Research of the Electrode Material Radiation in Pulse Discharge in Atmospheric Pressure Helium

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Abstract

We present experimental studies of the spectral characteristics of a pulsed discharge in helium at atmospheric pressure. The transition of the discharge from the volumetric combustion stage to the channel stage has been studied. We showed that cathode spots of a hemispherical shape appear in the stage of a high-current regime of burning a discharge with flat electrodes with a radius of curvature R = 30 cm. Vapor lines of electrode material has been detected in the emission spectrum of the near-cathode plasma. A strong influence of metal vapors on the ionization-drift characteristics of electrons in a gas has been established by the Monte Carlo simulating the kinetics of electrons. The velocity distribution function of the ions and the angular dependence of the ions bombarding the surface are investigated

The aim of work

to show the effect of small additions of metals on the kinetics of the discharge

Fig. 1. Frame-by-frame pictures of the formation of a volume discharge in He (d = 1 cm, p = 1 atm) for U_0 = 12 kV.

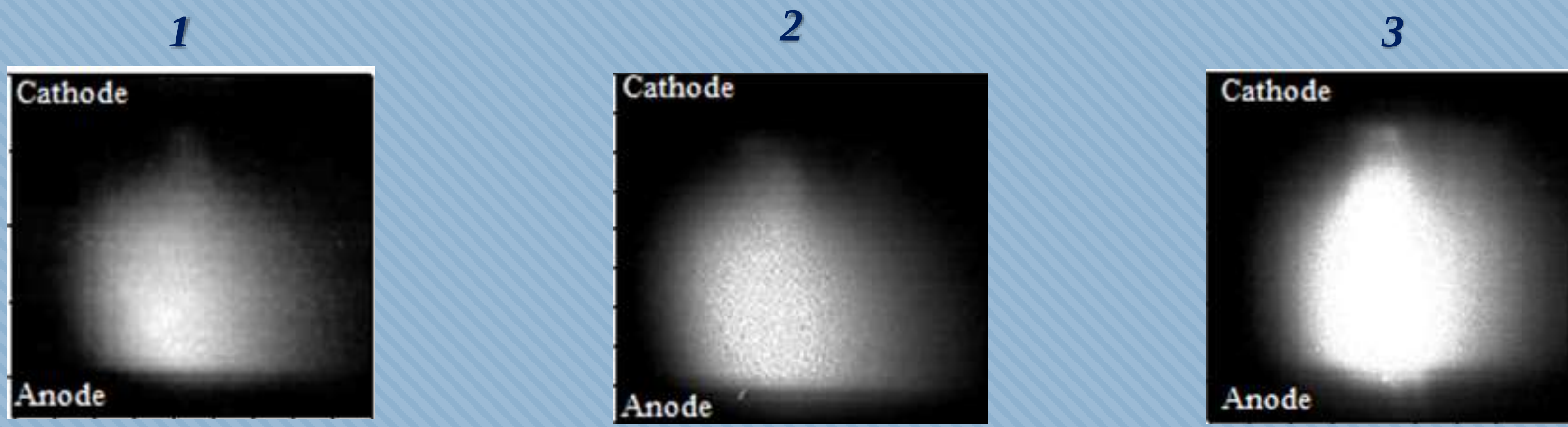
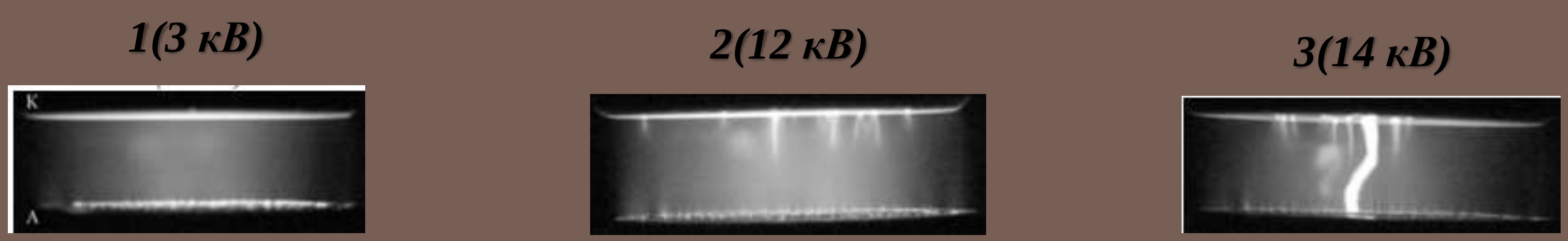


