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Gas breakdown by a focused beam of THz waves

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Introduction

The sources of submillimeter radiation have made significant progress recently [1-3] and so the possibility to study gas discharge phenomena in terahertz wave beams has appeared. Such gas discharge is of great interest from viewpoint of both general and applied physics.

This paper presents the results of experimental and theoretical investigations of gas breakdown thresholds for several gases (argon, krypton, xenon, nitrogen, oxygen) in a focused beam of pulsed and CW THz gyrotrons. The results of experiments for noble gases are in good agreement with theoretical calculations that were made based on a theory of breakdown of monatomic non-light gases in fields of any frequency from radio frequency to optical [4].

Experimental Setups

Two facilities with pulsed-mode [1] (0.67 THz, 20 µs, 40 kW, Fig. 1 [5]) and CW-mode [3] (0.263 THz, up to 1 kW, Fig. 2) gyrotrons were used in the experiments. Terahertz radiation was focused into a vacuum chamber where discharge occurred by means of quasioptical mirrors. The intensity of the radiation in the focal spot was 16 MW/cm^2 (rms electric field strength 80 kV/cm) for a pulsed-mode gyrotron and up to 15 kW/cm^2 (rms electric field strength 2.5 kV/cm) for a CW-mode gyrotron. Such electric field values were sufficient for the realization of a breakdown in the pressure range 1-1500 Torr.

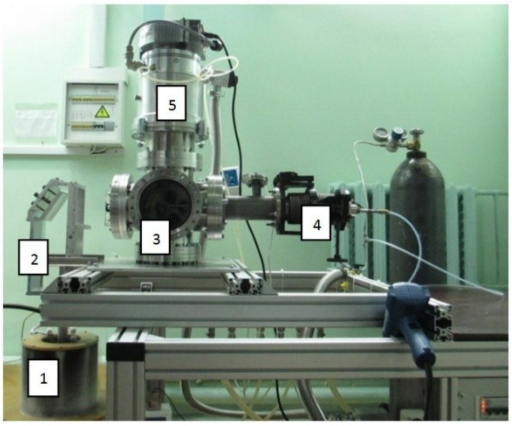

Fig. 1. Pulsed mode experimental setup (photo): 1 - pulsed gyrotron, 2 - quasioptical converter with focusing mirror, 3 - discharge chamber with optical window, 4 - gas injection system, 5 - vacuum pumping system (700 l/s).

Several photos of the discharge obtained in different working gases and at different pressures at the facilities described above are shown in Figs. 3 and 4.

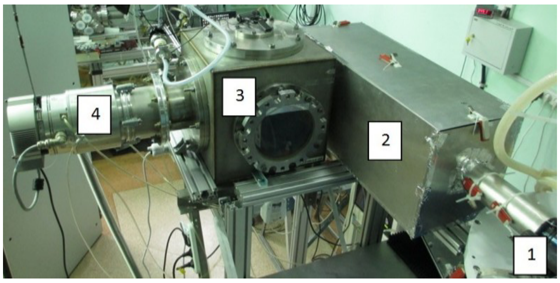

Fig. 2. CW mode experimental setup (photo): 1 – gyrotron output window, 2 – the protective cover of quasioptical beam line, 3 – discharge chamber, 4 – vacuum pumping system (2000 l/s).

a)

b)

Fig. 3. Time-integrated photo of the emission of the pulsed discharge plasma in the visible spectral range: a) xenon, the pressure is 63 Torr; b) oxygen, the pressure is 760 Torr. The terahertz radiation is propagated from left to right.

Fig. 4. Photo of the plasma glow of CW mode discharge in the visible spectral range. Argon, the pressure is 240 Torr, THz power is 950 W. The terahertz radiation propagates from top to bottom.

Experimental Results

The pressure breakdown thresholds for several gases in a focused beam of terahertz waves for a THz radiation power of 40 kW were determined during the experiments on a pulsed mode setup. The table shows the minimum gas pressures at which the discharge was observed.

Ar	Kr	Xe	N_2	O_2
8 Torr	1.5 Torr	1.5 Torr	12 Torr	18 Torr

At pressures lower than those listed in the table, the discharge could not be ignited.

Fig. 5 shows the experimental dependence of the threshold THz radiation power at which the discharge occurred, on the argon pressure for the case of the CW mode setup. According to experiments, the minimum pressure at which it was possible to ignite the discharge was about 23 Torr. The minimum of the breakdown curve is reached at pressures of 50-60 Torr.

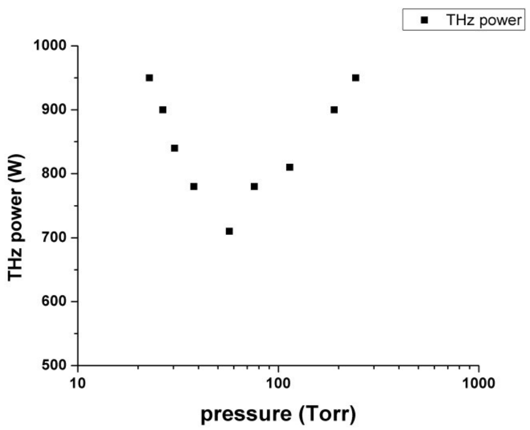

Fig. 5. Experimental threshold breakdown curve for Argon for 0.263 THz.

Discussion and Conclusion

Fig. 6 shows the calculated breakdown curve in comparison with the experimental one. The theoretical breakdown curve was calculated based on a theory of breakdown of monatomic non-light gases in electromagnetic field with frequency ranged from RF to optical [4]. The loss of electrons from the electric field area assumed to be diffusive with diffusion length Λ of 0.06 cm. The last one in our case was assumed as [6] Λ = R/2.4, where R = 1.5 mm – the radius of the wave beam in the focal spot. In this case, electron diffusion was assumed to be free.

The lower calculated curve corresponds to the diffusion length Λ = 0.6 cm. Such a value can correspond to the conditions when electron diffusion is ambipolar [6]. In this case one can see a good agreement between calculations and experimental results (black spots).

Thus, experiments were performed to determine the breakdown thresholds of various gases in focused beams of electromagnetic radiation with frequencies of 0.67 THz and 0.263 THz for the first time. Assuming that the electron losses are determined by diffusion, breakdown curves were calculated for the radiation frequency of 0.263 THz in argon. The calculations are in good agreement with experiment for the case of ambipolar diffusion.

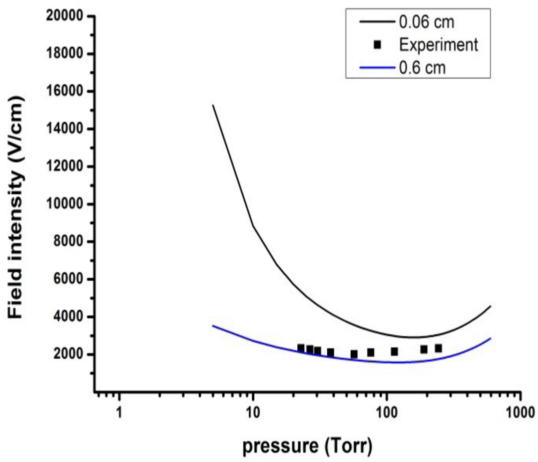

Fig. 6. Breakdown curves for 0.263 THz. Upper curve – results of calculations for Λ=0.06 cm, lower curve – Λ=0.6 cm. Black spots – experimental one.

Acknowledgements

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