STUDYING THE MODES OF ELECTRON BEAM GENERATION IN A MAGNETRON GUN WITH A SECONDARY-EMISSION CATHODE

A.N. Dovbnya, V.V. Zakutin, N.G. Reshetnyak, N.A. Dovbnya
NSC KIPT, Kharkov, Ukraine
E-mail: zakutin@kipt.kharkov.ua

Modes of electron beam generation and parameters were investigated using a magnetron injection gun with a secondary-emission cathode depending on the magnetic field value and distribution. For the first time it has been shown that the electron current direction in such source can be varied from axial (along the magnetic field direction) to the radial one (across the magnetic field direction) by controlling the amplitude and magnetic field distribution with retention of secondary emission processes on the cathode.

PACS: 41.75.Fr, 87.50.Mn

1. INTRODUCTION

In the accelerating technique a secondary-emission magnetron gun with a cold metallic secondary-emission cathode can be used as an electron beam source in microwave devices (klystrons, gyratrons etc) [1, 2].

The guns of this type operate by the principle based on the secondary-emission electron multiplication and electron beam generation in the crossed electron and magnetic fields. When a voltage pulse is applied onto the cathode, primary electrons go out into the gap between electrodes. In the course of voltage increasing (up to the overshoot peak) these electrons, removing from the cathode, are accumulated in the cathode-anode gap. On the overshoot falloff the primary electrons gain the energy higher than the first critical potential, bombard the cathode and provoke the processes of secondary-emission multiplication, electron cloud formation and electron beam generation.

The advantage of secondary-emission sources is the absence of an intense heat, the design simplicity, and that cathodes do not loss emission after atmosphere filling. Their main distinction from emission guns is a high-current density per unity of the cathode cross-sectional area. The secondary emission mechanism of beam generation, due to its nondestructive action on the cathode material, creates conditions for retention of emission properties of the electron source during long time period (according to estimations ~ 100000 hours). Therefore, of a great interest is the study on the physics of the processes in the source with crossed electric and magnetic fields.

The present paper describes the studies on the influence of the amplitude and longitudinal distribution magnetic field on the conditions of electron beam generation and direction in the magnetron gun.

2. EXPERIMENTAL SETUP AND RESEARCH METHODS

Experiments to investigate the beam parameters were performed at the setup schematically shown in Fig.1. A specially shaped voltage pulse with a peak at the top (Fig.2) from a pulse modulator [3] was applied to the gun cathode, its anode was connected to the ground via a resistor R3 that measured the anode current. The overshoot amplitude is adjusted within 60...100 kV, the amplitude of the flat part of the pulse was 20...55 kV, the overshoot falloff duration was ~ 0.3 ms, the pulse duration at half-height was ~ 8 ms, the pulse repetition rate ranged from 10 to 20 Hz.

