INFLUENCE OF ELECTRON EMISSION EFFECTIVENESS ON CHARACTERISTICS OF NEGATIVE CORONA DISCHARGE

O. Bolotov, V. Golota, V. Ostroushko
NSC "Kharkov Institute of Physics and Technology" Kharkov, Ukraine

To explain the results of experiments with negative corona in Trichel pulse mode it is proposed the assumption about decisive role of photoemission in supply of electrons from cathode. The results of numerical simulations correspond to experimental data and to simplified clear models.

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INTRODUCTION

Negative corona discharge is widely used in plasma-chemical techniques, in particular, in ozone synthesis. To intensify required reactions, it is worthy to use negative corona in Trichel pulse mode at relatively high voltage value but to keep discharge from turn to stationary mode. In the paper [1], there was studied the dependence of characteristics of pulses on transverse anode dimensions. It was revealed that for different transverse anode dimensions the total current dependences on time during the pulse are approximately the same, but interval between pulses increases with transverse anode dimension decrease. Also, a peculiar feature of mentioned discharge mode is considerable expansion of glow near cathode in direction transverse to electric field strength lines. And the common feature of the pulses is very small time of current pulse front (as small as 1 ns). To make clear the physical reasons of the observed phenomena the numerical simulations were carried out. Their results are presented below.

1. SIMPLE PULSE MODEL

At the beginning, it is worthy to remind Trichel pulse development. When sufficiently high voltage value is applied to discharge gap between anode and cathode and there is some amount of seed electrons in the gap then the ionization processes begin to develop. In the case of needle cathode the ionization rate is especially high in the region close to cathode. As electron mobility is much greater than ion mobility, the electrons are quickly removing from the near-cathode region and there are formed a positive ion cloud near cathode and a negative ion cloud somewhere farther from cathode (in presence of attachment). The charge of negative ions cloud makes electric field strength smaller between the cloud and cathode. The charge of positive ions cloud makes electric field strength greater between the cloud and cathode, but makes the strength smaller beyond the cloud farther from cathode. The formation of great amount of positive ions leads to considerable field weakening beyond them, to considerable decrease of rate of electrons removing from there, and to forming of plasma, in which the difference between the densities of particles with different signs (which determines the charge) is much less, than the densities themselves. The plasma region is positively charged, non-compensated charge is disposed in part of the region closer to cathode, and the plasma region is expanded to cathode. If the process was based on the impact ionization and ion-electron emission (without drawing of photoemission), and if the ionization coefficient was not dependent on the field strength then the spatial distribution of positive ions between plasma region and cathode would be close to exponential one with increment close to the ionization coefficient and the plasma region would approach to cathode with the velocity close to ion drift velocity. In reality, as ionization coefficient increases with field strengthening, the steepness of ions spatial distribution increases and the process of expansion of plasma region to cathode get the features of ionization wave. The speed of such wave is determined with the speed of electron removing from the ionization front and it much exceeds ion drift velocity.

After ionization wave going off, depending on balance of negative ion forming and removing from cathode the discharge may come to stationary mode or operate in pulse mode.

At the beginning let us consider the case when the applied voltage value is sufficiently great to ensure fast displacement of negative ions and their small density near cathode, so that screening influence of negative ions on the field near cathode is weak, comparatively with influence of positive ions. In this case, after arrival at the cathode of the main part of positive ions, the displacement of rest positive ions with renewal of the field screened by them earlier leads to intensification of ionization up to the level, at which the rate of positive ion forming in the gap compensates the rate of their going out, so that discharge comes to stationary mode.

Now let us consider the opposite case, when the applied voltage value is not sufficiently great to ensure fast displacement of negative ions from the cathode (whereas positive ions being in much stronger field are displaced to cathode much faster). In this case, at the time when displacement of the rest of positive ions to cathode begins to weaken the field screening, the contribution of negative ions to field screening turns out to be enough to ionization decay. And then, to develop new Trichel pulse it is necessary some displacement of negative ion cloud farther from cathode, to renew sufficiently strong field near cathode.

2. SIMULATIONS RESULTS AND DISCUSSION

The simulations were carried out for the axially symmetric system in the frames of model, which accounts only the main processes: ionization, attachment, electron-ion and ion-ion recombination, drift and diffusion of charged particles, ion-electron emission and photoemission from cathode. The voltage value taken in calculation was corresponding to one characteristic for Trichel pulse mode near the turn into stationary mode (approximately 10 kV for 1 cm gap and 50 μm cathode tip curvature radius).

