide nearly identical micro-ribbons with the minimum number of atoms per unit of length, and to position them within ±0.5 mm of the desired location on C-shaped frames.

The foil strip targets to be described were 200–600 μm wide × 3.7–4.5 μg/cm^2 × 51 mm long. These were produced from 25-mm-wide carbon film deposits that were scribed using a jig prior to dissolving the betaine/sucrose release agent under ethanol.

Both types of targets required methods and devices that differed significantly from those reported previously for substrate texturing, masking, vacuum deposition, releasing from the substrate, and mounting. Sets of 12–24 of the targets have been made for the 2006 run period at BNL.

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Keywords: Carbon—C; Micro-ribbon target; Vacuum deposition

1. Introduction

Initial interest in developing vacuum-deposited carbon micro-ribbons (CMRs) resulted from their promise as solid internal targets and target backings for the Cooler synchrotron at the Indiana University Cyclotron Facility (IUCF). Eventually that work [1–3] could produce self-supported targets of 3.6–4.2 μg/cm^2 × 3.3–8 μm width × 25-mm length, although never with great ease.

The idea to use the left-right asymmetries to quantify beam polarization with circulating beams via proton-carbon elastic scattering in the coulomb-nuclear interference (CNI) region was first proposed in 1998 [4]. In 1999, CE75 [5], a latter-day experiment with polarized protons in the Cooler, demonstrated that the CMRs could be used for this purpose. During the 2001–2002 run period of Brookhaven National Laboratory (BNL), an internal CNI polarimeter was tested successfully in the Alternating Gradient Synchrotron (AGS) [6]. The AGS is the last in a series of three accelerators that feed beam into the Relativistic Heavy Ion Collider (RHIC). Subsequently, in the 2002–2003 run period, a CNI polarimeter began service in the RHIC ring. From then, through the date of this report, CNI polarimeters with CMR targets in RHIC, and C-foil strip targets in the AGS have been essential to experiments with polarized protons.

As one might expect, the various devices and equipment used at IUCF and BNL were not identical. This report includes that information, with hope it could shorten the development time at other facilities.

2. Devices and procedures for micro-ribbon production

2.1. Mask and mask stretcher

A key to the development of the micro-ribbons was the mask used in vacuum depositions of carbon. Until the

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present collaborative effort, wire-grill masks wound with 50 μm diameter wire were used to set the widths. The best grill-winding resolution achieved at IUCF produced mountable ribbons with widths of 3.3–10 μm. The variation required microscopic determination of the width of each one, a tedious process.

As the luminosity of the beam increased in RHIC, only the narrowest CMRs were useable. Driven by a low production rate per carbon deposit, a source was found to fabricate evaporation masks with 6 ± 2 μm wide slots in a supporting web of 1 mm wide strips (Tecan Inc., Dorset DT4 9TU, UK). The masks were electroformed in 70 μm thick nickel foil. A slot-width resolution of ± 2 μm was achieved by electro-thinning to 10 μm, 106 μm wide strips into one side of the foil. Slots 6 μm wide were then produced in the center of these thinned strips. Because ribbons with sharply defined edges were desired, care was taken to orient the non-thinned side of the mask toward the glass substrate.

The first trials with an electroformed mask made evident that during the deposition close contact between the mask and glass substrate was not maintained by simply clamping them together near the ends. The heat absorbed by the 1 mm wide strips between the slots of the masks caused them to lengthen and sag away from the substrates. This resulted in carbon under-coating that persisted even at a source-to-substrate distance of 29 cm. To produce deposits with well-defined edges, it was necessary to provide dynamic tensioning with a spring-loaded stretcher (Fig. 1a).

The stretcher at IUCF was constructed from type 304 stainless steel. Contacts between the device and the ends of the mask were at a raised ridge (1 mm wide × 25 mm long) on the inner surface of the upper part of the clamps. The steps to mount a mask in the stretcher were to: (a) Tighten the set screws of one cross piece to secure it to the 6.35 mm diameter rods. (b) Slide the other cross piece toward the first one until the separation distance was appropriate for the mask length and, thereby, compress the springs between them. (c) Use the set screws to secure the position of the second cross piece. (d) Mount the mask and clamp it via the four machine screws. (e) Release the four set screws. The last step was necessary to avoid heat-inducted twisting of the stretcher and, consequently, twisting of the mask during carbon deposition.

