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Time evolution of colliding laser produced magnesium plasmas

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ABSTRACT

Fast photography is used to investigate expansion dynamics of colliding laser produced magnesium plasmas. A ruby laser pulse is split into two beams by the help of a movable glass wedge and focussed onto two magnesium targets placed at 90° to each other. The intensity ratio of the two laser beams is 7:1 that created hot and cold plasmas on the target surfaces. A collision region is observed 6 ns after the laser maximum and its emission is found to increase with time.

Keywords: Laser produced plasma, Colliding plasma, Charge exchange

1. INTRODUCTION

Lasers have been extensively used for ablation because of its increasing number of applications. To understand the process of laser ablation it requires an understanding of the initial stages of various processes involved during laser-target interaction, evaporation, plasma formation, and its subsequent expansion into vacuum or ambient gas [1,2]. The simplest experiment one can do with laser-produced plasma is to photograph it. High speed cameras with electronic gates and image converters can be used to image the plume emission. Photography and other imaging techniques add another dimension to ablation diagnostics by providing two-dimensional snap shots of the three-dimensional plume propagation. This capability becomes essential for hydrodynamic understanding of the plume propagation and reactive scattering.

Several applications of laser produced plasmas involve an experimental situation where a plasma collision occurs. Laser produced colliding plasmas found potentially attractive applications in the field of X-ray lasers, stimulated Raman scattering experiments and are of relevance for the design of inertial confinement fusion (ICF) hohlraums [3,4]. In addition to these applications, the interpenetration of two plasmas occurs in a number of other systems like astrophysical plasmas after a super nova explosion ejects plasma into the interstellar medium, releases of barium into solar wind, and the interaction of comets with the solar wind [5,6]. Despite considerable experimental and theoretical progress in the dynamics of single laser produced plasmas, little attention has been paid to studying the nature and dynamics of laser produced colliding plasmas. When two streaming plasmas collide various interactions can arise. These may be of collisionless type in which case collective plasma effects occur or they are collision dominated. Depending upon collisionality of the plasmas, which in turn depends on temperature, density and ionic charge, varying amounts of interpenetration are predicted [7,8].

In this article we report the time evolution of colliding laser produced magnesium plasmas using fast photography. A 5ns gated XUV pinhole camera was used to record two-dimensional time resolved images of the colliding plasmas.

2. EXPERIMENTAL SET UP

A pulse from a ruby laser (6 J, 15 ns) is split into two beams with different intensities by means of a movable glass wedge. Details of the experimental set up are given elsewhere [8]. Changing of the position of the wedge can vary the intensity ratio of the two beams. These two beams are focussed onto two magnesium slabs which are placed at 90^0 to each other kept in a vacuum chamber by a plano-convex lens with a focal length f = 300 mm. The target slabs are placed on a motorised linear mount so that fresh surface is presented to the laser for each shot. This prevents the creation of craters that will occlude emission from the hot core of the plasma. The distance between the two foci at the target surface is given by the relation

$$d = f\gamma(n-1) \qquad (1)$$

where n = 1.5, the refractive index; γ, the acute angle of the wedge. In the present studies we used a glass wedge with an acute angle of 17'02'' which corresponds to a distance of separation between the foci of d = 0.75 mm. The estimated spot sizes were approximately 400 μm. A gated (5 ns gate width) XUV pinhole camera is used to record two-dimensional time resolved images of the colliding plasmas. For this we used a 50-micrometer pinhole with a microchannel plate combined

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with a charged-coupled device (CCD). The pin hole camera had an aluminium filter (thickness 0.2 μm), resulting in a spectral sensitivity of the system of < 80 nm. The pin hole pictures are taken from a direction perpendicular to the plane of the two laser beams.

3. RESULTS AND DISCUSSION

XUV pinhole pictures of plasmas reveal more details about expansion dynamics of the plasma plume. As XUV radiation is emitted only by hot and dense plasma where higher ionisation stages dominate, this technique is suitable for studying the plasma plume in the earlier stages. In the present experiment, the targets are mounted at an angle 90° to each other. This arrangement leads to a good interpenetration of the two plasmas because of higher relative velocities than in the case of laterally colliding plasmas. The intensity ratio of two laser beams are made 7:1 that gives power densities 2×10^{11} $\mathrm{Wcm^{-2}}$ and 3×10^{10} $\mathrm{Wcm^{-2}}$, respectively. The positions of the foci of the hot and cold plasma on the target surfaces are very important parameters because this governs the relative velocity with which the plasmas collide. In order to account for the higher expansion velocity of the hot plasma the hot laser spot is placed closer to the common edge compared to the weak beam spot. A slight change in the geometry causes drastic change in the shape and position of the interaction region.

