Subnanosecond microscopic holographic interferometry of plasmas produced by 1-nsec CO_2 laser pulses*

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Two-dimensional distributions of the electron density within plasmas produced by 1-nsec-duration high-intensity ($>10^{13}$ W/cm^2) CO_2 laser pulses on solid polyethylene targets have been obtained with the aid of microscopic holographic interferometry. Short 700-psec pulses, derived from a synchronized ruby laser, were used to illuminate the interferometric system, which had a spatial resolution of $\sim 10\ \mu$.

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The study of plasmas created by short-duration high-intensity CO_2 laser pulses is now of considerable interest, primarily because of their possible incorporation into schemes designed to induce supercompression of spherical microtargets. In such studies, a precise knowledge, both spatially and temporally, of the electron density distribution in the plasma is implicit to the understanding of the interaction process and the subsequent development of the plasma. Subnanosecond measurements of the electron density within plasmas created by high-intensity ruby or neodymium glass lasers have been made using a variety of interferometric techniques.[1–4] However, although interferometric studies have already been made of plasmas produced in glasses and from solid targets by focused CO_2 laser pulses of several hundred nanoseconds duration,[5–9] no such studies have so far been reported of plasmas created by ultrashort CO_2 laser pulses.

In this letter we wish to describe the measurements made of the electron density profile of plasmas produced by 1-nsec-duration 10.6-μ laser pulses, of energy up to 3.6 J, focused onto solid polyethylene targets with intensities in the focal region of up to 5×10^{13} W/cm^2. These were obtained with the aid of a microscopic holographic interferometric system, having a spatial resolution of $\sim 10\ \mu$, illuminated with 700-psec-duration 0.694-μ laser pulses. Analysis of the interferograms has lead to the production of two-dimensional profiles of the electron density within the plasma, with peak values greater than 10^{19} cm^{-3} being recorded. In addition, the technique, which permitted the measurement of electron densities as low as 3×10^{17} cm^{-3}, provided a sensitive method of detection of cold low-density plasma, produced by low-intensity laser radiation incident on the target prior to the laser pulse.

The experiments were made using a high-power short-pulse CO_2 laser described earlier.[10] This system, comprising of a uv-preionized actively mode-locked oscillator,[11] an electro-optic pulse isolation unit, and several stages of uv-preionized amplifiers, is capable of producing diffraction-limited 1-nsec-duration laser pulses of energy up to 30 J. The laser output was focused in a vacuum of 10^{-5} Torr onto solid CH_2 plane targets by a NaCl lens of 40-cm focal length. The measured focal spot size on the target was $\sim 100\ \mu$.

The holographic interferometric system is shown schematically in Fig. 1. An actively Q-switched ruby laser, producing 35-nsec-duration pulses, was synchronized to the generation of the mode-locked CO_2 laser pulse train. This pulse train consisted primarily of four or five pulses of high intensity, and invariably, the second pulse was selected.[10] In synchronism with the isolation of the single mode-locked CO_2 laser pulse, a short 700-psec-duration 0.694-μ pulse was cut out of the smooth long ruby laser pulse by means of an ultrafast Pockels cell shutter,[12] activated by a spark gap pulse generator triggered by the CO_2 laser. The short 0.694-μ pulse then passed through a spatial filter-beam expansion element comprising a 100-μ pinhole situated between two lenses of focal length 10 and 20 cm. Synchronization between the two short laser pulses could be adjusted in increments of less than 1 nsec by variation of the cable length between the laser-triggered spark gap and the Pockels cell. The illuminating 0.694-μ pulse, which had an energy of $\sim 200\ \mu$J, was equally divided into two beams, one passing through the plasma region and a second, acting as a reference beam, following an equidistant path before being incident on the holographic plate (Agfa Geavert 10E75) at an angle of 10°. The phase disturbance of the illuminating beam in the plasma region was imaged on to the holographic plate with a magnification of 6 with a simple lens of focal length of 7.6 cm. The phase difference was recorded on the holographic plate by firing the ruby laser

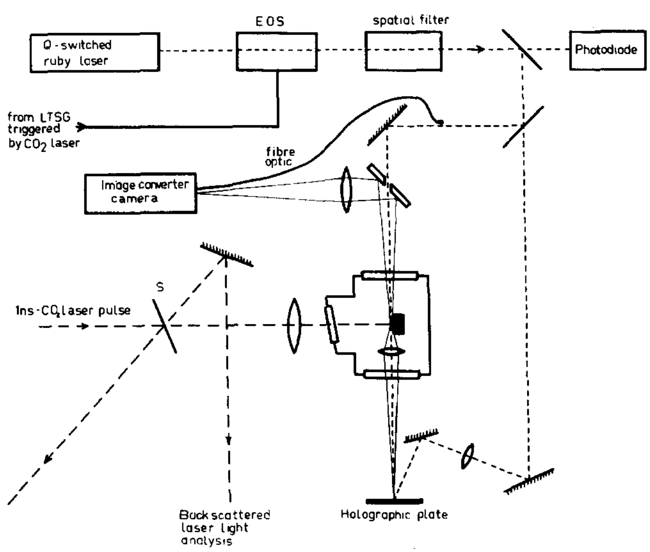

FIG. 1. Schematic of experimental arrangement for subnanosecond microscopic holographic interferometry of the CO_2 laser plasma.