A mask may remain in the stretcher and used until it becomes damaged. Carbon deposited on the surface was removed with common Scotch® adhesive tape, always pulling it free along the major axis of the web. Compressed air was used to ensure that no small particles remained in the slots.

The stretcher at BNL (Fig. 1b) is very similar in design to the IUCF stretcher. The rods used had a diameter of 1.25 cm and the springs had a rating of 1.58 kg/cm.

2.2. Air/slurry-textured glass substrates

The deposition surfaces of the glass substrates used at both facilities were textured using the technique reported in Ref. [3]. It employs an easily made spray gun to etch small, uniform pits in glass microscope slides. Details of the spray gun are shown in Fig. 2. Unlike the earlier texturing methods, it does not produce random surface scratches that occasionally result in CMRs too short to mount, or otherwise inexplicable target breakage.

The glass was from microscope slides of 25 mm × 75 mm area scored and broken to dimensions of 15 mm × 60 mm. The slurry for etching consisted of 75 g of 5 μm alumina particles in 250–275 ml of de-ionized water.

Pressurized air at 6.8–8.5 bars powered the gun and pulled slurry from a constantly stirred reservoir beneath the support stage for the glass. The two ends of the glass pieces were secured beneath the heads of small nylon screws.

The working end of the gun was held ~2 mm from the surface of the glass and moved at a rate of ~1 mm/s back and forth along the length. After ~5 min of etching, the glass was rinsed, dried and evaluated, both with the unaided eye and at a magnification of 1000. The process was repeated until the surface had a uniform, slightly milky

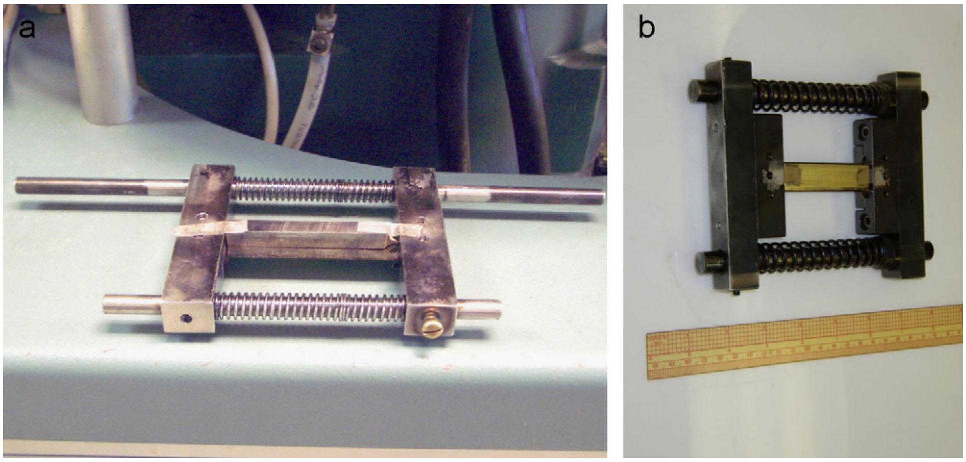

Fig. 1. (a) IUCF mask stretcher shown with a mounted mask and a weighted substrate glass and (b) BNL mask stretcher sans weighted substrate glass.

