L.5: Novel aspects of JxB acceleration of fast electrons in ultrashort intense laser-metal foil interaction

Interaction of intense laser pulse with metallic solid target has been an interesting subject for particle acceleration, x-ray generation as well as for fast ignition based fusion concept. Among various laser absorption mechanisms, $J\times B$ acceleration is most important for intensity exceeding 10^{18} W/cm^2. Fast electron generation is very sensitive to laser and plasma parameters. Studies on some novel aspects of fast electron acceleration in thin foil of Cu through direct measurements of fast electrons and their energy spectra have been performed.

The experiment was performed using ultrashort (~25 fs), Ti: sapphire laser (150 TW laser system) focused using an off-axis parabolic mirror to few micrometer focal spot on a thin metal foil target. The focused intensity (I) was ~ 4×10^{19} W/cm^2 and 7×10^{19} W/cm^2. The fast electrons emitting from the interaction region were detected using a phosphor screen coupled with a CCD camera. The phosphor screen was shielded from ions, plasma light, and low-energy x-rays using an aluminium filter. The energy spectrum of the electron beam was measured using a custom built magnetic spectrograph. Laser polarization was changed from p to s by inserting a half-wave plate in the laser beam path.

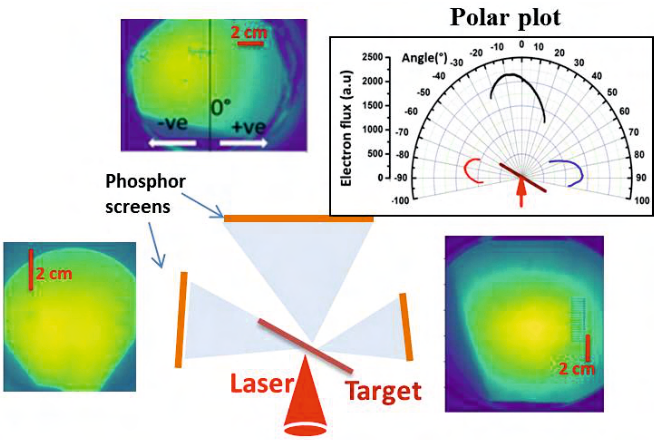

Fig. L.5.1: Experimental setup geometry with typical spatial profile of fast electrons. A polar plot is shown in the inset for Cu (7 μm) at an incidince angle of 30° at $I\sim10^{19}$ W/cm^2. Laser and Cu foil are indicated by the red arrow and the brown line, respectively.

Figure L.5.1 shows the measured electron beams along laser propagation direction as well as transverse direction. Observation of fast electrons along laser beam direction shows generation by $J\times B$ mechanism. Peak of the forward emitted electrons was found to be slightly deviated towards the target surface (e.g. ~10°) due to the self-generated surface magnetic field at the front surface. Next, the generation of transverse electrons is attributed to acceleration and ejection along laser polarization direction. It was verified by changing the polarization from p to s, which leads to drastic reduction in flux and energy. At relatively lower laser intensity, electrons oscillating in laser electric field get scattered due to ponderomotive scattering and come out along the electric field direction as observed in the experiment.

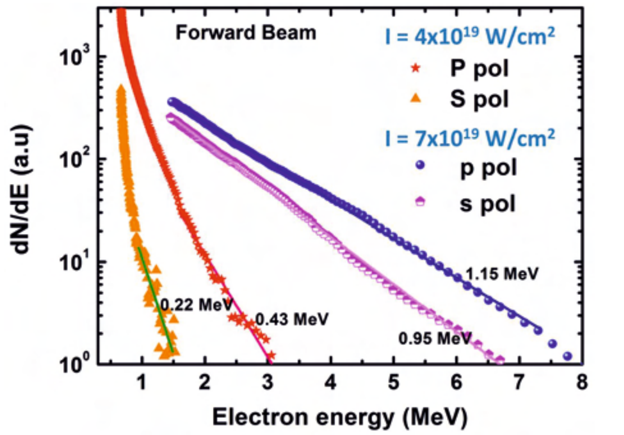

Fig. L.5.2: Fast electron spectra for the forward emitted beam at different laser intensities for Cu (7 μm) foil for different laser polarizations (p and s).

Further, the effect of laser polarization was also studied on the $J\times B$ accelerated forward emitted electrons. The change in polarization from p to s leads to a reduction in beam charge from ~1160 ± 80 pC to 290 ± 50 pC for intensity of ~ 4×10^{19} W/cm^2. Cu K_α x-ray emission also showed a significant reduction (~ 12 X) on changing the polarization from p to s. Further, the fast electron maximum energy (and temperature) also reduced from ~ 3 MeV (0.43 MeV) and ~8 MeV (1.15 MeV) to ~1.5 MeV (~ 0.22 MeV) and ~6.6 MeV (~0.95 MeV) for the intensity of ~4×10^{19} W/cm^2 and ~7×10^{19} W/cm^2, respectively (Figure L.5.2).

Based on our observation, we conjecture that pre-acceleration of electrons is responsible for polarization dependence behavior. In the leading edge of laser pulse where the intensity is in the range of 10^{15}-10^{18} W/cm^2, initial low energy electrons can be generated through polarization dependent processes such as resonance absorption. This will lead to high energy, high flux electron beam in p polarization as compared to s polarization. These pre-generated electrons further get accelerated along the laser propagation direction due to the $J\times B$ acceleration at the peak intensity. Although initially polarization dependent mechanisms generated electrons are along target normal direction, they are finally emitted along laser direction once $J\times B$ mechanism takes over.

In conclusion, the dominance of $J\times B$ mechanism in fast electron generation was demonstrated. Transverse beams along laser polarization direction were also observed due to the ponderomotive scattering. Strong polarization dependence of $J\times B$ accelerated fast electron was observed. For more details, please refer to: *T. Mandal, V. Arora, A. Moorti, A. Uphadhyay and J. A. Chakera, Phys. Plasmas, 30, 023106 (2023).*

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