

# Radiography with protons generated by ultrashort high intensity lasers

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The recent development of ultra-intense short-pulse lasers has opened a new field of investigation. Experiments, using laser pulses with intensities exceeding  $10^{19}$  W/cm<sup>2</sup> have shown, that proton beams with very low emittance, high intensity (up to  $10^{13}$  particles) and high energy (up to 50 MeV) can be produced by irradiating thin conductive foils with a smooth rear surface. The dominant acceleration process can be described within the TNSA (Target Normal Sheath Acceleration) model. Thereby the interaction of the laser pulse with the target front surface produces relativistic electrons with temperatures of several MeV, which are ponderomotively pushed through the foil. Those electrons envelope the target foil and form an electron plasma sheath on the non-irradiated rear surface. The electric field, which reaches out a few  $\mu\text{m}$  can reach up to  $10^{12}$  V/m and hence field ionize the atoms on the surface and accelerate them laminarly and normal to the surface. Due to their largest charge-to-mass ratio preferentially protons from contaminants on the surface are accelerated. The protons form a collimated beam with an emittance better than any conventional accelerator and a pulse duration of only a few picoseconds. These exceptional, high quality properties of the proton beams make them interesting for some applications, which are now performed with radio-frequency accelerator beams or x-rays, and open new fields of applications, where conventional techniques reach their limits. One such application is to radiograph objects by energy-loss imaging of transmitted protons. Because protons interact differently with matter than either x-rays or neutrons, such proton imaging can provide complementary information about a particular sample, with high temporal resolution.

To demonstrate the feasibility of the laser accelerated proton radiography applications first experiments were performed at the 100 TW laser at LULI, with pulses up to 30 J at 350 fs and a wavelength of  $1.05 \mu\text{m}$ . Intensities of  $5 \times 10^{19}$  W/cm<sup>2</sup> were reached by focusing the beam to a spot size of  $8 \mu\text{m}$ . To image objects we placed them about 3 cm behind the target, which was usually a 10 - 20  $\mu\text{m}$  thick gold foil. Directly behind the objects we used a stack of radiochromic films. Due to the pronounced energy loss of the protons at the end of their range (Bragg-peak) different layers of the RCF allow the imaging of the object with different mass distributions. Fig. 1 shows the imaging of a 1 mm thick epoxy ring with engraved names of the collaborating institutes, 250  $\mu\text{m}$  thick copper wires, a hollow cylinder with 300  $\mu\text{m}$  walls of steel, four sheets of 100  $\mu\text{m}$  thick Ti and a glass hemisphere of 900  $\mu\text{m}$  di-

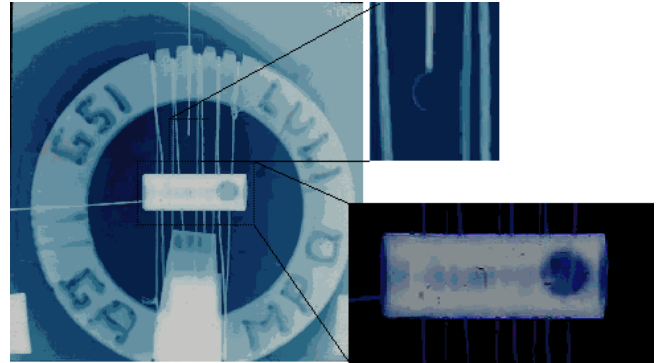


Figure 1: *Proton radiography of an epoxy ring with wires, hollow cylinder and glass hemisphere*

ameter and 20  $\mu\text{m}$  wall thickness. All details are clearly visible. The spatial resolution of the images was  $\approx 20 \mu\text{m}$ , which is determined by the resolution of the RCF.

A great advantage to x-ray imaging is the fact, that with proton radiography low-Z material can be analyzed even behind high-Z walls. To demonstrate this we imaged four stripes of 50  $\mu\text{m}$  thick kapton foil behind a layer of 100  $\mu\text{m}$  thick Tantalum. The image and a line scan is shown in Fig. 2. All four kapton stripes are clearly separated. The three peaks on the right in the line scan belong to copper wires.

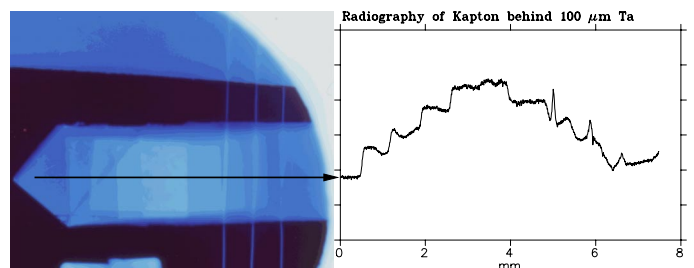


Figure 2: *Proton radiography of four 50  $\mu\text{m}$  thick kapton foils behind 100  $\mu\text{m}$  Ta.*

Hence this technique may become a new and promising tool for target diagnostic in the GSI future project, where a heavy ion beam heats a cylindrical target to compress a low-Z material in the center.

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