Preparation of different carbon stripper foils and application in beam diagnostics

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Abstract. The production of carbon stripper foils that are mounted at different locations of the heavy-ion accelerator is an important task of the target laboratory, and the process for the preparation of carbon foils is constantly improved. Recently, we tested additional heat treatment of the carbon stripping foils following our standard procedure to reduce stress in the foils, since the performance and the durability of these stripping foils is a crucial factor for effective operation. We investigated the properties of foils produced some time ago and of foils freshly produced with the standard procedure, and foils treated thermally after the standard procedure. For the beam diagnostic department at GSI radiation resistant target materials for transverse ion beam profile measurement is an ongoing research topic. In that framework, the feasibility of Optical Transition Radiation (OTR) generation due to ion beam interaction with metal target for beam profile determination has been investigated. Here, carbon stripper foils are applied to enhance the OTR signal. The differently prepared foils were applied in many different experiments of the beam diagnostic department. We describe the performance of the foils during irradiation and compare the features of foils before and after irradiation.

1 Introduction

In the target laboratory of GSI, we produce carbon foils by resistance heating for the last two decades [1]. We advance the process constantly; especially refining the thermal treatment of the foils at several stages during the whole process to reduce the stress in the carbon layers and enable the production of thicker carbon foils [2].

An important application for carbon foils is as stripper foils needed at different locations of the GSI accelerator to increase the charge state of the ions for further acceleration. The strain on the foils introduced by the heavy-ion beam can be high and the durability of the stripper foils is a major challenge [3]. When the beam travels from the linear accelerator to the transfer channel towards the synchrotron, it passes through the foil stripper, where carbon foils from 200 µg/cm² up to 1000 µg/cm² are mounted. The highest requirement for the stripper foils is the charge stripping of the uranium beam from U^{+28} to U^{+73}.

We developed an additional heat treatment of the separated foils and compared the performance of these foils as stripper foils with those produced following our standard procedure. The enhanced durability of the stripper foils produced with the additional heat treatment opens the opportunity for a new application in beam diagnostics to serve as a beam monitor in parallel to the stripping function.

2 Production of carbon stripper foils

As described in detail in Kindler et al. [2], we can produce carbon foils by resistance heating with a thickness of up to 600 µg/cm² or even thicker today. In one evaporation run, we can add about 100 µg/cm² thickness to the carbon layer with each carbon rod. For releasing thick carbon foils successfully, we developed a process of cooling, relaxation and thermal treatment: The coated glass plates remain in the evacuated chamber for 24 h to allow the layers to relax. Then we dismount the plates, place them in a furnace for 1 h at 100 °C in air and allow them to cool down to room temperature afterwards. In a second step, we heat the coated plates for 4 h at 130 °C and allow them to cool down and relax overnight. Now, the foils can either be floated directly very slowly or they are stored - still on the glass plates - in a drying cabinet until needed.

Because of the hygroscopic nature of the release agent betaine sucrose, it is crucial for the handling and thermal processing of the coated glass plates that our laboratory has a ventilation that provides for stable temperature and stable relative humidity of about 32 %.

Nevertheless, the carbon foils produced by this process, now standard procedure, still have intrinsic strains, as can be seen in figure 1, visible by the curling of the foils. We can glue these foils flat on stripper frames without problems; an example is shown in figure 2. For this, we uncurl the foil onto the frame and apply carbon glue (Leit C nach Glocke from PLANO, with

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butyl acetate as solvent) with a fine brush on the edges of the foil to fix the foil on the frame.

Fig. 1. Carbon foils 570 µg/cm² thickness released from glass plate, prepared by standard procedure.

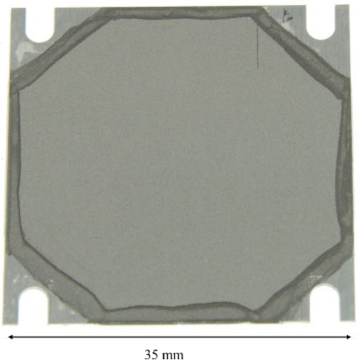

Fig. 2. Carbon foil with 570 µg/cm² thickness on a stripper frame.

Charge stripping with heavy ion beams is an ongoing research topic for several decades now, and currently carbon foils produced by our department with beam spot scanning provides the longest and most reliable operation in terms of stripped beam transmission Nevertheless, the stripper foils deform significantly during irradiation, as clearly demonstrated in figure 3. You see three of those stripper foils on a ladder inside the beam diagnostic chamber. The two foils on the left have been irradiated with uranium, whereas the foil on the right side was not irradiated. In the centre, where the beam deposited most of its intensity, the foils bulge strongly.

Fig. 3. Carbon foils with 570 µg/cm² thickness in the beam diagnostic chamber. The two foils on the left have been irradiated with U^{28+}.

