Breakdown characteristics of a laser-triggered pseudospark discharge

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Breakdown characteristics of a laser-triggered pseudospark discharge

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Experimental observations are presented on the breakdown characteristics of a pseudospark discharge when a pulsed laser is used to illuminate the back surface of the cathode. The breakdown delay and jitter of the discharge are observed to be controlled by the laser. Observations are presented on the effect of the relative timing of the laser pulse with respect to the fast rising applied voltage. It is found that mJ illumination at up to tens of microseconds before the application of the voltage reduces significantly both delay to breakdown and jitter. High laser energy, applied after the voltage is established across the anode-cathode region, leads directly to breakdown with a delay of less than 100 ns.

The pseudospark is a low-pressure pulsed hollow cathode discharge with a constricted cathode hole.[1,2] The pseudospark discharge is characterized by a short voltage fall time, typically under 100 ns, and low impedance.[3] The delay to breakdown in untriggered discharges in air ranges from tens of microseconds at pressures of the order of 40 μbar to less than 100 ns at 100 μbar.[2] These properties make the device particularly attractive as a high-voltage, high-power, low-jitter fast switch. Several triggering schemes have been investigated: a trigger electrode behind the cathode,[3] an auxiliary glow discharge,[4] electron beam triggering,[5] UV flash tube light,[6] and illumination by unfocused UV laser light at 308 nm on the back cathode surface.[7] These results show that a pseudospark switch compares favorably with thyratrons and other high-power switching tubes.[8]

Previous investigations[2,9] have established that breakdown in the pseudospark discharge is associated with plasma formation in the hollow cathode region. Preliminary results[10] have shown that control of the pseudospark breakdown using a laser-generated plasma in the hollow cathode region is a viable means to obtain a high current controlled switch. In this letter we present detailed measurements on the effect of a focused laser light pulse of 20 ns at 532 nm on the back surface of the cathode. The results show that the laser-formed plasma dramatically reduces breakdown times as well as jitter, and pseudospark breakdown is initiated even at pressures below those at which spontaneous discharge takes place. The laser is found to have a significant effect in reducing breakdown times even at μJ illumination levels and also when the laser precedes the voltage edge by up to tens of microseconds. The difference in behavior when using dry air, N_2, and H_2 as the filling gas is presented.

The pseudospark discharge is obtained in a 10-cm-long and 4.5-cm-diam chamber. A 30–50 kV critically damped pulse with a source impedance of 10 Ω and rise time of less than 50 ns, generated from a Marx circuit, is applied across the anode-cathode gap. A schematic diagram is shown in Fig. 1. A 5-mm-diam hole is used in both cathode and anode. The electrode material is aluminum. The cathode is operated at ground potential. The laser light at energies between 8.6 μJ and 16 mJ in a 20 ns pulse is focused to a 60 μm spot size just inside the edge of the cathode by a 15 cm lens used at f/7. A quartz fiber is available to collect light from the hollow cathode volume. Time and spectrally resolved measurements have been carried out on the hollow cathode light emission and will be published elsewhere.

The breakdown time delay in the absence of laser light on the cathode in dry air is shown in Fig. 2. The applied voltage is 50 kV. Below 30 μbar, indicated by the segmented line, there is no breakdown. This threshold depends on the applied Marx voltage (decreasing with increasing voltage) and the cathode hole diameter (increasing with smaller diameter holes), and exhibits a weak dependence on the investigated cathode material (aluminum, titanium, and brass). The equivalent curve using nitrogen is almost identical.

The breakdown time delay with the laser applied 600 ns after the Marx voltage edge is shown in Fig. 3 as a function of pressure over a range of energy 8.6 μJ to 13.5 mJ. A change in laser illumination over three orders of magnitude results in a change in delay times by a factor of approximately 20. There is a marked reduction in jitter to less than 5 ns at higher laser energies. The minimum delay to breakdown reduces to approximately 100 ns, a time which is related to essential ionization processes in the hollow cathode region

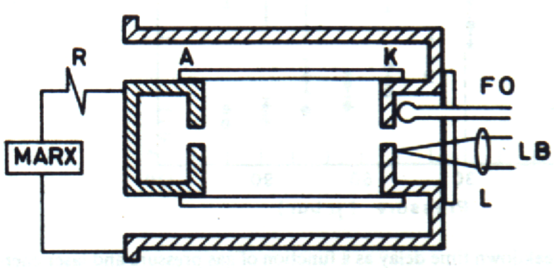

FIG. 1. Schematic of the apparatus. Dimensions: 10 cm long, 4.5 cm diameter. (K): cathode with 5-mm-diam axial orifice, (A) anode, (FO) quartz fiber. (L) 15 cm focal length lens, (LB) laser beam.

