STRIPPER FOIL DEVELOPMENTS AT NSCL/MSU*

Felix Marti#, Scott Hitchcock, Peter Miller, Jeffry W. Stetson, John Yurkon,
NSCL/MSU, East Lansing, MI 48824, U.S.A.

Abstract

The Coupled Cyclotrons Facility (CCF) at NSCL/MSU includes an injector cyclotron (K500) and a booster cyclotron (K1200). The beam from the K500 is injected radially into the K1200 and stripped at approximately one third of the radius at energies of approximately 10 MeV/u. Stripping is done with a carbon foil. The lifetime of the foil is very short when stripping heavy ions and does not agree with the estimates from formulas that work quite well for light ions. We will present in this paper the studies performed to understand the limitations and improve the lifetime of the foils. A foil test chamber with an electron gun has been built as part of the R&D for the US DOE Facility for Rare Isotope Beams (FRIB) project. It has been used to study different ways of supporting the carbon foils and effects of high temperature operation. Different foil materials (diamond-like carbon, graphene, etc) have been tested in the cyclotron.

INTRODUCTION

The stripper foils are mounted on a C frame with one side open, toward the large radius, where the beam will pass by in the next turn, see Figure 1.

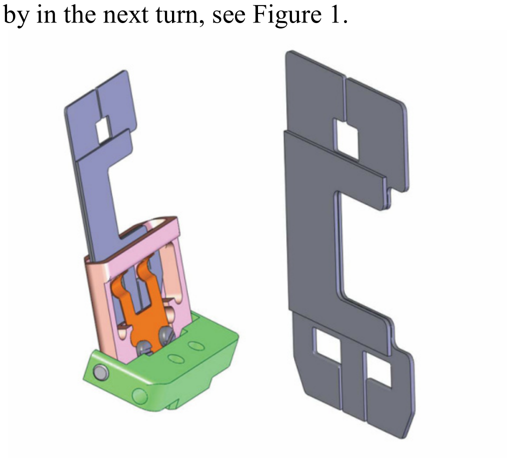

Figure 1 Stripper foil mounting frame (right) and frame holder that attaches to chain.

The lifetime of the foils for light ions is in good agreement with the estimates from Baron's formula [1]. When accelerating heavy ions (xenon and higher) the lifetime of the foils is much shorter than predicted. The foil performance decays so fast that when running high intensity uranium the extracted current has a fast decline in just fifteen minutes, making it impractical to use in regular operation.

The stripper is located inside one of the dees in the K1200 cyclotron, Figure 2. This aggressive environment (in vacuum, in a 5 T magnetic field and inside the high [1]voltage accelerating structure) makes it difficult to install any diagnostics to observe the stripper foil.

Figure 2 K1200 cyclotron. The upper half of the dee has been removed, as well as the RF shield that covers the stripper mechanism. The platter with the chain that drags the stripper foil holders has also been removed. The water cylinders used to drive the platter and locate the platter in the correct position are shown.

To study the thermal and mechanical stresses on the stripper foils under consideration for FRIB we have built a stripper foil test chamber with an electron gun mounted on the side. This chamber allows us to have a detailed look at the foils while irradiating them with the electron beam, overcoming some of the limitations we have to observe the foils inside the cyclotron.

WHY DO FOILS FAIL?

The main reasons for foil failure are thermal and mechanical stresses and radiation damage. In the case of light ions we observe that foils usually develop a tear or the area where the beam hits the foil seems to be sputtered away.

The wrinkling of the foils is a general observation for all ions. In the case of light ions we notice that in many cases the foils detach from the supporting frames. They are mounted with aquadag or similar media. To correct this failure we are testing foil holders with pockets, see Figure 1, where the foils are inserted but not held fixed to the edges.

The failure mode for intense heavy ions (Pb, U) is different. The foil becomes thinner and thinner, moving away from the equilibrium thickness, shifting the charge state distribution toward lower charge states.

*This material is based upon work supported by the Department of Energy Office of Science under Cooperative Agreement DE-SC0000661 and NSF Grant PHY-0606007
marti@nscl.msu.edu

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

TEST CHAMBER STUDIES

The test chamber allows us to observe the foils with diagnostics that we do not have in the cyclotron, but being exposed only to an electron beam.

The test chamber arrangement is shown in Figure 3. An electron gun beam is focused with an einzel lens. The third electrode of the einzel lens is divided in four segments to allow different potentials to be applied and steer the beam, see Figure 4.

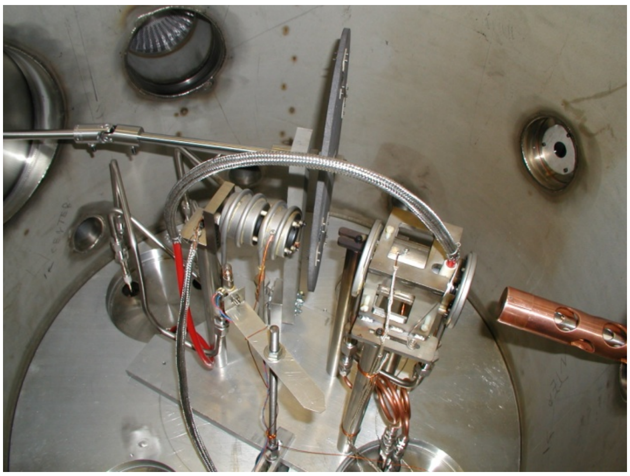

Figure 3 Photo of the inside of the stripper foil chamber showing the electron gun on the right, the einzel lens, the rotating wheels that supports the different targets and on the left the Faraday cup with the secondary electron suppression ring.