Fig. 2. Integral breakdown patterns in helium: d = 1 cm, p = 760 Torr.

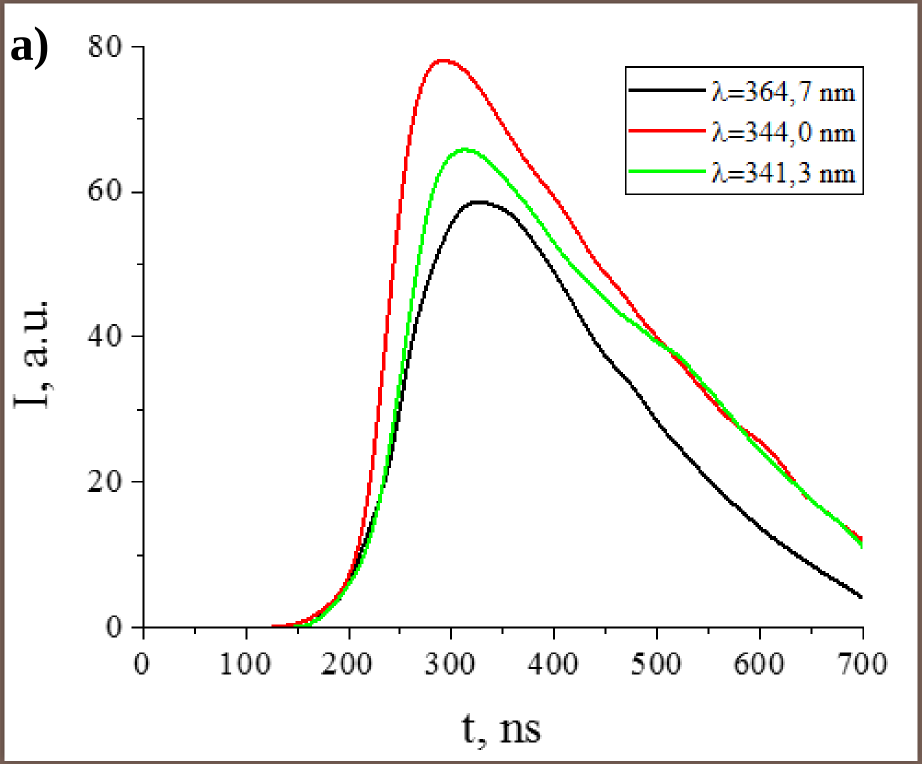


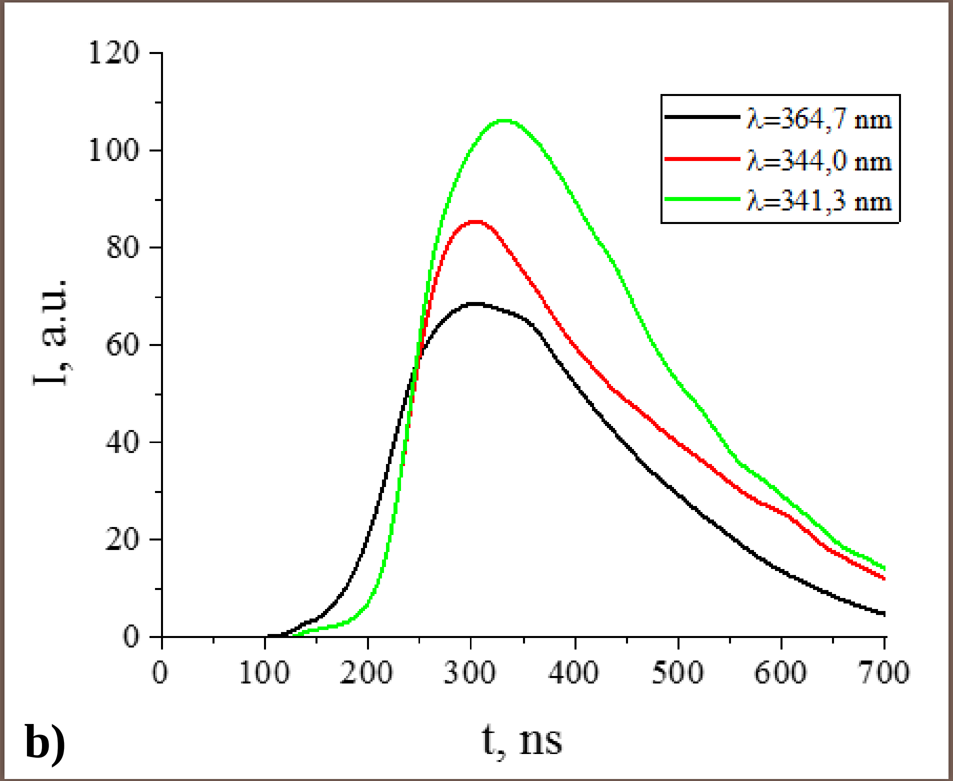
RESULTS OF EXPERIMENTAL STUDIES

- **From the discharge formation pictures recorded using FER-2 (look at fig. 1) it can be seen that after applying a high-voltage voltage pulse to the pre-ionized gap with an initial electron concentration $n_0 \approx 10^8$ cm^{-3}, the first detected glow appears at the anode. Subsequently, it propagates in the form of diffuse glow to the cathode with a characteristic velocity of ~10^7 cm/s.**
- **With the arrival of the glow front at the cathode, a plasma column of a volume discharge is formed in the discharge. The electron concentration in the plasma column, estimated from the discharge current density, reaches values of the order of 10^{13}-10^{14} cm^{-3}. As can be seen from the figures: fig. 1 (photo 3) and fig. 2 (photos 2 and 3)), current channels are formed in the discharge that are attached to the cathode and anode spots. The presence of near-cathode and anode spots indicates sputtering of the electrode material, respectively, emission lines of metal ions and atoms appear in the emission spectrum of the near-electrode plasma.**

Fig. 3. Characteristic time dependences of the intensity of the spectral line of Fe from the near-cathode (a) and near-anode regions (b) of the discharge for an applied field of 10 kV

Fig. 3 shows the characteristic time dependences for the spectral lines of iron with a length of 364.7 nm, 340.0 nm, and 341.3 nm from the electrode regions of the discharge for an applied voltage of 10 kV.

