Characterization of plasma jets from thin foils irradiated at high laser intensity

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Abstract: Evolution of plasma jets from micron to sub-micron thickness foils following the interaction of ultra intense (up to 3 $\times 10^{20}$ W/cm^2) laser pulses is investigated. The dynamics of the collimated plasma jet from the target rear surface was followed by time resolved optical interferometry. We found a correlation between laser intensity and target areal density in the formation of supersonic dense plasma jets. With the maximum achievable intensity on target, jets with Mach number up to 10 have been observed from 1 um thick Cu foils expanding longitudinally with a velocity of 2×10^6 m/s.

Introduction: Matter in an extreme state (high temperature, high density) can be produced by using high power lasers, that can be diagnosed and compared to astrophysics situations. Jets and collimated outflows are omnipresent in the universe associated with the formation of young stars, planetary nebulae, X-ray binaries and active galactic nuclei (AGNs)[1]. Although the experimental jets driven by high power lasers are of much smaller scales compared to stellar or extragalactic objects, they may provide an excellent opportunity to study in trhe laboratory the underlying mechanisms.

In laboratory experiments, plasma jets relevant to astrophysics have been generated typically by employing ns long laser pulses of hundreds of joules energy [2]. In this Letter, we have characterised the conditions for the formation of supersonic jets driven by pico-second laser pulses of similar energies, as observed previously by Kar et. al.[3]. At such high irradiance (around 10^{20} W/cm^2), jets can be produced by the strong ponderomotive pressure exerted on thin targets by the laser. Via parametric scans (laser intensity, target areal density) we have identified the suitable conditions for the formation of a sustained supersonic jet. The temporal evolution of the jets up to ns time is studied by time resolved optical interferometry.

Experiment: The experiment was carried out in the Vulcan Nd: glass laser of Rutherford Appleton Laboratory, U.K., operating in chirped pulse amplification (CPA) mode. An f=4:5 (f=3) off-axis parabola was used to focus the laser down to a 10 μm full width at half maximum (FWHM) spot, attaining peak intensity of 3×10^{20} W/cm^2 on the target. The intensity on the target was varied, as required by the interaction intensity scans, by increasing the laser spot size on the target by translating the parabola along the focussing axis. Targets of various materials and thicknesses (free standing thin foils, 10 μm to 100 nm) were used in this experiment. The plasma outflow from the target was probed by employing a transverse Nomarsky interferometer[4] and shadowgraphy with high spatial (few microns) and temporal (ps) resolution. Figure 1 shows a schematic of the experimental arrangement. The probe beam was frequency doubled from a portion of the main CPA pulse to a wavelength 527 nm. The converted beam was splitted into two parts and projected onto the target, transverse to the interaction axis, from two different angles. The time of arrival of each beam on the target was controlled separately by delaying their path length. The setup was designed to achieve two ps snapshots of the interaction at different times in a single shot. The interferograms were recorded by 12 bit dynamic range CCD cameras. The plasma electron density profile from the interferogram was reconstructed by retrieving the phase map using fast Fourier transform of the fringe pattern in the interfeogram, followed by Abel inversion of the phase map assuming a cylindrical symmetry [5].

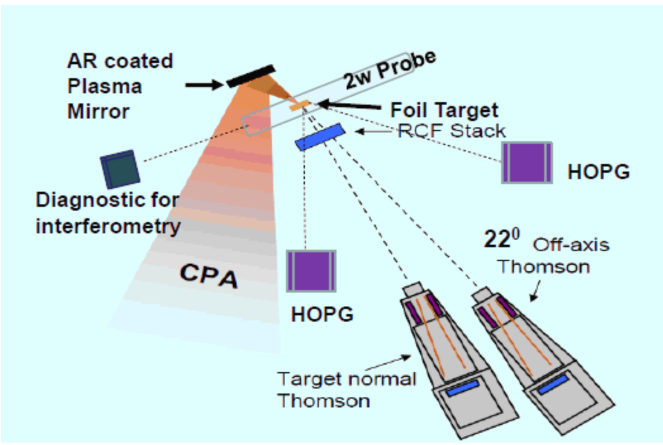

Fig 1. Schematic of the experimental set up.

Result and Discussions: The temporal evolution of the collimated plasma jets at the target rear side was observed from 150 ps to 1.1 ns, after the arrival of the CPA on the target, over many shots. 1 μm thick Cu foil was used for this temporal scan and the laser intensity on target was kept at its maximum (2-3×10^{20} W/cm^2). The plasma jets maintained their degree of collimation over ns time scales as shown in the fig. 2(a). From the temporal scan the transverse and longitudinal dimensions of the jets were inferred at different probing time, as shown in the Fig. 2(b). Over this probing time period, the results suggest a non-linearly decreasing (a power law) time dependent velocity for the longitudinal expansion of the jets, whereas an almost constant expansion velocity is observed in the transverse direction. Consequently, the Mach number of the jets, estimated as a ratio between the longitudinal to transverse velocities, has a strong time dependence during the first few hundreds of ps after the interaction as shown in the Fig. 2(c).

