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Preparation of DLC strip targets for the tabletop storage ring synchrotrons MIRRORCLE

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ABSTRACT

The tabletop storage ring synchrotrons MIRRORCLE-6X and MIRRORCLE-20SX can generate powerful extreme ultraviolet (EUV) radiation. They are applicable as sources for EUV lithography and for EUV photoemission spectroscopy. EUV radiation is emitted from a strip target consisting of a vertical strip with a width of ~3 mm mounted on a frame with an inter-arm distance of 10 mm. The highest EUV power is expected to be achieved by using a diamond-like carbon (DLC) strip with a thickness of 55–150 nm.

Two technologies were developed for preparation of such DLC strip targets. In the first technology, the DLC strip is backed by a 15-nm-thick formvar layer. Such a strip is floated on a water surface, and lifted from there directly onto an open frame. Since the strip tends to curl around its vertical axis while being lifted from the water, it curls mostly around the inter-arm center, and hence has its smallest width there.

In the second technology, the DLC strip is not backed. A temporarily closed frame is constructed using two extra blades, and the foil is attached easily to that frame. Subsequently, the two free strip edges are formed, via cutting with a surgical blade along the edges of the two extra blades. Lastly, the extra blades are released and left to fall. Using these two technologies, strip targets containing a 55 nm DLC+15-nm-thick formvar strip, as well as 85-nm-thick and 150-nm-thick DLC-only strips were prepared.

1. Introduction

1.1. Design characteristics of optimized EUV emitting targets for MIRRORCLE

Compact sources of powerful extreme ultraviolet (EUV) radiation are needed for performing EUV lithography (EUVL) and EUV photoelectron spectroscopy [1,2]. There is great interest in finding optimal EUV sources for these applications [3]. Our table top storage ring synchrotrons, MIRRORCLE-6X and MIRRORCLE-20SX, designed and developed by Yamada [4–8], can generate powerful EUV radiation, and are candidates for these applications. These machines accelerate and store relativistic electrons at 6 and 20 MeV, respectively. EUV is emitted via transition radiation (TR) as a result of relativistic electrons passing multiple times through a target [9].

Development of a theory of TR emission by a target in a low-energy storage ring [10,11] led to the design of optimized TR targets for X-ray lithography [12]. Experimental data for the total TR power emitted by MIRRORCLE are in agreement with calculated results [13].

Further work led to the design of optimized TR targets for performing EUVL by MIRRORCLE [14]. Due to the very strong absorption of EUV in the target and scattering of the relativistic electrons by the target, more EUV power is emitted from a single-foil TR target than from a multi-foil target [11]. The electron beam in MIRRORCLE has an elliptical cross-section with a width of 15–30 mm and a height of ~3 mm. To ensure a small, square, emitting area, the TR target should preferably be a vertical strip of one foil, approximately 3 mm in width. Such a strip should be mounted on our open frame, which has a distance of 10 mm between its two arms (Fig. 1). A target consisting of a narrow piece with two quasi-parallel free strip edges mounted on an open frame is classified as a strip target.

It is shown in Ref. [14] that the most in-band EUVL power is generated from MIRRORCLE by using a target strip made of diamond, while the second best strip material would be carbon. If

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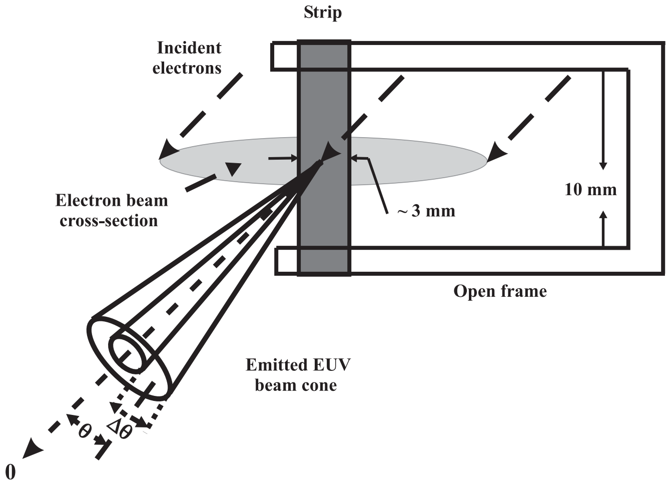

Fig. 1. Illustration of the geometry and the usage of our strip target, consisting of a strip mounted on an open frame.

diamond, with a density $\rho = 3.5\,\mathrm{g/cm^3}$, is employed, the optimal thickness of the target strip is expected to be 50–90 nm. For carbon, with $\rho = 2\,\mathrm{g/cm^3}$, the optimal strip thickness should be 70–150 nm [11]. Within these thickness ranges, thinner strips are preferable for MIRRORCLE-6X, and thicker ones for MIRRORCLE-20SX. Based on these results, and the fact that such very thin diamond foils are not manufactured, we focused our effort on using diamond-like carbon (DLC) as a material for preparing strip targets having two free 10-mm-long strip edges and a strip width of ~3 mm across the inter-arm center.

