Study of the effect of the lattice structure on the transport of MA fast electron currents at the PHELIX laser facility*

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The electrical resistivity of a material in solid state is dependent on the electron mean free path, and thus the lattice structure of the material [1]. Due to the short duration of the laser-generated fast electron bunch (ps), compared to the lattice melt time (tens of ps), the same is true for a solid irradiated by an intense laser pulse. Here, the effects of the electrical resistivity on fast electron transport in solid targets for the cases of diamond and vitreous carbon are considered. Whilst the Z of each is the same, both materials possess significantly different resistivity-temperature profiles in the transient WDM temperature regime (1-100eV), as shown by Maclellan et al. 2013 [2].

For materials where the electrical resistivity is high, the growth rate of resistive magnetic fields within the target is greater, as described by equation (1) :

$$\frac{\partial \vec{B}}{\partial t} = \eta \nabla \times \vec{j}_f + \nabla \eta \times \vec{j}_f \qquad (1)$$

The growth of resistive magnetic fields acts to pinch the fast electron beam, contributing to perturbations in the beam profile by creating localised regions of pinching fields around variations in electron density in the beam [3]. Thus, the beam becomes filamented [4]. This results in a sheath field that is non uniform, and the resulting protons accelerated by the TNSA mechanism also exhibit a highly structured profile, from which the dynamics of the fast electron propagation in the target can be inferred [5, 6]. For materials where the electrical resistivity is lower, the growth rate of instabilities is reduced and, as such, similar structure is not induced in the beam.

In our recent experiment at the PHELIX laser facility, we studied the effects of material lattice structure of carbon allotropes on the resulting electron transport at high laser intensities. We further investigated the effects of laser parameters such as pulse duration and delivered energy on the observed proton spatial profile. The PHELIX laser delivered 200 J of energy to the front surface of the solid targets in approximately 500fs (full width at half maximum, FWHM) duration pulses, resulting in peak intensities of $1 \times 10^{21} W/cm^2$. The spatial intensity profile of the proton beam accelerated from the rear surface was measured by a stack of radiochromic film (RCF) placed 5cm from the target rear surface. Example results from this investigation are shown in figure 1.

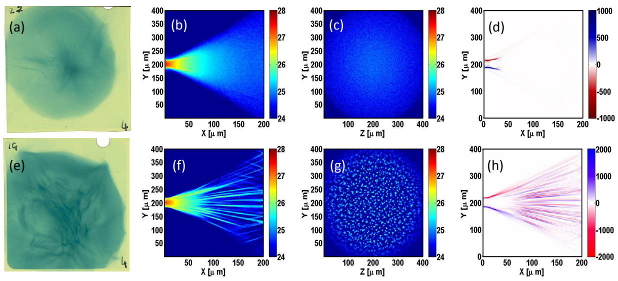

Figure 1: Experimental and simulation results for (top row) diamond and (bottom row) vitreous carbon showing: from L to R, proton spatial dose distributions, $\log_{10}$ fast electron density maps (m^{-3}), in the [X-Y] mid-plane, $\log_{10}$ fast electron density maps (m^{-3}), in the [Y-Z] rear-surface plane, and [X-Y] mid-plane maps of the magnetic flux density (B_z component in Tesla)

The results indicate that when an ordered material is considered, the onset of resistive instabilities inside the target is reduced and fewer instabilities are seeded in the fast electron beam, with a relatively smooth rear surface electron beam profile. In the opposite case of a disordered lattice, structure was seen, implying that growth of instabilities is enhanced with increased resistivity in the transient WDM temperature regime, and that these are a key influence on the onset of resistive instabilities in fast electron beam transport within the target. The RCF images of the proton beam show the obtained experimental results which qualitatively agree with the simulation results. Additional investigations are currently ongoing in order to further characterise the influence of low-temperature resistivity on the propagation of fast electrons.

References

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