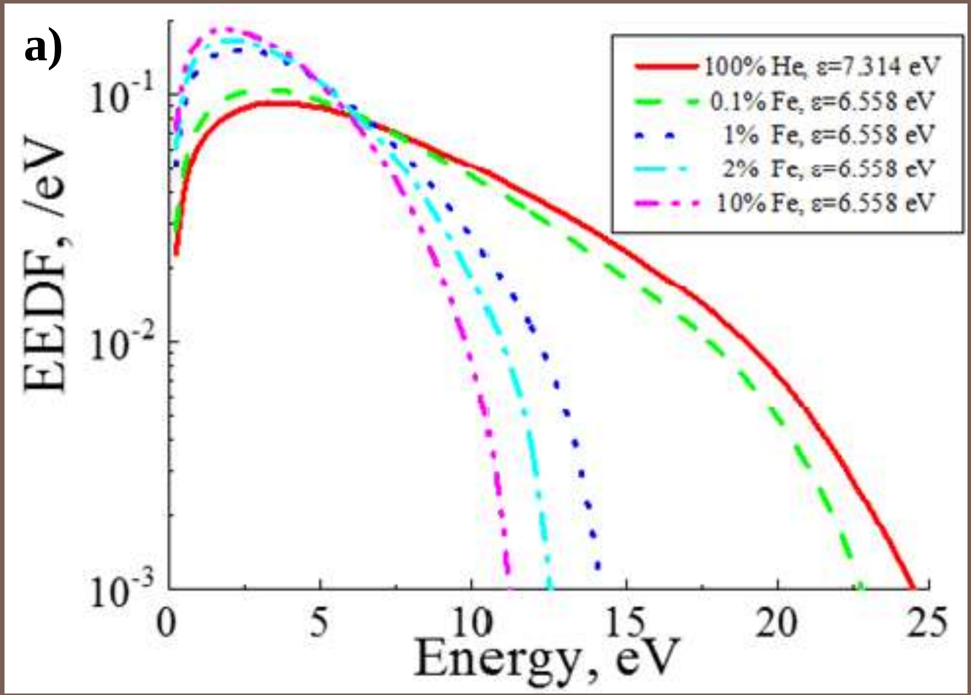


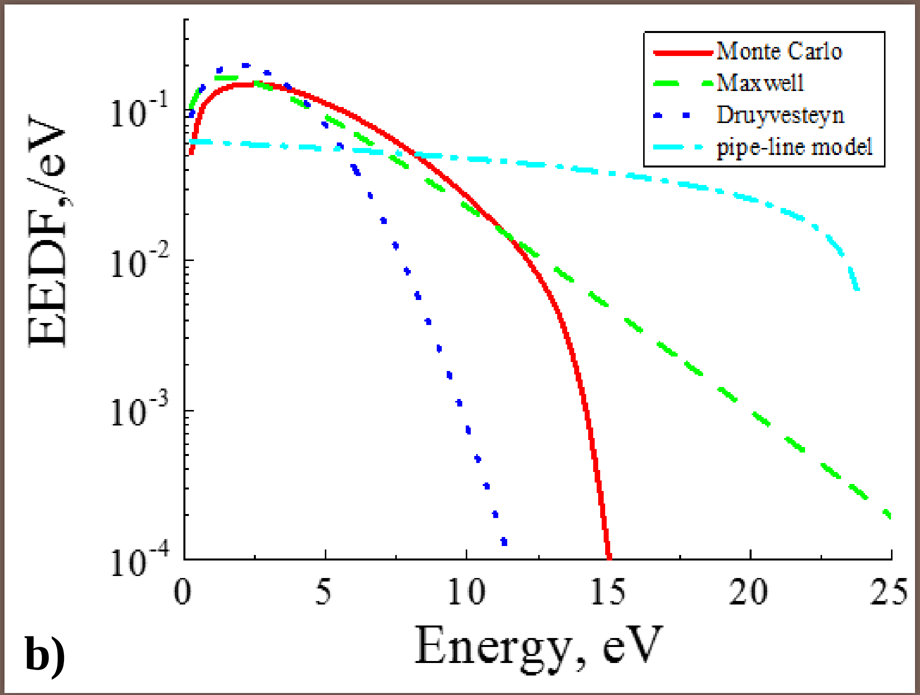


It can be seen that the emission lines of iron vapor are present both in the near-cathode and in the anode plasma, and the intensity of the emission of iron lines from the anode region weakly depends on the amplitude of the applied voltage. The radiation intensity of spectral lines increases with an increase in the energy input, and new spectral lines are excited in the discharge.

Fig. 4. Characteristic dependences of the electron energy distribution function for in helium with iron impurities at E/N=15 Td

Fig. 4a demonstrates characteristic dependences for the electron energy distribution function in pure helium and helium with 0.1%, 1%, 2%, and 10% iron atoms.





