ELECTRON NUMBER DENSITY MEASUREMENT BY RUBY LASER INTERFEROMETRY IN A CO_2 LASER-INDUCED GAS BREAKDOWN PLASMA

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ABSTRACT

Using a ruby laser beam with [illegible] nsec full width at half magnitude, [illegible] spatially and time-resolved, two-dimensional interferometric measurements of electron number density in CO_2-laser produced plasma in hydrogen near the focal spot. The focal plane of the CO_2 laser is arranged to be at the exit of a free-expansion jet, with the beam incident from the vacuum side. Several nanoseconds after breakdown, a shock wave is formed, propagating transverse to the incident laser beam direction. Behind the transverse propagating shock is an on-axis density minimum, which results in laser-beam self-trapping. During the initial pulse duration of the CO_2 laser, the radial boundary of the plasma column increases linearly in time.

INTRODUCTION

The advent of long pulse, high energy CO_2 lasers has led to the consideration[1] of using such lasers to heat a magnetically confined plasma column for controlled thermonuclear reaction purposes. The configuration most frequently suggested is a linear device with a plasma column about 1 km long, a few millimeters in diameter, confined radially by a magnetic field of several hundred kilogauss strength, and heated from the ends by powerful, long-pulse CO_2 lasers. The absorption length for 10.6 μm radiation in the heated plasma, if one assumes inverse bremsstrahlung to be the dominant mechanism, would be comparable to the length of the plasma column in order to continue its penetration along (and heating of) of the plasma column.

The present paper reports two-dimensional interferometric measurements of electron density in underdense plasma produced by gas breakdown at the focal spot of a 30-J CO_2-laser, whose pulse width at half magnitude is 1[illegible] nsec. The temporal and spatial resolution of the measurements are [illegible] nsec and [illegible] μm, respectively, sufficient to show the evolution of the electron density except in the first few nanoseconds after the laser-induced gas breakdown.

EXPERIMENT

The experiment is shown schematically in Fig. 1. A 0.[illegible] mm thick diaphragm with a 6 mm diameter orifice separates and interconnects two chambers, one on each side of the focal plane. The downstream chamber is pulse-filled with a solenoid valve, while the upstream side is held under relative vacuum. The CO_2 laser is pulsed with a preset time delay relative to the time of valve opening, and gas pressure at the time of the laser pulse can be varied by

