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Optical radiation in breakdown of the acceleration gap of a forevacuum pressure, wide-aperture, plasma-cathode, pulsed electron source

We have investigated the spectrum of optical radiation during breakdown in the acceleration gap of a wide-aperture, plasma-cathode, pulsed electron source based on a vacuum arc discharge in the forevacuum pressure range (3–20 Pa). The analysis shows that breakdown considerably increases the spectral line intensity and results in additional gas and metal lines. The spectrum is dominated by atomic and molecular lines from the working gas. The presence of metal lines under breakdown conditions suggests that cathode spots arise at the emission electrode, assisting the gas discharge in the acceleration gap.

Keywords: Plasma electron source, pulsed electron beam, arc discharge, acceleration gap, breakdown.
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Pulsed plasma-cathode electron sources operating at forevacuum pressures of 3–50 Pa allow electron beam treatment of conducting and dielectric materials without any additional equipment for surface charge compensation [1, 2]. However wider application of such sources is limited by a series of factors, among which is the breakdown strength of the e-beam acceleration gap.

Breakdown phenomena have been investigated for forevacuum plasma sources of continuous electron beams based on a hollow-cathode glow discharge [3, 4] and of small-aperture (less than 10 mm) pulsed electron beam sources with current less than 10 A [5], but the cause of breakdown in fore-vacuum sources of wide-aperture electron beams with long pulse duration and currents higher than 10 A is still little understood.

Among the possible causes of breakdown in an acceleration gap is the backward ion flow and «secondary plasma» in the gap [3], ion charging of dielectric inclusions at the emission electrode or stabilizing grid [6], acceleration system geometry, and change in perveance of the gap [7]. All these factors contribute to accelerating gap breakdown, but which factor dominates in forevacuum wide-aperture pulsed electron sources is not clear. Here we report on our studies of the spectrum of optical radiation produced in breakdown of the acceleration gap of a forevacuum-pressure pulsed plasma-cathode electron beam source based on an arc discharge.

Experimental setup and research technique

The fore-vacuum plasma electron source used is described in detail elsewhere [8]. A schematic of the experimental setup is shown in Fig. 1.

Cathode *1* of the plasma source is a copper rod enclosed in ceramic insulator *2*. Anode *3* is a hollow copper cylinder at the base of which is an emission window of diameter 90 mm covered with fine stainless steel grid *4*. The arc discharge is initiated by an insulator flashover between cathode *1* and trigger electrode *5*.

The acceleration gap is formed by emission grid *4* and stainless steel grid extractor *6*. The electrodes of the acceleration gap are electrically insulated by high-voltage insulator *7*.

The electron source is located on flange *8* of the vacuum chamber pumped by a mechanical forevacuum pump. The pressure (3–20 Pa) is controlled directly through gas supply to the vacuum chamber. The working gas is air.

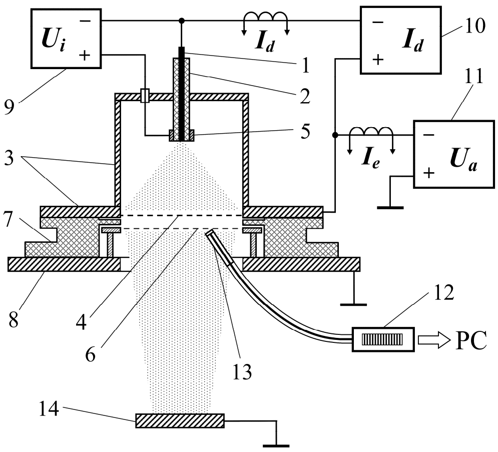

Fig. 1. Schematic of the experimental setup: *1* – cathode; *2* – ceramic insulator; *3* – anode; *4* – emission grid electrode; *5* – trigger electrode; *6* – accelerating electrode (extractor); *7* – high-voltage insulator; *8* – vacuum chamber flange; *9* – trigger generator; *10* – pulsed discharge power supply; *11* – DC accelerating voltage source; *12* – optical spectrometer; *13* – optical probe; *14* – collector

