Cs-Ba diode and triode current modulators for efficient current management using Bursian-Pierce instability

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At present, the problems of current control in the electrical circuits of space nuclear power plants are topical. This talk deals with the results of experimental studies of the diode and triode current modulators, intended for use in terrestrial and space current conversion systems. These devices effect current modulation through propagation of nonlinear oscillations in the inter-electrode gap and does not require use of any external forces. Such structures have place due to the Bursian-Pierce instability in plasma. Experiments conducted in a Knudsen diode with a Cs–Ba filling demonstrated the feasibility of full modulation of current at voltage of 5-6 V and discharge current density of ~10 A/cm^2. A stable modulation of current and voltage with frequencies of 5-20 kHz and complete current brake existed at Cs pressures range of $1{,}5\cdot10^{-3}$–$3{,}5\cdot10^{-3}$ Torr. Investigations of triode device also demonstrated that mechanisms of discharge extinction and spontaneous current breakage are associated with nonlinear oscillations. Stable modulation at frequencies of 1-10 kHz of specific electric power of 5 kW/cm^2 and an efficiency of more than 95 % was obtained at the anode voltage 50 V.

In connection with modern requirements of current control in electrical circuits of nuclear reactors for space (NRS) there is a necessity in effective radiation-resistant electronic devices: key elements, thermoemission transducers, current and voltage stabilizers, transformers, generators, etc., reliably working in instrument compartment of the NRS [1, 2]. It is also necessary to develop methods for studying the distribution function of charged particles in anisotropic plasma [3, 4]. It's connected with the requirements of an output electric power of 100-500 kW at a specific gravity γ < 40 kg/kW, providing a sustained power supply of the payload modules of spacecraft.

To solve this problem, the electrokinetic parameters of diode and triode (Fig. 1) current modulators with Cs-Ba filling were investigated. The advantages of this filling are due to the fact that barium, which has a high heat of adsorption on refractory metals, ensures high emission of the cathode at low pressure, and cesium with a low ionization potential serves as a plasma-forming component.

Figure 1a shows scheme of Cs–Ba diode current modulator. The emitter 1 and the collector of flat geometry 3 were made of polycrystalline tungsten and molybdenum respectively and had a diameter of 15 mm. Emitter was warmed up by electronic bombardment. The collector was a massive stock, which was fastened through insulators 4 inside the flange. The flange was connected to the body of the device through a flexible tantalum diaphragm. This made it possible to smoothly change the value of the inter-electrode gap from 0 to 2 mm. The graphite bush 5 was additionally inserted into the flange so that when the collector is moved, there are no misalignments.

A schematic diagram of Cs–Ba triode current modulator is shown in Fig. 1b. Tungsten cathode 1 and molybdenum anode 2 were made in the form of flat discs with a diameter of 11 and a thickness of 3 mm. The cathode was heated by electron bombardment.

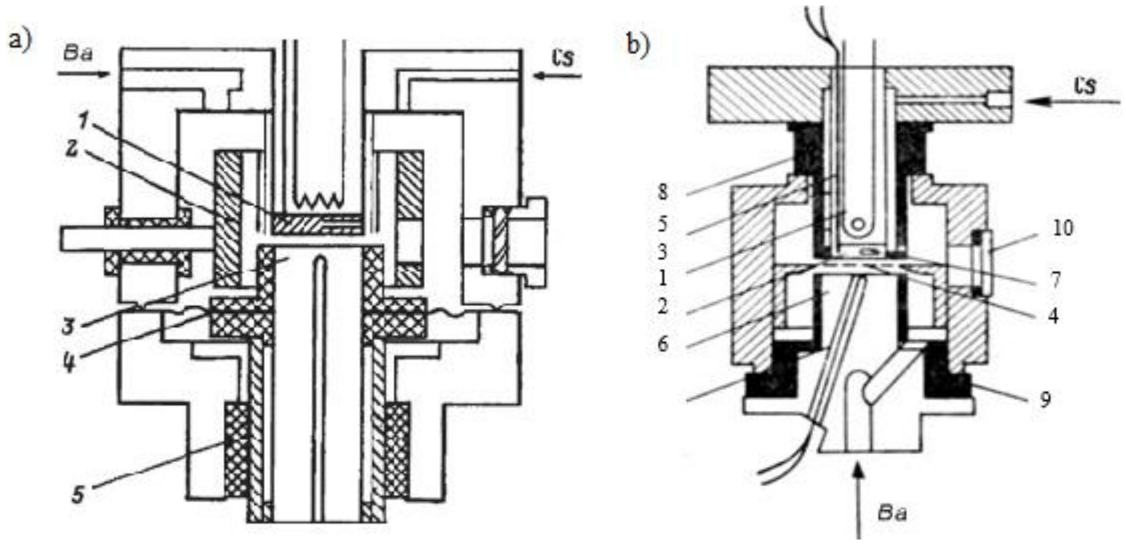

Fig.1. Cs-Ba current modulators a) diode device: 1 – cathode, 2 – anode, 3 – electron gun, 4 – grid, 5, 6 – thermocouples, 7 – cavity for pyrometry, 8, 9 – alundum insulation, 10 – sapphire window; b) triode device: 1 – emitter, 2 – ring electrode, 3 – collector, 4 – insulators, 5 – graphite bushing

Current control in the modulators is carried out due to the development of plasma structures in the inter–electrode gap and does not require use of any external influences. Such structures are formed due to the development of electronic Bursian–Pierce instability in the plasma. In order to realize current modulation with frequency, acceptable for practice ($f \sim 10^4$ Hz), two conditions must be met:

1) current in the plasma must brakes in a time much less than $1/f$;

2) locked state of the device must be maintained for a period of time of the order of $1/f$.

