Electron beam generation with variable current amplitude during its pulse in a source with a grid plasma cathode

M S Vorobyov, N N Koval, P V Moskvin, A D Teresov, S Yu Doroshkevich, V V Yakovlev and V I Shin

Institute of High Current Electronics SB RAS, 2/3 Akademichesky Ave., Tomsk, 634055, Russia

E-mail: vorobyovms@yandex.ru

Abstract. In electron sources with grid plasma cathodes, the boundary of the emission plasma is stabilized by a fine-structured grid, the cell size of which is comparable to the size of the Langmuir layer. The correct choice of the cell size of the emission grid allows to stabilize the emission plasma boundary, reaching a wide range of the parameters adjustment of the generated electron beam with a weak dependence of these parameters on each other. Since the beam current amplitude is most often controlled by a proportional change of the discharge current in the plasma cathode, which allows to change the emission plasma concentration, this paper is investigated the possibility of generating the electron beam having variable amplitude by predicting the change in the discharge current amplitude during its pulse. The described advantage of plasma cathodes makes it possible to obtain electron beams with both a falling and a rising current amplitude of the beam during its pulse. The obtained regimes of electron beam generation open up new possibilities for using this source for both scientific and technological purposes.

1. Introduction

The principle of operation of any electron source, as well as methods for adjusting the parameters of the generated electron beam is primarily determined by the type of cathode. In most cases, for generating an electron beam used thermal cathodes, cathodes based on explosive electron emission, ion-electron emission, plasma cathodes, etc. [1]. It is important to note that, regardless of the type of cathode used, in most cases, similar problems are solved and, neglecting the complexity of solving the latter, there are many electron sources that generate electron beams of various configurations and have a very wide range of beam parameters. In general, for example, as compared with other alternative methods of surface treatment of various materials using electron beams has a high energy efficiency, high energy density uniformity across the beam, pulses good reproducibility, high frequency of repetition and others [2–6]. From this and other literature it is possible to make an unambiguous conclusion about the prospects of using electron beams in various technological and scientific purposes, allowing to achieve effects that cannot be realized using alternative methods.

Electron sources based on thermionic cathodes are conventional, however, have significant drawbacks associated with low resource of cathodes, the influence of magnetic fields in a filament on the initial conditions of electron beam, high inertia et al., which can often limit their field of
application. Sources in which the emission of charged particles is carried out from the plasma of the vacuum or gas discharges have several advantages compared with sources based on thermal cathode or the explosive emission cathode sources, and in some cases, for example, to generate ions - generally are only acceptable. Thus, for example, welding gun with the plasma cathode, having a high resource, greater resistance to the bombardment with accelerated ions and low sensitivity to changes in vacuum conditions, provide high beam brightness and satisfactory weld quality. In addition, more rational than sources with explosive emission cathodes, sources with plasma cathodes solve the problem of obtaining a large cross section in the micro- and millisecond range of pulse durations [1, 7–8].

Electrons in such sources are emitted from a bulk plasma, the emission surface of which is most often comparable in area with the beam cross section, therefore it is possible to exclude the appearance of small-scale inhomogeneities in the current density distribution characteristic of emitters with a discrete emission structure. Since the discharge power supply system and the electron's acceleration system is separated, the control parameters of the beam in such sources may be within a wide range and independent from each other.

A special place among such electron sources is occupied by electron sources with grid plasma cathodes, which have been developed for a long time in the Institute of High Current Electronics SB RAS in the Laboratory of Plasma Emission Electronics [9–17]. The prospect of such a pulse-periodic sources included in the list of Russia's unique installations "UNIKUUM", it has been repeatedly demonstrated. In particular, the electron source "SOLO" is most often used to modify the surface of various inorganic materials in vacuum, whose properties in some cases improve by an order of magnitude and higher [18–19]. The purpose of this work is to demonstrate the capabilities of electron sources with grid plasma cathodes, which consist in the ability of a controlled change in the beam power during a pulse by predicting a change in its current amplitude using the electron source "SOLO" as an example.

