Development of Efficient Switching Converters, Based on Cs-Ba Plasma

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Nowadays cosmic and earth-based nuclear power industry specifies stringent requirements to the research and development sector in view of its necessity for the total control over the current density, smooth failure-free operation of energy-generating plants under extreme conditions at high radiation levels and temperatures above 1000 K. The application of high-current thermionic cesium-barium switching devices meets one of those requirements. The results of the research into plasma's electro kinetic parameters of Knudsen high-current diode and triode switching devices are presented below.

The investigations of the spontaneous arc extinction in a switching Cs-Ba diode and triode with a fine-mesh grid, operating in the collisionless mode, have been carried out. The use of Cs-Ba mixture, where cesium is a plasma-forming component, allowed to obtain emission currents from the cathode up to 100 A/cm^2 in Cs-pressure range 10^{-3}-10^{-2} Torr and, thus, easily attain the limits of gas current-conduction capacity[1,2].

It is shown, that the critical current j_{crit}, preceding the spontaneous extinction of the arc (the upper current limit), doesn't depend on Ba pressure and is proportional in a wide range to Cs pressure (Fig. 1). It is ascertained, that j_{crit} is the density of electron current, which can be compensated at the complete ionization of the plasma-forming atoms

$$j_{crit} = (e\bar{v}_i/kT)P\sqrt{m_i/m_e},$$

here $\bar{v}_i$ - average ion velocity in the plasma, m_i, (m_e) - ion (electron) mass, P - gas pressure, T -temperature. Time of existence of the arc discharge under conditions, when the critical value of the discharge current is exceeded, is inversely proportional to $\Delta j=j-j_{crit}$ (Fig. 2) and is almost by an order of magnitude longer, than the similar period in the case of the inert gas discharges. Such a prolonged existence of the current conduction state may be explained by desorption of the plasma-forming atoms from the electrode surfaces. It is found, that the spontaneous arc extinction is followed by a relaxation period - the time, in which the ignition of the arc discharge doesn't occur. This time proves to be commensurable with the time of existence of the plasma conduction state. Further, it is found, that the arc extinction is preceded by the appearance of plasma instability and the development of plasma oscillations.

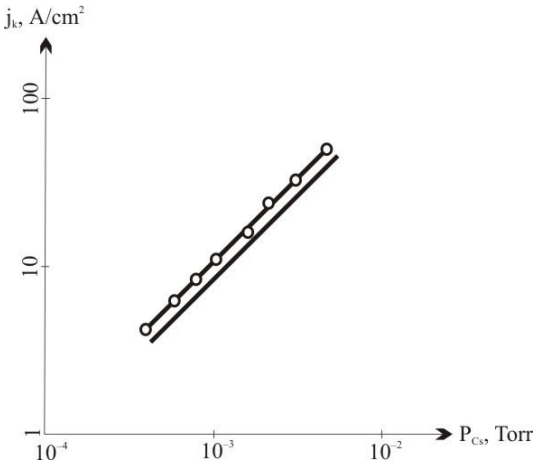

Fig. 1. Critical current density as a function of cesium pressure: 1 - experiment, 2 - theory

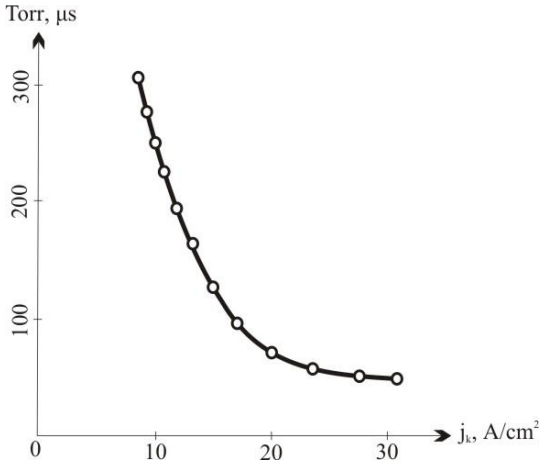

Fig. 2. Time of existence of the arc discharge as a function of the subcritical current density; $P_{Cs}=8\cdot10^{-4}$ Torr, $P_{Ba}=2\cdot10^{-4}$ Torr

In order to study the mechanism of the spontaneous arc extinction the time dependencies of the luminosity of a series of CsI, BaII and BaI lines were obtained; the luminosities of all lines investigated were measured in the subcritical (points A - C), critical (point D) and super-critical (point E) discharge modes, as well as at seven points across the interelectrode spacing (Fig. 3).

Recording and processing of the experimental data were performed with the use of the multichannel measuring and calculational system, intended for the investigation of non-stationary periodic processes, the resolution of the order of 1 μs being provided. All the analogue signals were being strobed simultaneously.