At the beginning, there were carried out the calculation with ion-electron emission, but without photoemission. The pulse mode obtained in calculation was characterized by time interval between pulses approximately 100 ns, while in experiment it was 1 μs and more. The small time between pulses may correspond to situation when for pulse development it is sufficient the region length, at least, not much greater than cathode tip curvature radius, and in which there is strong field determined with cathode charge; then, to screen the field effectively, the negative ions had to be situated near the pulse development region, so, in sufficiently strong field, and then, the ions, quickly displacing, had to weaken screening and to create conditions for new pulse development during short time. Considerable increase of time between pulses may be achieved in the case when at the first stage of pulse development the positive ion density is maximal in the region, where the field in the empty gap is considerably weaker than at cathode (so, at the distance from cathode, considerably greater than cathode tip curvature radius). If the applied voltage value is small (close to threshold of negative corona ignition) it is just the case. If the voltage value is great (close to one corresponding to turn corona into stationary mode) the increase of length of the near-cathode region necessary for pulse development may be achieved through decrease of ion-electron emission coefficient. If ion-electron emission coefficient was 10^{-3}, as it is usually used in calculations, then to ensure the process on the base of ion-electron emission and impact ionization it would be enough near 10 subsequent ionization acts for which, in the field strong enough, it is sufficient electron drift length approximately 50 μm, which for the same or greater cathode tip curvature radius leads to the mentioned small interval between pulses. It is worthy to note that about low effectiveness of ion-electron emission, in comparing with photoemission, in atmospheric air conditions, it is written in [2, p. 94].

In view of stated above there were carried out calculations, in which ion-electron emission was replaced with photoemission, and for the number of electrons, which would be emitted from cathode by photons generated on unit length of electron drift, in the case of direction of all these photons to cathode, it was taken the exponential dependence from reciprocal field strength with the factor 1 cm^{-1} at exponent. As a result, the interval between pulses increases up to microseconds and becomes more close to experimental data. Also, in the calculations, there were realized some features of the studied discharge mode mentioned above.

The first such feature revealed in the experiments [1] is increase of the interval between pulses with decrease of characteristic transverse anode dimensions. In calculations with different values of anode tip curvature radius such tendency was obtained. It deals with field redistribution in the gap. With decrease of characteristic transverse anode dimension (which remains much greater than one of cathode) the field strength increases near anode and decreases near cathode (for the given voltage value over all gap), and, in particular, the field in the region of negative ion cloud weakens, leading to slowing down of negative ions displacement from the cathode and making it greater the time interval between pulses.

The second experimental feature of the studied discharge mode is considerable expansion of glow near cathode in direction transverse to the field. The spatial distribution of the charged particles density and the reactions intensity obtained in the calculations were in accordance with such glow expansion. There are, at least, two reasons of such expansion of the region with intensive electron processes. The first reason is relatively large distance between cathode and the region, which at the beginning of pulse development is the region of large positive ion density (it is situated near the point, in which, in the case of empty gap, the derivative of reciprocal ionization coefficient with respect to distance from the cathode is equal to 1) and then becomes the part of plasma region closest to anode. The positive charge weakens the field near the symmetry axis of the system to a greater degree than it weakens the field far from the axis, somewhat decreasing transverse variation of the glow at relevant distance from the cathode, comparing with that variation, which would be in absence of space charge. The second reason, which promotes the expansion of the region of intensive electronic processes in the transverse direction in calculation results, is replacing of ion-electron emission with photoemission. If pulse develops on the base of ion-electron emission and impact ionization then mutual influence of the processes, which takes place on different field strength lines, is relatively small. If there was no transverse diffusion and time variation of the field then self-consistent multiplication of charged particles would develop separately on each strength line, because the electron emitted from the cathode due to the positive ion impact would move and form new positive ions on the same strength line, as the mentioned positive ion. And the relation of the densities of charged particles even on the very close strength lines in these assumptions formally may become with time as large as you like. Diffusion and time variation of the field of space charge only somewhat diminish the described sharp spatial variation of the densities. In contrary to ion motion, the photon motion is not connected with field strength lines, and the photons generated by electrons in the region of intensive electronic processes may cause the emission of electron from any point of cathode surface (not shading from the point of the photon generation) and start electron multiplication there. So, the role of photoemission in transverse expansion of glow is in supplying of electrons from cathode to different strength lines independently on ionization intensity and positive ion density on that strength lines. Being expanded in such way, the glow to some degree surrounds cathode, although the distance between cathode and the points with equal glow intensity farther from symmetry axis increases, in connection with weakening of ionization intensity on relevant strength lines.

As an example of calculations results, in the Fig. 1, there are shown the distributions of electron density near cathode at instants of pulse development, corresponding approximately maximal transverse expansion of electrons near cathode ((a) in the case of only ion-electron emission account, (b) in the case of only photoemission account).