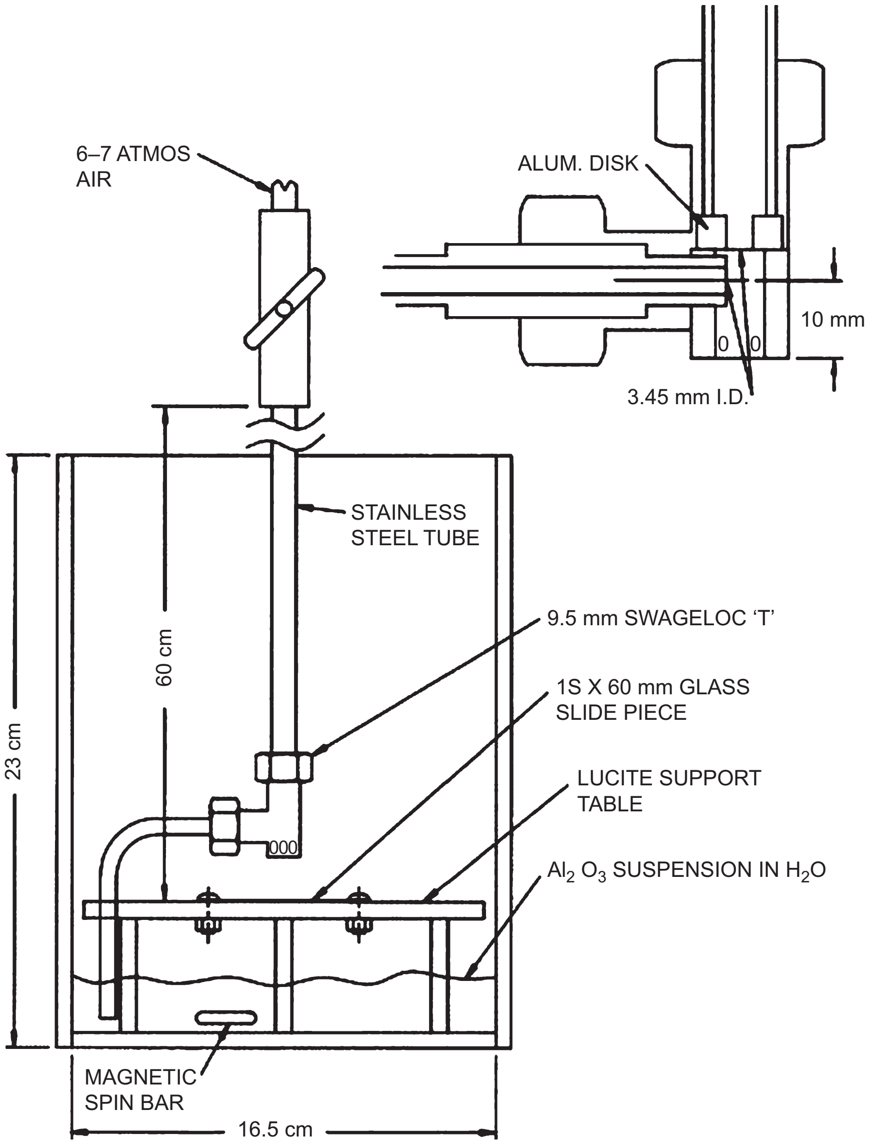

Fig. 2. Apparatus used to texture the surface of glass substrates with use of an alumina/water slurry and pressurized air.

appearance. The design features of the slurry gun are not thought to be critical.

Individual substrates with good surface uniformity were used many times. When a substrate had an excessive amount of carbon from previous evaporations, it was cleaned using an ungloved finger coated with a thin mix of water and 12.5 μm alumina powder. After a DI-water rinse followed by an acetone rinse, it was returned to service.

2.3. Substrate preparation

Shortly before a carbon deposition, ~10 μl of the detergent Tergitol 8 (Sigma Chemical Co., St. Louis, MO) was spread on the textured surface of the substrate. Invisible to the unaided eye, the residue remaining on the surface after it was polished with a Kimwipe® (Kimberly Clark, USA) was sufficient to release CMRs onto the surface of water. Tissue particles left on the surface were removed with jets of air from a rubber bulb fitted with a transfer pipette.

An 18 g lathe tool was used to hold the substrate glass in position on the stretched mask (Fig. 1a). The lathe tool was secured with 5-mm-wide strips of adhesive tape to the cross pieces of the stretcher frame.

2.4. Electron guns and deposition parameters

The single-hearth, 3 kW, permanent-magnet e-gun reported in Refs. [1,2] was used for all the carbon depositions at IUCF (Fig. 3a). The center of the substrate/mask assembly was positioned to the rear ~15° behind a vertical line drawn from the hearth of the e-gun. This prevented a line of sight between the e-gun filament and the mask. Discs of carbon 2–3 mm thick cut from a 9.5 mm diameter rod (Poco Graphite, stock no. AXF-5Q) was the source material. The source-to-substrate distance was ~30 cm.

