COLD-CATHODE KILOAMPERE ELECTRON GUN WITH SECONDARY EMISSION AT RELATIVISTIC VOLTAGE

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Abstract

Magnetron Injection Gun with voltage up to 1000 kV and current more 1 kA was calculated, designed and manufactured. The gun was tested in microsecond and nanosecond operating modes. The cathode testing in microsecond mode permitted to obtain beam pulse with amplitude up to 1.2 kA at voltage of 400 kV in magnetic field of 0.3 T. There were obtained beam traces on the copper plate. Traces had the form of rings with diameter of 125 mm and width of 5 mm. The application of nanosecond voltage pulses with amplitude up to 600 kV permitted to obtain the secondary-emission current up to 5 kA. The secondary emission nature of the cathode current was established. The identification was held basing on considered features of the exciting and on the maintenance of the secondary emission current. However, there is the probability of the parasitic explosive emission at extremely high voltage values since 800 kV. The gun may be used for charge particle accelerators in injectors and RF power sources. Results of the work and prospects of the secondary emission gun development are discussed.

INTRODUCTION

The lifetime of modern powerful electron sources is not long enough (10-10,000 hours), while other components of the accelerator equipment serve much longer (more than 100,000 hours). Relatively short lifetime depends on application of a heating thermionic cathode. Nearly twenty years ago secondary emission mode in magnetron injection gun with a cold cathode [1-2] was achieved. Thus the Secondary Emission Magnetron Injection Gun (SEMIG) [3] was realized as an alternative for powerful electron sources with thermionic cathode. SEMIG is a novel universal electron source with a cold cathode. It may be used for charge particle accelerators in injectors and powerful electron vacuum devices (RF and pulse). The gun is based on an unconventional principle. The principle is the self-sustained secondary-emission multiplication in cross-fields. The SEMIG may have higher current density and lifetime much longer (up to 100,000 hours) than conventional thermionic guns.

However, up to nowadays these sources didn't reach the current and power levels featuring the most of thermionic guns. In last experiments maximum secondary emission current in cross-fields was little bit above 200 A [4]. This work deals with investigation of the possibility to increase significantly the current and the power of secondary emission sources.

TEST SET-UP

Secondary electron emission in the magnetron gun (SEMIG) was investigated experimentally in the pulse voltage range of 0.3-1.0 MV using the accelerator "Start". Both microsecond and nanosecond output circuits of the accelerator were used. In both cases the stainless steel cathode with diameter 102 mm was used.

The scheme of the microsecond channel is shown on Fig. 1.

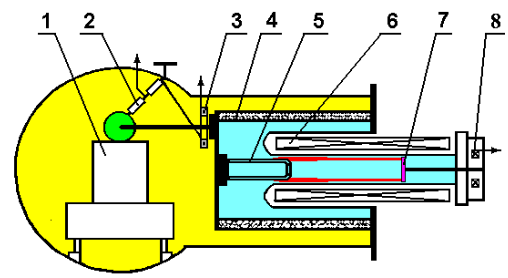


Figure 1: Scheme of the microsecond output with SEMIG. The electron beam is marked by red.1 – 8-stage Marx generator; 2 - voltage divider; 3 - Rogowski coil for total current measurement; 4 - insulator; 5 - cathode; 6 - solenoid; 7 - collector with copper target; 8 - Rogowski coil for beam current measurement.

The short-pulse output of the set-up is shown on Fig. 2.

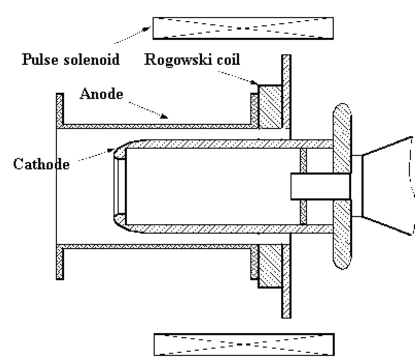


Figure 2: The gun design for nanosecond mode.

RESULTS

At microsecond output beam current and gun voltage oscillograms are shown on Fig. 3. Pulse fronts are restored because of recording system of the oscilloscope gives blanks. It is due to too fast motion of the ray on the screen.

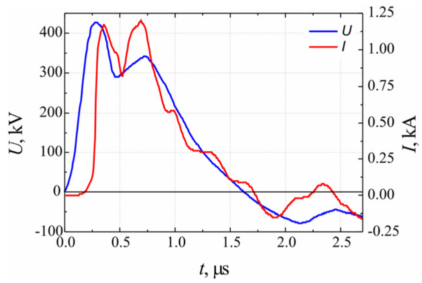
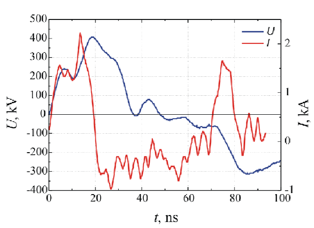
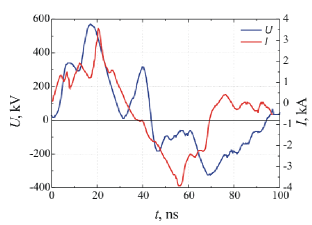


Figure 3: Beam current and gun voltage at magnetic field B=0.34 T at the microsecond output.