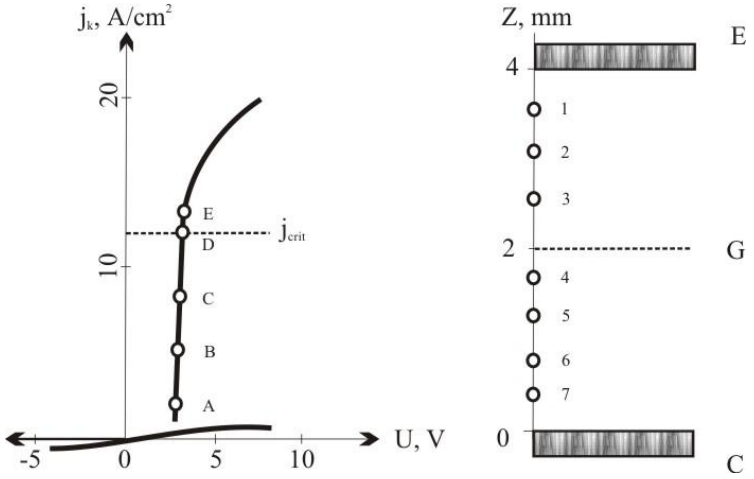

Fig. 3. Volt-ampere characteristic of the discharge and the schematic view of the interelectrode spacing; $T_k=1660$ K, $P_{Cs}=1.1\cdot10^{-3}$ Torr, $P_{Ba}=1\cdot10^{-3}$ Torr

The recording with the time resolution of 0.2 μs was being performed by the single - channel analogue strobe - integrator. For increasing the ratio "signal - noise" the numerical averaging in the computer was employed (N=128). The synchronous recording of the electrical and

optical relationships using the multi-channel system made possible to reveal the time shift between these relationships, as well as between optical processes at different points of the interelectrode spacing.

To determine the value of the time shift the correlation analysis was employed. The correlation function

$$K = 1/n \sum_{i=1}^{n} [f_1(t_i) - \bar{f_1}][f_2(t_i - \tau) - \bar{f_2}]$$

for the luminosity relationships, obtained for the BaII line (λ=7060 Å) in the cathode (point 2) and anode (point 6) regions of the discharge, is presented in Fig. 4. The examination of the correlation method, being applied in our case, showed, that the measurement error of the time shift values didn't exceed 20% of the time step, i.e. was equal to 0.2μs.

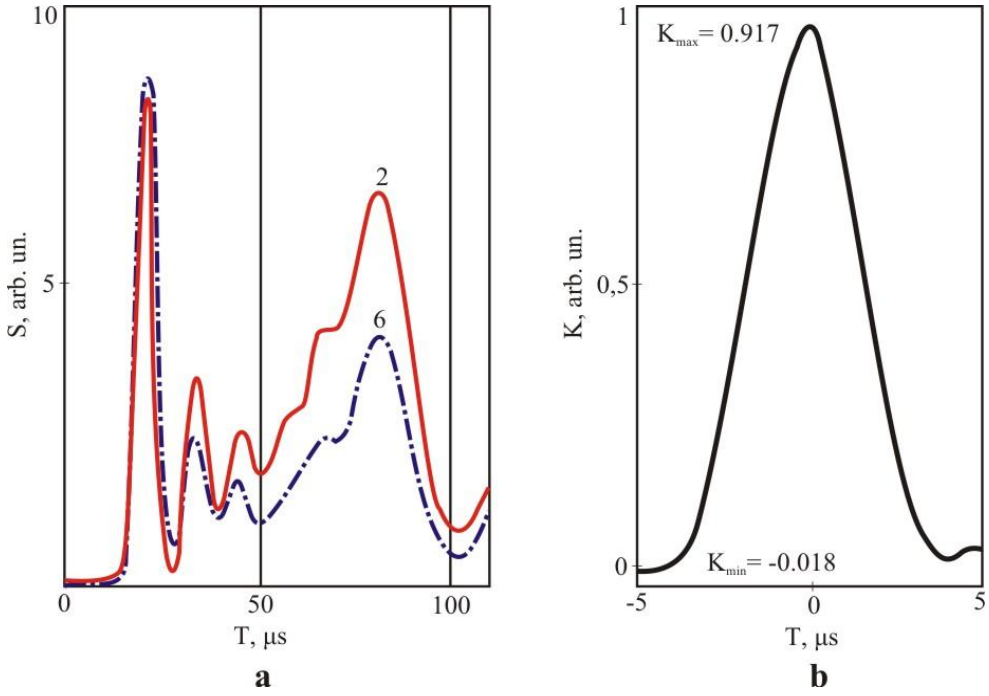

Fig. 4. Time dependence of the BaI line (λ=7060 Å) luminosity at the points 2 and 6 in the spacing (mode B) - **a**, correlation function - **b**

