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Dependence of cathode aperture in pulsed hollow-cathode discharges

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The effect of electric field penetration in the hollow-cathode region of self-initiated pulsed hollow-cathode discharge is investigated. The discharge is operated in hydrogen at pressures between 30 and 200 mTorr with applied voltages between 10 and 30 kV. Aluminum cathodes with aperture diameters and lengths from 1 to 5 and 2 to 18 mm, respectively, are used. The results show that the effect of the hollow cathode in discharge initiation is particularly strong at low pressures. In the range of parameters investigated, the time delay to breakdown and the jitter decrease when cathode aperture with larger diameters and shorter lengths are used. At high pressure the pulsed hollow-cathode effect is less important as ionization processes in the main gap become dominant.

The pulsed hollow-cathode discharge which includes the pseudospark[1] and back-lighted thyratron (BLT)[2] is a specific type of electric discharge which operates at low pressure and high voltage, with axisymmetric parallel electrodes and a narrow opening in the cathode. High brightness electron-beam generation and highly reproducible breakdown are important features of pulsed hollow-cathode discharges with many potential applications.

In this type of discharge, three well-defined phases can be identified in the process leading to electric conduction in the interelectrode region:[3] the predischarge phase, the hollow-cathode phase, and the conducting phase. Previous investigations, both experimental[4] and numerical,[5,6] have shown that the unique properties of this type of discharge are closely related to the formation of a highly localized plasma in the hollow-cathode region immediately behind the cathode aperture. It is the injection of a large number of electrons in a short time into the main discharge region from the hollow-cathode plasma source that significantly enhances the breakdown process.[7,8] These two processes, localized plasma formation in the hollow-cathode region and electron injection in the main gap, define the first two characteristic phases of pulsed hollow-cathode breakdown.

Any transient ionization process in the hollow-cathode region will depend on the local electric field. The local static field due to the applied potential is totally determined by the geometry of the cathode aperture. To investigate the local field effect on the initial phases of the pulsed hollow-cathode phenomena we have performed a detailed study of the influence of the cathode aperture on the breakdown properties of the pulsed hollow-cathode discharge in hydrogen. The effect of electric field penetration on breakdown delay is clearly identified.

The discharge apparatus uses a pulsed charged capacitor scheme to produce a 10–30-kV step across the anode and cathode with a rise time less than 50 ns. A schematic of the circuit is shown in Fig. 1. A more detailed description of the circuit has been published in Ref. 4. In the present experiment the anode-cathode separation was kept at 2.5 cm. Aluminum cathodes with a range of different cylindrical apertures were used in the experiments. The dimensions of the apertures ranged from 2 to 18 mm in length with diameters from 1 to 5 mm. The anode was a coarse steel gauze with 1.8-mm wire spacing. The discharge was operated at 0.2 Hz in hydrogen at pressure between 30 and 200 mTorr.

In all breakdown delay measurements, time zero corresponds to the rising edge of the applied voltage pulse. The delay for electric breakdown in hydrogen at a given voltage and as a function of pressure is shown in Fig. 2 for different diameters and constant length of the cathode aperture. The effect on delay with constant diameter and different length of the aperture is shown in Fig. 3. It is seen that at a constant aperture length the time delay and jitter improves when the diameter of the aperture is increased. The minimum pressure at which breakdown takes place is also reduced when the diameter of the aperture increases. At high pressure the diameter of the aperture plays a less significant role and delay to breakdown tends to a constant value independent of the particular diameter. At a constant aperture diameter the delay to breakdown decreases and the jitter improves when the length of the aperture is reduced. At high pressures the delay and jitter becomes also

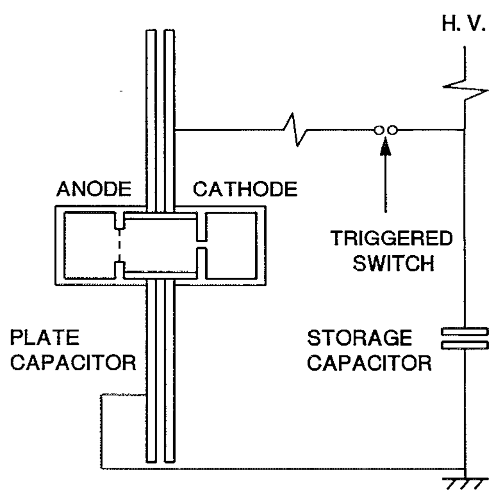

FIG. 1. Schematic of the experimental apparatus.