To demonstrate the difference between the function of electron distributions obtained as a result of the simulation and the known analytical dependences such as Maxwell, Druyvestein or the infinite flow approximation (pipeline model) fig. 4b shows their graphs in a semi-logarithmic scale. Note that large differences exist not only in the tails of the distribution functions, but also in the region of thermal energies.

Fig. 5. Dependences of the electron runaway coefficient in helium on E/N.

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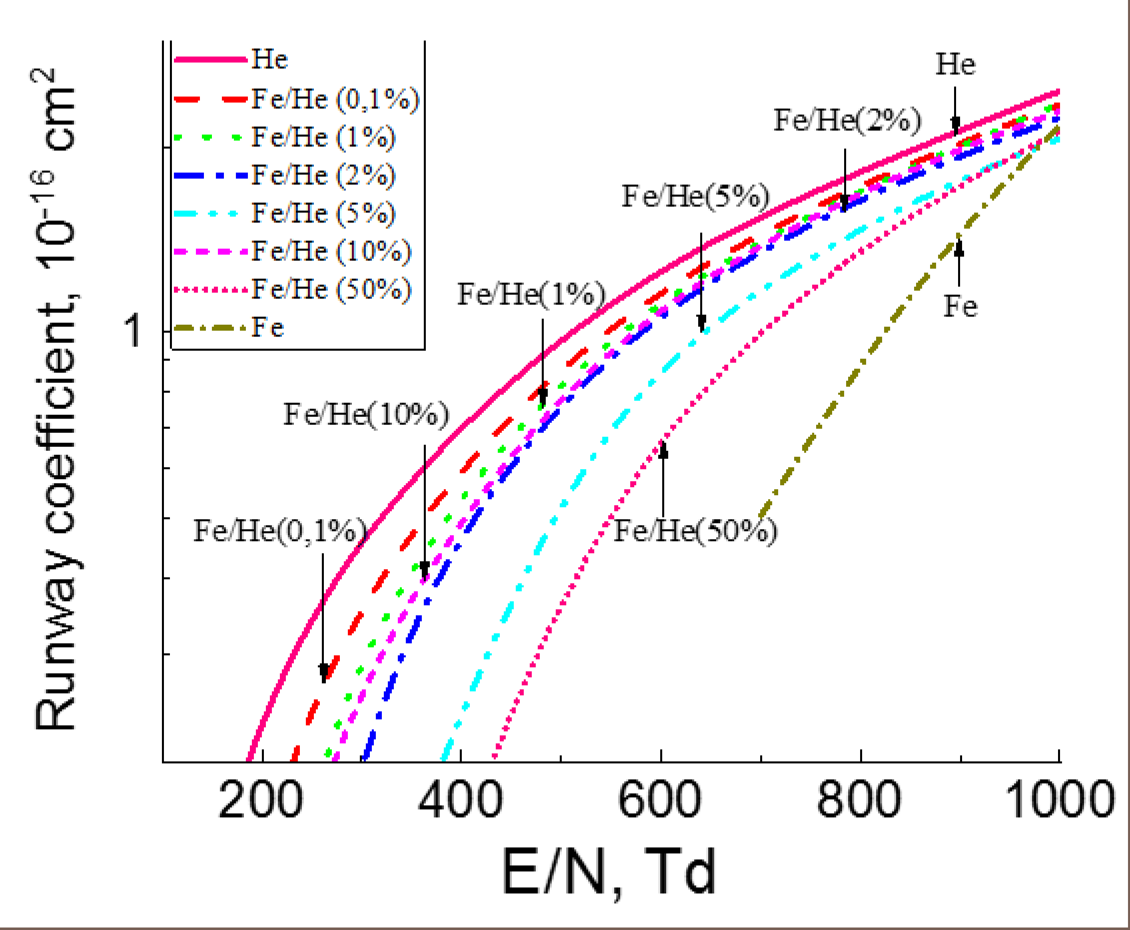
Fig. 5 show the indicate a sharp change in the characteristics of ionization and runaway electrons, when iron vapor is added to helium.