The arc discharge, which is the source of the emission plasma, is ignited using pulsed trigger generator *9* and is powered by pulsed discharge power supply *10*. The extraction of electrons from the arc discharge plasma and their acceleration is provided by DC accelerating voltage source *11*. In the experiment, the pulse-averaged discharge current I_d was 25–30 A, and the pulse duration was 1.8 ms; the voltage across the acceleration gap was U_a = 8–12 kV. The discharge current I_d and the emission current I_e were measured with current transformers.

The spectra of optical radiation produced in the acceleration gap during its breakdown were analyzed using optical spectrometer *12* (Ocean Optics 2000USB) with a wavelength range of 200–1100 nm. The signal to the spectrometer was transmitted via fiber optics from an optical probe *13* screened with quartz glass. The probe was located in the vacuum chamber at 7 mm from the extractor, and the entrance aperture of the probe was directed toward the acceleration gap so as to view most of it. The spectral lines observed in the experiment were indentified according to [9–11].

Results and analysis

Breakdown of the acceleration gap was judged from the accelerating (gap) voltage U_a and emission current I_e. Upon gap breakdown, the emission current I_e first increases steeply and then decreases to 0 within about one hundred microseconds while the accelerating voltage U_a immediately drops to zero. Figure 2 shows waveforms of the discharge current I_d, emission current I_e, and accelerating voltage U_a under (a) normal and (b) breakdown conditions. The normal condition provides stable generation of electron beam without breakdown of the accelerating gap.

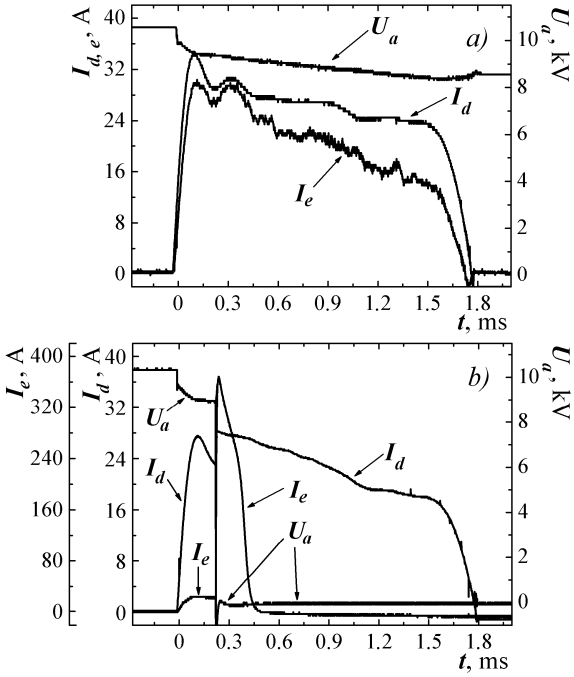

Fig. 2. Discharge current I_d, emission current I_e, and accelerating voltage U_a under (*a*) normal, and (*b*) breakdown conditions

Figure 3 shows optical radiation spectra under (*a*) normal, and (*b*) breakdown conditions.

With no breakdown in the gap (Fig. 3, *a*), the spectrum reveals lines of the working gas. In the forevacuum pressure range (with a mechanical pump only), the residual atmosphere consists mainly of nitrogen, oxygen, and water vapor. Thus the optical spectrum contains atomic lines of H and O, molecular lines of N_2, and molecular lines of OH from water vapor. The atomic lines of O and H, like the OH lines of, can also be due to water vapor [11]. In addition to the lines of neutral atoms and molecules, the spectrum reveals lines of singly charged N_2^+ ions which are most intense at 391.4 and 427.1 nm.

