Boundary effects on the dynamics of channels generated by laser-initiated discharges

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The dynamics of unbounded and bounded reduced density channels have been characterized by means of ruby laser schlieren photography. These channels are produced by CO_2 laser-initiated discharges in clean atmospheric pressure air. Bounded channels exhibit a significant compression in width and earlier onset of fine scale turbulence. These results could impact proposed designs for inertial fusion reactors relying upon reduced density channels for particle transport through gas blankets.

Recent research[1–4] at other laboratories has produced long-reduced density channels in atmospheric pressure air and investigated the feasibility of electron beam injection into these channels. Reduced density channels could have important applications to inertial fusion reactors since they provide a means of transporting particle beams through a high-density shielding gas blanket.[5–7] Most channel experiments in atmospheric pressure air[1–4] have been performed in essentially unbounded conditions in which the walls were far enough away to have negligible interaction. The effects of solid boundaries on the dynamic behavior of reduced density channels could, however, have important implications on the design of fusion reactors in which channels may be in close proximity to reactor components. Effects which could degrade channel stability include reflected shock waves[7] and boundary induced asymmetries which can decrease the onset time for turbulent convective mixing.[8]

We have employed a ruby laser schlieren diagnostic to investigate the dynamics of laser-initiated discharges and to characterize the channel behavior for three cases:

(1) Unbounded channel conditions,

(2) A planar insulating boundary on one side of the channel, and

(3) Two planar insulating boundaries on opposite sides of the channel.

The experimental configuration is depicted schematically in Fig. 1. A TEA CO_2 Laser (Lumonics 601A) generates a triangular 100 nsec pulse of annular cross section. Calorimetric measurements made downstream of the propylene absorption cell yielded an incident laser energy of 12.3 J for these experiments. The discharge current is supplied by low-inductance capacitors switched through a precision triggered spark gap. In these experiments the delay between the laser pulse and the application of high voltage to the electrodes was 7.6 μsec. Schlieren data and open shutter photographs have verified that, with a 2.5 m focal length mirror, the laser breakdown beads almost completely bridge the 9 cm gap with a plasma channel, permitting discharge voltages of 30 kV. For these parameters, the discharge current is 10 kA, with a ringing period of 2.5 μsec. The Ohmic power deposition time is approximately 20 μsec, which is longer than the experiments of Refs. 1–4 but shorter than the typical 100 μsec current pulses in lightning return strokes.[9] The schlieren photography system is similar to that reported in Ref. 2, employing a 20 nsec Q-switched ruby laser with a circular aperture in place of the usual knife edge. By varying the relative delay between the discharge initiation (t_1) and the ruby laser pulse (t_2) we obtain, on separate discharges the temporal evolution of the channel structure. Multiple schlieren photographs at a given time showed reproducible discharge-to-discharge behavior. Planar lucite boundaries were inserted parallel to the discharge axis to compare the behavior of channels bounded on one or two sides with unbounded channels. The two boundaries were positioned symmetrically across the channel approximately 1.6 cm from the center line of the discharge. The upper boundary was designed to fit in the open center of the annular laser beam to minimize interception. The lower boundary intercepted roughly the same fraction of the beam as the electrode and the support for the upper boundary. The data were taken during a single experimental run so that laser and atmospheric conditions would be identical for all three cases.

Schlieren photographs for the three cases are compared at significant times in Fig. 2. At a time (t) 13 μsec after discharge initiation the channels are virtually identical since the shock waves have not yet impinged on the boundaries. At this time the discharge current is still flowing, which accounts for a discernible electrode effect on the right-hand side of the photos. At $t = 31\,\mu$sec the shock waves have propagated to and reflected from the boundaries, possibly ac-

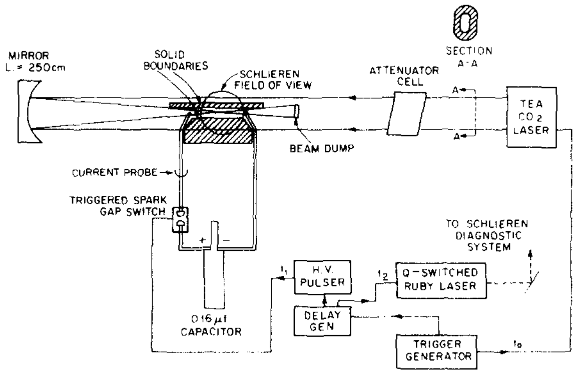

FIG. 1. Experimental configuration.

