Measurements of the sensitivity and spatial resolution of radiochromic film using ion beams and X-rays

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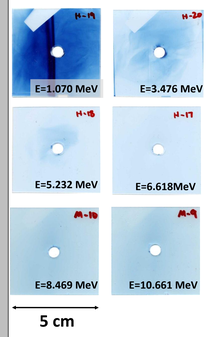
Abstract

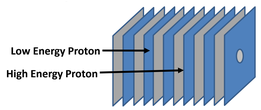
Radiochromic film (RCF) is used to study protons and other ions that are accelerated from the rear side of targets illuminated with ultra-intense laser light. An experiment is underway to characterize the response of RCF to protons, deuterons, and alpha particles of various energies using the 1.7 MV tandem Pelletron accelerator at SUNY Geneseo. A monoenergetic ion beam from the accelerator is incident on a thin (0.1 um) gold foil placed in the center of a 28-inch diameter scattering chamber. A strip of RCF is positioned in a circular arc that is centered on the gold foil. The ion beam strikes the gold foil, causing the RCF to be exposed to elastically backscattered ions. The scattered ion fluence on the RCF strip varies as a function of the scattering angle. After removal from the chamber, the RCF is scanned in transmission mode using an Epson 10000 XL flatbed scanner and the resulting image was analyzed to determine the optical density. The sensitivity of various types of RCF to X-rays using a PTW X-Rad 160 X-ray irradiator unit which was recently obtained at SUNY Geneseo.

Background and Motivation



Radiochromic Film (RCF) stack

- RCF film alternates with aluminum foil
- Stack placed 4 cm from TCC



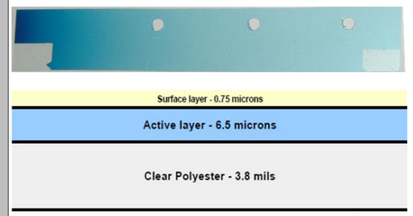
- Laser Pulse: 5 Joules in 1 ps
- Focused spot size: approx 6um x 6um
- Target: 50um x 50um x 2um Copper Foil

Evidence for proton production with energies above 5.2 MeV, and possibly up to 10.6 MeV

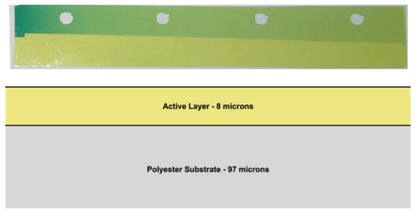
Radiochromic film (RCF) is a layered dosimety film developed by gafchromic, which has been used at the Laboratory for Laser Energetics (LLE) to study ions accelerated from the rear side of targets illuminated with ultra-intense laser light. The active layer of the film turns blue when exposed to ionizing radiation, eliminating the need for lengthy exposure times. This means that measuring the sensitivity to exposures of this film would prove invaluable in making quantitative measurements of the number of ions of a given energy. By placing RCF in a stack, the energy of incident ions can be determined by measuring how far they penetrate into the stack.

Further complicating matters however, is the fact that Gafchromic has discontinued the original HD film that was being studied in favor of a new HD-V2 model. The new film has a thicker active layer and no surface layer in addition to its slightly yellowish hew of the unexposed film. Thus in addition to continued study of the HD film, experimentation is also underway to look characterize the response and spatial resolution of the new HD-V2 Film.

Gafchromic HD (OLD)



Gafchromic HD-V2 (NEW)

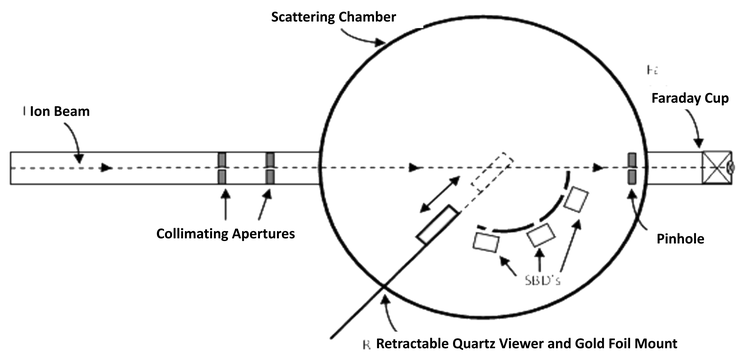


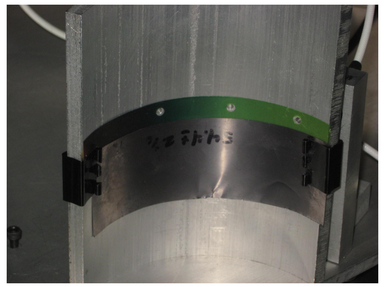
*A Side-by-side comparison of the original and New films being studied in the Geneseo Accelerator Lab.