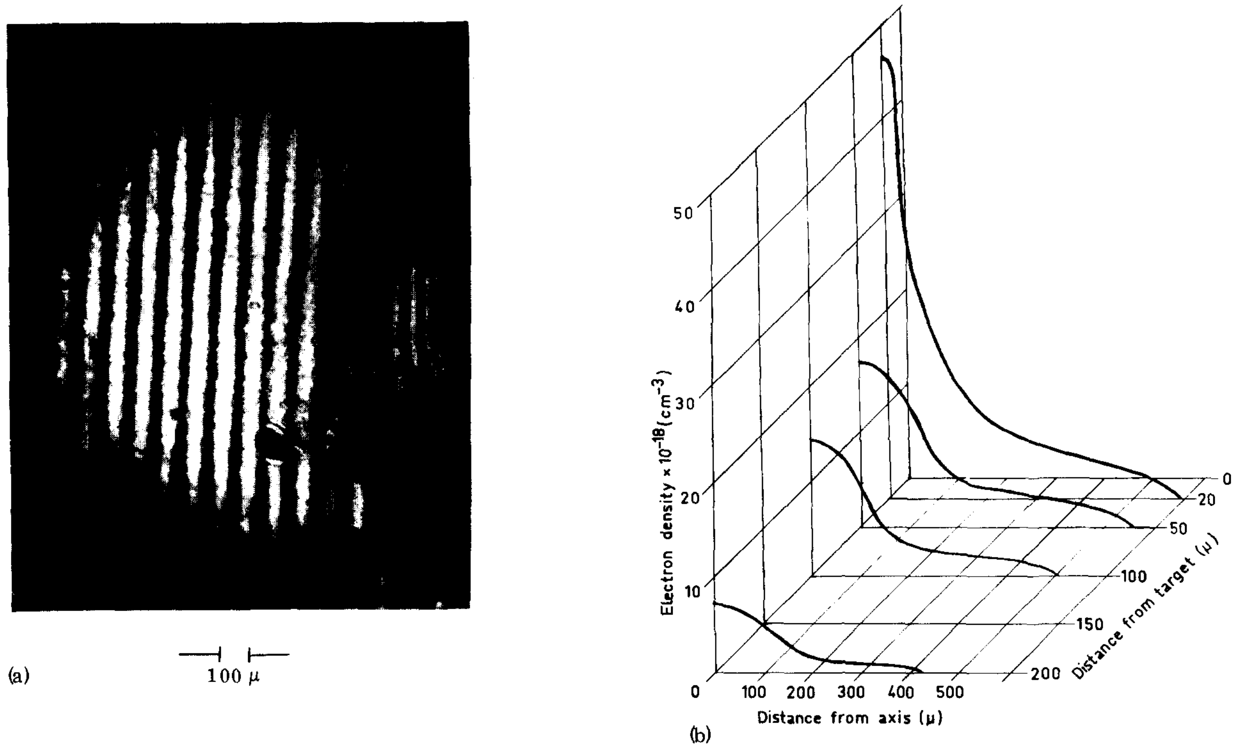

FIG. 2. (a) Interferogram produced 2.5 nsec after the production of a plasma by a 0.3-J 1-nsec-duration CO_2 laser pulse. (b) Two-dimensional electron density profile of the plasma, produced by a 0.4-J 1-nsec-duration 10.6-μ pulse, 2.5 nsec after its production.

a second time without the CO_2 laser, and a set of constant background fringes was imposed on the interferograms by reorientation of one of the reference beam mirrors by 10^{-3} rad between these two shots. Reproduction of the holograms, with any desired magnification, was made with a similar optical system illuminated with a He-Ne laser. The spatial resolution of this interferometric system, as recorded with test pattern objects, and from spatial features in the plasma, was ~10 μ. Synchronism between the probing of the plasma and its creation was measured by means of photodetectors monitoring both laser pulses, and also with the aid of a streak camera which recorded the temporal development of the plasma calibrated with a small sample of the illuminating ruby laser light.

A typical interferogram, obtained 2.1 nsec after the production of a plasma by a 1-nsec CO_2 pulse of 0.3 J energy, is shown in Fig. 2(a). It can be seen that the plasma has expanded several hundred microns from the target, indicating initial expansion velocities in the backward direction in excess of 10^7 cm/sec. Two-dimensional profiles of the electron density were obtained from these interferograms with the aid of numerical Abel inversion,[7,13] assuming both negligible fringe shift produced by ion and neutral components and axial symmetry of the plasma about the laser beam axis. Figure 2(b) shows the resultant electron distribution obtained for the case of a plasma produced by a 0.4-J

