High-pressure gases breakdown in strong longitudinal magnetic fields

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Introduction

Breakdown of high-pressure gases in short intervals sequentially resembles a series of stages. The avalanche-streamer stage develops in the entire volume of the inter-intercut and forms a glowing volume discharge with an electron concentration $n_e \sim 10^{14}$-10^{16} cm^{-3}. As the plasma streamer reaches the cathode surface, the electric field is redistributed between the cathode and the anode, with a significant gain up to 10^7-10^8 V/m, mainly between the plasma front and the cathode. The enhanced electric field leads to the formation of a cathode spot and the electron beam drift through the glow discharge plasma, with the formation of a narrow spark channel $2r \sim 10^{-2}$ cm. In the same time there are observed the increases in the electron emission and in the current. Thus, energy is poured into the spark channel with an electron beam, which leads to its sharp expansion. Considering that the expansion rate of the spark channel is greater than the diffusion rate of the magnetic field lines in the channel plasma, the expanding plasma front of the spark channel shifts the magnetic field lines, reducing it in the center and increasing them near the electrodes (cathode and anode). This system leads to the limitation of energy losses with a simultaneous increase in the internal energy of the plasma. Thus, in a strong longitudinal magnetic field, the plasma channel (formed as a result of electron beam drift) acquires the properties of a magnetic trap. [1-3]

Experiment

The experimental setup consisted of two independent electrical circuits operating synchronously using a synchronization unit: an impulse voltage generator and a pulsed magnetic field generator [4,5].

The discharge gap was irradiated with ultraviolet (UV) light from a spark discharge. The UV radiation of a discharge with the energy of ~ 0.3–0.4 J brings the concentration of catch electrons to $n_0 \sim 10^6$–10^8 cm^{-3}.

The external magnetic field was created by the discharge of a capacitor battery through a solenoid, inside which there was a gap under study. The parameters of the capacitive storage-solenoid system were selected according to the requirements for ensuring the quasi-stationarity of the external magnetic field (the magnetic field period of up to 400 kOe is about 600 μs, and the voltage pulse of the electric field is up to 10 μs). Registration of discharge radiation was carried out through the side holes in the central coil of the solenoid.

The spectrum was recorded using a quartz spectrograph ISP-30 articulated with the high-speed photo-recorder VFU-1, and the intensity of the spectral lines was registered by the dual monochromator DMP-4 in combination with photomultiplier tubes FEU-29, FEU-79.

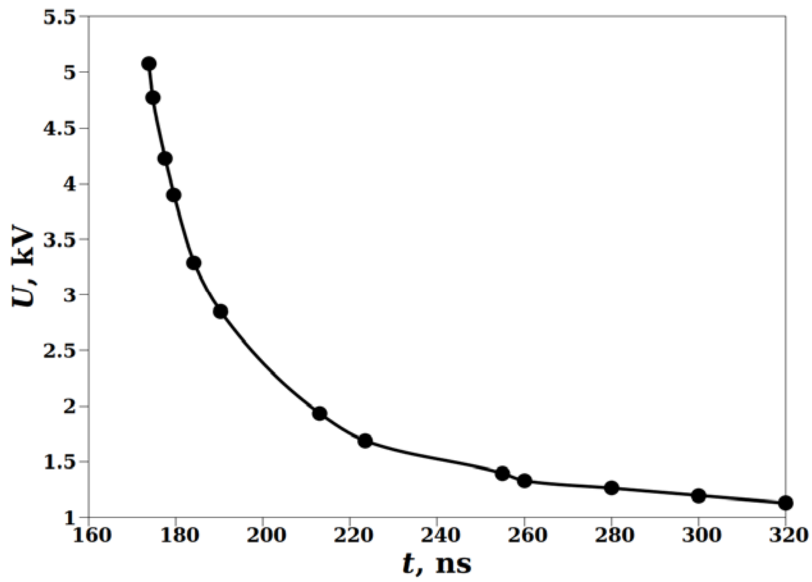

Fig. 1.

Results and discussion

Fig. 1 and 2 show typical experimental time dependences of the voltage and current density respectively in the channel (argon, H=1.6·10^7 A/m, P=3 atm.).

Since spectral methods for the registration of the concentration of electrons in the channel yielded the value n_e~10^{17}–10^{18} cm^{-3}, then at our pressures the degree of ionization is η=10^{-1}–10^{-2}, i.e. we have the case of a highly ionized plasma [6, 7]. In the quasi-stationary stage of a high-pressure pulsed discharge, when the energy losses are mainly determined by radiation, the dependence of plasma electrical conductivity on temperature, which differs from Spitzer's well-known formula by the correction factor taking into account the decrease in electrical conductivity due to plasma non-ideality [8-10], is:

$$j = 10^9 T^{3/4} p^{1/2} \exp\left(-\frac{500\varepsilon_i}{kT}\right) \quad . \qquad (1)$$