The third experimental feature of the studied mode is the common feature of Trichel pulses: the small time (approximately, 1 ns) of current rise in pulse development. In the calculations with account of photoemission this feature also was realized. The comparatively large time of current rise (approximately, 10 ns) in the calculations with ion-electron emission, but without photoemission, is mostly determined by the time necessary for positive ion to come to cathode. In contrary, the photon after its generation comes to cathode and causes emission of electron practically instantly, so, in the calculations with account of photoemission the time of current rise is mostly determined by the time necessary for electrons to make the sufficient number of ionization acts resulting in formation and propagation of ionization wave, as it was described above.

CONCLUSIONS

So, to explain the experimental data, concerning the time of current rise during Trichel pulse developing, the time interval between pulses, and the spatial distribution of glow near cathode in negative corona discharge under conditions, which correspond to pulse mode, but are close to conditions of mode turning into stationary one, in the present work, it is proposed the assumption about weakness of ion-electron emission and decisive role of photoemission in the conditions of the considered experiments. The numerical simulations having been carried out gave the results, which are in accordance with experimental data and simplified clear models.

REFERENCES

1. V.I. Golota, O.V. Bolotov. Anode curvature influence on characteristics of negative corona discharge under Trichel pulsed mode. // *Problems of atomic science and technology*, 2011, №. 1, *Series «Plasma Physics»* (17), p. 113–115.
2. Ju.P. Raizer. *Gas discharge physics*. Moscow: «Nauka», 1992 (in Russian).

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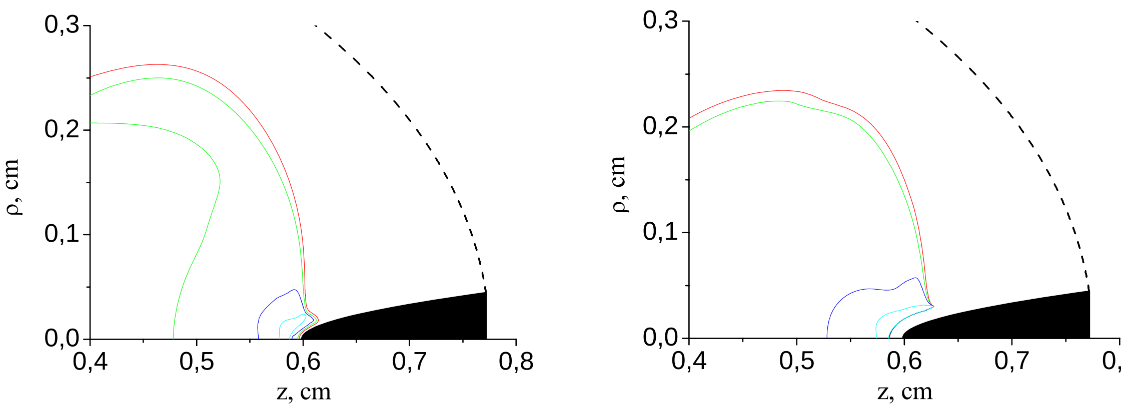

(a) (b)

Electron density distributions near cathode at instants of pulse development, corresponding approximately maximal transverse expansion of electrons near cathode: (a) in the case of only ion-electron emission account, (b) in the case of only photoemission account; the lines corresponds to the densities 10^9, 10^{10} 10^{11}, and 10^{12} cm^{-3}

ВЛИЯНИЕ ЭФФЕКТИВНОСТИ ЭЛЕКТРОННОЙ ЭМИССИИ НА ХАРАКТЕРИСТИКИ ОТРИЦАТЕЛЬНОЙ КОРОНЫ

О.В. Болотов, В.И. Голота, В.Н. Остроушко

Для пояснения результатов экспериментов с отрицательной короной в режиме импульсов Тричела выдвинуто предположение об определяющей роли фотоэмиссии в поставке электронов с катода. Результаты численного моделирования соответствуют экспериментальным данным и упрощенным наглядным моделям.

ВПЛИВ ЕФЕКТИВНОСТІ ЕЛЕКТРОННОЇ ЕМІСІЇ НА ХАРАКТЕРИСТИКИ НЕГАТИВНОЇ КОРОНИ

О.В. Болотов, В.І. Голота, В.М. Остроушко

Для пояснення результатів експериментів з негативною короною в режимі імпульсів Тричела запропоновано припущення про визначальну роль фотоемісії у постачанні електронів з катода Результати чисельного моделювання відповідають експериментальним даним та спрощеним наочним моделям.