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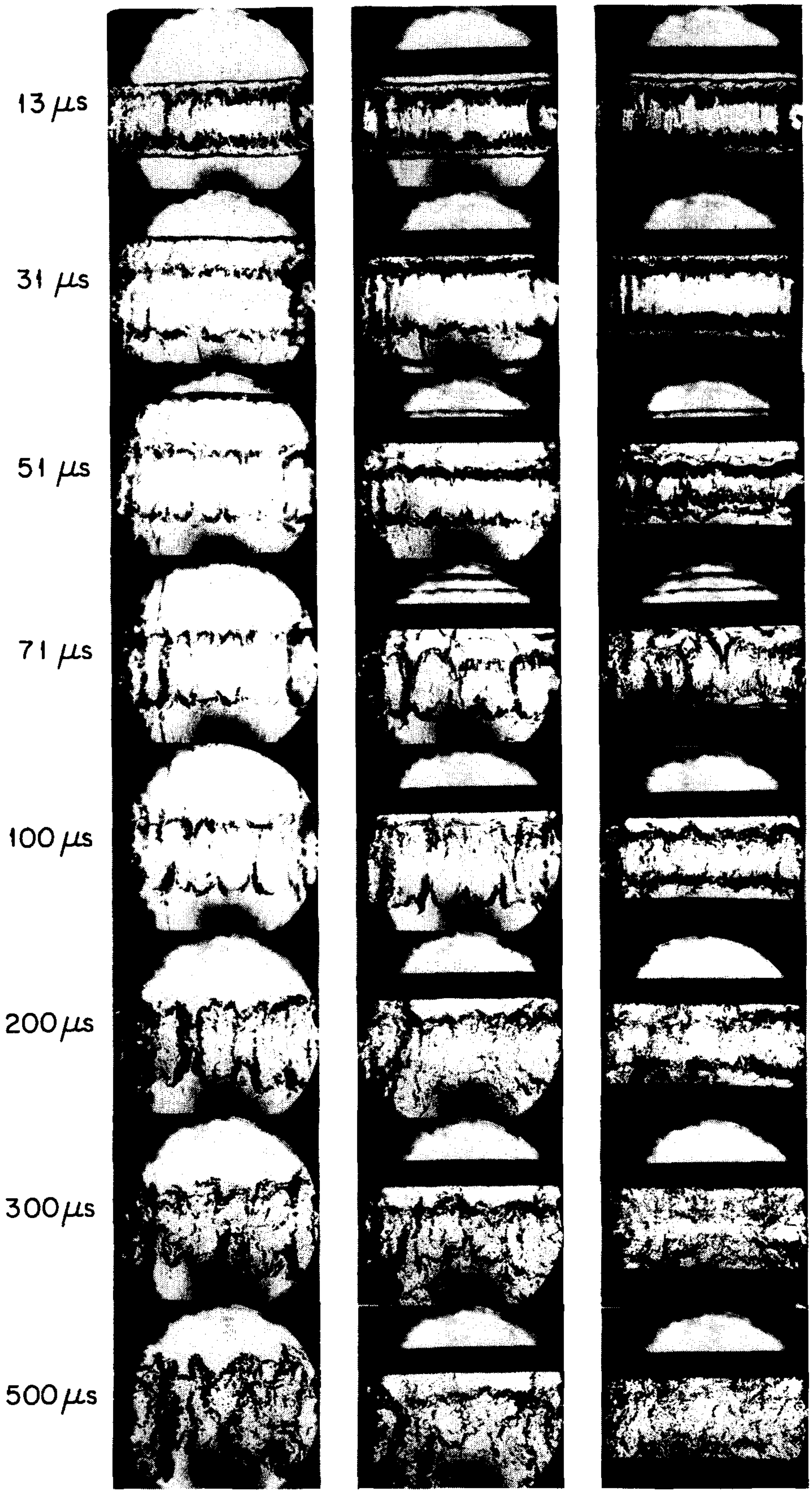

FIG. 2. Sequence of schlieren photographs for: unbounded channels (left-hand column), channels bounded on upper side (center column), and channels bounded on two sides (right-hand column). The times at the left-hand side of each row indicate the delay between discharge initiation and schlieren ruby laser pulse. Magnification is indicated by the 3.2 cm spacing between the upper and lower boundaries.

counting for the increased density gradients at the channel edge. A significant compression of the channel width (30%–50%) occurs at 51 μsec as the reflected shock waves push the channel edge away from the boundaries. Note that for the single boundary at $t = 51$ μsec the channel axis is shifted downward by 0.6 cm. Large scale breakup of the channel becomes apparent at $t = 71$ μsec. From 100 μsec through 500 μsec, bounded channels appear to develop small scale turbulence more rapidly than the unbounded channel.

Theoretical research[8,9] by other investigators has identified convective mixing as the dominant decay mechanism for unbounded reduced density channels. In the case of bounded channels, reflected shocks are also expected to play a major role in channel decay. The data of Fig. 2 suggest that the convective mixing in unbounded channels is associated with longer scale length turbulence, whereas in the bounded cases reflected shock waves appear to drive fine scale turbulence. Further theoretical modeling is required to properly account for boundary effects.

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