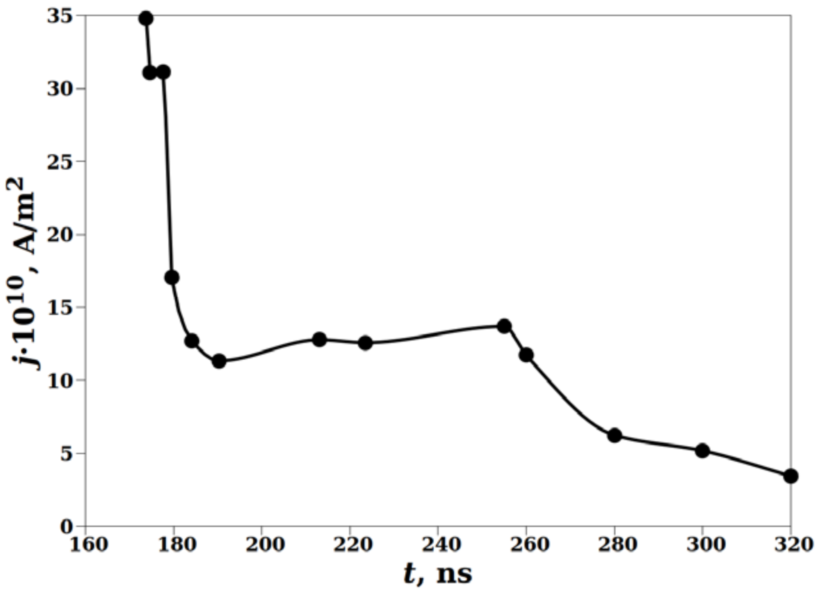

Fig. 2.

Here p is the pressure in atm., T is the temperature in K, is the ionization potential of the gas, j is the current density. By constructing a dependence $I(t)/\pi r^2(t) = f(T_e)$ graph by Eqn. (1), we can to find the electron temperature.

The time-dependence of $T_e(t)$ is shown in Fig. 3. It should be particularly noted that the creation of high-temperature plasma in small volumes may be promising for the implementation of laboratory modeling of high-temperature plasma. Indeed, small plasma devices in which hot plasma is realized in little volumes (insufficient to obtain any energy gain as a result of thermonuclear fusion, but sufficient for research that can be used to predict the behavior of hot plasma and fusion in large installations both with magnetic and with inertial confinement) recently attracted increasing attention. [11]

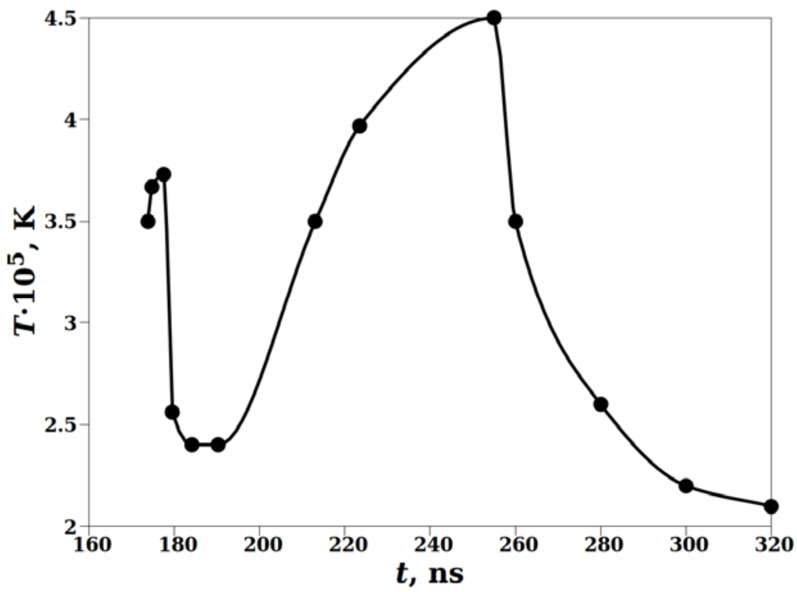

Fig. 3.

Conclusion

Finally we've found that a longitudinal magnetic field leads to: (i) an increase in current density, conductivity, specific energy input, and plasma temperature, (ii) a decrease of formation times in all stages, transverse integral radiation, channel expansion rate, and (iii) the shifts the maximum spectral radiation density in the ultraviolet region with the generation of new spectral lines.

Explaining our results we can conclude that because of the expansion rate of the spark channel is greater than the diffusion rate of the magnetic field lines, the expanding spark channel shifts the magnetic field lines, reducing them in the center and increasing at the electrodes, and therefore the system acquires the properties of a magnetic mirror trap [1], and it leads to the significant increase in the channel temperature. This approach can be used to create a source of intense X-ray and ultraviolet radiation and other applications.

References

[1] O.A. Omarov, et al. 2019 *High Temperature* **57** 156-163
[2] G.I. Budker, in Fizika plazmy i problema upravlyaemykh termoyadernykh reaktsii (Plasma Physics and the Problem of Controlled Thermonuclear Reactions), Leontovich, M.A., Ed., Moscow: Akad. Nauk SSSR **3** 3
[3] R.F. Post, in Proc. 2nd United Nations Int. Conf. on the Peaceful Uses of Atomic Energy, Geneva: United Nations 1958 **32** 245.
[4] O.A. Omarov, et al., Gazovye razryady vysokogo davleniya vo vneshnem prodol'nom magnitnom pole (High Pressure Gas Discharges in an External Longitudinal Magnetic Field), Makhachkala: Dagestan. Gos. Univ., 2014.
[5] O.A. Omarov, et al. 2013 *Inzh. Fiz.* **5**. 50.
[6] Engel, A., Ionized Gases, Oxford: Clarendon, 1955
[7] Plasma Diagnostics, Lochte-Holtgreven, W., Ed., Amsterdam: North Holland, 1968
[8] A.F. Aleksandrov, and A.A. Rukhadze, Fizika sil'notochnykh elektrorazryadnykh istochnikov sveta (Physics of High-Current Electric-Discharge Light Sources), Moscow: Atomizdat, 1976
[9] Plasma Diagnostic Techniques, Huddlestone, R.H. and Leonard, S.L., Eds., New York: Academic, 1965.
[10] Podgornyi, I.M., Lektsii po diagnostike plazmy (Lectures on Plasma Diagnostics), Moscow: Atomizdat, 1968.
[11] L. Soto, et al. 2017 *Physics of Plasmas* **24** 082703