L.2: Electron radiography of metallic and plant sample using laser plasma accelerator

Laser plasma accelerator (LPA) is seen as a potential alternative over RF based accelerators. LPA can generate electron beams with energy ranging from few tens to few hundreds of MeV, which can be used in many potential applications, e.g. electron beam radiography. We have demonstrated the electron beam radiography of both metallic and biological plant (leaf, Aloevera) objects. Electron beam radiography experimental study was carried out using two types of electron beams: high energy and low divergence (~150 MeV and ~7 mrad) and low energy and high divergence (~15-50 MeV and ~70 mrad), generated by interaction of Ti: Sapphire laser pulses of ~120 fs duration (intensity ~ 2.2×10^{19} W/cm^2) with underdense plasma of Ar and He gas targets of 4 mm length, respectively. Figure L.2.1 shows the typical electron beam profiles and spectra. Radiographs were recorded at a distance of 70 cm from the source.

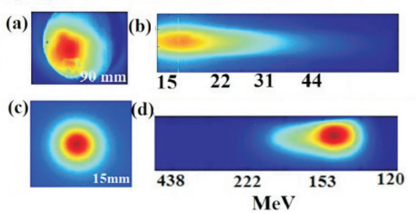

Fig. L.2.1: Electron beam profile and spectrum for Ar gas jet (a) and (b), and He gas jet (c) and (d), respectively.

Figure L.2.2 shows the recorded radiograph images of an IC chip with leg thickness of 300 µm, Cu mesh with wire thickness of ~ 250 µm, and cross section of Aloevera of 1.1 cm thickness with Ar (~15-50 MeV) electron beams. In IC chip image, legs of the chip and inner structure of electronic circuit are clearly visible. Cu mesh structure of wire thickness 250 µm and separation of 500 µm was also resolved. Radiograph image of a thick leaf (biological plant) also shows clear finer veins. Next, radiograph of a 5 cm thick brass block (60 mm × 20 mm) with 4 grooves (2 mm × 12 mm) was recorded using He (~150 MeV) beams (Figure L.2.3(a)). A resolution of ~ 75 µm was achieved in the radiograph recorded using 20 MeV electron beams. Resolution of the radiograph using He electron beam could not be retrieved due to saturation of the signal, however, it is expected to be better as can be seen from the image quality governed by the higher electron energy and lower energy spread.

Geant4 Monte Carlo simulations were performed and radiographs of various samples used were reconstructed to support the experimental observations. Radiograph image of brass groove reconstructed by Geant4 simulations is shown in Figure L.2.3(b), which shows sharp edges as expected from low scattering of the high energy electrons in the sample. Hence, it faithfully reproduced the radiograph recorded experimentally. Further, dose deposition rate (Figure L.2.3(c)) in adipose tissue was performed using Geant4 simulation, for 20 MeV and 150 MeV monoenergetic electron beams. It shows that the lower energy (20 MeV) electrons have a maximum dose deposition depth of 5 - 6 cm in the adipose tissue, beyond which the dose deposition decreases rapidly within 10 cm of length. But for the 150 MeV electron beams, the maximum dose deposition length increases to about 20 - 30 cm, and with further depth, the dose decreases to ~ 50% within 40 cm. For comparison, in case of photons of similar energy (20 MeV), the dose deposition rate first increases slightly to a maximum at the same depth of ~ 5 - 6 cm and falls slowly with further depths. This suggests that photons would deposit substantial dose to the inner healthier tissues compared to electrons and for this reason electron beam radiotherapy becomes a better option compared to the photon radiotherapy for treatment of tissues at a particular depth. Hence, it is clear that lower energy electron beams of few tens of MeV can penetrate upto certain length within biological samples of thickness of few cm and hence can be applicable for treatment of superficial tissues such as skin, brain, etc. Next, very high energy electron beams (VHEE) of ~ 150 - 200 MeV would be useful for inner deep seated tissues such as prostrate, lungs, etc.

Fig. L.2.2: Radiographic images of (a) IC chip, (b) Cu mesh and (c) Thick leaf.

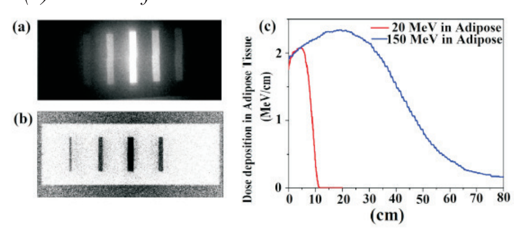

Fig. L.2.3:(a) Radiograph of a brass groove using 150 MeV energy. (b) Geant4 simulated radiographic image of brasss groove. (c) Energy dose deposition rate in adipose tissue using Geant4 simulation for 20 MeV and 150 MeV energy electron beams.

For more information, please see *D. Hazra, S. Mishra, A. Moorti, and J. A. Chakera, Phys. Rev. Accelerators and Beams, 22, 074701, 2019.*

Reported by:
S. Mishra (shikham@rrcat.gov.in) & colleagues