2. Beam power control during its pulse

To demonstrate this possibility, the source of electrons “SOLO” with a grid plasma cathode and a plasma anode with an open plasma boundary was chosen [9]. This source has no direct world analogues and allows to generate a broad intense submillisecond electron beam with a wide range and the possibility of mutually independent control of such parameters (table 1) as:

| Electron energy (keV) | Beam current (A) | Duration (μs) | Diameter (mm) |
|-----------------------|-----------------|--------------|--------------|
| up to 25              | up to 200       | up to 200    | up to 40     |

This advantage allows to search for an optimal mode of irradiation surfaces of various materials and products in wide ranges. In most cases, surface modification leads to an improvement of its properties [18, 19], which strongly supports the need for further development of this type of electron sources. However, in some cases during the irradiation of materials, for example, aluminum-silicon alloy, it was noted that it is necessary that the beam power, or rather the beam power density, change during its impulse according to a known law, which will allow controlling the rate of energy input into the samples surface.

Previously, in a number of works [17, 20] it was shown that using grid plasma cathodes, it is possible to obtain intense electron beams with constant amplitude in a burst mode of 100 μs or more with a pulse repetition rate of up to 100 kHz. The control of the beam current in these works was carried out at a constant amplitude of the discharge current using a control grid, which was a necessary measure to solve the problem associated with the high repetition rate of the beam current pulses, since the solution of this problem by generating individual pulses of the discharge current in this case was not suitable. First of all, this is due to the time of filling the cavity with plasma (the space of the plasma cathode – expander), which can reach tens of microseconds and which depends on the volume of the cavity, the type of working gas, its pressure and other factors. However, it is also known from
the literature that the characteristic crystallization times of the surface of materials such as aluminum or titanium are tens of microseconds (about 50 microseconds) [21], which is significantly higher than the characteristic times of the rising and falling edges of the beam current in the plasma cathode source using an additional grid. Therefore, such a relatively complicated method of controlling the generation of an electron beam using a control grid is impractical, and to solve the problem of generating an electron beam with its variable, but controlled power, it is easier to use another way to control the beam current, namely, by a controlled change in the amplitude of the beam current during a pulse of submillisecond duration.

A relatively simple way to change the arc discharge current during its pulse (figure 1) is to use a set of ballast resistances $R_N$, each of which sets a certain amplitude of the discharge current flowing through these resistances from a single capacitor bank $C$, during the open state of the corresponding transistors $VT_N$. In this case, the use of four transistors $VT_N$ makes it possible to obtain $2^n = 2^4 = 16$ values of the amplitude of the beam current during the pulse, including a zero value, which may also be necessary, for example, when energy is introduced into the sample surface by several pulses existing in the submillisecond range.

![Figure 1](image-url)

**Figure 1.** Scheme of the arc discharge power supply in the electron source with a grid plasma cathode, generating a variable discharge current during its pulse, $r_d$ is a variable impedance of the discharge.

In figure 2 shows characteristic oscillograms of the discharge current, the shape of which can have almost any shape in the discrete mode. This discharge power supply circuit allows to change the amplitude of the current in the range (0–220) A every 10 μs with a total pulse duration of up to 300 μs.

In figure 3 shows characteristic oscillograms of the generation of an electron beam $I_b$ with a variable amplitude during its pulse by a controlled change in the amplitude of the discharge current $I_d$. The large duration of the front is primarily due to the influence on the generation of the inductance beam of an isolation transformer that provides high-voltage galvanic isolation between the power supply circuit of the plasma cathode and the high-voltage power source. When the discharge power circuit is located on the high potential side, the duration of the beam front can be reduced by > 5 times, and the duration of the front of the discharge current can be adjusted by introducing a choke with a certain inductance into the output circuit of discharge power supply. It can be seen from the presented oscillograms that during the total beam duration of about 300 μs, a multiple change in its amplitude is possible. Under the condition of a constant or slightly varying magnitude of the accelerating voltage, this allows the generation of an electron beam, the power of which can be controlled in a predictable manner during a beam of submillisecond duration.
Figure 2. Examples of the arc discharge current generation with a variable amplitude. Scale: vertical – 100 A/div., horizontal – 50 μs/div.
Conclusion

Thus, using electron sources with a grid plasma cathode, the possibility of generating an electron beam, the power of which can predictably change during the beam current pulse, by a controlled change in its amplitude, has been demonstrated. This possibility, which is unique and inherent specifically to electron sources with plasma cathodes with a grid (layer) stabilization of the emission plasma boundary, opens up additional possibilities for using this electron source to modify the surface of various materials and products, which is the subject of further research.