The results of data processing demonstrated, within the accuracy indicated above, the absence of time shifts during the oscillation development in the discharge modes A - D. It means, that the oscillations in the subcritical mode are not connected with the propagation of potential waves, potential jumps and other disturbances across the interelectrode spacing and are accompanied by the synchronous change of the potential at all points in the spacing. The results, obtained in the mode E, in which the spontaneous arc extinction occurs, are different. As is seen from Fig. 5 and 6, under these conditions the process is non-synchronous throughout the spacing: before the arc extinction flashes of the highly excited BaI and BaII

lines radiation occur in the anode region by 3 μs earlier, than in the cathode region, which is due to the abrupt change of the plasma potential. The spontaneous arc extinction is preceded by preparatory processes involving atom concentration depletion, manifested by the decrease of luminosity with time.

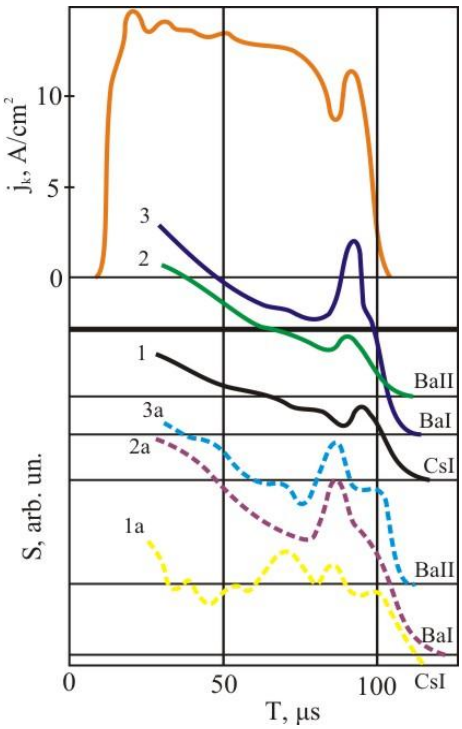

Fig 5. Time dependencies of the current and luminosity of Ba and Cs lines (mode E); the points chosen are denoted by: solid line - point 2, dashed line - point 6; 1, 1a - CsI, λ=7279 Å; 2, 2a - BaI, λ=5535 Å; 3, 3a - BaII, λ=4934 Å

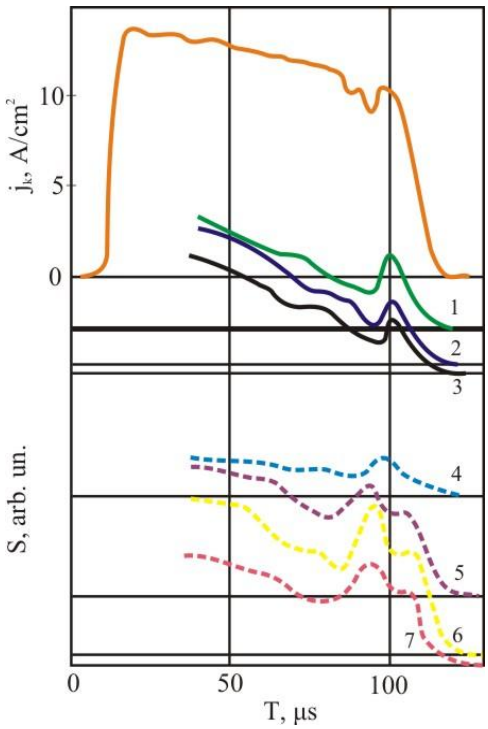

Fig. 6. Time dependencies of the current and luminosity of BaII line (λ=4934 Å) at various points of the spacing (mode E)

From the optical measurements it may be concluded, that the oscillatory processes in the subcritical mode occur synchronously at all points in the spacing; these measurements confirm also the assumption about the spontaneous extinction of the high-current low-pressure discharge being due to the atom depletion in the spacing.

Thus, the arc extinction in the triode, having the fine-mesh, highly-transparent grid, is due to the high degree of atom ionization and to the escape of atoms from the spacing, while the large duration of the current pulse is determined by atom desorption from the electrodes.

References

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2. A. Mustafaev, V. Soukhomlinov, O. Murillo. Fifty-Eighth Annual Meeting of the APS Division of Plasma Physics, 2016, P. JP10.00161. (San Jose, California, USA).