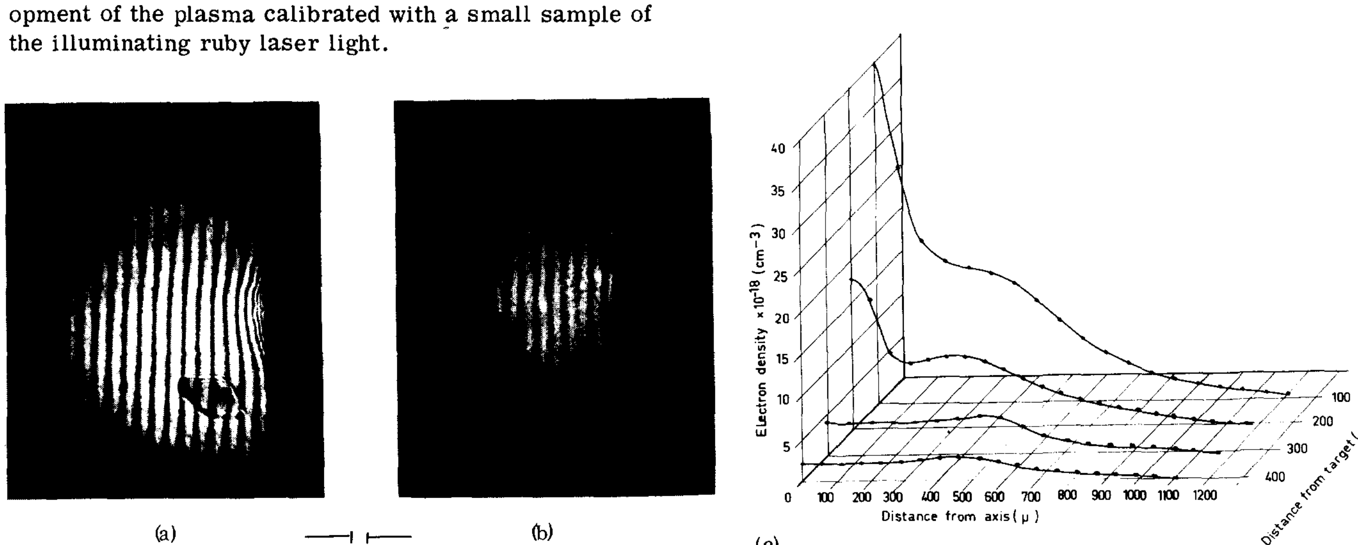

FIG. 3. (a) Interferogram obtained of the plasma existent 22 nsec before incidence of a 3.6-J CO_2 laser pulse on the target. (b) Interferogram obtained 2.5 nsec after incidence of the 3.6-J, 1-nsec-duration CO_2 laser pulse on target. (c) Two-dimensional electron density distribution of the plasma derived from (b).

pulse, 2.5 nsec after its production. It is seen that minimum values of the electron density of 4.5×10^{19} cm^{-3} are recorded within 20 μ from the target surface. Data inaccuracies arising from inversion resolution lead to estimated errors of 20% in the computed values of the electron density in the sharp central peak, and errors of ±8% in the outer regions of the distribution. Also the sensitivity of length calibration gives rise to an additional error of ±15% in the absolute value of the electron density.

When CO_2 laser pulses of considerably greater energy were incident on the target, radial structure in the interferograms was in general observed. This is illustrated in Fig. 3(b) which shows the interferogram obtained 2.6 nsec after the incidence of a 3.6-J CO_2 pulse on the target. As can be seen there is a distinct, approximately axially symmetric, radial modulation of the fringes. This manifests itself in the two-dimensional electron density distribution, Fig. 3(c), as a conical zone of anomalously high electron density emanating from the focal region at the target. The cause of this structure is probably difficult to identify definitively. Although the power density in the focal region (5×10^{13} W/cm^2) is well above the threshold for the onset of predicted anomalous absorption processes, the effects of possible nonuniformities in the laser beam distribution cannot be ignored. In addition, interferograms made of the focal region before the incidence of CO_2 laser pulses of this energy indicated the existence at the target surface of some plasma produced by amplified coherent noise. This primarily results from leakage through the pulse isolation unit of small fractions (< 1%) of the mode-locked laser pulse prior to the selected pulse. This is incident on the target 25 nsec before the high-energy pulse, and an example of the plasma it produces is shown in the interferogram of Fig. 3(a). This interferogram was obtained 2.8 nsec after the production of the plasma by the amplified prepulse, that is 22.2 nsec before the incidence of the high-energy laser pulse. It can be seen that plasmas with electron densities approaching 10^{19} cm^{-3} may be produced by this prepulse, although interferograms produced immediately prior to the incidence of the high-energy pulse indicate that the prepulse plasma density has decayed to values of $\sim10^{18}$ cm^{-3}. Nonetheless, the effect of this plasma in the vicinity of the target at the time of incidence of the high-energy CO_2 laser pulse must be considered.

Thus, in addition to providing some initial measurements of the electron density distribution in plasmas produced by high-intensity short-duration CO_2 laser pulses, the study also indicates the potentialities of short-duration high-spatial-resolution interferometry as a sensitive means of diagnosing the effects produced on target by low-power prepulse laser radiation.

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