Fig. 1(a-h) gives pinhole pictures taken at different times after the maximum of the laser pulse. The bright plume in the lower part of the image is the hot plasma and the plume in the upper part is the cold plasma. The expansion velocities of both plasmas are measured from the time evolution of the pinhole pictures. The estimated expansion velocities of hot and cold plasma in the initial stages are $(8 \pm 2) \times 10^6$ cm/s and $(4 \pm 2) \times 10^6$ cm/s, respectively. Initially both plasmas expand freely. As time evolves, a thin interaction region (75 μm) begins to evolve at the collision region of the two plasmas and the intensity of the interaction region becomes brighter with time. It is interesting to note that the thickness of the interaction region becomes wider as time elapses. The length of the interaction region becomes ~1mm (including penumbral image) at 15 ns after the laser maximum.

At later times the collision region is found to be tilted towards the direction of the hot plasma (anti-clockwise). The tilting of the collision region is expected to be due to the lower density of the cold plasma at the outer region of the target. At times greater than 30 ns, a radiating region appeared at the target slab close to the hot plasma. The high energetic ions and electrons from the hot plasma hit the target surface, which in turn creates a secondary plasma near the hot plasma. Finally, this secondary plasma also interacts with oncoming plasma, which leads to a brighter emission from the collision region (fig. 2h).

The pin hole pictures show a jet-like emission starting in the collision region ~6 ns after the laser maximum. The spatial and temporal properties of this emission strongly depend on the laser power densities at the foci and the position of the spot from the point of contact of the target surfaces. The lifetime of the colliding plasma is found to be greater than the lifetime of the hot and cold plasmas. Figure 2 represents the temporal evolution of the brightness (taken from the image) of the three plasma clouds *viz.* hot, cold and colliding with time elapsed after the maximum of the laser pulse. It is observed that the emission intensities of hot and cold plasmas increase up to a certain time and then decrease with time. The colliding region appears after a certain delay after the maximum of the laser pulse. The overall intensity of the colliding plasma is found to enhance with time and peaks around 20 ns after the maximum of the laser pulse. It is worth noticing that the plume intensity of the colliding region is higher at later times compared to the hot and cold plasma.

As the plasma expands from the solid surface it rapidly cools. Its outward expansion velocities are large. For sufficiently low plasma densities where the ion-ion mean free path exceeds the dimensions of the system, the two plasmas interpenetrate with little collisional interaction. Interpenetration of the plasmas takes place at short times (< 1ns) and during interpenetration the population density is perturbed by charge exchange collisions. At high plasma densities, where the ion-ion mean free path is smaller than the plasma density scale lengths, the region of plasma interpenetrating is relatively small. In this case, plasma stagnates. It is reported that for colliding plasmas with relatively large velocity and/or low density, interpenetration is expected, leading to a wide heated region building up at relatively later times, and in the case of low relative velocity and/or high density, the plasmas will collide and stop almost immediately, leading to very localized heated region. A recent paper [9] describing the experimental study of the collision of aluminium plasma with magnesium plasma confirms that the plasmas interpenetrate each other at early times and stagnate at later times. When these plasmas collide the directed kinetic energy can be converted into thermal energy, the plasmas heat up and slow down. The relative velocity of the plasmas will be reduced by the interaction and the momentum transfer cross-sections increased. This in turn will create a rapid build-up of stationary plasma in the interaction region having the appearance of a jet.

