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Photoemission Induced Plasma Breakdown

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Laser-induced photoemission of electrons offers opportunities to trigger and control plasmas and discharges. However, the underlying mechanisms are not sufficiently characterized to be fully utilized. Photoemission is highly nonlinear, achieved through multiphoton absorption, above threshold ionization, photo-assisted tunneling, etc., where the dominant process depends on the work function of the material, photon energy and associated fields, surface heating, background fields, etc. To characterize the effects of photoemission on breakdown, breakdown experiments were performed and interpreted using a 0D plasma discharge circuit model [1] and quantum model of photoemission [2].

At low currents (<100 μA), it is found that laser induced photoemission can be sufficiently de-coupled from space charge effects to be observable. Photoemission induced plasma breakdown is investigated with high-speed imaging for different reduced electric fields and laser intensities and photon energies. Experiments were performed using a tunable picosecond laser that allowed the use of a two-temperature model for electrode heating.

The laser-induced breakdown voltage was found to be lower than the Paschen breakdown voltage, as shown in Fig. 1 (a). High speed imaging at 750 nm like that shown in Figs. 1 (b) and (c) assisted in determining the laser-induced breakdown voltage. The waveforms presented in Figs. 1 (d) and (e) were acquired at applied voltages below Paschen (the current is 0 μA before the laser pulse arrives at t = 0 μs). The laser-induced photoemission creates a breakdown where a sheath is formed, as shown in Fig. 1 (b). However, the applied voltage is insufficient for secondary electron emission to maintain the plasma, causing the decay in current. We find that this behavior can be described with a 0D model developed by Phelps [1] as shown in Figs. 1 (d) and (e). However, Phelps' 0D discharge model requires an empirical fitting of the breakdown assuming photoemission current on a time scale commensurate with the ion transit time (~6 μs). Therefore, to fit the measured breakdown voltage and current, the 0D model is employed with a laser pulse width of 25 μs (instead of 25 ps) and a charge transfer of ~10^{-12} C (instead of ~10^{-10} C predicted by the photoemission model). While these initial results are promising, approaches for including higher order effects of photoemission into the discharge characteristics equation are needed and are being investigated.

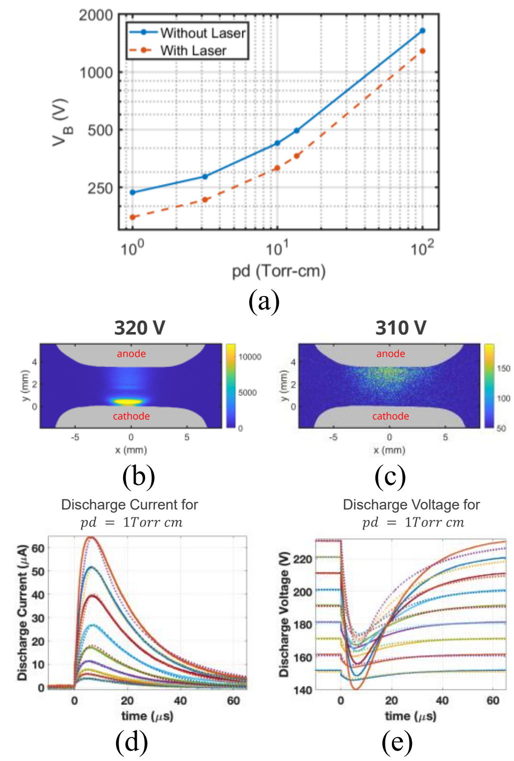

Fig. 1 – (a) Breakdown voltage versus pressure times distance (pd) in argon with and without laser-induced photomeission. (b) and (c) show images of laser-induced breakdown at 10 Torr-cm and the transition to Townsend discharge at 315 V. (d) and (e) show that, for 1 Torr-cm, the laser-induced discharge current and voltage (solid lines) can match a 0D model at low currents/space charge (dotted lines).

[1] Z. L. Petrović and A. V. Phelps, *Phys. Rev. E* **47**(4), 2806, 1993.
[2] Y. Zhou and P. Zhang, *J. Appl. Phys.* **127**(16), 164903, 2020.

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