

Dynamics of the gas discharge sustained by the powerful radiation of 0.67 THz gyrotron

A. Sidorov, S. Razin, A. Veselov, M. Viktorov, A. Vodopyanov, A. Luchinin, and M. Glyavin

Federal research center "Institute of Applied Physics", Nizhny Novgorod, Russia

Abstract.

This paper presents the results of studies of the discharge dynamics sustained by the gyrotron radiation (40 kW@0.67 THz). The discharge propagation velocity towards electromagnetic radiation was measured in various gases and their mixtures (helium-argon, argon, krypton, nitrogen). It was shown that the discharge propagation velocity in noble gases decreases with an increase in the atomic mass of the gas (from helium to krypton).

The dependence of the discharge propagation velocity in wide gas pressure ranges (0.1 - 2 atm) was investigated. It was shown that in all gases the discharge propagation velocity decreased with an increase in pressure value and for noble gases was at the level of 10^5 – 10^6 cm/s, and in nitrogen — 10^4 – 10^5 cm/s.

Introduction.

At present, the THz frequency range is still the least studied from the point of view of gas discharge physics. The study of the discharge, sustained by the powerful focused beams of THz radiation, has become possible recently due to the development of powerful sources in this range (FELs and gyrotrons) [1-4] and is of interest both from a fundamental research and from possible applications.

Studies on the propagation of discharges supported by powerful electromagnetic radiation were carried out in both the optical and infrared ranges (laser spark) [see review 5 and references in it], and in the microwave range [6-9]. It is worth noting that most studies in the microwave range were carried out in the air [6-8]. It can be concluded that the propagation of the discharge front in noble gases has not been investigated in the terahertz and sub-terahertz ranges either in the microwave range, except of air discharge. In the paper [9] it was studied the propagation of the discharge in krypton under the action of millimeter radiation (wavelength - 6.8 mm). It is demonstrated that the propagation of a discharge is different from molecular gases, and is most likely associated with the ionization of atoms from the excited state, which occurs under the action of radiation from the discharge front. The characteristic propagation speeds in this case were 10^5 - 10^6 cm/s. In [10] a model was proposed according to which the adequacy of this

hypothesis was demonstrated on the basis of numerical calculations and their comparison with experiment.

This work is a continuation of the research held in Institute of applied physics RAS on the study of a discharge sustained by high-power radiation of THz gyrotrons [2-4] and is devoted to experimental investigation of the dynamics of the gas discharge sustained by the powerful radiation of 0.67 THz gyrotron. In particular, this work presents the results of experiments aimed on research of discharge propagation in noble gases (argon, krypton, helium) and molecular one (nitrogen).

Experimental setup and results.

This experiment was carried out on a setup with a pulsed gyrotron with a frequency of 0.67THz and pulse duration of 40 μ s [3]. The terahertz radiation from the exit window of the gyrotron is converted into a Gaussian beam by a quasi-optical convertor and is focused into the center of the discharge chamber, which is filled with the working gas. The radiation power in the beam in the center of the discharge chamber, measured using a calorimeter, was 40 kW. In order to eliminate the influence of external impurities, first of all, it is oxygen from the atmosphere, the chamber was preliminarily pumped out to a pressure of 10^{-6} Torr using a turbomolecular pump. In the center of the chamber, in the beam waist, there was an additional focusing mirror, which allowed reducing the minimum possible pressure for standing gas breakdown to units of Torr in noble gases [11]. The setup photo and its scheme presented on figs 1 and 2.

To measure the discharge propagation velocity, two photodetectors were installed outside the vacuum chamber. The area of the photoactive element is 1 mm^2 . Since the distance to the discharge was about 10 cm, to reduce the visibility areas of the photodetectors, additional diaphragms with a diameter of 1 mm were installed on them at a distance of 2 cm from the photodetector, which allowed observing only the discharge area of no more than 1.5 cm. Both photodetectors looked strictly across the propagating discharge. The first was aimed at an additional focusing parabolic mirror, on which the discharge was ignited, the second stood at a distance of 5 cm from the first in the direction of the discharge propagation.