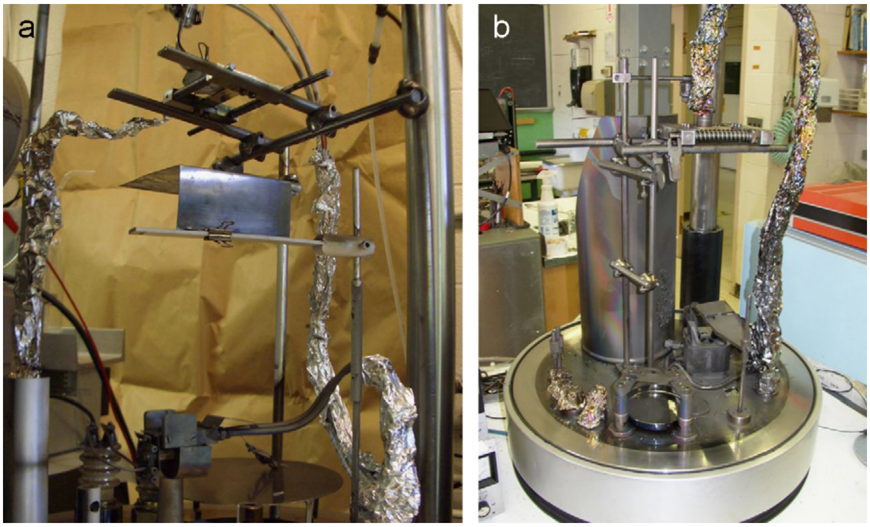

Fig. 3. (a) IUCF deposition setup, shown with the 3 kW e-gun, mask, and thickness monitor. (b) Comp. BNL deposition setup, shown with the 3 kW Temescal® e-gun.

A quartz-crystal thickness monitor was positioned ~5 mm above the plane of the mask and adjacent to the middle of the front edge. During the outgassing phase of the deposition, a shutter shielded the mask and monitor. The temperature of the carbon disc was increased at a rate that maintained the pressure in the bell jar below 6.7×10^{-4} Pa (5 μtorr). During deposition, the pressure was allowed to rise as high as 1.7×10^{-5} Pa (8 μtorr). The deposition rate was 0.6–1.5 nm s^{-1}. Although the thickness monitor was water cooled, the heat it absorbed drove down the indicated thickness during the depositions. Consequently, it was necessary to interrupt the depositions briefly 2–4 times to avoid over-shooting the useful range (3.6–4.2 μg/cm^2).

A Temescal® CV-3, 3 kW e-gun (Fig. 3b) was used at BNL. The substrate/mask was placed directly over the hearth. No attempt was made to shield the substrate/mask assembly from direct line of sight of the e-gun filament. The source-to-substrate distance was maximized (approx. 34 cm). The pressure at BNL was a factor of 5–10 higher than at IUCF, with most depositions occurring at a pressure of ~9.3×10^{-3} Pa (70 μTorr). The deposition rate is very similar to that reported at IUCF.

2.5. Release of micro-ribbons from the substrate

Historically, the mechanical device used for all water float-off operations at IUCF was a motor-driven rack-and-pinion arm. A carbon-coated substrate was clamped to the arm then slowly lengthwise it was driven beneath the surface of a water bath. The angle of the substrate to the surface of the water was ~30°. The method's shortcoming was that deposits of 6 ± 2 μm wide ribbons often bunched at the water–air interface.

The problem was resolved with use of vertical motion to immerse substrates positioned at an angle of ~30° to the surface of the water. As seen in Fig. 4a, the focus adjustment of an old microscope base was adapted for the purpose.

At BNL initial attempts for controlled vertical immersion was accomplished by adjusting the level of the water in the bath using a scissor jack and a drive motor. However, the movement of the scissor jack was not smooth enough to successfully release the CMRs. The scissor jack was abandoned for a modified microscope base (Fig. 4b), similar to the one used at IUCF, that allowed much finer manual immersion of the substrate.

The nearly transparent floating corrals in Fig. 4a and b were cut from 0.25 mm thick mylar sheet. They were necessary to control the destructive fan-like spreading of the CMRs that occurred during float-off. They also served to constrict fully released micro-ribbons (consistently difficult to see) to a manageable surface area in the water bath.

2.6. Lifting micro-ribbons from the water

Three-axis positioners fitted with flexible two-section arms (Fig. 5a and b) assisted three actions:

(a) Attachment of a micro-ribbon end to a pick-up stick fitted with a 10–12 mm length of 20 μm diameter wire. First, the end of the wire was positioned ~2 mm above the surface of the water bath. Second, the light-weight two-section arm was moved directly by hand to position the end of the wire near the end of a floating ribbon. Third, the flexible arm was bent down (by hand) until the end of the wire was 1–2 mm below the surface of the water. Fourth, pressure on the arm was released. If this last step failed to attach a ribbon end to the wire, it was repeated as necessary. Patient probing along the side edges of the corral was often required to locate ribbons aligned along them.

