Dense Capillary Discharge Plasma Waveguide Containing Ag Ions

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***Abstract* - Interferometry of plasmas generated by fast discharge excitation of Ag_2S microcapillary channels shows the formation of dense plasma waveguides capable of guiding intense laser beams. Discharge ablation of capillaries, 330 μm or 440 μm in diameter, with 3-5.5 kA current pulses formed concave plasma density profiles with axial electron density > 1 $\times 10^{19}$ cm^{-3}. These dense plasma waveguides containing highly ionized metal atoms are of interest to the development of a longitudinally pumped soft x-ray lasers.**

Plasma waveguides can extend the interaction length between intense laser pulses and plasmas beyond the limits imposed by diffraction and ionization induced refraction [1]. Several schemes for the generation of plasma waveguides based on either laser or discharge excitation have been studied. Some of these guides have been utilized in the development of soft x-ray lasers [2-5]. However, plasma guides containing metal vapor ions that are of interest for the generation of laser amplification by collisional electron excitation at wavelengths below 20 nm remain to be developed. Herein we report the use of a fast (~ 55 ns first half-cycle) micro-capillary discharge of larger peak current (3-5.5 kA) for the generation of dense plasma waveguides containing a large concentration of Ag ions. The results are particularly relevant to the development of a longitudinally excited collisional soft x-ray laser at 13.9 nm in Ni-like Ag ions.

The plasmas were generated by discharge ablation of the walls of Ag_2S capillaries 330 μm or 440 μm in diameter and 2 to 4 mm in length. The discharge current pulses had a peak amplitude of 3 to 5.5 kA and a half-period of ~ 55 ns. To enhance the uniformity of the plasma column and its shot-to-shot reproducibility a pre-plasma was generated by filling the capillary channels with 0.6 Torr of He and pre-ionizing the gas with a low current pulse. The plasma density distribution was measured using the third harmonic (267 nm) from a sub-picosecond Ti:Sapphire laser system (~1 mJ, 800 nm) in a Mach-Zender interferometer.

Figure 1 shows a sequence of interferograms that map the temporal evolution of the electron density distribution within the 400 μm diameter Ag_2S capillary. It is observed that at these discharge conditions the time span during which concave electron density profiles are generated ranges from about 50 to 70 ns from the beginning of the current pulse. For times longer than ~70 ns the concave density profile starts to degrade rapidly. It is of interest to notice that late in time, after a few half-periods of the current (e.g. 220 ns frame in Fig.1) the curvature of the fringes reverses direction, indicating the presence of a convex electron density profile with maximum density on axis.

Figure 2a shows an on-axis interferogram corresponding to a 440 μm diameter 2.2 mm long Ag_2S capillary excited by a 5.2 kA current pulse, obtained 59 ns after the initiation of the current pulse. Figure 2b shows an overlay of the experimental interferograms and interferograms computed from an electron density profile that was adjusted to fit the experimental data. The resulting radial electron density profile found by this procedure is shown in figure 2c. The electron density difference between the axis of the channel and the vicinity of the walls is measured to be $\Delta Ne \sim 1.0 \times 10^{19}$ cm^{-3}. The absolute value of the electron density on axis was determined measuring the absorption of a 267 nm wavelength probe beam of ~100 μm diameter propagated along the capillary axis assuming an electron temperature of 20 eV and a mean ionization of Z=8.6 estimated from the code RADEX. The measured absorptions for the majority of the strongly guided shots (~50-70 ns) amount to axial electron densities of ~ $2\text{-}3\times 10^{19}$ cm^{-3}. The discharges through 330 μm diameter capillaries were measured to generate plasmas with higher electron density on axis and steeper density walls. The measured electron density profile for a 440 μm diameter capillary shown in Fig. 2 can be computed to guide a beam with a matched mode size of ω_0 = 27 μm. Beam propagation experiments were conducted focusing 120 ps, 100 mJ, Ti:Sapphire laser pulses at the entrance of the capillary channel into a ω_0 ~30 μm spot. Exit mode patterns corresponding to a 440 μm diameter, 4 mm long capillary, showed an output mode pattern with a well defined peak of ~54 μm FWHM and a relatively low pedestal.