The average propagation velocity of the discharge front was determined from the delay between the maxima of the signal at the two detectors. Figures 3 and 4 shows the dependences of the propagation velocity of the discharge front for argon and krypton on the gas pressure in the chamber. As can be seen, with an increase in pressure, the velocity drops; in this case, the lighter the gas, the higher the velocity at the same gas pressure. This was also

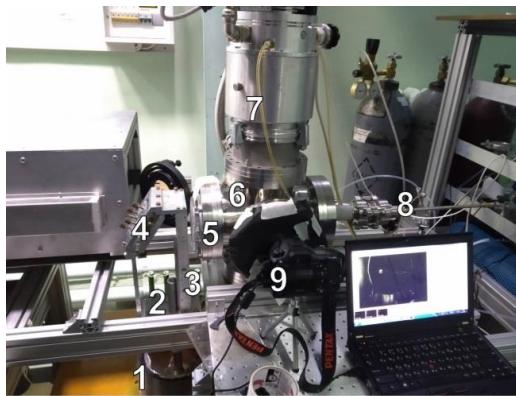


Fig.1. Photo of the experimental setup. 1) gyrotron, 2) quasi-optical converter, 3) the first mirror of the quasi-optical line, 4) the second mirror of the quasi-optical line, 5) THz radiation input flange, 6) discharge chamber, 7) turbomolecular pump, 8) gas inlet tube, 9) optically transparent flange for recording discharge radiation.

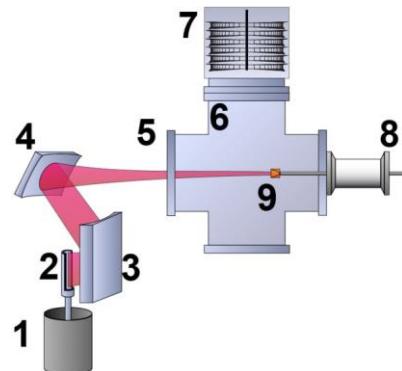


Fig. 2. The scheme of the experimental setup. 1) gyrotron, 2) quasi-optical converter, 3) first mirror of the quasi-optical line, 4) second mirror of the quasi-optical line, 5) THz radiation input flange, 6) discharge chamber, 7) turbomolecular pump, 8) gas inlet tube, 9) beam waist region/location of an additional parabolic mirror.

confirmed in experiments with a mixture of helium-argon. This mixture is helium with a small (a few percent) addition of argon. The addition of argon provides a significant reduction in the breakdown field due to the Penning effect (ionization of argon atoms by excited metastable helium). At the same time, from the point of view of gas dynamics, the discharge propagates in helium as the main gas. Unfortunately, in this mixture, even at high pressures, the rate of propagation of the discharge was quite high (10^7 cm/s at 2 atm), which caused propagation from one detector to another to take fractions of microseconds, which was at the level of measurement error. Therefore, it was not possible to correctly measure the dependence of the propagation velocity on the gas pressure. This is also caused a more significant scatter of measured velocities when propagating in lighter argon in comparison with heavier krypton. However, the trend of a decrease in the propagation velocity with an increase in the atomic mass of the gas was observed.

In the case of a discharge in nitrogen, the length over which the discharge had time to propagate during the duration of the gyrotron pulse was not more than 2 cm, therefore, the scheme for measuring the velocity by two detectors lagging 5 cm apart from each other did not work. In this case, a streak-camera was used to measure the rate of discharge propagation. Measurements have shown that the discharge propagation velocity in nitrogen also decreases with increasing pressure. The characteristic propagation speeds in this case were 10^4 – 10^5 cm/s.

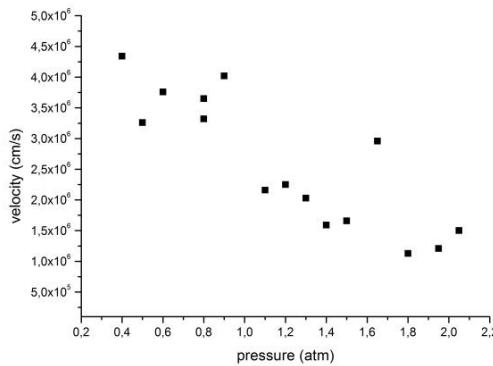


Fig. 3. The dependence of the propagation velocity of the discharge in argon on the gas pressure.

