# SECONDARY EMISSION IN COLD-CATHODE MAGNETRON INJECTION GUN

S.A.Cherenshchikov, A.N.Dovbnya, A.N.Opanasenko,
National Science Center, Institute of Physics & Technology, Kharkiv, 310108 Ukraine.

*Abstract*

The experiments of secondary emission in the magnetron injection gun and using of such a gun in electron linear accelerator are described. Up to now it was attained 65 amperes of beam current in short-pulse regime of the gun and 3 milliseconds of pulse duration in the low current regime. Characteristics of the gun operating in the secondary emission regime and the methods of calculating it are adduced. Main advantages of this regime may be long life time of the gun and high stability of beam current at employing purely-metal cathodes. Prospects of using the gun in the secondary emission regime in linac technology (mainly in high power RF-sources) are discussed.

## I. EXPERIMENT AND RESULTS

The magnetron injection gun is a well known device. The experiments with the cold-cathode devices of such a type are known too [1]. We describe some new experiments with the cold-cathode magnetron injection gun that are made in our institute [2-6].

The representation of the gun are shown in Fig. 1.

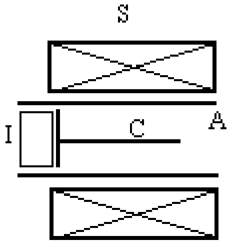

Figure 1: Schematic representation of the cold-cathode magnetron injection gun. S is the solenoid, A and C are the anode and cathode accordingly, I is the insulator.

It was established that if between the anode and cathode a short pulse of voltage (several tens nanoseconds duration and several tens kilovolt amplitude) is applied, then the gun will generate the short pulse of an electron beam. If the magnetic field is less than its value at which return of the electrons to the cathode is impossible then the beam current will be absent. We had supposed that the cause of the beam current generating was the secondary electron emission. Later the investigation confirmed this idea. For example, long-pulse regime (3000 μs) had been obtained [5]. Such a regime is impossible at plasma explosion phenomenon at the cathode. In Tab. 1 it is shown the regimes of the gun operation and the parameters of the beam. Further on we will call the gun operating in the regime secondary emission a secondary-emission magnetron-injection gun (SEMIG).

In process of the investigations [6] it was observed the possibility of controlling (switching) SEMIG. At the very small but quick variation of the gun voltage the deep pulse modulation of the beam with the modulation frequency about 200 MHz and the pulse duration 1 ns was noted. The pulse current reached 12 A at 60 kV voltage. More smooth variation of the gun voltage did not cause the beam modulation and the current behaved in accordance with the C-V law (see Fig. 2).

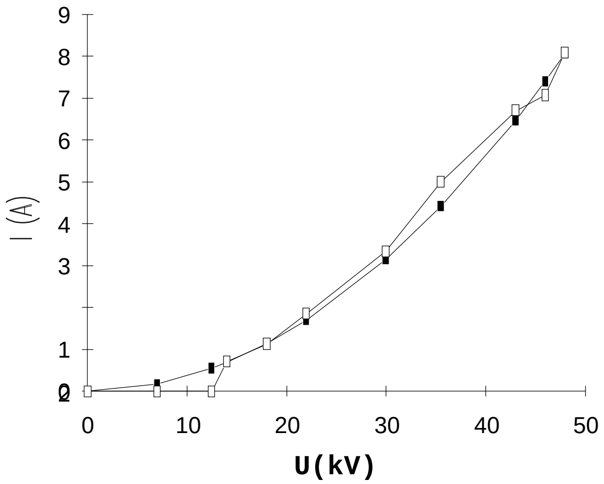

Figure 2: Current-Voltage (C-V) performances of SEMIG at 0.135 T magnetic induction. The transparent squares are the experimental points , and the shaded squares are corresponded to the approximation using the quadratic parabola [3].

The full control effect is reached by possibility to drive the energy of back electron bombardment and then the control of the secondary emission is acquired, too.