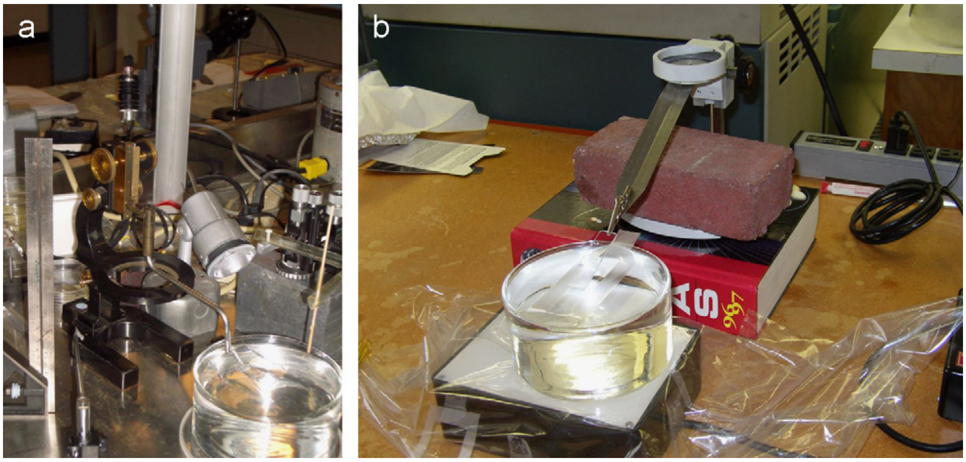

Fig. 4. (a) Setup at IUCF to immerse C-coated substrates vertically in a water float-off bath, shown with a Mylar ribbon corral. (b) Comp. setup at BNL.

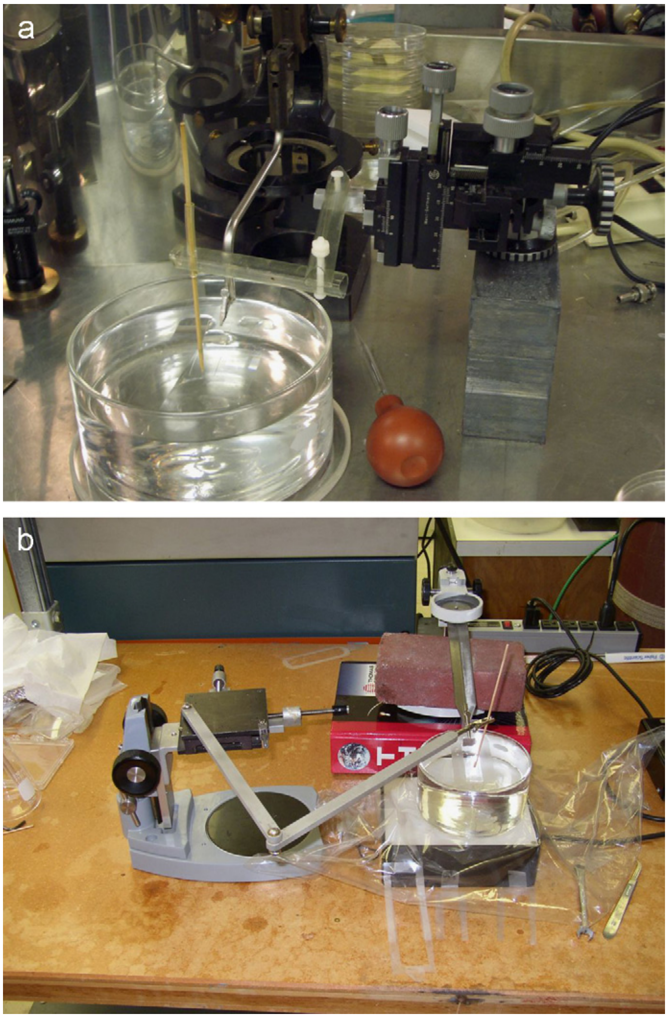

Fig. 5. (a) Three-axis positioner to lift CMRs from water and mount them on target frames. (b) Comp. positioner at BNL.

(b) Slow withdrawal of ribbons from the water bath. This allowed water that would exceed the tensile strength of the ribbons to drain away and evaporate.