Acknowledgments

The work was supported by the grant of President of Russian Federation (Projects No MK-123.2019.2).

References

[1] Bugaev S P, Kreindel Yu E and Schanian P M 1984 *Large section electron beams* (Moscow, EAI) p 112 (in Russian)
[2] Kadyrzhano V K, Komarov F F and Pogrebnyk A D 2005 *Ion-beam and ion-plasma modification of materials: Monograph* (Moscow: Publishing House of Moscow State University) (in Russian)
[3] Gribkov V A, Grigoryev F I, Kalin B A and other 2001 *Promising radiation-beam technologies for processing materials: Textbook* (Moscow: Krugly stol) 528 (in Russian)
[4] Uglov V V, Cherenda N N, Anishchik V M, Stalmashonak A K, Kononov A G, Petuhov Yu A, Astashynski V M and Kuzmiotski A M 2007 *J. High Temp. Mater. Proces.* 11 (3) 383
[5] Abdullin E N, Vaysburd D I, Koval N N, Kreindel Yu E, Mesyats G A, Chmukh V N and Schchanin P M 1978 *Technical Physics Letters* 4 (4) (in Russian).
[6] Richter K B, McCormick A V, Scriven L E and Weiss D E 2006 *13th International coatings science and technology symposium*, Denver, Colorado, September 10
[7] Gavrilov N V, Gushenets V I, Koval N N and Oks E M 1993 *Sources of charged particles with a plasma emitter*, Yekaterinburg: UIF “Nauka” 148 (in Russian)
[8] Koval N N, Oks E M, Protasov Yu S and Semashko N N 2009 *Emission Electronics* (M: Publishing House of MSTU. N.E. Bauman) 596 (in Russian)
[9] Devyatkov V N, Koval N N and Shchanin P M 2001 *Izvestiya VUZov Physics* 9 36 (in Russian)
[10] Grigoriev S V, Koval N N, Devyatkov V N and Teresov A D 2008 Proc. 9th Intern. Conf. on Modification of Materials with Particle Beams and Plasma Flows, Tomsk 19
[11] Efremov A M, Kovalchuk B M, Kreindel Yu E, Tolkachev V S and Shchanin P M 1987 Instr. and Experim. Tech. 1 167 (in Russian)
[12] Kreindel Yu E 1983 Sources of Electrons with a Plasma Emitter (Novosibirsk: Nauka) (in Russian)
[13] Vorobyov M S, Gamermeister S A, Devyatkov V N, Koval N N, Sulakshin S A and Shchanin P M 2014 Tech. Phys. Letters 40 (12) 24 (in Russian)
[14] Vorobyov M S, Koval N N and Sulakshin S A 2015 Instr. and Experim. Tech. 58 (5) 687
[15] Kazmin G S, Koval N N, Kreindel Yu E, Tolkachev V S and Shchanin P M 1977 Instr. and Experim. Tech. 4 19 (in Russian)
[16] Gavrilov N V, Kovalchuk B M, Kreindel Yu E, Tolkachev V S and Shchanin P M 1981 Instr. and Experim. Tech 3 152 (in Russian)
[17] Gushenets V I, Koval N N, Kuznetsov D L, Mesyats G A, Novoselov Yu N, Uvarin V V and Shchanin P M 1991 Tech. Phys. Letters 17 (23) 26 (in Russian)
[18] Ivanov Yu F and Koval N N 2007 Ch. 13 in the book “Structure and properties of promising metallic materials” S 345 (Tomsk: NTL Publishing House) (in Russian)
[19] Koval N N and Ivanov Yu F 2016 The evolution of the structure of the surface layer of steel subjected to electron-ion-plasma processing methods (Tomsk: NTL Publishing House) (in Russian)
[20] Gushenets V I and Shchanin P M 2001 Izvestiya VUZov. Physics 9 57 (in Russian)
[21] Teresov A, Koval T, Moskvin P, Kim A and Koval N 2018 Proceedings 2018 20th International Symposium on High-Current Electronics (ISHCE) (Tomsk, Russia) 10