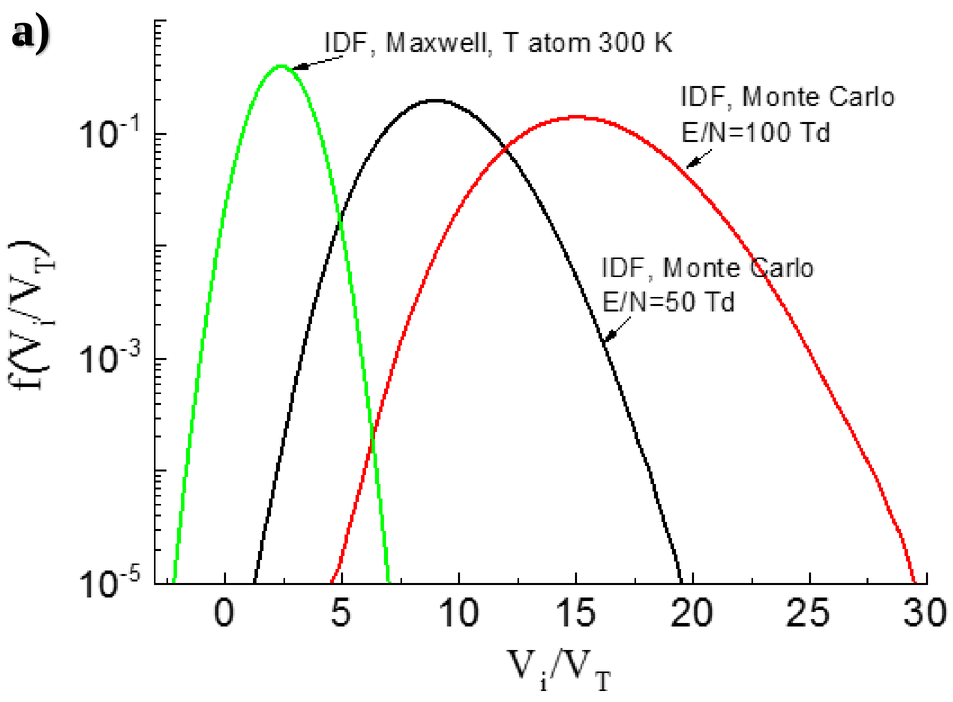


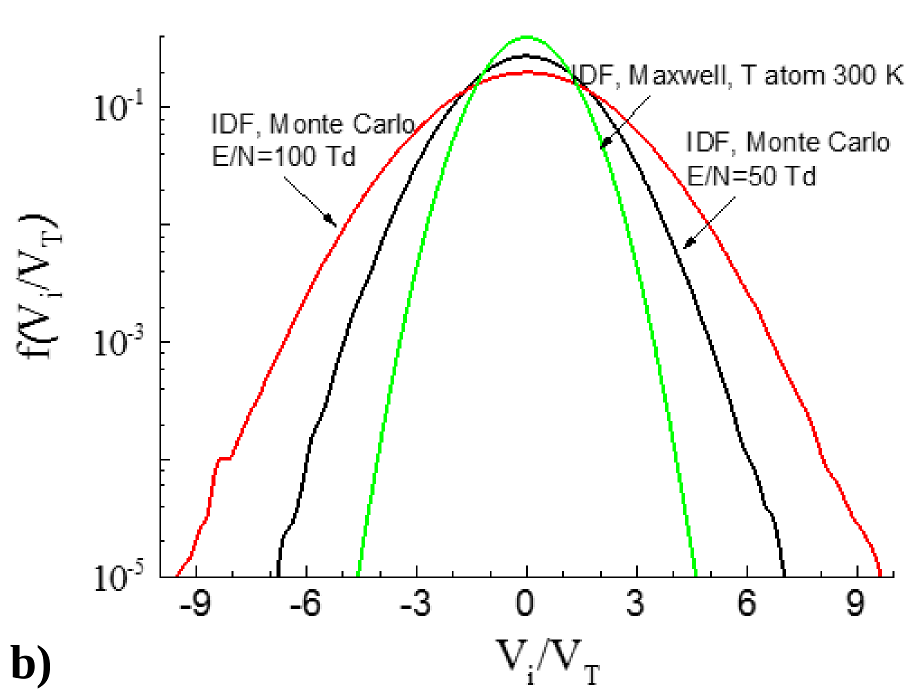
As can be seen, starting from a fraction of a percent, due to the strong ionization of iron atoms, a sharp change in the electron distribution function occurs, which leads to a significant increase in the ionization frequency and the appearance of a significant number of impurity ions, the dependence of the number of runaway electrons on the concentration of iron vapor has complex, non-monotonic character. The calculation results give a fairly complete picture of the mechanism of the effect of small additions of iron vapor on the characteristics of a gas discharge in helium. The most interesting and important fact from a practical point of view is a strong increase in the ionization frequency with an insignificant (fraction of a percent) addition of iron vapor. In addition, it should be noted that in this case iron atoms are mainly ionized.