SEMIG was also tested as the injector for the resonance linac of S-band (3 GHz) [4]. The gun was located near RF-buncher so that RF-field could influence the gun work. In the case of the RF-field absence, it was obtained and accelerated the short electron pulses with 20 ns duration and 0.5 A current at 20 A current from the gun. Presence of RF-power in the buncher allowed to generate the more lengthy beam pulse up to 1 μs with 20 mA accelerated current at 1 A current from the gun. Such regime was observed in narrow interval of the magnetic fields corresponding the frequency of electron cyclotron resonance. It should be noted that the low acceptance of particles in acceleration was because of the insufficient voltage on the gun.

Table 1. SEMIG's experimental regimes of operation.

| Cathode material | Gun voltage kV | Beam current A | Current density $A/cm^2$ | Beam diameter mm | Pulse duration µs | Repetition rate Hz | Magnetic induction T | Pub. year, [ref.] |
|---|---|---|---|---|---|---|---|---|
| Copper | 68 | 12 | 20 | 9 | 0.01 | single | 0.19 | 1991 [2] |
| Copper | 48 | 8 | 10 | 8 | 1.3 | single | 0.14 | 1992 [3] |
| Copper |  | 20, (1.0) |  |  | 0.02, (1.0) | 50, (50) |  | 1993 [4] |
| Stainless-steel | 10÷150 | 0.005÷65 |  |  | 0.4÷3000 | 3÷50 | ...÷0.29 | 1994 [5] |

## II. METHOD OF CALCULATION

On the base of the scale method of modeling for magnetron gun with cylindrical electrodes [7], it was derived the following relationships of beam current $I$ and beam diameter $D_b$ depend of diameters of cathode $D_c$, anode $D_a$, magnetic field $B$ and gun voltage $U$:

$$I = C_1 \frac{U^2}{BD_c \ln^2(D_a / D_c)}, \qquad (1)$$

$$D_b = D_c + C_2 \frac{U}{B^2 D_c \ln(D_a / D_c)} \qquad (2)$$

$C_1$, $C_2$ are constants extracted from experimental data and depending on emission properties of cathode materials used.

As shown in Fig. 2, the experimental current-voltage characteristic corresponds to the formula (1) quite accurately. The preliminary estimates showed that the beam current dependence on the magnetic field corresponds to the formula (1) qualitatively. That way, it is possible to calculate the gun parameters at not very distinctive values of the magnetic field. It should be marked, with increasing of the magnetic field the measured beam current was more then calculated by (1).

## III. ADVANTAGE OF SEMIG

After applying of full voltage to SEMIG the speed excitation of secondary-emission current allows to produce a very short beam pulse directly from the gun. Apart from that, out estimates indicated that secondary emission from pure metal may provide higher current densities then those in thermionic or photo-emissions at the same energy inputs. This observation gives hope for production of high current densities that are otherwise precluded by cathode destruction from evaporation or pulsed heating [8].To date, secondary-emission current density more than 50 $A/cm^2$ already produced [9]. Associated with this fact is the principal advantage of secondary-emission metallic cathodes, i.e. their long life times, exceeding in our appraisal 100,000 hours. The underlying physical reason for this is the impossibility of principle of occurrence of electron-stimulated cathode material desorption, and, accordingly, its destruction in case of the metallic connection loading at bombarding electron energies sufficient for secondary-emission to occur [10].

## IV. OUTLOOK ON APPLICATION OF SEMIG IN HIGH POWER RF-SOURCES

In review on secondary electron emission sources [11] it was shown the SEMIG had the best beam parameters of current density and total current among secondary emission guns. In the review the secondary emission gun was consider as an alternative of the thermionic magnetron-injection gun [12] in the high power RF-source project, the Immersed Field Cluster Klystron [13]. As shown in the report [7] the application of SEMIG may be solution of the problem of increasing of a cathode life time.

As shown above, the main advantage of the SEMIG in comparison with a traditional thermionic magnetron-injection gun is a possibility to obtain high current density as well as a very long life time (above 100,000 hours) of a secondary emission metallic cathode, simultaneously. Apart from that, insensibility of a purely metallic cathode (platinum) to poisoning and to atmospheric air allows to create an accelerator and RF-source with common vacuum system, that cuts off the problem of an exit window.