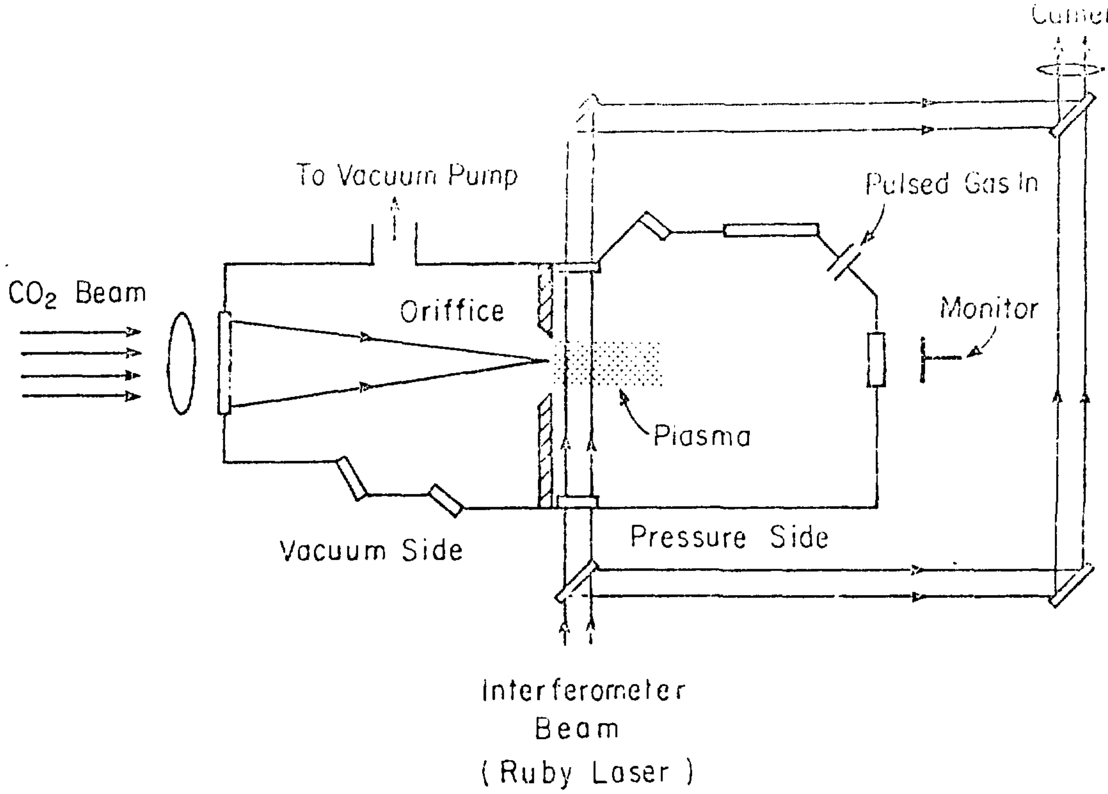

Fig. 1 Schematic of test section. A steep gas pressure gradient is established at the exit of the orifice when the pressure side is pulsed-filled just prior to laser pulse.

adjusting this time delay. The gas pressure is monitored by measuring the fringe shift resulting from the gas pressure change or by a fast-rise pressure gauge. The laser pulse duration is ~10^{-7} sec, the gas pressure filling process is ~10^{-4} sec, and its exit velocity at the orifice is ~ 10^4 cm/sec. Thus, the gas can be considered as stationary both in space and time during the laser pulse duration, and has a steep axial gradient across the laser beam focal plane.

The plasma is initiated at the focal spot of a transversely excited, atmospheric-pressure CO_2 laser with unstable resonator optics, which gives an annular output beam with [illegible] cm i.d. and [illegible] cm o.d., and beam divergence less than 1 mrad. The beam is focused by a KCl lens of [illegible] cm focal length. The radial intensity distribution at the focal spot, which was determined by attenuating the beam after passage through the lens and observing the burn patterns in and near the focal plane, is roughly gaussian, with a focal spot diameter of less than 1 mm. (Spherical aberration in the lens gives a limiting spot diameter calculated to be 0.7 mm.) Photon drag detectors monitor the incident and transmitted beam. The central portion of the annular transmitted beam has negligible intensity when no plasma is present. With laser-induced gas breakdown, CO_2 laser radiation appears abruptly at the transmitted beam monitor. The beginning of this signal is taken to be the onset time of laser-plasma interaction.

Electron density is measured side-on to the plasma with a ruby laser-illuminated Mach-Zehnder interferometer. The illuminating ruby laser beam has an energy ~25 mJ, a pulse duration of [illegible] nsec FWHM, and an available beam diameter 6.3 cm. The recombined interferometer beam passes through an interference filter to block out plasma luminosity at wavelengths outside 694.3 ± 0.5 nm. A lens focuses the plasma onto photographic film. If azimuthal symmetry is assumed, Abel inversion can be performed on the interferograms to obtain electron number density distribution in the (r,z) plane at the time of