Fig. 6. The results of calculating the distribution function of iron ions in helium $f(v_i/v_T)$ on the relative velocity v_i/v_T at atom temperature T_a = 300 K along (a) and across (b) the field direction.

Fig. 6 shows the characteristic distributions of the longitudinal and transverse components of the distribution function for various values of fields and temperatures. For comparison, the Maxwell distribution for atoms at Ta = 300 K is also plotted:

a)





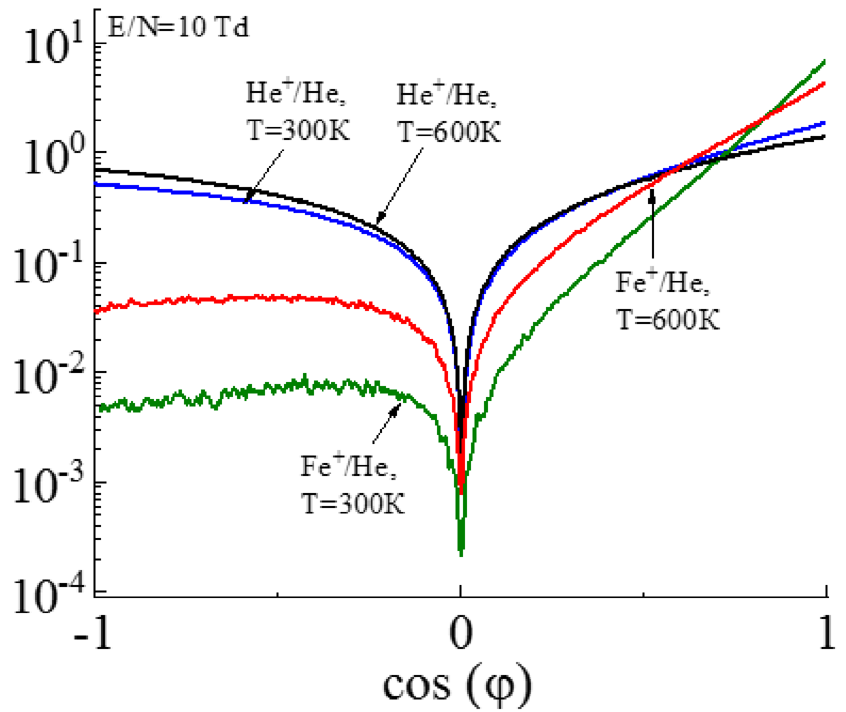
b)