Manuscript received 2004

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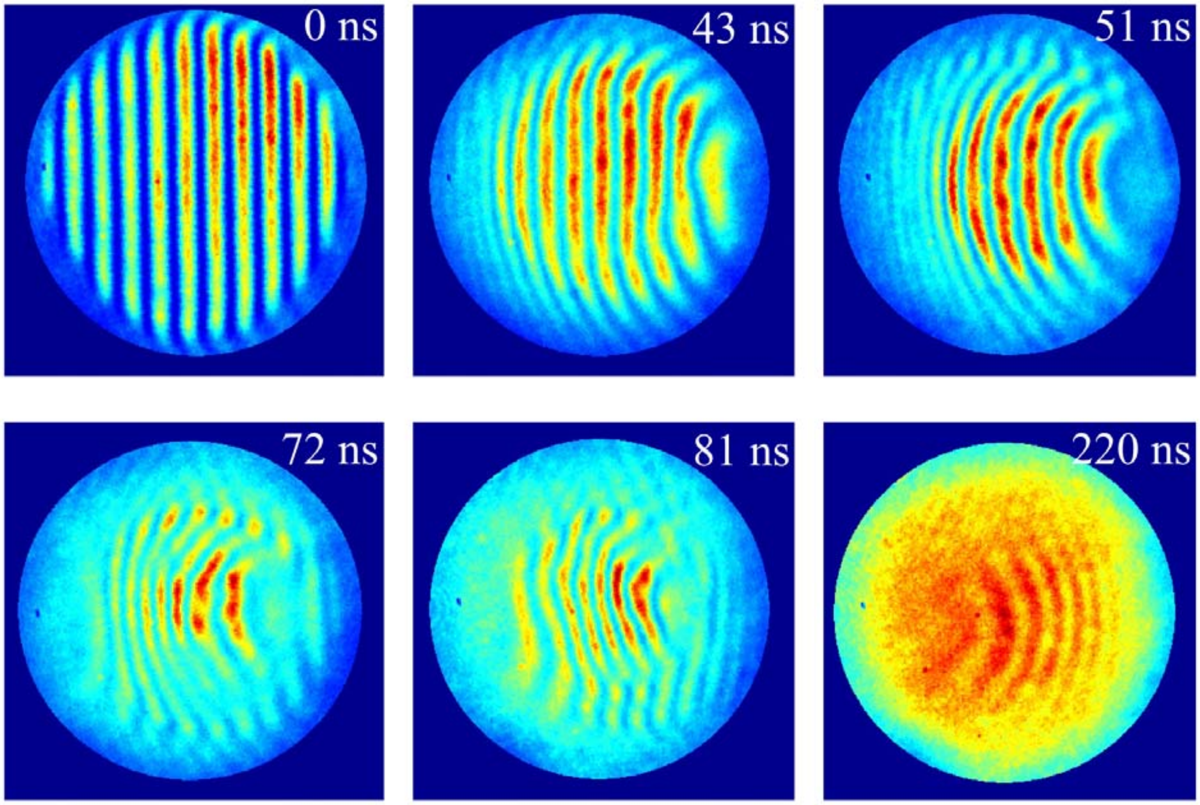

Figure 1. Shown is a sequence of interferograms corresponding to a 440 μm diameter Ag_2S capillary. The times are measured with respect to the beginning of the current pulse.

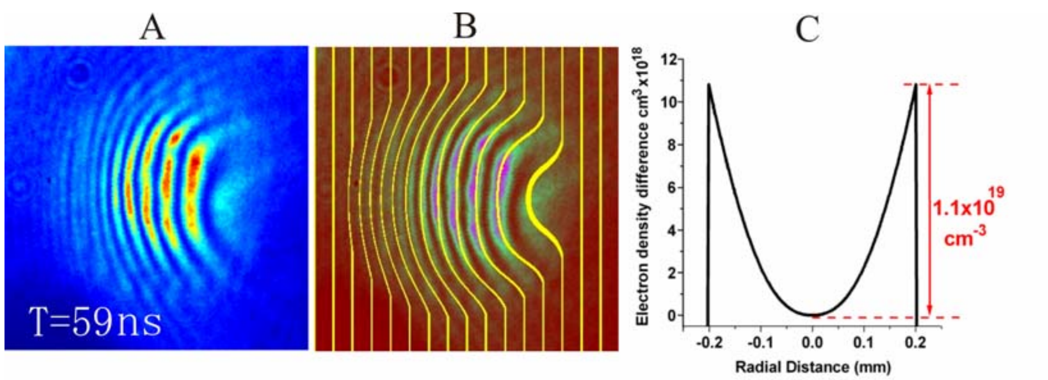

Figure 2. Interferograms of a 440 μm diameter, 2.2 mm long, Ag_2S capillary discharge plasma A) 59 ns after the initiation of the current pulse. B) Overlay of measured and best-fit simulated interferogram. C) Corresponding radial variation of the electron density distribution. Note that the on-axis electron density value was determined from absorption measurements.

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