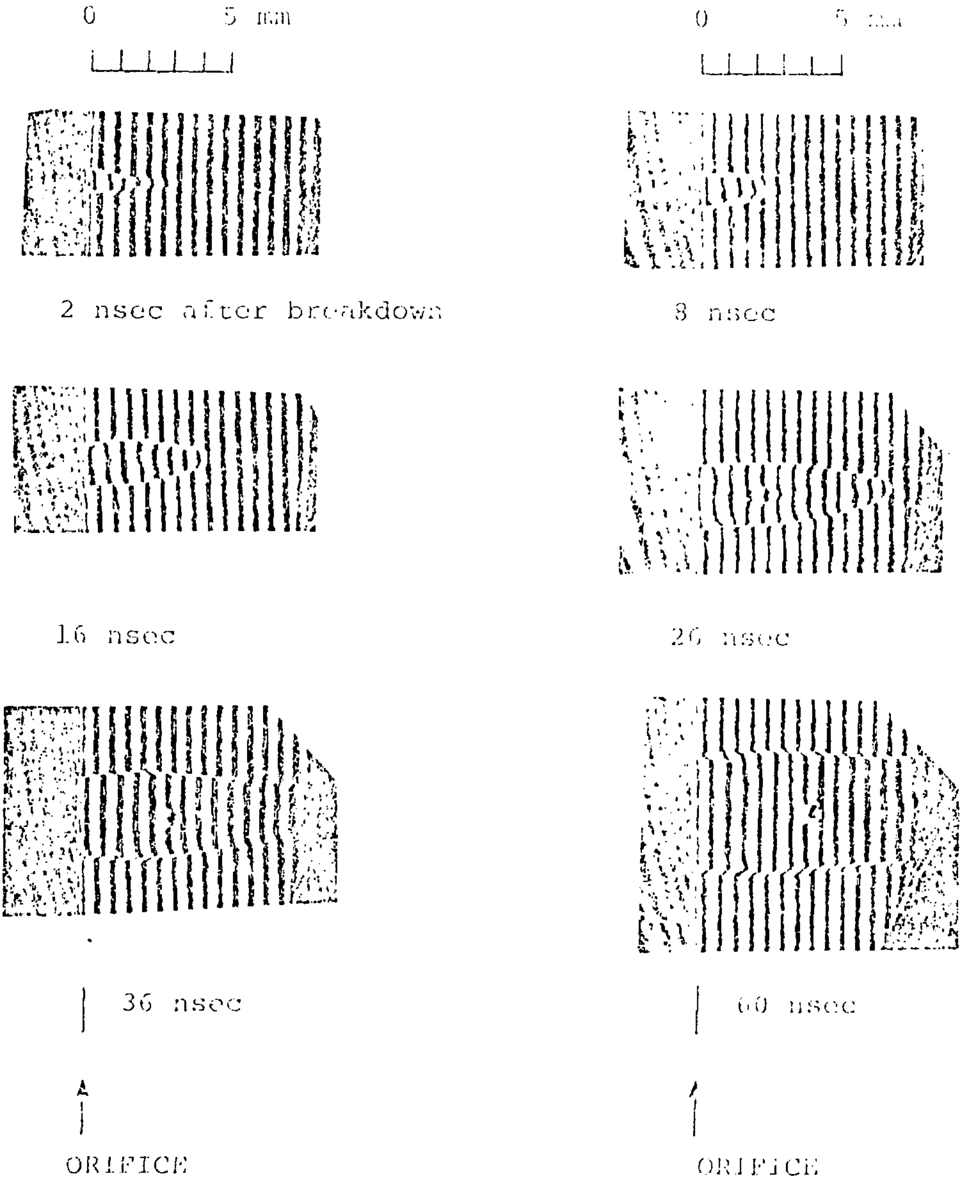

Fig. 2. Ruby laser interferograms of CO_2 laser-created plasma in 37 torr Hydrogen filling pressure. CO_2 laser is incident from the left. The CO_2 focal point is in the plane of the orifice. The small perturbation in the fringes in the last three interferograms is the fringe shift caused by the Thomson scattering (not described in the present paper) ruby laser beam exciting the plasma.