Under breakdown conditions in the gap (Fig. 3(*b*)), the spectral line intensity increases considerably, and additional gas and metal (Fe) lines appear in the spectrum. The gas lines dominate over the metal lines both in number and in intensity. The lines of neutral molecular nitrogen N_2 are more intense than those of ionized N_2^+ and than the lines of neutral OH and O. At λ = 574–775 nm, the spectrum reveals three groups of lines which, according to ref. [12], belong to the first positive system (FPS) of molecular nitrogen N_2.

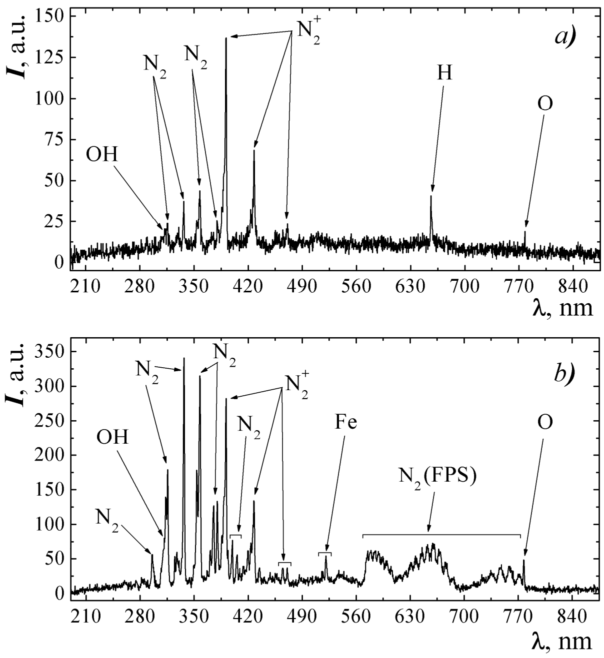

Fig. 3. Optical spectra under (*a*) normal, and (*b*) breakdown conditions; p = 15 Pa

In the breakdown spectrum, only lines of Fe are distinguishable among the metal lines, due to the high percentage of Fe (higher than 70%) in the electrode material (stainless steel) of the gap, and only lines of its neutral atoms.

Thus the predominance of atomic and molecular lines of the working gas and the presence of N_2^+ ion lines in the breakdown spectrum suggest that breakdown in the acceleration gap of the source is due to the ignition of a gas discharge. Early in the breakdown, cathode spots may arise at the emission electrode, assisting the gas discharge in the gap. The formation of a cathode spot is evidenced by spectral lines of the metal contained in the material of the emission electrode.

Conclusion

Our study shows that the optical radiation spectrum produced in breakdown of the acceleration gap of the forevacuum wide-aperture pulsed plasma electron source is dominated by atomic and molecular lines of the working gas. Also observed are lines from ions of the working gas. The presence of metal lines in the spectrum suggests that a cathode spot (or spots) is formed at the emission electrode, assisting the gas discharge in the acceleration gap of the source.

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Бурдовицин В.А., Казаков А.В., Медовник А.В., Окс Е.М., Браун Я.Г.

Исследование оптического излучения пробоя ускоряющего промежутка форвакуумного широкоапертурного импульсного плазменного источника электронов

Проведены исследования оптического излучения, возникающего при пробое ускоряющего промежутка импульсного широкоапертурного плазменного источника электронов на основе дугового разряда, функционирующего в форвакуумном диапазоне давлений (3–20 Па). Показано, что по сравнению с оптическим излучением при нормальной генерации пучка при пробое ускоряющего промежутка значительно увеличивается интенсивность спектральных линий и появляются дополнительные линии газа и металла. Установлено, что в оптическом спектре излучения при пробое доминируют спектральные линии атомов и молекул рабочего газа, а также наблюдаются ионы рабочего газа. Появление спектральных линий, соответствующих металлу, свидетельствует о формировании катодного пятна на эмиссионном электроде, которое способствует развитию газового разряда в ускоряющем промежутке источника.

Ключевые слова: плазменный источник электронов, импульсный пучок электронов, дуговой разряд, пробой ускоряющего промежутка.