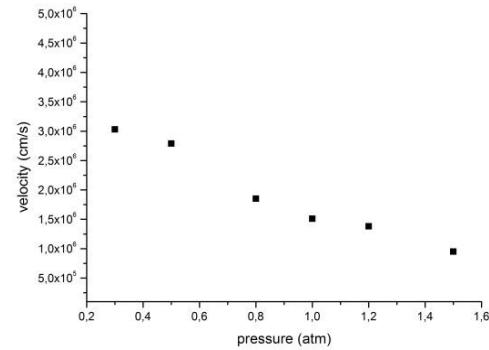


Fig. 4. The dependence of the propagation velocity of the discharge in krypton on the gas pressure

Acknowledgement.

The work was supported by Russian Science Foundation, grant # 17-72-20173.

References

- [1] V.P. Bolotin, V.S. Cherkassky, I.K. Igumenov, D.A. Kayran, B.A. Knyazev, E.I. Kolobanov, V.V. Kotenkov, V.V. Kubarev, G.N. Kulipanov, G.L. Kuryshev, et all, “Status of the Novosibirsk free electron laser and first experiment with high power terahertz radiation”, Proceeding of the 1st International Conference on Submillimeter Science and Technology, pp. 1–8, Ahmedabad, India, 2004.
- [2] G.G. Denisov, M.Yu. Glyavin, A.P. Fokin, A.N. Kuftin, A.I. Tsvetkov, A.S. Sedov, E.A. Soluyanova, M.I. Bakulin, E.V. Sokolov, E.M. Tai, M.V. Morozkin, M.D. Proyavin and V.E. Zapevalov, Rev. Sci. Instrum. **89**, 084702, 2018.
- [3] M. Yu. Glyavin, A. G. Luchinin, G. S. Nusinovich, J. Rodgers, D. G. Kashyn, C. A. Romero-Talamas, and R. Pu, Appl. Phys. Lett. **101**, 153503 (2012).
- [4] M. Y. Glyavin, A. V Chirkov, G. G. Denisov, A. P. Fokin, V. V Kholoptsev, A. N. Kuftin, A. G. Luchinin, G. Y. Golubyatnikov, V. I. Malygin, M. V Morozkin, et al, Rev. Sci. Instrum., **86**, 054705 (2015).
- [5] Yu. P. Raizer, *Laser-Induced Discharge Phenomena* (Consultants Bureau, New York, 1977).
- [6] Vu. Va. Brodskii, S.V. Golubev, V.G. Zorin, A.G. Luchinin, V.E. Semenov, JETP, **57**, p. 989 (1983).
- [7] N. A. Bogatov, Yu. V. Bykov, N. P. Venediktov, S. V. Golubev, V. G. Zorin, A.G. Eremeev, and V. E. Semenov, Sov. J. Plasma Phys. **12**, 416 (1986).
- [8] S. V. Golubev, S. I. Gritsinin, V. G. Zorin, I. A. Kossyi, and V. E. Semenov, in “High-Frequency Discharge in Wave Fields” (IPF AN SSSR, Gor’kii, 1988), p. 136 [in Russian]
- [9] N.A. Bogatov, Yu.Ya. Brodsky, S.V. Golubev, V.G. Zorin, “Dynamics of a microwave discharge in krypton produced by a high-density radiation field”, Proceedings of XVIII International conference on phenomena in ionized gases, pp. 864-865, Swansea, UK, 1987.
- [10] Mnatsakanyan A.H., Najdis G.V., Fizika Plazmy, **16**, 481-486, 1990 [in Russian].
- [11] A V Sidorov, S V Golubev, S V Razin, A P Veselov, A V Vodopyanov, A P Fokin, A G Luchinin and M Yu Glyavin, J. Phys. D: Appl. Phys. **51**, 464002, 2018.