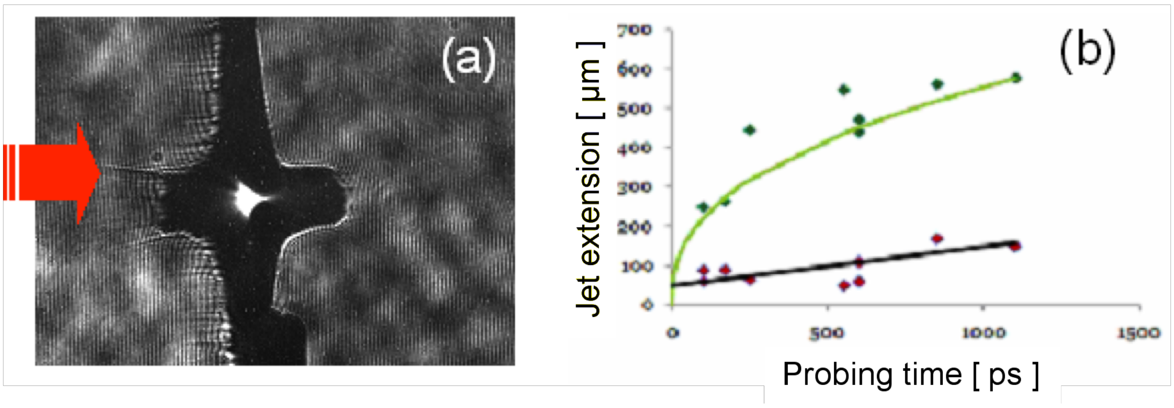

Fig 2. (a) Plasma jet at 600 ps after the interaction with 5 um Cu target. (b) Temporal evolution of the plasma jets produced from 1 um thick Cu target irradiated at 2-3x10^{20} W/cm^2.

In order to understand the underlying mechanism behind the collimated jet formation, scans were made observing the rear side plasma jets at different laser intensity for same target and at same intensity for different target areal density (thickness x density). For a given laser intensity, the jet velocity increases as we decrease the areal density (moving to thinner targets or lower Z targets) and attains maximum at a certain value of areal density. As we decrease the areal density further, the jet velocity drops sharply. In fact for the lower areal density targets the interferograms shows plasma density profiles, which one would expect from a standard blow-off target. However in this regime, the ion spectrum shows features which suggest the onset of the radiation pressure acceleration mechanism [6]. A similar trend of jet velocity variation with areal density is observed for two different laser intensities and the areal density for which the jet velocity is maximum is lower, as expected, for lower irradiance [see fig 4(a) and (b)].

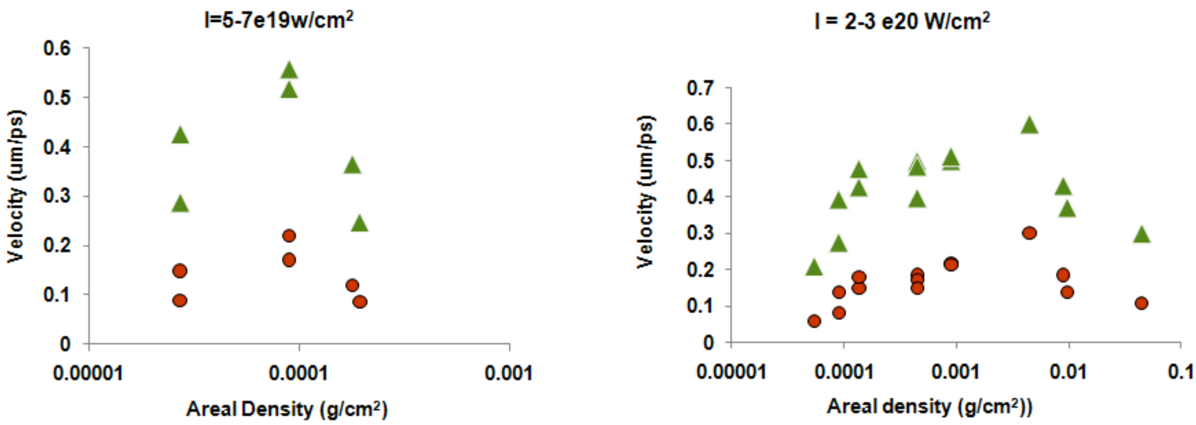

Fig 4(a) and (b). Velocity of jet for different target areal densities (at given laser intensity)

Conclusion :

The dynamics and characterization of highly collimated supersonic plasma jets produced from thin targets irradiated by ultra-intense laser pulses is reported. Preliminary analysis suggests a role of the radiation pressure of the intense laser beam in the jet formation.

Acknowledgements:

This work was funded by EPSRC (LIBRA Consortium, Grant No: EP/E035728/1) and by STFC Facility access. We acknowledge the support and contribution of the Target Preparation Laboratory, TAP laser staff and the Engineering workshop at CLF, RAL.

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