As a result of the development of Bursian–Pierce instability, an interesting physical phenomenon may arise – a sharp current brake. This occurs at certain conditions, when a potential barrier (virtual cathode) for electrons is formed near the emitter. Electrons are intensely reflected from the barrier, which leads to a strong decrease in the current reaching the collector. Because of the formation of a virtual cathode goes about the same time of the mean transit time of electrons between the electrodes (approximately several nanoseconds), it can be said that the current changes instantaneously.

Thus, as a result of studies of the **diode current modulator**, it can be seen:

- it has been established, that full modulation of current density ~10 A/cm^2 at burning voltage 5–6 V can be implemented due to the development of Bursian–Pierce plasma instability [5] and the formation of nonlinear structures in the plasma;
- using these instabilities the modulation frequencies of 5–20 kHz have been achieved (see Fig. 2): the discharge develops in a time that is small in comparison with the time of its burning. After about 100 μs after the ignition, the current breaks. The current breakage process takes place in a time of the order of 1 μs (current level after the break is close to zero). Immediately after the current breaks in the circuit, a transient process with duration of 100 μs begins. The diode retains the electrical strength of another 140 μs, only 180 μs after the current breakage the discharge ignites again;
- the possibility of controlling the current modulation by means of an auxiliary discharge, as well as external electric and magnetic fields has been founded.

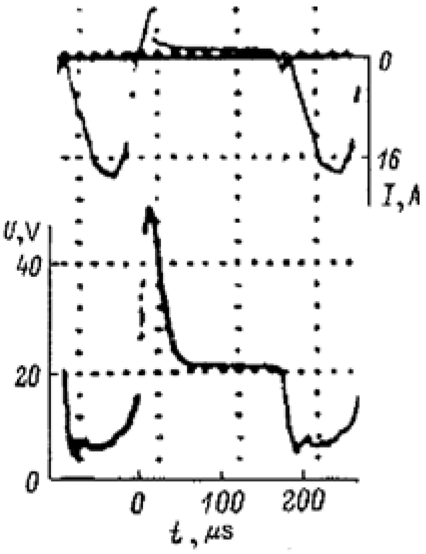

Fig. 2. Waveforms of current (from above) and voltage (from below) in the diode modulator: $P_{Cs} = 2.3 \cdot 10^{-3}$ Torr; $P_{Ba} = 5 \cdot 10^{-4}$ Torr; $T_E = 1315$ °C

The phenomenon of spontaneous current breakage was observed also in **triode current modulator**. It has been established, that mechanism of current breakage and discharge extinction in triode, as well as in diode, is associated with nonlinear oscillations in the Knudsen plasma. The main results are:

- it was found that current brake occur when a current reaches a certain critical density j_{cr}, the magnitude of which is proportional to the pressure of cesium vapor. For $j > j_{cr}$, steady burning of the discharge was observed;
- stable modulation at frequencies of 1–10 kHz of specific electric power of 5 kW/cm^2 and an efficiency of more than 95 % was obtained at the anode voltage 50 V;

- the use of fine–mesh grid as a control electrode provides high power in the range of cesium vapor pressures of 10^{-4}–10^{-2} Torr and low voltage losses in the open state of 0.8–2.5 V;
- a triode device in non–stationary operating mode is promising not only from the point of view of management effectiveness, but also from the point of view of limiting parameters (Fig. 3).

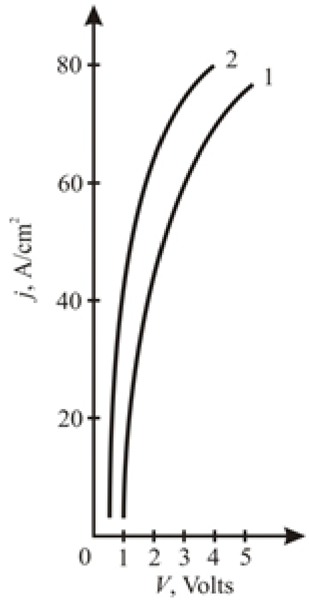

Fig.3. IV traces of Cs–Ba triode current modulator for $T_к$ = 1700 K (1) and 1970 K (2); P_{Cs} = 10^{-2} Torr; P_{Ba} = 10^{-3} Torr

Thus, the results of research on the current modulators of the new generation show that in an unstable regime of discharge burning, when the current density increases, the control costs decrease. In this way the relevance of a new effective method of current modulation and its binding to the phenomenon of spontaneous current breaking associated with the appearance of the Bursian–Pierce instability is confirmed.

References

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