Geneseo Pelletron Accelerator

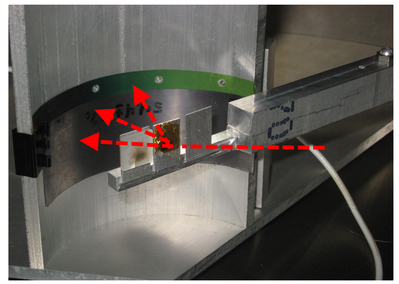
The Accelerator Lab at SUNY Geneseo utilizes a 1.7 MV Tandem Pelletron Accelerator from the National Electrostatics Corporation (NEC). An Alphatross RF Alkali Charge-Exchange ion source produces proton, deuteron, or helium beams which are injected into the accelerator. Maximum beam energies are 3.4 MeV for protons and deuterons and 5.1 MeV for helium beams. This facility was installed at Geneseo in 2007.

Experimental Setup





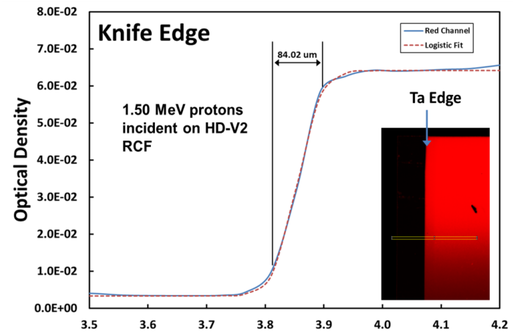
Mounted exposed RCF shown. The area blocked by the binder clips was used for background subtraction. Holes punched through the RCF allow scattered ions to reach a surface barrier detector placed behind the RCF mount. The film is partially covered with a piece of tantalum foil known as a "knife edge" to allow for spatial resolution comparison.



RCF positioned before closing the chamber lid with incident beam direction indicated. The photo shows the gold foil and quartz viewer mounted on the target manipulator. Due to the Rutherford scattering formula, proton fluence falls off sharply as a function of scattering angle.

Analysis

Films were scanned in 48 bit color (16 bits per channel) at 600 dpi on an Epson 10000 XL flatbed document scanner in transmission mode. Three silicon detectors placed around the film allowed absolute ion fluence to be determined. The optical density was plotted as a function of position along an axis that is perpendicular to the knife edge. The resulting optical density profile is then fit with a logistic function. The position resolution is defined as the distance between the 10% and 90% of maximum. The position resolution measured with this technique was approximately 84 µm. The position resolution of the original HD-810 film to 1.0 MeV protons was also measured and gave a similar, smaller value of 81 µm. The red curve shown on the graph represents a least-squares fit using the dose-response formula provided by Gafchromic:



$$OD = \log(2^{16}) - log\left(\frac{a+bD}{c+D}\right)$$

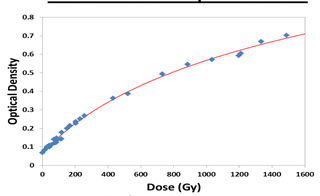
Results and Future Goals

We observed response of the film by finding the slope of the optical density versus dose curve near the origin. This sensitivity parameter is obtained from a Taylor expansion of OD equation:

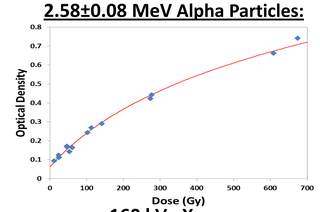
$$S = \frac{a - bc}{ac\ln(10)}$$

The sensitivity parameter for the two different alpha particle energies was found to be 9.77×10^{-4} Gy^{-1} for the 2.58 MeV alpha particles and 2.21×10^{-3} Gy^{-1} for the 1.58 MeV alpha particles. For X-rays it was found to be 7.79×10^{-3} Gy^{-1} for the 70 kVp X-rays and 6.02×10^{-3} Gy^{-1} for the 160 kVp X-rays.

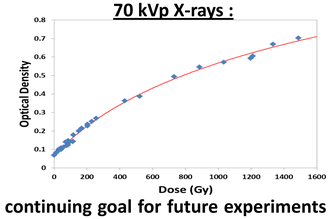
1.40±0.05 MeV Alpha Particles:



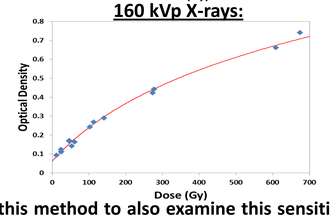
2.58±0.08 MeV Alpha Particles:



70 kVp X-rays :



160 kVp X-rays:



Our continuing goal for future experiments is to use this method to also examine this sensitivity parameter for various energies protons and deuterons as well as alpha particles.