Observation of a core in an exploded lithium wire plasma by reflection of laser light*

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A thin lithium wire which was extruded and exploded *in vacuo* was probed with a Q-switched ruby laser. Strong reflections of the ruby laser light were observed from a "core" in the plasma when the pressure was greater than 5×10^{-4} Torr. Changes in the plasma and discharge properties near this pressure suggested the possibility of a core of unvaporized wire due to current shunting through the surrounding air. The presence of this core was unexpected because of the relatively large discharge current and small wire diameter. When the pressure was below 5×10^{-4} Torr a "core" was never observed and there was no evidence of current shunting.

A recent study of the interaction between a Q-switched ruby laser beam and an exploded lithium-wire plasma has shown strong reflection of the laser light from a "core" in the plasma under certain conditions. This strong reflection occurred only when the ambient pressure in the scattering chamber was greater than 5×10^{-4} Torr. This pressure dependence correlated with other distinct changes in the plasma which will be discussed shortly.

The system used for these observations has been previously described.[1] It consisted of a 14-μF capacitor charged to 15 kV and discharged through a 0.0075-cm-diam lithium wire with a spark-gap switch. A maximum current of 104 kA was reached in 3.1 μsec. A unique feature of the system was that the wire was extruded *in vacuo* from the same electrode used to explode it. A Q-switched ruby laser with 0.4-J total energy in a 20-nsec pulse was focused to a 2-mm-diam focal area at the original wire location. The laser was plane polarized in the vertical direction and the observations were made at 90° in the horizontal plane.

Figure 1 shows two sets of framing pictures taken with an image converter camera with an S-20 photocathode. There is a clear difference between the confined column emission at 5×10^{-5} Torr pressure and the diffuse emission at 0.2 Torr. This change in appearance of the discharge took place over a few mTorr range with the emission clearly confined to a distinct column below 5×10^{-4} Torr.

The channel formed in the low-pressure case always disrupted within 3 μsec due to an $m=0$ sausage instability. These constrictions can be seen developing in the example shown with the column eventually breaking at the center at 2.1 μsec. Streak pictures usually showed many strong oscillations in diameter before disruption.[2]

Strong rf emissions from the "column"-type plasma caused a great deal of experimental difficulty. Associated with the rf emissions were rapid fluctuations in the rate of change of the discharge current. With pressures above 5×10^{-4} Torr there was relatively little rf emission and the dI/dt trace was very smooth.

One explanation for the foregoing behavior is of course current shunting around the wire material at the higher pressures. Rapid changes in plasma conductivity because of hydrodynamic instabilities resulted in large voltage oscillations which in turn led to breakdown and conduction through the surrounding gas at pressures above 5×10^{-4} Torr. A lower pressure prevented this shunting and the total current was restricted to flowing through the wire material.

Exploding-wire (EW) work reported in the open literature at pressures low enough to prevent current shunting is very limited.[3-6] Most EW studies have been at atmospheric pressure or "in a vacuum". Investigation usually reveals that this means a pressure greater than 5×10^{-4} Torr [7] which may result in current shunting[8,9] and for a short time, a "core" of unvaporized wire.

Cores have been seen in EW plasmas but only with large wires and low input energy. The reflected ruby laser light provided a sensitive means of showing that an unvaporized core remained even in this high-current thin-wire discharge if current shunting occurred. Figure 2(a) is a view of the wire and electrodes with no discharge.

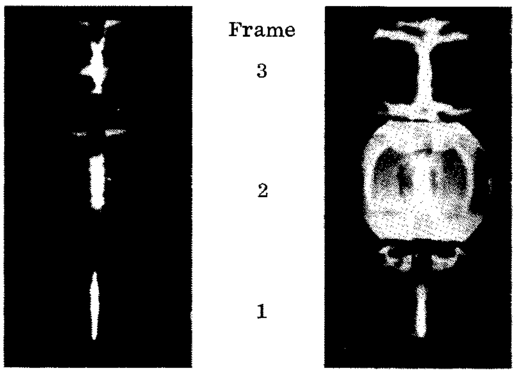

FIG. 1. Framing pictures of plasma emission at 5×10^{-5} Torr and 0.2 Torr. The distance between the electrodes is 5.2 cm with an initial wire diameter of 0.0075 cm. A peak current of 104 kA is reached at $T=3.1$ μsec, where $T_0=0$ at the start of current flow. The bright line to the right of the column in the second frame is a defect in the camera photocathode.