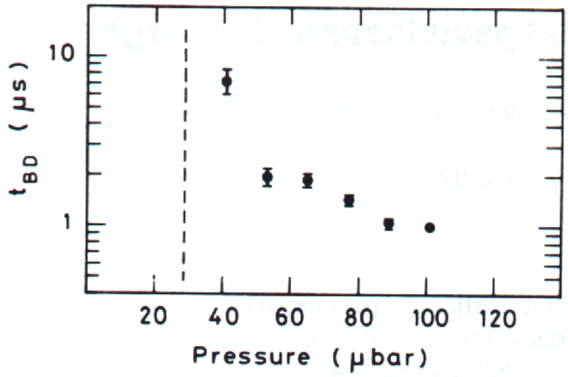

FIG. 2. Spontaneous breakdown time delay in dry air as a function of pressure. The applied voltage is 50 kV. Below 30 μbar, indicated by the segmented line, there is no spontaneous breakdown.

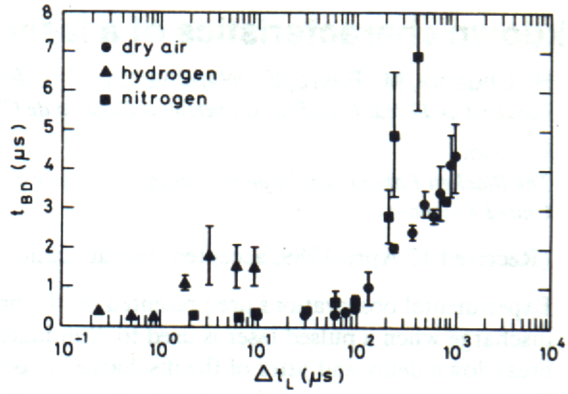

FIG. 4. Breakdown time delay when the laser is applied before the voltage pulse. The laser energy is 16 mJ. $t_{BD} = 0$ at the voltage edge. Δt_L is the relative delay between the laser and the voltage pulse. The filling pressure is 29 μbar, which is below the threshold for spontaneous breakdown.

and in the main discharge volume. It is seen that with laser energies in the mJ range, or higher, breakdown is induced even at pressures below the threshold for spontaneous breakdown. It is found that the time between the application of the laser pulse and subsequent breakdown increases slightly as the interval between the voltage edge and the laser pulse increases. Much of this weak dependence may be ascribed to the decay of the applied voltage which has a time constant of 35 μs.

Figure 4 shows the results of a series of measurements in hydrogen, nitrogen, and dry air with the laser preceding the voltage edge. In all cases the pressure is 29 μbar, which is below the self-breakdown threshold, and the laser intensity is 16 mJ. In nitrogen and air there is no observed change in breakdown time over a very wide range of laser-voltage edge delay, remaining essentially constant up to a delay of 100 μs. In hydrogen the maximum laser-voltage edge delay allowable for nearly constant breakdown delay is about 1 μs.

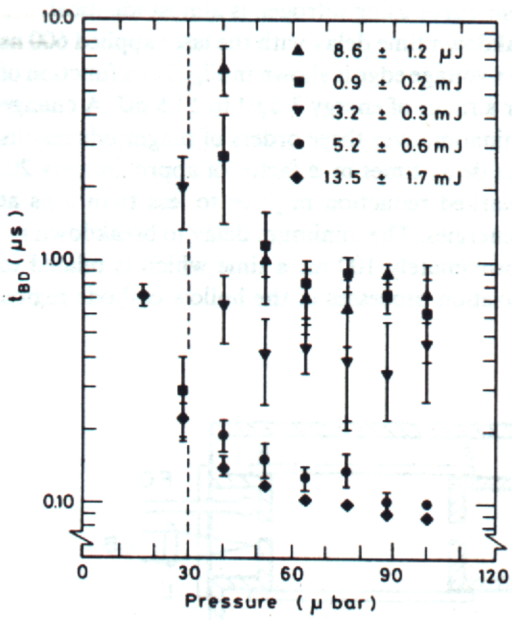

FIG. 3. Breakdown time delay as a function of gas pressure and laser energy. The filling gas is dry air. The laser is applied 600 ns after the leading voltage edge and $t_{BD} = 0$ at the time of the laser pulse. The threshold for spontaneous breakdown is indicated by the segmented line.

A further observation is that the breakdown delay times are significantly reduced if the laser is allowed to illuminate the cathode at 10 pps for several seconds. This "memory" effect is particularly obvious in air and nitrogen, and may be observed even when the rapid pulse illumination stops a few seconds before a single-pulse laser triggering shot.

The results show that when the laser is applied after the voltage edge, the jitter and breakdown delay decreased with increasing laser energy; however, they are relatively large even at high laser energy if the filling pressure is low enough to hold off an applied voltage of 50 kV indefinitely. On the other hand, when the pseudospark is operated at a pressure above the self-breakdown threshold, the jitter behavior is markedly improved. The voltage fall time also improves with increasing pressure. The near constant breakdown delay observed when the laser is applied before the voltage pulse indicates that the laser-produced plasma does not have to directly participate in the breakdown process of the main discharge volume. The importance of long-lived metastable states can be inferred from the observation that direct laser triggering is observed in nitrogen and air when the laser precedes the voltage edge by up to 1 ms. A similar conclusion may be drawn from the memory effect. This observation is likely to have important consequences on the design of a pseudospark switch at high repetition rate.

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