Magnetron gun is already employed in klystrons and gyrotrons. Such devices with the proposed SEMIG can have the all above advantages.

Observed current modulation may be the base for creation of high power electron tubes with high efficiency. In relatively low frequency band it may be a prototype of injectrons and klystrodes and for shorter waves it may be a klystron or gyrotron. Injectrons using SEMIG may be the base for creation of highly efficient high voltage pulse modulators with high repetition frequency.

## REFERENCES

[1] M.Friedmun and M.Ury, "Microsecond duration intense relativistic electron beams". The Rev. Sci.. Instrum., vol. 43, No. 11, 1972, p.1659-1661.

[2] V.S.Balagura, B.G.Safronov, S.A.Cherenshchikov. "Short-pulses electron guns with no heating cathodes for linacs". Abstract to reports of 12-Th. all-Union seminar of charge

particle linear accelerators. (Kharkov, 28-30 of May 1991) Kharkov, p.40, 1991. The article with the same title: Vopr. At. Nauki i Tekh. Ser. Yadernofiz. Issled (Teor. Exp.) (Kharkov) 14(25), p.48-51, 1991.

[3] S.A.Cherenshchikov. "The maltipactor emission of electrons in the cold-cathode-magnetron gun". Abstract to reports of 13-Th. conference of charge particle accelerators. JINR, Dubna (13-15 October, 1992) p.143. (The full text of the report will be published in the proceeding of that conference.)

[4] G.M. Ivanov, S.A.Cherenshchikov " The magnetron gun with no heating cathode as an electron source for a resonance electron liner accelerator". Abstract to reports at 13-Th. Kharkov seminar of charge particle linear accelerators. (Kharkov, 25-28 of May 1993) Kharkov, p.27, 1993.

[5] S.A.Cherenshchikov, G.M.Ivanov, B.G.Safronov "Secondary-emission crossed-field discharge as an electron source with a cold cathode". Abstract to reports of EPAC, (London, 27 June to 1 July 1994).

[6] B.G.Safronov S.A.Cherenshchikov "Possibility of full munipullation with high speed in a cold-cathode magnetron gun". Abstract to reports at 13-Th. Kharkov seminar of charge particle linear accelerators. (Kharkov, 25-28 of May 1993) Kharkov, p.27, 1993.

[7] S.A.Cherenshchikov, A.N.Opanasenko, A.N.Dovbdya, V.V. Zakutin, "Secondary emission magnetron ingection gun as high current durable electron source". Proceeding of the Workshop on Pulsed RF Sources for Linear Colliders. (RF-94), Montauk, US, October 2-7, 1994.

[8] V.F.Kovalenko, Thermally-physical processes and electrically-vacuum devices: Moscow: "Sov. radio", 1975.

[9] I. M. Vigdorchik, V. D. Naumenko, V. P. Timofeev, "The secondary-emission-cold-cathode magnetrons of the millimeter wavelength". Reports Academy of Sciences, Ukrainian SSR, Ser.A, 1 7, p. 634-637, August, 1975.

[10] V.N.Avgeev, Yu.A.Kuznecov, B.V.Yakshinskiy, "Electron stimulated desoption of atoms of cesium from oxided wolframite.". Solid State Physics , vol. 24, No. 24, 1982, p. 349-355.

[11] S.A.Cherenshchikov, A.N.Opanasenko, A.N.Dovbdya, V.V. Zakutin, "Review of secondary electron emission sources". Work supported by of the US Department of Energy, contract WC-716344 (BNL).

[12] H.Wang, R.Palmer, J.Gallardo, "The magnetron-injection-gun design for the cluster klystron". International Workshop on Pulsed RF Power for Linear Colliders (RF-93), Dubna, Russia, July 5-9,1993.

[13] R.B.Palmer, W.B.Herrmannsfeld K.R.Eppley "An immersed field cluster klystron", Particle Accelerators vol. 30 No. 1-4 1990 p. 197-209.