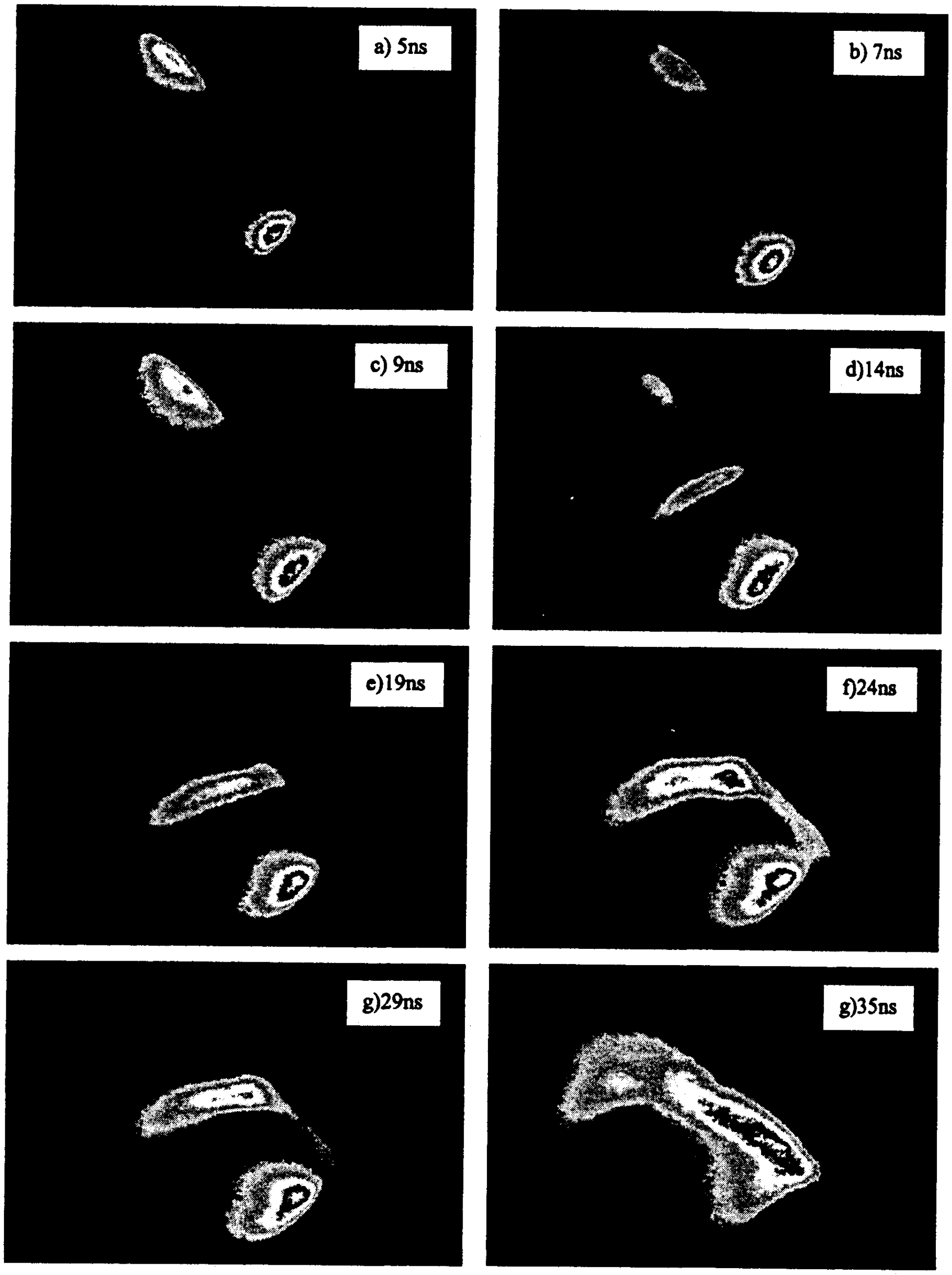

Fig. 1 Pinhole pictures of colliding plasmas. The time given in the pictures is the delay of the gate pulse after the laser pulse maximum The gate width was set at 5ns.

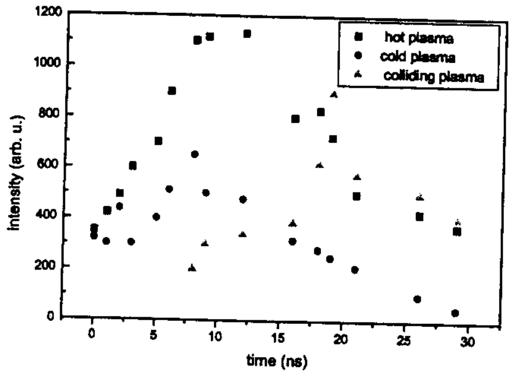

Fig. 2 The temporal evolution of the brightness taken from the pinhole pictures of the three plasma clouds *viz.* hot, cold and colliding with time elapsed after the maximum of the laser pulse

4. CONCLUSION

Time resolved photographic studies of colliding laser produced magnesium plasma have been carried out to gain an insight into the expansion dynamics of the collision region. Enhanced emission from the collision region is observed at later times. More spectroscopic studies are needed in the present case to find out whether the emission of the collision zone is due to stagnation of the plasmas or if the plasma interpenetrates and show stronger emission due to charge exchange collisions.

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