There are two observation ports where several instruments are located. We routinely use a FLIR camera that works in the long wavelength area (7-11 µm) capable of measuring temperatures between room temperature and 900°C. The port is equipped with a ZnSe viewport. In the second port a large quartz window is used and a short wavelength IR Mikron M9200 camera is located. This camera works above 900°C up to 3000°C. A fibre optic spectrophotometer (FOS) is also located in this second port as well as a standard B&W high sensitivity TV camera.

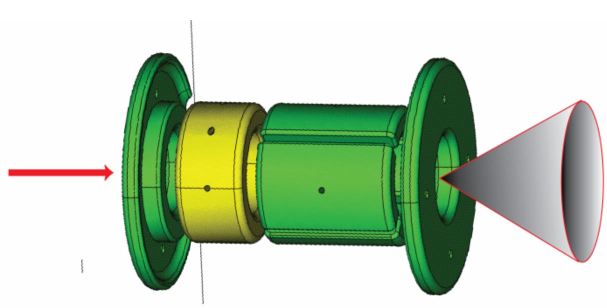

Figure 4 Einzel lens showing the high voltage electrode (yellow) and the exit electrode split in four independent components.

One of the goals of using the test chamber was to gain confidence and verify the models we use to estimate the sublimation damage. The foils can reach temperatures high enough that sublimation of the graphite is a fast process. The lifetime estimate for a 0.5 mg/cm^2 foil is shown in Figure 5. We see that temperatures close to 1900°C should be avoided to reduce the sublimation of the foils. We have modelled the thermal effects and compared with the measurements in the test chamber and found them in good agreement.

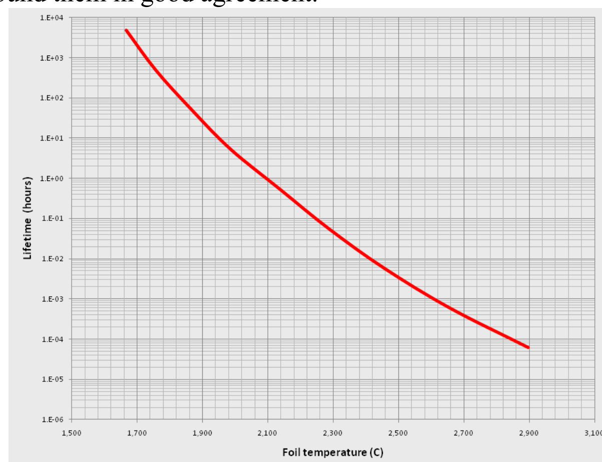

Figure 5 Lifetime of a 0.5 mg/cm^2 foil defined as loosing 20% of its thickness to sublimation, as a function of the foil temperature.

One of the issues in doing thermal imaging with IR cameras is that they expect the user to input the emissivity of the object. We used the FOS to determine the corresponding emissivity. The FOS itself was calibrated with a standard source that allowed us to determine the transmission of the whole system (window, fibre, sensor, etc). The spectra from 400 to 800 nm were used to fit a black body curve and from this we determined the temperature of the foils.

We experimented with a stationary beam and a rotating beam. The comparison of the stationary beam is shown in Figure 6.

By applying two sinusoidal voltages in quadrature the beam can be steered in a circular pattern and simulate the effect of a rotating stripper foil (one of the options considered for FRIB and used at RIKEN). These results also verified our thermal simulations.

RADIATION DAMAGE

The experience with heavy ions (Bi, Pb, U) at NSCL had shown that intense beams damaged the foils very fast after switching from tuning to running experiment mode. The extracted current could be seen decaying significantly in fifteen minutes. To study this effect in a more systematic way we loaded the stripper mechanism with foils from different manufacturers, MicroMatter, KEK and Arizona Carbon Foil (ACF). An 8.1 MeV/u Pb was accelerated in the K500 cyclotron and after stripping in the K1200 accelerated to 85 MeV/u and extracted.

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

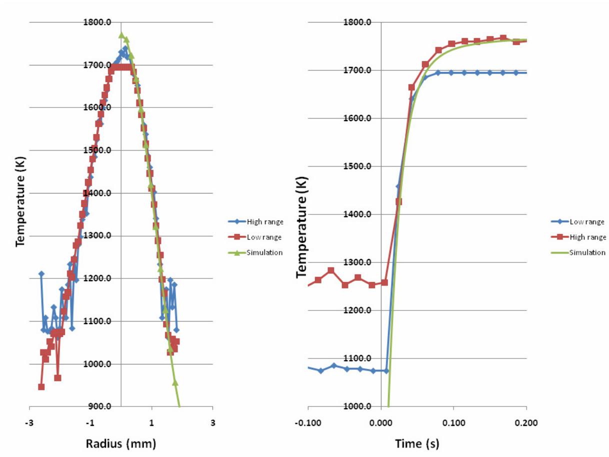

Figure 6 Comparison of the simulation with experimental results for a stationary electron gun beam. The left hand side shows the temperature vs. radius and the right hand graph shows the time dependence.