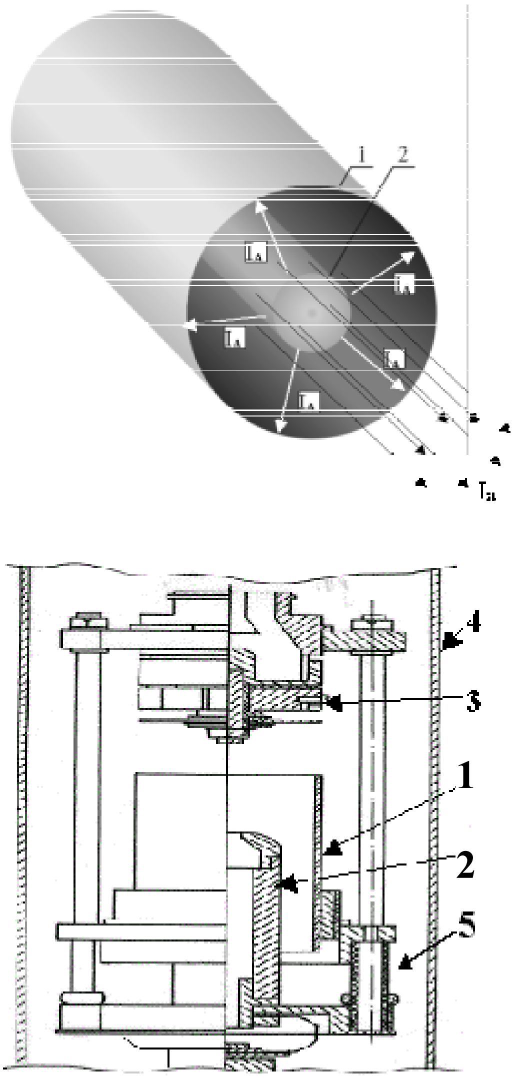

Fig.1. Schematic of the experimental setup and direction of propagation of the electron beams. 1 – cathode ∅40 mm (Cu); 2 – anode ∅70 mm; 3 - Faraday cup; 4 - vacuum chamber; 5 – insulator. I_A – radial beam; I_B - axial beam

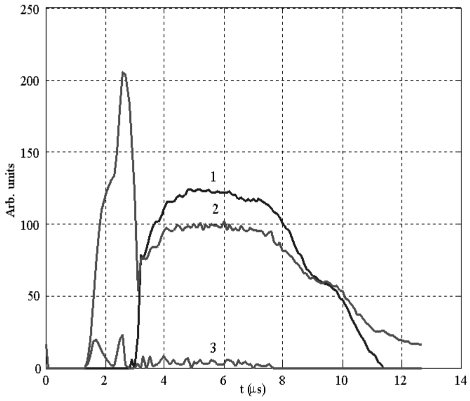

Fig.2. Pulses of beam current (1), anode voltage (2) and current (3). Vertical axis scales: 1 - 0.4 A/div, 2 - 0.5 kV/div, 3 - 0.04 A/div

The studies were made on the magnetron gun of a coaxial construction (Fig. 1), which had a secondary-emission cathode of 70 mm in length, an anode of 140 mm in length; cathode material was copper, anode material was steel. The cathode diameter was 40 mm. The magnetron gun was placed in the vacuum chamber, where a vacuum of ~ 10^{-6} Torr was maintained.

The magnetic field for beam generation and transport was created by the solenoid (consisting of 4 sections used for adjusting the magnetic field by varying the current value in the sections of the solenoid). The solenoid was energized by the constant-current source. The amplitude and longitudinal magnetic field distribution were set by changing the current value in the sections of the solenoid. Experiments were carried out with different magnetic field distributions (decreasing, increasing, bell-shaped) along the axis of the system (see Fig.3).

The studies of beam parameters were performed by means of a 8-channel sectionalized Faraday cup and a computer-assisted measuring system. The measurement error is within 1 to 2%. Measurements were taken of the beam current from each of 8 segments of the Faraday cup, of the cathode voltage and the anode current. These parameters were measured and averaged over 16 voltage pulses following one after the other.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experiments have shown that the electron beam direction in the gun can be varied (along the gun axis or perpendicular to it - on the radius), by adjusting the amplitude and distribution of the longitudinal magnetic field. In this case, several modes of electron beam generation are realized: open (when practically all the electron current is going along the gun axis to the Faraday cup), closed (when the electron current is flowing perpendicularly to the gun axis - on the radius to the anode) and intermediate (when the electron current is flowing along the gun axis and perpendicularly to it).

In the open regime and magnetic field decreasing along the axis of the system to the Faraday cup (Fig.3, curve 1) at a cathode magnetic field strength of ~1300 Oe, a cathode voltage of 50 kV, the beam current is 50 A, the anode current is 1% of the beam current (Fig.2, curve 1). In the case of the magnetic field increase in the cathode region up to 1800 Oe, the anode current was decreasing down to the value of an order of several milliamperes that is due to the enhancement of the electron flux magnetic insulation.