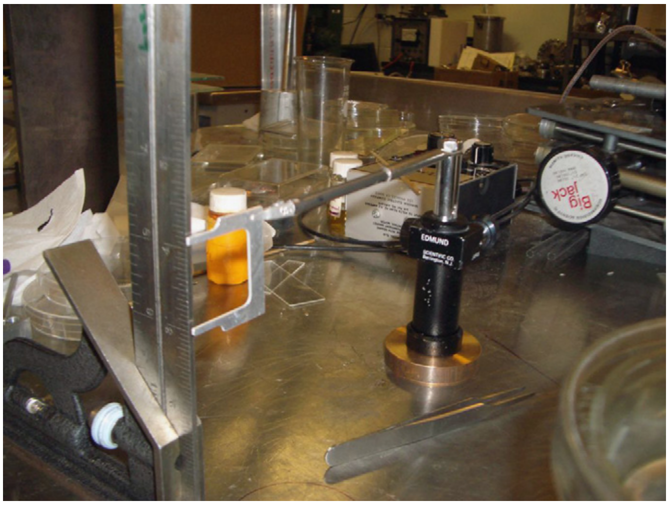

Fig. 6. Height-adjustable post and rotatable arm used to position a target frame for mounting a CMR at IUCF.

(c) Attachment of ribbons at a desired location on the target frames. Rather than lifting the entire length of a ribbon from the water, 3–5 mm was left floating on the surface. To stabilize the location of a ribbon held tautly this way, it was necessary only to control air currents in the vicinity of the water bath.

2.7. *Mounting on C-shaped target frames*

For mounting, target frames were clamped to the end of a rigid arm fixed to a rack-and-pinion height-adjustable post, as shown in Fig. 6. Prior to contact with a suspended ribbon, the plane of the target frame was rotated to ensure the upper fork made contact slightly before the lower one. This alignment was done with a machinist's square positioned along an arc to the suspended ribbon. Thus, a rotation and slight changes in the surface position of the device brought the frame forks into contact with a suspended ribbon. The frames were machined from 0.5 mm thick aluminum sheet.

Adhesion of a CMR to the desired locations on the forks was accomplished with contact cement (Feather Disc Adhesive 08041, 3 M Company, USA) diluted in cyclohexane. The solution was applied with a needle probe to 2-mm size areas. When dry, the coating (areal weight ~140 μg/cm^2) was slightly sticky. Immediately after mounting, better bonding and electrical contact between the ribbon and the frame was made with droplets of colloidal silver in water or silver conductive adhesive (Electron Microscopy Sciences, Hatfield, PA 19440, USA) applied at the points of contact.

2.8. Storage and shipping of mounted targets

The targets have been stored and shipped in the lightweight boxes shown in Fig. 7. The outer shell, lid, and inner liner were made of 0.5 mm thick aluminum sheet cut and bent to shape. Aluminum tape was used to seal the sides of the outer shell. The frame guides in the sides of the inner liner were formed by placing flat sheet on 2 mm thick Pb strips and then pressing the shank sections of 2.5 mm diameter drills into the surface. Thus far, these targets have been stored and shipped with ambient air in the boxes. For many years, bubble-wrapped boxes of targets in larger cardboard boxes filled with shipping peanuts have been commercially shipped successfully between our facilities. Breakage has occurred but, at most, three in a shipment of 24.

3. Devices and techniques for carbon strip production

Development of C-strip targets of 200–600 μm wide × 3.7–4.5 μg/cm^2 × 51 mm long was, by comparison, straightforward. The device shown in Fig. 8 enabled vacuum-deposited carbon films to be cut into strips with a width resolution of ±25 μm. Each degree of screw thread rotation moved the platform 2.52 μm vertically. The pointer arm on top was glued to a disc that was magnetically attracted to another disc glued to the adjustment wheel for the screw thread. The arrangement allowed the pointer to be reset prior to each movement. To cut a strip, the tip of a sharpened scalpel blade was held lightly to the hardened, ground-steel surface on the adjustable platform, and then moved along the surface of a film. During the first years of polarimeter development in the AGS ring, the scribing device was used to supply targets across the full stated range.