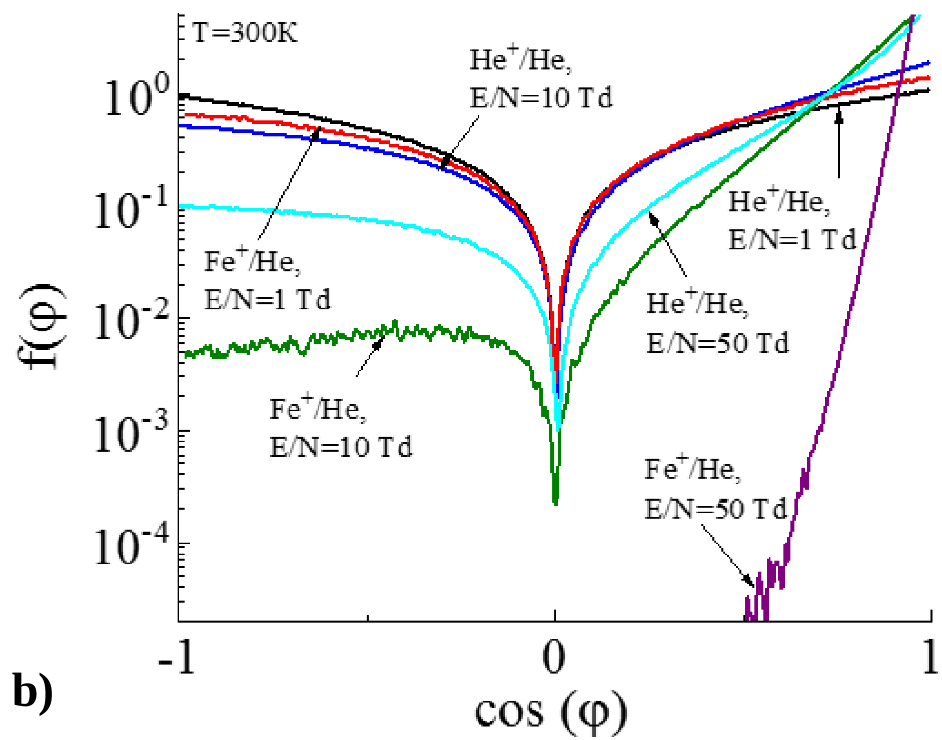
$$f(u) = \left(\frac{m}{4\pi T_a}\right)^{1/2} \exp\left(-\frac{mu^2}{2T_a}\right)$$

Fig. 7. Results of calculating the distribution function of ions in helium over the cosine of the angle between the direction of flight of the ion and the direction of the electric field for different values of E/N (a) and gas temperatures Tg (b).

It can be seen from the figure that for the angular distribution at *E/N*=10 Td, the two-term approximation is also strongly violated. Moreover, this deviation is clearly expressed for iron ions and decreases with increasing gas temperature.

a)





b)

The results of calculations of the angular characteristics of the ion flux during drift in a gas can be used to estimate the remaining characteristics of a gas-discharge plasma, when considering a magnetron discharge, barrier, probe characteristics, etc.

CONCLUSION

- Thus, depending on the E/N, various modes of discharge burning are possible: a homogeneous volume discharge, a homogeneous volume discharge with incomplete anode-directional channels attached to cathode spots with high conductivity, and the discharge gap overlapping by a plasma channel. The discharge spectrum is characterized by intense lines of iron atoms, which indicates the atomization of the material of the electrode material. Small metal impurities significantly change the kinetics of the discharge.
- It should be noted that cathode sputtering takes place in almost any experiment with discharges, and the above calculations show that changing the characteristics of the discharge with small additions of easily ionizable impurities can be used to search for new active media for various plasma technologies in microelectronics, processing materials, and applying thin films, creating light sources, plasma panels, medicine. Thus, a discharge in helium with iron vapor has features that can be useful in the search for new and more efficient radiation sources and the ability to significantly influence the discharge parameters by choosing the mixture composition and its percentage ratio also is extremely interesting.

ACKNOWLEDGMENT

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Thank you for attention