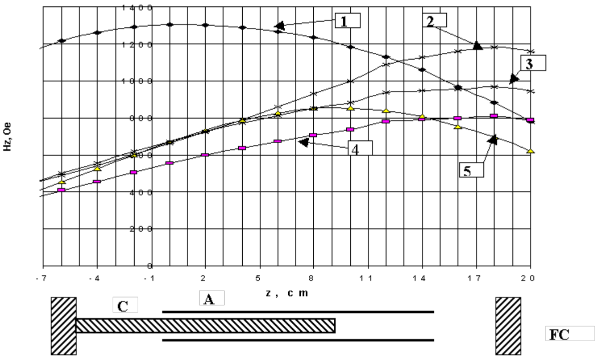

Fig.3. Distribution of a longitudinal magnetic field H_Z and arrangement of the magnetron gun and the Faraday cup along the axis of the system z

In the course of experiments the existence of the closed mode of magnetron gun operation (magnetron mode) has been found. In this case the electron current was flowing to the anode, the secondary-emission multiplication of electron being retained (see Fig.3). This mode was attained by reducing the magnetic field H in the cathode region down to the Hell cutoff field value of 1.1...1.2 order ($H_{Hull}=6.72U^{1/2}[r_a(1-r_c^2/r_a^2)]-1$, where U is the cathode voltage, r_c and r_a are the cathode and anode radii in centimeters, respectively. At a voltage of 45 kV the Hell field is ~600 Oe).

The closed mode of magnetron gun operation is realized with two magnetic field distributions − increasing (Fig.3, curve 2) and bell-shaped (Fig.3, curve 5). In the increasing magnetic field (the magnetic field in the point of introduction of the cathode into the anode was ~ 660 Oe, and a average magnetic field strength on the cathode ~ 800 Oe, on the Faraday cylinder ~ 1150 Oe) at a cathode voltage of ~ 45 kV, the current to the anode was ~10 A, and the current to the Faraday cup practically was absent. In the second case in the point of introduction of the cathode into the anode was ~ 660 Oe, and on the Faraday cup ~710 Oe. At a voltage of ~45 kV and a average magnetic field strength on the cathode ~775 Oe , the current on the anode was ~5 A, and the current to the Faraday cup was absent (Fig.4).

In the intermediate mode at a average magnetic field strength on the cathode ~ 850 Oe and on the Faraday cup ~980 Oe (Fig.3, curve 3) the direct beam current was ~7 A, the anode current was ~5 A at a cathode voltage ~45 kV (Fig.5). The beam current and the anode current could be adjusted by varying the magnetic field distribution along the axis of the gun.

Besides the above described modes, we have investigated the mode when in one pulse of the voltage U ~46 kV (the magnetic field in the point of introduction of the cathode into the anode was ~540 Oe, and average magnetic field strength on the cathode ~620 Oe (Fig.3, curve 4), of the order of Hell cutoff field, on the Faraday cylinder ~ 800 Oe) two modes of beam generation were realized (Fig.6): – closed mode during ~5 µs U_1~45 kV, I_A ~3 A), and then at a pulse voltage decrease after 1.5 µs realized was: – intermediate mode during ~2 µs (U_2 ~23 kV, I_B ~1 A, I_A ~3 A).