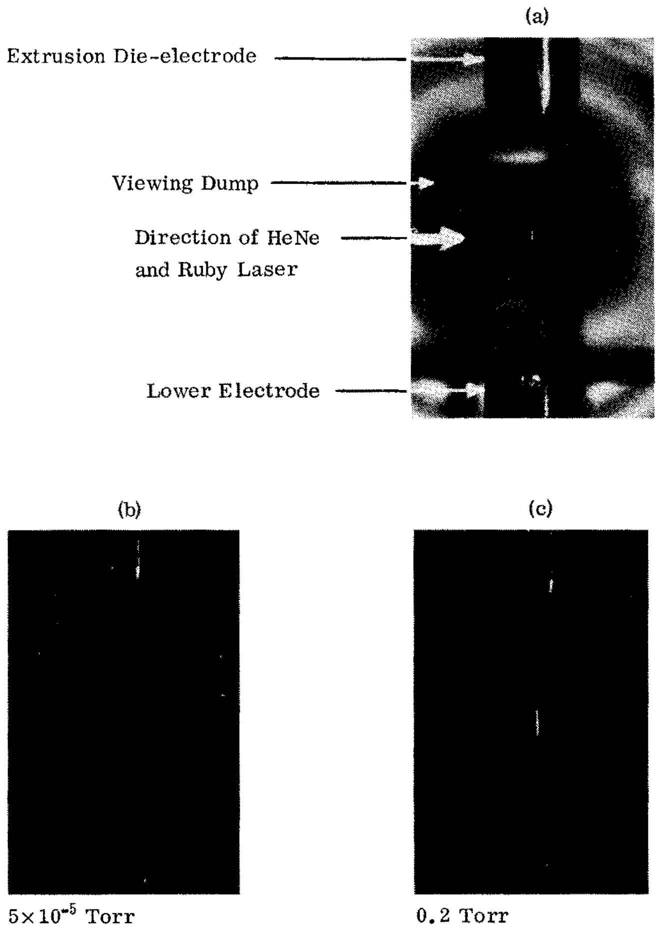

FIG. 2. (a) View of the wire with the HeNe alignment laser incident at the focal position of the ruby laser. The dark rectangular background is a viewing dump (razor-blade stack) 15 cm behind the wire. (b) and (c) Time-integrated photographs of discharges at different pressures with the ruby laser Q switched 2.0 μsec after T_0. At 5×10^{-5} Torr pressure there is no evidence of a reflection, but at 0.2 Torr a strong reflection is seen at the original wire location.

A HeNe alignment laser is incident on the wire at the focal point of the ruby laser. In Figs. 2(b) and 2(c) the wire was exploded and the ruby laser was Q switched 2.0 μsec after the start of current flow. Very little plasma emission is seen in both of these photographs because a narrow-bandpass 6943-Å filter was used to limit the bandwidth to a few Å. No reflection is seen in Fig. 2(b) where the pressure was 5×10^{-5} Torr and in fact no strong reflection was ever seen at any time during the discharge for pressures below 5×10^{-4} Torr.

Figure 2(c) shows an example of the reflected light which appears to come from an unvaporized core of wire material. This strong reflection was always seen for the first 3 μsec of a discharge above a few mTorr pressure. The total energy reflected into the solid viewing angle was 10^{-7} of the original beam or greater. This is only slightly less than the amount reflected from an unexploded wire.

The presence of this core was never discernable in any streak or framing pictures of the plasma emission. Backlighting of the plasma was not attempted. A higher sensitivity did reveal scattered light at pressures below 5×10^{-4} Torr but at lower intensities and definitely not from the original wire location. Its interpretation as Fresnel reflection, and in some cases, Thompson scattering, is discussed in a separate report.[2]

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