Soft X-Ray Laser Interferometry of a Dense Plasma Jet

Jonathan Grava, Michael A. Purvis, Jorge Filevich, Mario C. Marconi, James Dunn, Stephen J. Moon, V. N. Shlyaptsev, and Jorge J. Rocca, *Fellow, IEEE*

***Abstract*—Soft X-ray laser interferograms were acquired to map the evolution of a dense plasma jet created by the laser irradiation of a solid copper triangular target. The plasma is observed to rapidly expand along the symmetry plane of the target, forming a narrow plasma plume with measured electron densities of up to 1.2×10^{20} cm^{-3}.**

***Index Terms*—Plasma diagnostics, plasma jets, soft X-ray laser, soft X-ray laser interferometry.**

UNDERSTANDING the formation and evolution of jets is of significant interest both in astrophysical [1] and laboratory plasmas where jets can result from the irradiation of solid targets with intense lasers [1]–[3]. Detailed experimental data is needed to aid the understanding of the physics of plasma jets and to validate the codes used to model them. Laboratory plasma jets can have large density gradients that cause optical laser probes to be refracted. In contrast, short wavelength light can propagate in dense plasmas with greatly reduced refraction, probing regions that cannot be accessed with optical lasers. In particular, soft X-ray laser interferometry can yield detailed 2-D maps of the electron density. Our group has previously used soft X-ray interferometry at 46.9 [4], [5] and 14.7 nm [6] to study a variety of dense plasmas.

Herein, we present a snapshot of the density distribution in a dense plasma jet. The jet was created by irradiating $\sim 90^\circ$ triangular Cu grooves at an intensity of 1.1×10^{12} W $\cdot$ cm^{-2} with $\lambda = 800$-nm Ti:Sapphire laser pulses that were 120 ps in duration. The grooves were 220 μm deep, 500 μm wide, and 1 mm long. This laser-created plasma was probed along the length of the groove with a 46.9-nm beam generated by a capillary discharge-pumped tabletop Ne-like Ar amplifier [6], which delivers laser pulses of $\sim$1-ns duration. The capillary discharge laser was combined with a soft X-ray amplitude division interferometer that uses diffraction gratings to split and recombine the beam [7]. Varying the delay between the 46.9-nm probe pulse and the laser irradiation pulse enabled the acquisition of high-contrast interferograms at different times during the plasma evolution.

The interferograms show that a very narrow plasma jet with a large length to width ratio ($> 10:1$) is formed at the bottom of the groove. The jet expands nearly 300 μm along the symmetry plane of the cavity within the first nanosecond after laser irradiation. Fig. 1(a) shows a soft X-ray laser interferogram obtained 4.2 ns after the irradiation of the target. The shift in the fringes indicates that, at this time, the plasma jet has already expanded outside the groove, reaching a length of ~ 600 μm, while simultaneously broadening to a width of ~ 65 μm. The analysis of the interferogram [Fig. 1(b)] shows that, at a distance of $\sim$100 μm from the bottom of the cavity measured along the symmetry plane, the electron density exceeds 1.2×10^{20} cm^{-3}.

Two-dimensional simulations performed by using the hydrodynamic code HYDRA show that the jet formation is initiated by accelerated material ablated from the vertex that is augmented by the continual sequential arrival of wall material along the symmetry plane, where it collides and is redirected outward. Early on, radiation is found to play a significant role in cooling the plasma, which reduces the initial pressure, maintaining a collimated jet over an extended period of time. Later in the evolution, the pressure in the jet is no longer counterbalanced by the momentum of plasma ablated from the sidewalls and causes it to widen. The collision of the expanding plasma jet with the plasma generated at the walls forms plasma side lobes.

The results illustrate that soft X-ray laser interferometry is a powerful tool to generate 2-D maps of the electron density in dense large-scale plasmas that cannot be probed with optical lasers.

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J. Grava, M. A. Purvis, J. Filevich, M. C. Marconi, and J. J. Rocca are with the Department of Electrical and Computer Engineering, Colorado State University, Fort Collins, CO 80523 USA (e-mail: rocca@engr.colostate.edu).

J. Dunn and S. J. Moon are with Lawrence Livermore National Laboratory, Livermore, CA 94551 USA.

V. N. Shlyaptsev is with the Department of Applied Science, University of California-Davis, Livermore, CA 94551 USA.

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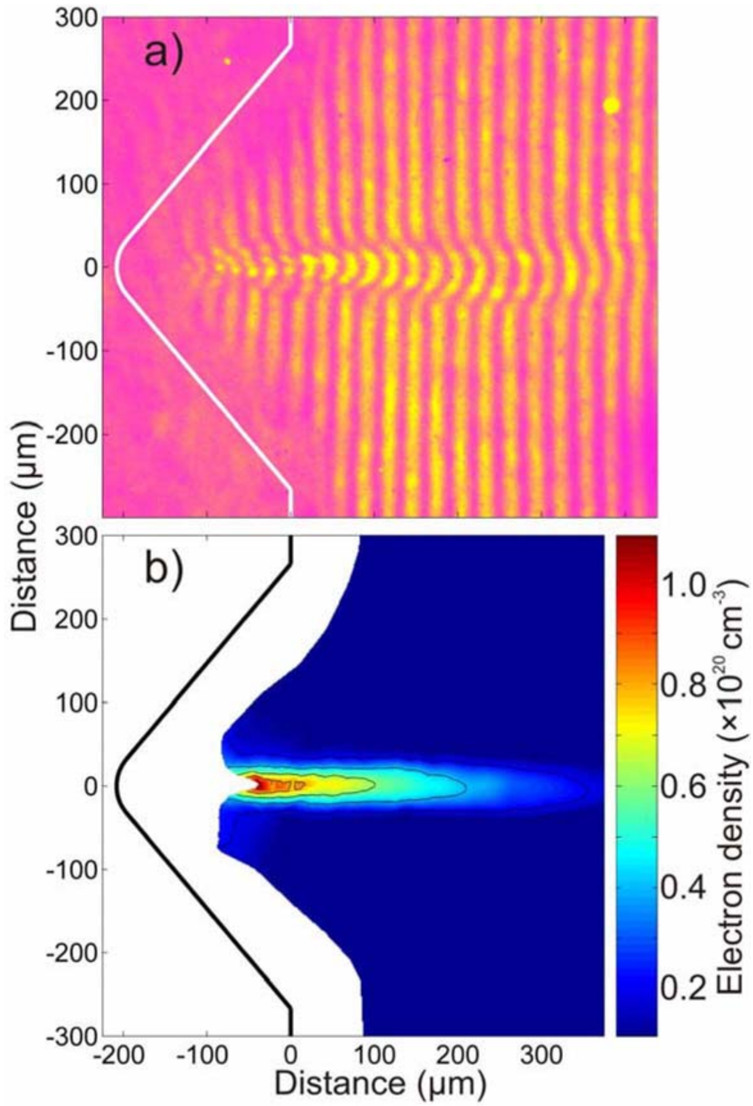

Fig. 1. (a) Soft X-ray interferogram and (b) corresponding plasma density map of a plasma jet created by the laser irradiation of a triangular copper groove. The interferogram is taken 4.2 ns after the irradiation of the target surface (outlined on the figure by the solid black line) by a 120-ps-duration optical laser pulse with an intensity of 1.1×10^{12} W · cm^{-2}.

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