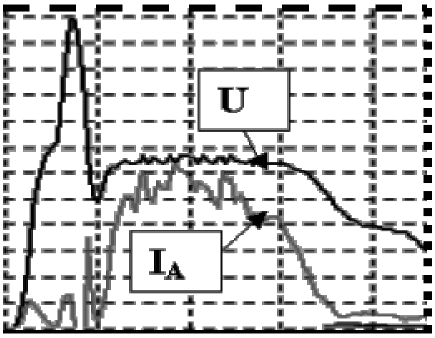

Fig.4. Oscillograms of anode (radial) beams $\boldsymbol{I_A}$ *(magnetron mode) - a) in the rising magnetic field* $\boldsymbol{I_A}$*~10A; U=45 kV. Horizontal –2 µs/div*

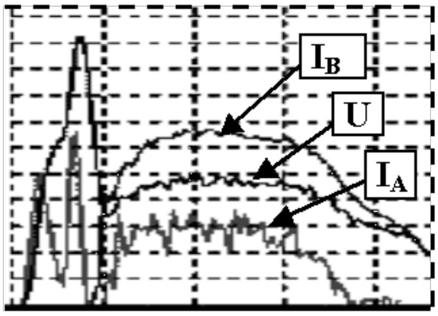

Fig.5. Oscillograms for the borderland mode (I_A *– radial beam and* I_B *–axial beam)* $\boldsymbol{I_A}$*~5A;* $\boldsymbol{I_B}$ *~7 A,U=45 kV. Horizontal – 2 µs/div*

Fig.6. Oscillograms for the private case magnetron mode (I_A *– radial beam and* I_B *–axial beam). Horizontal – 2 µs/div*

4. CONCLUSIONS

The studies evidence that using the above-described electron source it is possible to realize the mode with an axial current only (open mode), the mode with an anode current only (magnetron mode) and the mode with almost equal values of the axial and anode currents.

REFERENCES

1. Yu.Ya.Volkolupov, A.N.Dovbnya, V.V. Zakutin et al. Generation of an electron beam in a magnetron gun with a secondary-emission metallic cathode //*Sov. JTF*. 2001, v.71, p.98-104.
2. Yu.M. Saveliev, W. Sibbett, D.M. Parkes. Characterisation of electron produced by cross-field secondary emission diodes //*J. Appl. Phys*. 2001, v.40, Part 1, N 2B, p.940-943
3. A.N. Dovbnya, N.G. Reshetnyak, V.P. Romas'ko et al. *Pulsed modulators for feeding the powerful microwave-devices based on magnetron guns with secondary-emission cathodes.* Proc. of the Part. Accel. Conf., Chicago, USA, 2001, v.5, p.3759-3761.

ИССЛЕДОВАНИЕ РЕЖИМОВ ГЕНЕРАЦИИ ЭЛЕКТРОННОГО ПУЧКА В МАГНЕТРОННОЙ ПУШКЕ С ВТОРИЧНО-ЭМИССИОННЫМ КАТОДОМ

А.Н. Довбня, В.В. Закутин, Н.Г. Решетняк, Н.А. Довбня

Проведено исследование различных режимов генерации и параметров электронных пучков в магнетронной пушке с холодным металлическим вторично-эмиссионным катодом в зависимости от величины и распределения магнитного поля. Впервые показано, что в таком источнике можно осуществлять изменение направления электронного тока от осевого (вдоль направления магнитного поля) к радиальному (поперек направления магнитного поля), регулируя амплитуду и распределение продольного магнитного поля при сохранении вторично-эмиссионных процессов на катоде.

ДОСЛІДЖЕННЯ РЕЖИМІВ ГЕНЕРАЦІЇ ЕЛЕКТРОННОГО ПУЧКА В МАГНЕТРОНННІЙ ГАРМАТІ З ВТОРИННО-ЕМІССІЙНИМ КАТОДОМ

А.М. Довбня, В.В. Закутін, М.Г. Решетняк, Н.А. Довбня

Проведено дослідження різних режимів генерації та параметрів електронних пучків у магнетронній гарматі з холодним металевим вторинно-емісійним катодом в залежності від розподілу магнітного поля. Вперше показано, що в такому джерелі можна отримати зміну напряму електронного струму від осьового (вздовж магнітного поля) до радіального (поперек магнітного поля), змінюючи амплітуду та розподіл магнітного поля при збереженні вторинно-емісійних процесів на катоді.