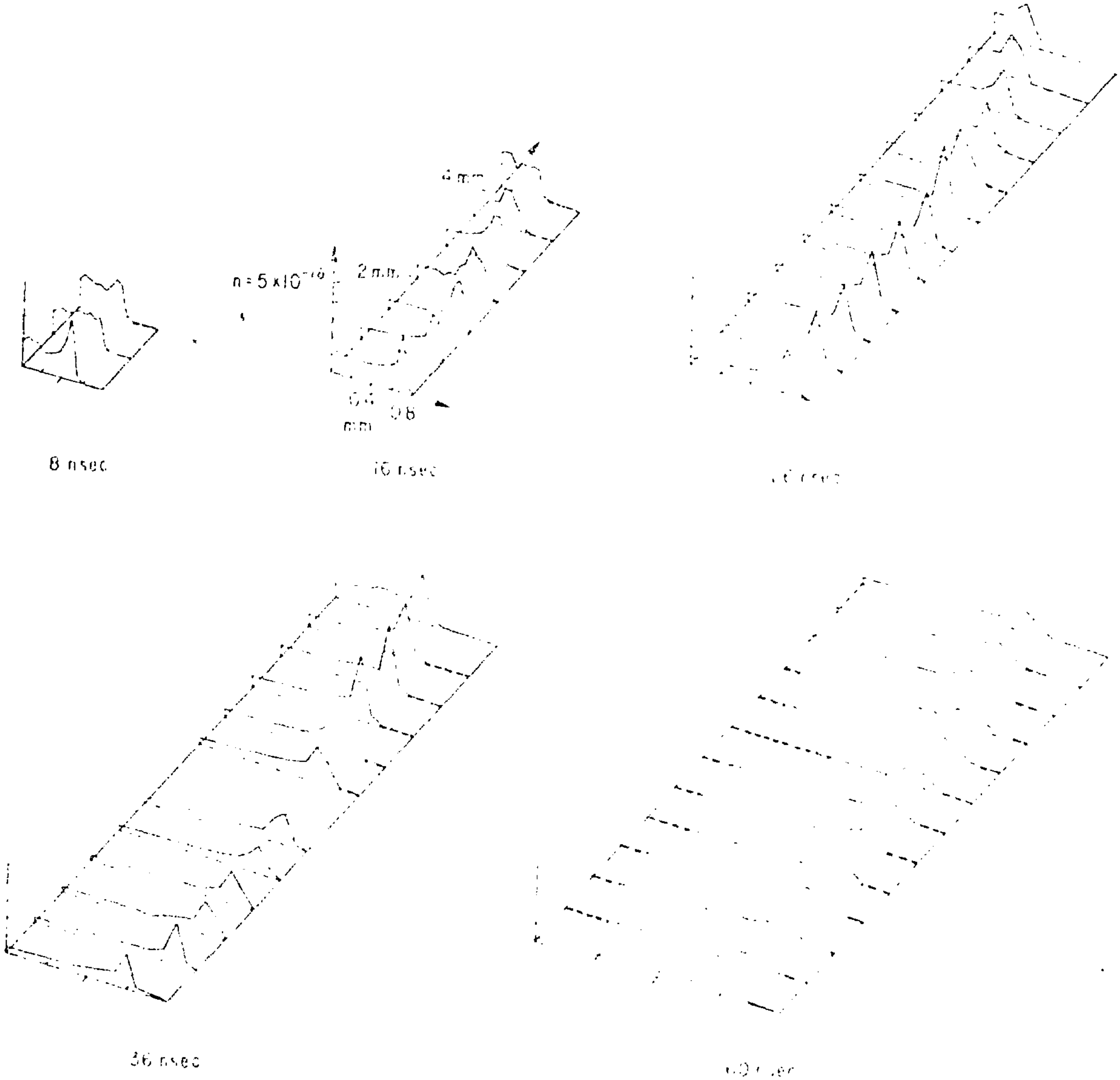

Fig. 3. Electron number density distribution in the axial plane as obtained by Abel inversion of the last 5 interferograms in Fig. 2.