1.2. Mounting carbon strip targets

We are not aware of the literature describing the mounting of DLC strip targets. The most common application of nano-scale-thick carbon foils is for preparation of carbon targets in negative ion beam accelerators to strip electrons off the ions [15]. To suit that application, mounting nano-scale-thick carbon foils on closed frames is a well-developed and documented process [16]. The preparation and characteristics of collodion-backed carbon foils are reported in [17]. Mounting of carbon targets on frames with only one free edge is described by Lozowski and Hudson [18]. The only articles discussing mounting carbon strips, which is more difficult, were also published by Lozowski [18,19]. He mounted 15–25-nm-thick and 0.2–0.6-mm-wide strips on open frames using a different technology than ours. In his works he introduced the methods for constructing a temporarily closed frame and attaching foil to such a frame, and forming a free foil edge (although only one) by surgical blade cutting.

It is known, however, that CVD diamond foils released from substrates curl badly [20]. Furthermore, ~3-mm-wide strips curl much more than 0.2–0.6-mm-wide strips, which additionally complicates their mounting.

In this paper we describe the preparation of optimized DLC strip targets for EUVL by MIRRORCLE. We used DLC films with thicknesses of 55–150 nm. The density of these strips is $\rho = 2.1$–$2.2\,\mathrm{g/cm^3}$, which is closer to the density of carbon than to the density of diamond.

2. Separating and floating DLC strips

The DLC films used in this study were prepared by pulsed laser deposition in TRIUMF's Carbon Foil Laboratory in Vancouver, Canada. The films were delivered on 25 mm × 65 mm glass substrates, with detergent as a parting agent. The film thickness was 55, 85, or 150 nm, as measured with a Dektak stylus. The films were supplied either "as deposited" or after being annealed to 423 K (150 °C).

To prepare a DLC strip target for our MIRRORCLE storage rings, we needed to separate 3–6-mm-wide and ~25-mm-long DLC strips from the supplied specimens. To achieve this, the specimen was initially laid on a working table, with its DLC film facing up, and a hard ruler was fixed on two short stands above the film surface, without touching it. Then, the head of a diamond cutter was moved along the line formed by the ruler, while the cutter head was pressed down onto the specimen with enough force to break the film and scratch the glass below it. Next, the glass was turned round until the free edge parallel and closest to the scratched line was fixed on the table, so that the glass plane formed an angle of ~45° with the table plane. The scratched surface was facing down. Then the glass was pushed gently with two fingertips, parallel to the projected scratch line, until the glass broke, forming a DLC strip on glass. During the process of pushing and breaking the glass, the forming strip was supported by two other fingers, to prevent the DLC surface from touching the table.

When floated off the glass, and kept on its own either in air or in ethanol, the DLC strip rolled into a cylinder with a diameter of ~1.5 mm, due to its significant internal stress. It could not be reshaped to a planar strip after drying. Furthermore, our DLC strip could not be floated off of the glass in ethanol. However, the strip floats easily off the glass onto a water surface. Therefore, we used water, rather than ethanol, for floating the DLC strips off the glass, as well as the standard floating-off technique [17,18].

3. Preparation of strip targets using plastic-backed DLC

Our DLC strips always broke when lifted from the water surface onto our open frames, which are 3 mm thick. This problem could be circumvented by covering the DLC specimen on the glass with a plastic film. Lifting the DLC strip from a 2% solution of collodion in isoamyl acetate produces a ~65-nm-thick backing film. Unfortunately, after such a backed DLC on glass strip was separated from the rest of the specimen, the DLC strip still breaks while lifting it from the water. Utilizing a 0.5% solution of formvar in ethylene dichloride produces a ~15-nm-thick backing film. Such a backed strip could always be lifted successfully from the water surface onto our open frame. Backing by formvar is also a better choice for us than backing by collodion, because formvar can withstand higher temperatures and contains more carbon atoms, ~33%, as against ~22% for collodion. Our preference for using a backing material with a larger concentration of carbon atoms is a result of reported darkening and distortion of plastic targets in electron synchrotrons, which could be associated with partial decomposition of the plastic [21]. The observed better mechanical support of the DLC strip, ability to withstand higher temperatures, and higher concentration of carbon atoms were the reasons for choosing formvar, rather than collodion, for backing our DLC strip.

To lift a backed DLC strip directly onto our open frame, the frame was inserted into the water, with its upper, narrower frame arm kept above the lower, wider frame arm. The frame was moved in the water to position its upper arm beneath one of the two short edges of the floating strip. The frame was tilted at ~45° with respect to the water surface, with its wider frame arm staying away from the strip area. Then the frame was slowly raised. Subsequently, the prospective upper end of the strip was fixed on the narrower frame arm; the upper end area of the strip was then suspended on that arm and was hung from its front edge. When the wider frame arm approached the surface of the water surface,