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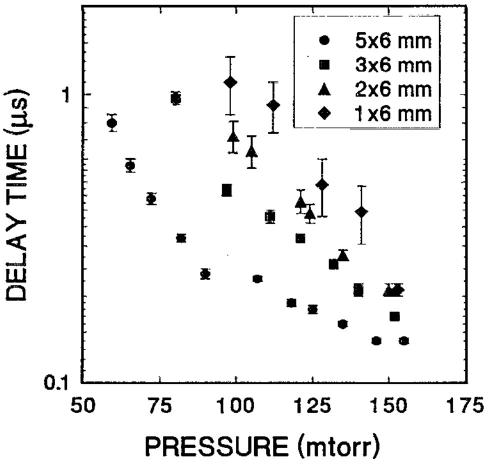

FIG. 2. Breakdown delay as a function of pressure for different aperture diameter and constant length. The applied voltage is 29 kV.

independent of the length of the aperture in the range investigated.

Electric-field penetration in the hollow-cathode region can be controlled by varying the applied voltage. Figure 4 shows the breakdown delay as a function of pressure for different applied voltages with fixed dimensions of the cathode aperture. In this case the broken line indicates the minimum pressure at which, for a particular voltage, electric breakdown in the main gap is observed. For a given voltage delay increases as pressure is lowered. The delay and jitter at a given pressure reduces as the voltage is increased. When one examines the dependence of the breakdown delay with voltage and pressure for different dimensions of the cathode aperture, a very interesting picture emerges. For instance, with 2- and 5-mm-diam apertures, with the length kept at 6 mm, the improvement in delay at low pressures with the larger-diameter aperture is reduced as the applied voltage is lowered. At voltages below 18 kV, no statistically significant differences in the breakdown delay and jitter are observed throughout the pressure range investigated. This is a good indication that the transient events taking place within the hollow cathode are no longer able to strongly influence the breakdown processes taking place in the main gap region, when the operating electrical stress falls below a certain value.

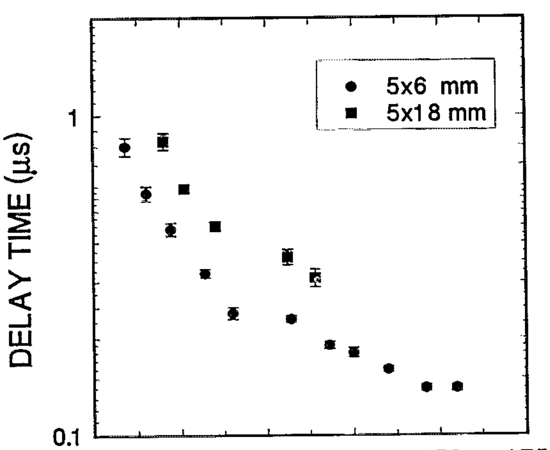

FIG. 3. Breakdown delay as a function of pressure for different aperture length and constant diameter. The applied voltage is 29 kV.

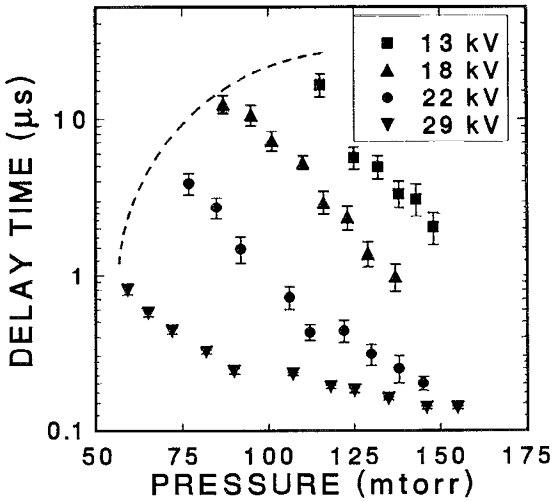

FIG. 4. Breakdown delay for different applied voltages as a function of pressure. Cathode aperture dimensions are 5 mm diameter and 6 mm length. The dashed line indicates the pressure below which, at any particular applied voltage, electric breakdown does not take place.