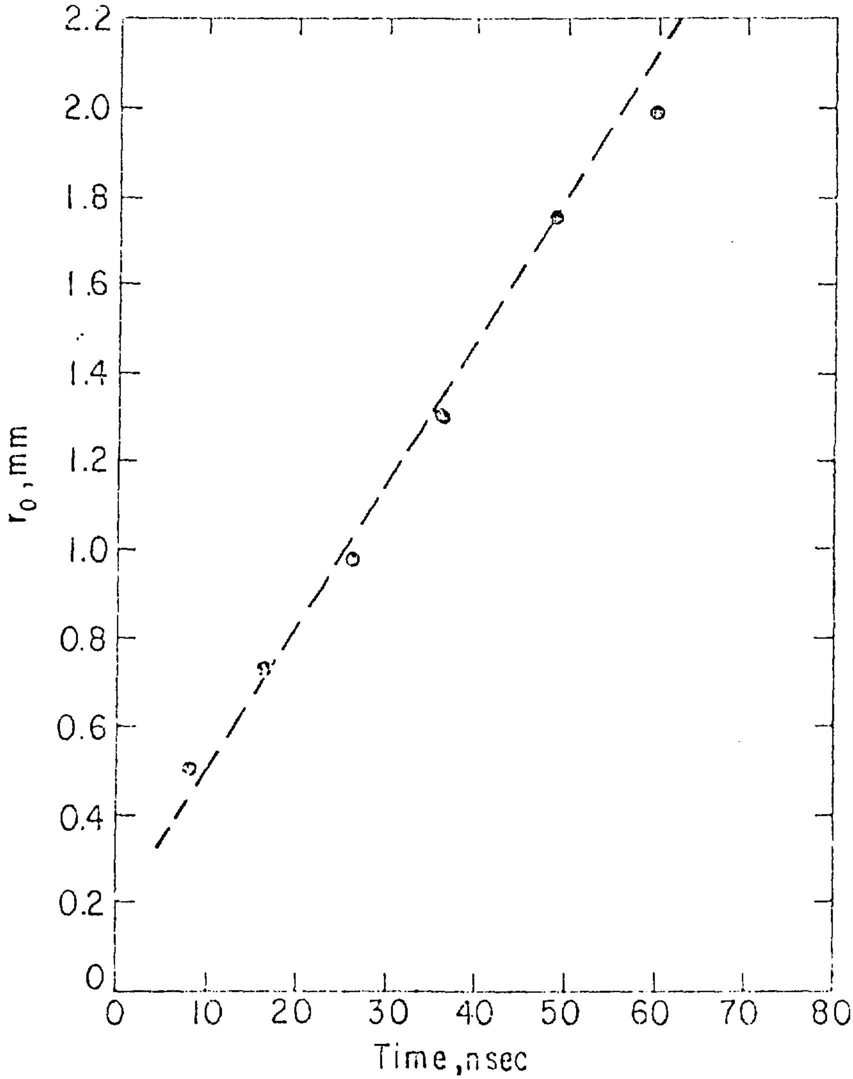

Fig. 4. Radial boundary position of the plasma as a function of time. The dotted line is from an earlier experiment with steady filling pressure 30 torr helium and without the orifice (Ref. 2).

The radial [illegible] to 5.2 x 10[illegible] [illegible].

RESULTS

Figure 2 shows six interferograms taken at [illegible] after breakdown was initiated at the focal point. The hydrogen gas fill pressure was 37 Torr. Qualitatively, all fringe shift patterns are [illegible], and reflect lower density on axis and thus a favorable density profile for laser beam self-trapping. (In the experiment, the diagnostic ruby laser was split into two beams: one for the interferometric measurement described in the present work, and the other for simultaneous Thomson scattering measurements. The [illegible] fringe pattern in the last three interferograms is the additional fringe shift due to breakdown induced by the Thomson scattering ruby laser beam as it exits the plasma. The fringe shift in the first interferogram, [illegible], was likely due to the combined effect of both the CO_2 and the ruby lasers. In the use of Abel inversion to obtain the density profiles, these small fringe patterns are ignored. Also, Abel inversion of these interferograms, [illegible] below, was not performed on the first interferogram. Results of the Thomson scattering experiment will be reported in a future publication.) Figure [illegible] shows the corresponding electron number density distribution in the (r,z) plane obtained by performing Abel inversion of the above interferograms assuming cylindrical symmetry. The on-axis density minimum clearly appears at [illegible] after breakdown. As time progresses, this density minimum becomes more pronounced and the on-axis density decreases from 1.5 x 10^{18} cm^{-3} at [illegible] to 2 x 10^{17} cm^{-3} at [illegible], leading to a favorable density profile for laser self-focusing. We note that the present two-dimensional interferometry maps out the electron number density distribution in the entire (r,z) plane as defined by the aperture in [illegible], while earlier experiments[1] [illegible] beam interferometer relied on the assumption of [illegible] reproducibility.

Figure [illegible] shows the position of the plasma radial boundary as a function of time. The solid lines are results of an experiment[2] [illegible] filling pressure [illegible] in [illegible] with the [illegible] the plasma radial boundary increases linearly in time during this period.

DISCUSSION

Two-dimensional interferometric measurements of electron density in a [illegible] laser produced plasma [illegible] at the focal [illegible] the existence of on-axis density minimum [illegible] after breakdown at the focal spot, thus providing a favorable density profile for laser beam self-trapping. During the initial pulse duration of the CO_2 laser, the radial boundary of the plasma column increases at a constant speed, in contrast with the after-pulse phase in which the radial boundary increases at a speed inversely proportional to the radial position of the boundary.

REFERENCES

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2. [illegible] Johnston and [illegible] Chen, Phys. Rev. Lett. [illegible], [illegible] ([illegible]).

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