To release more stress from the carbon foils, we tested an additional heat treatment of the already released foils. For this procedure, we carefully uncurled the rolled-up foils and held them flat by weighing the edges down with glass slides, as depicted in figure 4 on the left side. We then annealed these foils at 180 °C for 1 h in air. As a result, the carbon foils lie nearly flat after the 2nd annealing step, as shown in figure 4 on the right side.

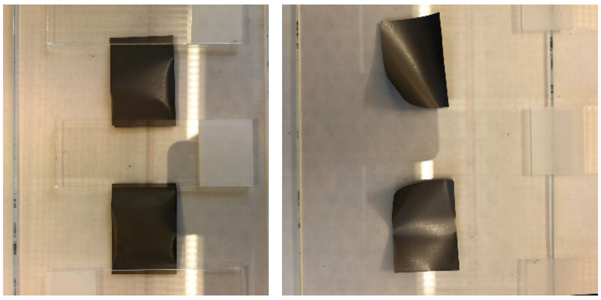

Fig. 4. Carbon foils 570 µg/cm² - Left: Stretched with glass slides before 2nd annealing step. Right: Stress-relieved foils after annealing.

Those foils were tested as strippers at the accelerator. They performed well without showing significant changes in surface structure or form, as can be seen in figure 5. The crack in the foil in the middle happened during removing of the ladder from the beam diagnostic chamber and was not caused by irradiation with the beam.

Fig. 5 Carbon foils with 570 µg/cm² thickness and treated with 2nd annealing process in the beam diagnostic chamber after irradiation with U^{28+}

For the irradiation tests, the beam parameters were comparable for each foil. The beam was delivered by GSI UNILAC operating with 36 MHz pulsed RF system. The beam macro-pulses were 300 µs long with a repetition rate of 1 Hz. Average macro-pulse had an integrated charge of ~ 1.5 nC ($3*10^8$ U^{28+} ions) with kinetic energy of 11.4 MeV/u. The uncertainty in the beam energy was below 0.1 %. The beam current and thus the integrated charge exposure variation under high current uranium operation was below 10 % for the integrated time in our experiment.

A notable observation was that the deformation of non-thermally treated foils occurred immediately after few heavy ion pulse shots on the foil and remained stable for the rest of the beam time. For thermally treated foils, deformation was barely noticeable. We operated all these foils for approximately 4 hours each during these experimental campaigns for beam diagnostics,

This improved shape retention during irradiation leads to a significant improvement in durability of the stripper foils. In addition, this flat surface opens the possibility to apply the stripper foils as beam monitoring device as well.

3 Optical transition radiation OTR

Parallel to the charge stripping of the beam, the beam diagnostics department operates an experimental setup to develop and test new methods for the detection of the beam.

When an ion crosses the interface of two media of different electromagnetic properties, Optical Transition Radiation (OTR) is produced. As described in equation (1), the number of emitted photons I is dependent on the charge state of the ion q, the velocity of the ion β and of the number of ions N crossing the interface.

$$I \sim q^2 \cdot \beta^2 \cdot \mathrm{N} \qquad (1)$$

Therefore, OTR signals can be applied in beam diagnostics for monitoring the beam properties like e.g. beam position or beam profile. The beam diagnostics department applied this concept at GSI already [4, 5].

In figure 6, the OTR signal for an uranium beam with and without a charge stripping foil is shown, visible on the OTR monitor target.

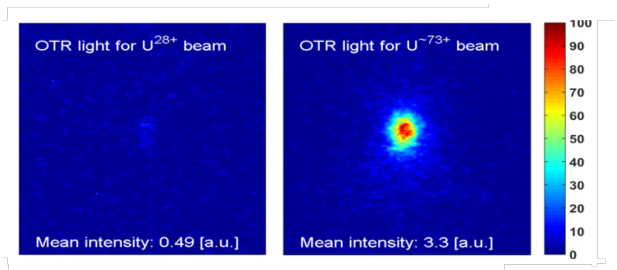

Fig. 6. OTR signal without and with carbon stripping foil.

In principle, an OTR signal is visible on the stripper foil as well as on the beam monitor. Nevertheless, for the evaluation of the OTR signal as a measure of the charge distribution in the beam, an undistorted projection in two dimensions is needed. Carbon foils produced with the described production process, stay stable and flat during irradiation, so the visible two-dimensional charge distribution can be evaluated.

4 Outlook

For the future upgrade, it is foreseen to apply the carbon foil as stripper and as beam profile monitor simultaneously at UNILAC intensities. With this dual usage possibility of the foils, the total matter in the ion beam path will be reduced. This is a helpful feature during the accelerator operation in the long-term science user experiments also referred to as "production mode" both from the perspective of accelerator maintenance and robustness of beam parameters achieved.

Consequently, the charge distribution of the beam can be observed permanently during production without additional beam diagnostic monitors.

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