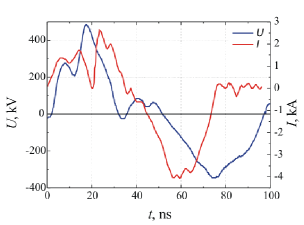
Figure 4: Ring beam track on a copper target with diameter 140 mm at the microsecond output.



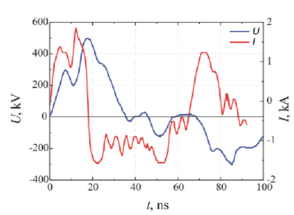
a) B=0 T



b) B=0.106 T



c) B=0.160 T



d) B=0.233 T

Figure 5: Synchronous oscillograms of the gun current and voltage at different values of magnetic field B. The charge voltage of the Marx generator was 32 kV.

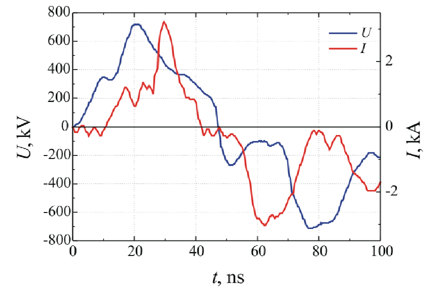


Figure 6: Oscillograms of the gun current and voltage at a magnetic field B=0.266 T. The charge voltage of the Marx generator was 40 kV.

If the current amplitude at 20-th ns on the Fig. 6 corresponds to secondary emission mode and if apply correction on displacement current the maximum achieved is estimated as 5 kA.

DISCUSSION OF THE RESULTS

Emission current reaches multi kiloampere level. Given results and their initial analysis point they can be secondary emission currents by their nature. The emission nature must be revised due to explosive emission can be excited at so high voltage values. Therefore, all possible identifiers of secondary emission with comments by their nature and realization are outlined by special items.

The absence of emission without magnetic field

Electrons would return on a cathode for the secondary emission initiation. That is possible only under transverse magnetic field action.

There is no emission current without magnetic field (see Fig. 5,*a*). The total gun current is displacement current. At voltage maximum a current is equal to zero. This is corresponds to 20-th nanosecond. The magnetic field turning on initiates the current at *b)* and *c)* picture of Fig. 5. The voltage value low than 600 kV is not enough in this case for the exciting of considerable field or explosive emission.

The emission pulse beginning is delayed relatively voltage pulse peak.

In this case the emission pulse beginning must be understood as difference between the total current in Fig. 5,*b*,*c* and displacement current in Fig. 5,*a*.

The secondary emission pulse delay increase with magnetic field value.

This is validated theoretically [5] and was observed in experiments with magnetrons in secondary emission mode [6].

The secondary emission current pulse has shorter rise time than voltage pulse rise time.

All above mentioned current pulses obtained during the research have rise time shorter than voltage pulse.

Rise time of the secondary emission current pulse is shorter than drop time.

There is the second current peak on oscillograms in a few nanoseconds after first peak.

The nature of this peak can be connected with electron flow transition to the turbulent state and with emission transition to the self-sustained mode. The emission value can be higher at such transition. In any case, such repeating peak was always observed at relatively low voltage nearly to 60 kV [2]. It was observed on the oscilloscope of nanosecond resolution when the emission mechanism doesn't require being proved. This was in cases when the explosive emission was hard for excitation due to low field and low voltage values. The secondary emission mechanism is remained only in high vacuum conditions. Repeat peaks are observed on Fig. 5*,b* nearly 25-th ns and *c)* nearly 30-th ns.

The secondary emission excitation is suppressed in high magnetic fields.

This takes place and corresponds to the Fig. 5,*d*. The emission suppression in the highest magnetic field observed in this research is well explained by secondary emission nature. This follows from shape of the initiation region obtained theoretically [5] in coordinates voltage-magnetic field. It can be considered as particular case of previous item 3 with infinitely high delay.

The secondary emission current value is lower considerably of the explosive emission current value.

Space charge forces limit the maximum current value. However, back electrons besides emitted electrons present in an electron flow. Back electrons increase space charge forces in an electron flow and reduce maximum current.

According to the known results from publications [7], the beam current value is up to 10 kA at the explosive emission in magnetic- insulated cathode. This is the diode with same cathode material and similar electrode diameters having operated at voltage values up to 600 kV.

For the comparison, the maximum current obtained in present research is not exceeded of 5 kA in magnetic field that points on the possibility of its secondary emission nature.

The current repeats the voltage shape on the pulse peak after the current exciting.

The identifier is observed as long microsecond triangle-shaped pulse (Fig. 3). At long pulses the current-voltage dependence is continues and is close to the order of 2 that follows from the scaling theory [3]. In case of the explosive emission the plasma boundary motion causes the current rising at constant voltage.

The beam trace on the collector is hollow.

The secondary emission is initiated only from the side surface where the electron bombardment is possible. The beam moves along lines of force of the magnetic field and the collector repeats the emission region. The experiment in low voltage secondary emission mode confirms this conclusion. Obtained results confirm generally this identifier (Fig. 4).

CONCLUSION

All above mentioned identifiers confirm the presence of secondary emission at high voltage values up to 600 kV. The achieving current level is enough high for replacement all types of heating cathodes in modern accelerator facilities up to pulse power klystrons [8] and linear induction accelerator. Another exotic application may be in high current polarized electron injectors [9].

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