Unlike other low-pressure discharges, the main feature of pulsed hollow-cathode effect is a highly reproducible breakdown. A properly chosen hollow-cathode configuration can lead to a significant reduction in breakdown delay and jitter. Despite the large electric field in the main gap region, Townsend ionization is not effective in the low-pressure environment there. The small cathode aperture provides a finite field penetration into the hollow-cathode region, where collisions and secondary processes can take place among the large hollow-cathode region and the near surface of the electrode. The ionization processes within the hollow-cathode region depend on the local value of E/N, the reduced electric field, and thus the finite penetration of the applied electric field will determine the initiation of the breakdown process. To improve breakdown performance several mechanisms involving the creation of space charge in the hollow-cathode region have been reported. In the BLT photoelectrons are produced by short-pulse ultraviolet (UV) illumination of the back surface of the cathode.[2] In the triggered pseudospark a diffuse plasma is produced by a glow discharge in the hollow-cathode region.[3] Initiation by a short laser pulse focused at the back of the cathode has also been reported.[9] In spite of these initiation mechanisms, the transient ionization in the hollow cathode region and the subsequent charge injection in the main gap to initiate breakdown are still strongly influenced by the initial applied field. The magnitude of the field penetration is totally dependent on the diameter and length of the aperture. The data presented clearly show that the breakdown delay increases with a reduction in the diameter of the aperture and an increase in length, and therefore a reduction of the field penetration. However, the transient development within the hollow cathode is in effect competing with the ionization processes taking place in the main gap region. Thus it can be seen from the measurements that the influence of the hollow-cathode geometry is stronger at the lower-pressure range, when Townsend ionization is ineffective. Our results are in qualitative agreement with numerical simulations[6-8] which indicate that transient processes prior to electric breakdown in the main gap are dominated by field penetration in the hollow-cathode region and cathode back space. A more direct comparison with numerical simulations will require a detailed diagnostic of transient events in the hollow-cathode region, which is now in progress. Further studies will also be required to isolate the roles of ionization processes in the main gap and that taking place within the hollow-cathode region in order to optimize the pulsed hollow-cathode effect, particularly in switching applications.

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[1] J. Christiansen and C. Schultheiss, Z. Phys. A **290**, 35 (1979).
[2] G. Kirkman and M. A. Gundersen, Appl. Phys. Lett. **49**, 494 (1986).
[3] W. Hartmann and M. A. Gundersen, in *Physics and Applications of Pseudospark*, edited by M. A. Gundersen and G. Schaefer (Plenum, New York, 1990), NATO ASI Ser. B Vol. 219, p. 77.
[4] P. Choi, H. Chuaqui, J. Lunney, R. Reichle, A. J. Davies, and K. Mittag, IEEE Trans. Plasma Sci. **17**, 770 (1989).
[5] K. Mittag, P. Choi, and Y. Kaufman, Nucl. Instrum. Methods A **292**, 465 (1990).
[6] J. P. Boeuf and L. C. Pitchford, IEEE Trans. Plasma Sci. **19**, 286 (1991).
[7] H. Pak and M. J. Kushner, J. Appl. Phys. **63**, 1342 (1988).
[8] B. M. Penetrante and J. N. Bardsley, in *Proceedings of the XX International Conference on Phenomena in Ionized Gases*, edited by V. Palleschi and M. Vaselli (Instituto di Fisica Atomica e Molecolare, Pisa, 1991), p. 1027.
[9] H. Chuaqui, P. Choi, M. Favre, and E. Wyndham, Appl. Phys. Lett. **55**, 1065 (1989).