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Switching devices – EPTRON with 100 kV operating voltage and sub-nanosecond switching times

P A Bokhan¹, P P Gugin¹, V A Kim¹, M A Lavrukhin¹ and D E Zakrevsky¹,²
¹ Institute of Semiconductor Physics SB RAS, 13 Ac. Lavrentiev Ave., Novosibirsk, 630090, Russia
² Novosibirsk State Technical University, 20 Karl Marx Ave., Novosibirsk, 630092, Russia

E-mail: gugin@isp.nsc.ru

Abstract. The data on the experimental study of the characteristics of a gas-discharge switching device consisting of an open discharge section with generation of counter propagating electron beams acting as an electron emitter, and a capillary discharge section providing a large time delay for the development of the discharge $\tau_d$ and a rapid recombination of the plasma after the passage of the current pulse are presented. The ability of this device to operate at voltages up to 100 kV, while maintaining a delay time $\tau_d$ of the order of several hundred ns and subnanosecond capillary breakdown $\tau_{sc}$, is demonstrated. The $\tau_{sc}$ voltage independence in the range of helium pressures $p_{He} = 6$–30 Torr was found.

1. Introduction

The modern technologies development [1–4] provokes the improvement and development of new high-voltage high-current devices based on various physical principles which one can be switched for nano- and subnanoseconds times. In addition to a subnanosecond pulse edge, some applications require high pulse repetition rate. To solve this problem, a gas-discharge device – eptron, which combining an open discharge with the counter propagating electron beams generation, providing electron emission, and a capillary discharge, providing the rapid electric strength recovery, was proposed [5]. The results of a study of this device in the operating voltage range up to $U = 20$ kV at a pulse repetition rate (PRR) of up to $f = 40$ kHz were presented in [6]. It is of interest to study the possibility of its operation at higher voltages at least up to $U = 100$ kV. The operation of the switching device based on the open discharge with the counter propagating electron beams generation – kivotron – in a similar voltage range was demonstrated in [7]. Its disadvantage is the short delay in the breakdown development $\tau_d < 20$ ns at $U = 100$ kV and $p_{He} = 3$ Torr. In [6], it was shown that the capillary section added to the kivotron as an inhibitor of discharge development increases $\tau_d$ by more than an order of magnitude, with all other conditions being equal, and the switching current rise time is determined by the external circuit and characteristics of the kivotron, whose working conditions in the device composition can be changed in various ways, for example, by organizing its preliminary ignition by analogy with pseudo-spark thyratron. Thus, this work will be devoted to the study of the possibility of extending the operating voltage range of the eptron to $U = 100$ kV.
2. Experimental setup
Since an eptron is an uncontrolled spark gap, it has a pulsed mode of operation. This means that it is powered by a pre-formed pulse. A pulsed power source similar to that in [7], consisting of a TPI3-10k/25k pseudo-spark thyatron and step-up transformer, was used as the primary generator. Since the expected $\tau_d$ should increase significantly compared with [7], the design of the transformer was significantly simplified, but at the same time its leakage inductance increased. Thus, the voltage front at a working capacitance of 100 pF was 450 ns. Additionally, one magnetic pulse compression circuit was installed. As a result, the duration of the charging voltage front was 200 ns. A set of resistors TVO-10 with a total resistance of $R_L = 400$ Ohms was used as the work load.

The design of the coaxial experimental cell is close to that in [5]. The kivotron consisted of a set of rings of reactionally sintered silicon carbide (SiSiC) with a total length of 80 mm as a cathode and a grid of the molybdenum wire of similar length with a geometric transparency of ~ 90% coaxially located inside it. The interelectrode distance was 3 mm. In this work, a slit capillary with a slit size of 0.3 mm×10 mm and a length of 67 mm was used. Increasing the length provided an increase in the impulse electrical strength, while a large cross section reduced the inductance and resistance of the capillary. To prevent surface breakdown, a capillary has fins formed by coaxial holes with a diameter of 20 and 10 mm, alternating with slit holes constituting the capillary. The experiments were carried out in pure helium at a pressure of $p_{He} = 6$–30 Torr.

3. Experiment
The first experiment was devoted to the possibility of eptron operating at voltages up to 100 kV. The oscillogram of the voltage at the anode at $U = 80$ and 100 kV and $p_{He} = 7.5$ Torr and PRR $f = 200$ Hz is shown in figure 1. It can be seen that, with the indicated parameters, the delay in the breakdown development reaches $\tau_d = 300$ ns, which is more than an order of magnitude higher than this parameter in [5]. The residual voltage on the eptron to the voltage $U \sim 80$ kV and, accordingly, the shunt current $I_{Sh} \sim 200$ A does not exceed 18% of the $U$ and the switching time is $\tau_s \sim 1$–2 ns. The increase in residual voltage at $U > 80$ kV is due to the insufficient characteristics of the used kivotron in the absence of preliminary ignition.

![Figure 1. Oscillograms of anode voltage at $p_{He} = 7.5$ Torr, $R_L = 400$ Ω.](image)

Figure 2 shows the dependence of $\tau_d$ on the applied voltage at the pulse half-height at a helium pressure $p_{He} = 7$–16 Torr. It can be seen that the data are in good agreement with [6], taking into account changes in the capillary length and voltage range.

In [6], it was suggested that at a pressure of $p_{He} \sim 25$ Torr and a voltage $U \sim 24$ kV the characteristic time of the capillary breakdown can reach $\tau_{sc} \sim 100$ ps. Figure 3 shows the dependence of the capillary
breakdown front \( \tau_{sc} \) on helium pressure. The measurements were carried out using a Tektronix MSO64 oscilloscope with a bandwidth of 8 GHz in a voltage range of \( U \sim 25–70 \) kV and a low-resistance capacitive sensor. A characteristic feature was that \( \tau_{sc} \) was practically independent of voltage. The minimum measured \( \tau_{sc} \sim 160 \) ps is explained by the restriction of the bandwidth of the detection circuit and the length of the capillary, which made registration difficult.

**Figure 2.** Dependence of the capillary breakdown development delay on voltage at different helium pressures.

**Figure 3.** The breakdown development in the capillary \( \tau_{sc} \), depending on the \( p_{He} \).

4. Conclusion

The paper presents the results of a study of the possibility of operating an eptron at elevated voltages. It is shown that this type of device, when selecting the appropriate parameters of a capillary, is capable of stably operating in the voltage range up to \( U = 100 \) kV. The delay in the breakdown development in this case amounts to \( \tau_d \succ 300 \) ns with characteristic switching times \( \tau_s \sim 1–2 \) ns. The minimum measured capillary breakdown front was \( \tau_{sc} \sim 160 \) ps at a helium pressure \( p_{He} \) of \( \sim 28 \) Torr and \( U \sim 70 \) kV.

Acknowledgments

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