BREAKDOWN MINIMA DUE TO ELECTRON-IMPACT IONIZATION IN SUPER-HIGH-PRESSURE GASES IRRADIATED BY A FOCUSED GIANT-PULSE LASER*

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Minima in the curves of threshold electric field versus pressure for ionization of super-high-pressure helium, argon, and nitrogen using a focused giant-pulse ruby laser are reported here. These minima are characteristic of electron impact ionization. Gold and Bebb[1] and others have analyzed ionization produced by focused lasers in terms of multiphoton absorption alone. Tomlinson[2] has shown that while multiphoton absorption may be the trigger mechanism, it cannot explain the subsequent growth of the ionization. Meyerand and Haught[3] have suggested that the mechanism is inverse bremsstrahlung. Askaryan and Rabinovich[4] have commented on the prospective role of electron impact ionization. This Letter presents definitive experimental data which are indicative of electron impact ionization where the heating of electrons occurs through energy transfer from the light wave to the electrons undergoing collisions with neutrals.

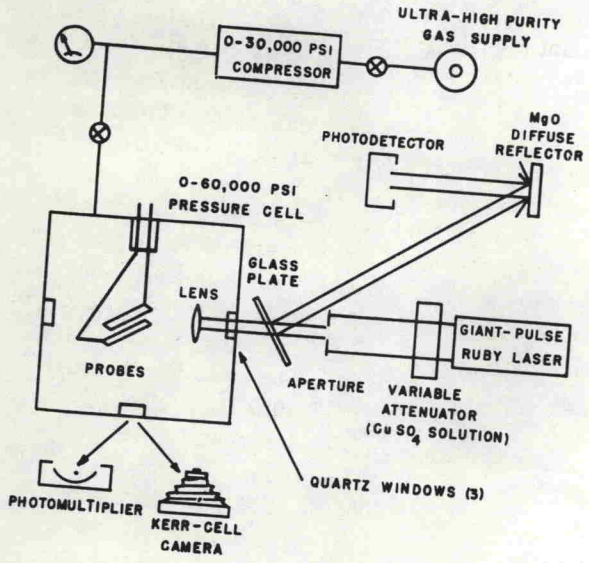

FIG. 1. Experimental apparatus for measurement of gas breakdown at super-high pressures using a focused laser beam.

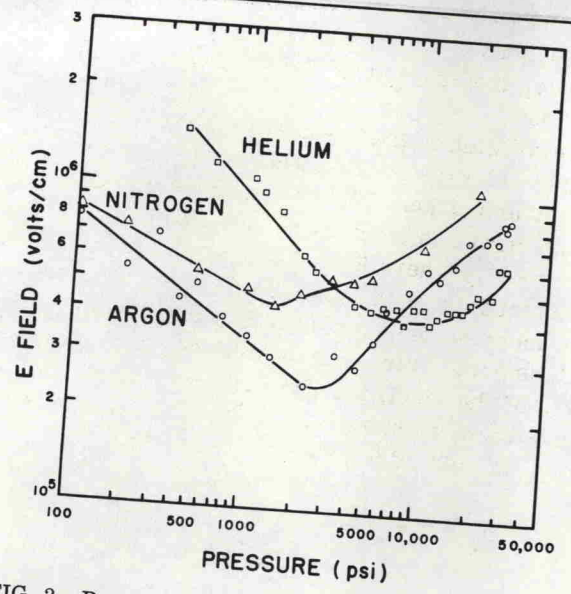

FIG. 2. Pressure dependence of breakdown field strength.

The experimental arrangement is shown in Fig. 1. Breakdown is produced in ultrahigh-purity helium, argon, and nitrogen at pressures up to 30 000 psi by focusing an attenuated 30-MW giant-pulse ruby laser beam within a super-high-pressure cell having three quartz windows. The cell has electrodes on either side of the focal point to sweep out the ionization products. The output pulse of the Kerr cell Q-switched giant-pulse laser has a pulse width at half-amplitude of 50 nsec. The laser beam passes through a $CuSO_4$ solution attenuator, a variable aperture, and a glass plate (microscope slide), and then into the cell where the beam is focused to a point by a 40× microscope objective. The glass plate reflects a small portion of the beam onto a diffuse reflector (MgO block). This monitor beam is then detected by a calibrated fast-rise photodiode. The detector assembly is calibrated prior to the experiment by removing the objective and measuring the intensity of the laser beam passing through the cell. The variable aperture reduces the laser-beam diameter to match the aperture of the objective.

Ionization is detected by a photomultiplier directed perpendicular to the laser-beam path. The input to the photomultiplier is band-block filtered so as to reject the incident and scattered 6943Å ruby laser light. Ionization can also be observed visually or by a Kerr-cell camera system.

Experimental results are shown in Fig. 2. For each pressure the threshold power was determined by successively attenuating consecutive pulses until no ionization occurred. Attenuation was achieved by increasing the density of the $CuSO_4$ solution. Peak electric fields were calculated using the measured power and the minimum focal area determined by burning holes in thin metal foil. The diameter of the minimum focal area was about 100 μ. These conditions give $E = (3.1\times10^3)P^{1/2}$, where E is in V/cm and P in watts.

The curves of threshold peak E field versus pressure in Fig. 2 clearly show minima. In He the minimum is broad and centered about 10 000 psi, with a value of 4×10^5 V/cm. In Ar the minimum is sharper and is centered at 2500 psi with a value of 2.5×10^5 V/cm. In N_2 the curve is also sharp and is centered at 1500 psi with a value of 4.4×10^5 V/cm. No previous work has been reported at pressures above 2000 psi. Below this pressure the He and Ar data presented here agree reasonably well with those of Meyerand and Haught,[3] falling somewhat below their curve (they did not report on N_2). The discrepancy is easily accounted for by the inaccuracy of measurement of the minimum focal area. It is important to note that the slopes of the curves below 2000 psi agree very well with those of reference 3.

The oscilloscope traces showing ionization were similar to those previously reported.