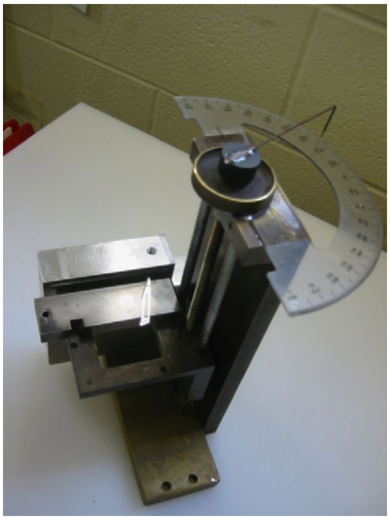

Fig. 8. Device used to scribe carbon films into strips with width uncertainties of ±25 μm.

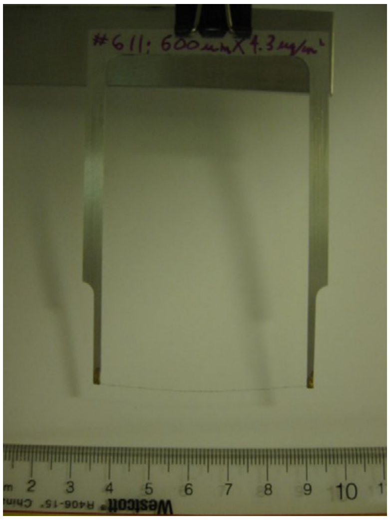

Fig. 9. A 600 μm wide C-strip target of 4.3 μm/cm^2 × 51 mm long.

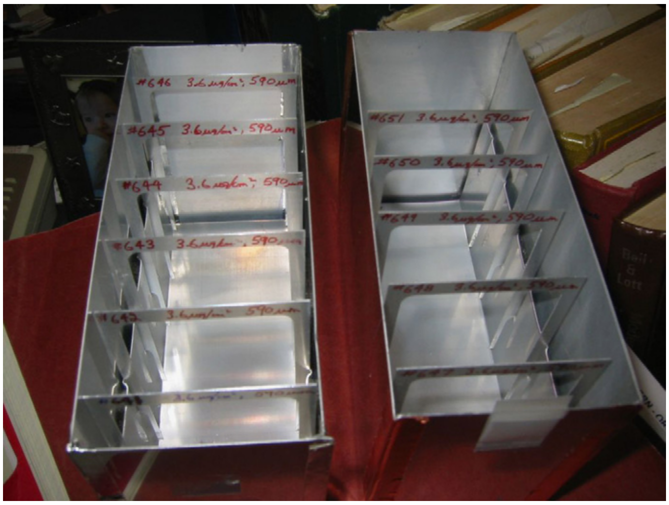

Fig. 7. Boxes for target storage and shipping.

Alternatively, strip targets have been produced using custom photo-etched deposition masks (Tech-etch, Plymouth, MA 02360, USA) with 125- and 600-μm wide slots. For fixed-width production, etched deposition masks offer increased width resolution. To date, these masks have been put in tension and mounted with glue onto aluminum rings. With careful attention to minimize the heat absorbed during depositions, carbon under-coating has been manageable.

Deposition for strip targets involved use of the betaine/sucrose parting agent applied to smooth glass substrates, as in Ref. [3]. Attempts to lift released strips from water were not successful, due to the forces exerted by capillary action and the weight of the water lifted with them. Immersion of the carbon-coated glass in ethanol worked well to dissolve the betaine/sucrose and ameliorate the tension forces. Mounting of the strips across 51 mm wide C-shaped frames was with the technique used for the micro-ribbons, except that the frames could be hand-held (Fig. 9).

4. Target lifetimes and conclusions

The CMRs are critical to the polarized proton program at RHIC. There are 10 CMRs mounted in each ring (6 in the vertical plane and 4 in the horizontal plane). The CMRs are only inserted into the beam to measure the polarization a couple of times per 5-h beam store with the CMRs being in contact with the beam for ~1 min per measurement. Despite a low duty factor the CMRs show a large variation in lifetime. Some CMRs will break on the first insertion while others have lasted beyond 3 weeks. Because the downtime associated with the replacement of the CMRs is long (~36 h), a greater emphasis is being placed on the quality control of the CMRs.

The C-strip targets in the AGS do not have lifetime issues. One or two targets will last the entire experimental run, which could be a couple of months long. Recent increases in the AGS beam intensity have resulted in a need for thinner C-strip targets. A new photo-etched deposition mask from Tech-etch has just been delivered with 125 μm wide slots. The thinner C-strip targets will be used for the next polarized proton experimental run.

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