The test procedure was to inject the beam at different average power levels (20, 50 and 100%) by varying the injection line chopper duty cycle. The fraction of the ions extracted divided by the number of ions injected gave us a measure of the foil performance, without changing the tune of the cyclotrons, see Figure 7.

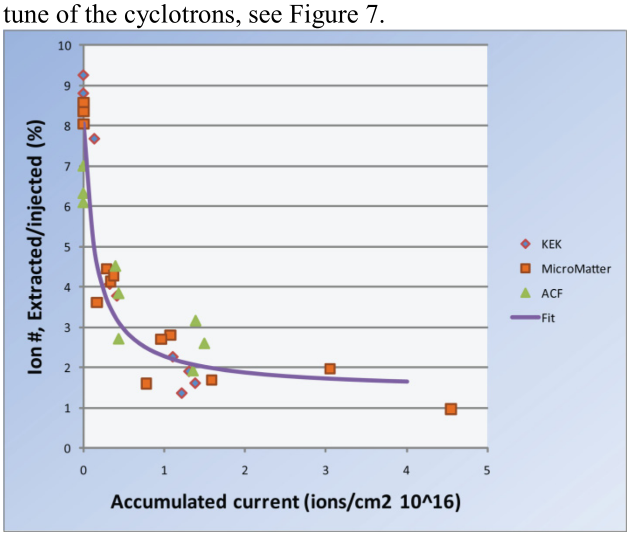

Figure 7 Fraction of ions extracted divided by the number of ions injected as a function of the beam dose for different foils.

The striking feature is the very fast decay observed in all foils. This process is so fast that it makes impractical to plan experiments at high intensities. After the experiment ended the foils were extracted from the cyclotron and examined. Many of them showed a significant growth in the transverse direction that we have not observed with light ions. At the same time a thinning of the foil was noticeable (and verified by measurements with an alpha source) in the spot where the beam was hitting it. Figure 8 shows an example of this effect.

After letting the residual activity decay for some months the foils were taken to the MSU Advanced Microscopy Laboratory and observed with a Scanning Electron Microscope (SEM). The modifications on the foil were striking as shown in Figure 9. A possible interpretation of this transverse expansion and longitudinal thinning can be found in the "ion hammering effect" described by Klaumunzer and collaborators [2]. This effect occurs above a certain threshold fluence for ions depositing a large amount of energy in the target electrons and these electrons contribute to the displacement of the target atoms.

It must be observed that the foils heated to 2000°C in the test chamber do not show this striking pattern, just the long wave wrinkling.

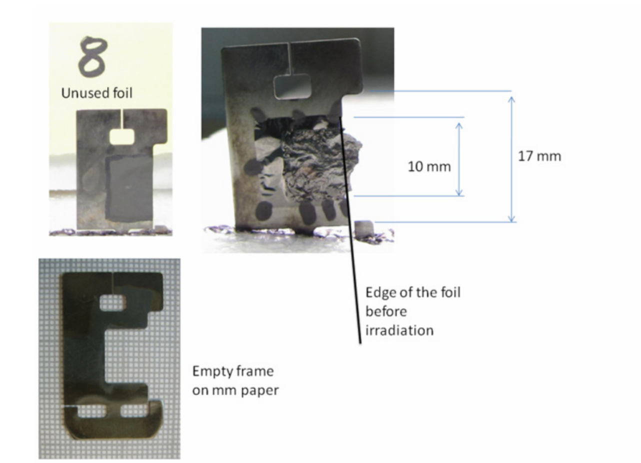

Figure 8 Upper left shows unused foil with straight edge, upper left shows the foil after irradiation with Pb beam and the growth in the transverse direction. Looking against the light a region of decreased thickness can be detected.

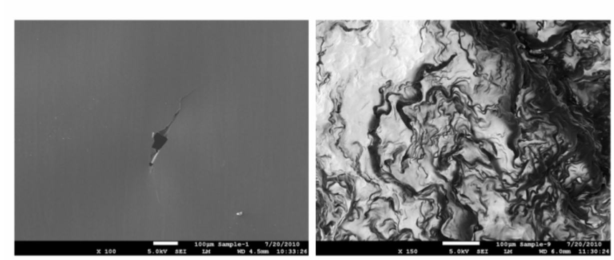

Figure 9 SEM photos showing unused MicroMatter foil on the left (100X) showing a pinhole and after irradiation with Pb beam at 8.1 MeV/u (150X).

REFERENCES

[1] E. Baron, 8th Intl. Conf. Cyclotrons, IUCF, 1979 p. 2411.

[2] A. Benyagoub and S. Klaumunzer, Radiation Effects and Defects in Solids, 1993, vol. 126, pp. 105-110

Copyright © 2011 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)