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METHODS OF FORMING CHARGED PARTICLE BEAMS OF LARGE CROSS SECTION

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Improving the efficiency and quality of electron-beam surface treatment of materials is one of the important issues in the process of developing technological equipment. To solve this problem, it is proposed to use electron-beam assistance, which implies alternating or simultaneous exposure to beams of charged particles of both types on the treated surface. In this paper, we consider a method capable of providing such an impact.

The development of the theory and practice of the formation of beams with a large cross section is associated with the prospects of their use for materials surface treatment. Such processing by beams in vacuum and in the residual atmosphere of various gases is used in plasma-chemical technologies, heat treatment of various materials, coating deposition, etc. In a number of cases, a significant increase in the quality of such technologies and the productivity of technological equipment involves the simultaneous action of electron and ion beams. At the moment, this technology is usually provided by using separate electron and ion sources. In this case, the most widespread application for the formation of plasma surfaces emitting ion or electron beams has received gas-discharge electrode structures in which magnetron discharges are excited [1; 2], or discharges with electron oscillations of the "Penning" type (PIG) [3], or with a hollow cathode [4; 5]. Under technologically necessary conditions of low gas pressure, to reduce the discharge voltage and the density of the emitting plasma in gas-discharge structures, hot cathodes are used [6]. A significant drawback of such sources is their fragility in gas discharges.

In the above sources, the emitting plasma is separated from the electrodes of the gas-discharge structure by near-wall electrical layers, the parameters of which are determined by the potential difference between the plasma and each electrode, as well as by the plasma density, as is customary at present, by the condition that the electric field strength at its boundary is equal to zero [7]. The emitting plasma surface also obeys this condition [8]; therefore, the electron (ion) optical conditions in the acceleration gap of electrons (ions) and beam formation depend on the position and shape of the emitting plasma boundary; on the accelerating voltage, the geometry of the electrodes and their potential. This creates certain difficulties in the formation of beams with a large cross section [9].

At the same time, the efficiency of using plasma sources in technological applications is due to the achievement of the necessary parameters of the beam itself in these sources, first of all, the energy of ions and electrons, the surface current density in the beam, and the current density distribution over the beam cross section. The inhomogeneity of the distribution of the current density over the cross section of the ion-electron beam will lead to uneven processing of the material surface; therefore, achieving a uniform distribution of the beam current density is an important task.

The known effect of the possible formation of secondary plasma in the accelerating gap [10] can provide a significant improvement in the emission-optical properties of a source with a plasma emitter: a decrease in the beam divergence due to a decrease in the radial potential gradient in the accelerating gap; an increase in the emission current due to the reverse flow of charges from the secondary plasma into the emitting plasma [11]; increasing the perveance of the accelerating system due to partial compensation of the space charge of the beam.

Also there are known works on electron-beam processing of surfaces when exposed to dielectric materials, in which the features of the effect of the surface charge introduced by an electron beam to the surface are studied. It is shown that this charge is effectively "removed" by the secondary plasma of the electron beam. However, the features of the formation of a "plasma blanket" over a large area to be treated when exposed to ion-electron beams have not been studied. Studying the behavior and parameters of plasma near the surface, depending on the beam current, energy of charged particles and gas pressure, will make it possible to determine and optimize the parameters of a multi-discharge system created for processing large surfaces.

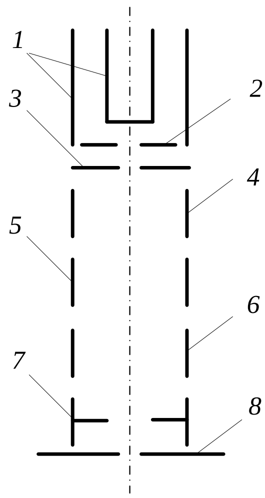
The above suggests:

1) the possibility of creating a plasma object with electrostatic layers in it, capable of providing the formation of ion and electron beams combined in a single space;

2) the multifactorial nature of such a structure and the absence of the necessary algorithms currently complicates the numerical simulation of such structures;

3) an experimental study of such structures at this stage seems to be the most effective for creating technological sources of combined ion-electron beams.

A schematic of the electrode structure of the experimental source is shown in Figure 1. In the volume bounded by electrode 1 (cathode) and electrode 2 (anode), a discharge with electron oscillation is excited [12; 13], from the plasma of which the electrons emission and acceleration is provided by the electrode 3. Electrodes 3–7 form a gas-discharge structure that forms a plasma, which is a source of sputtering ions. This structure consists of two PIG-type gas-discharge cells connected in series (along the axis). Elements 4 and 6 of this structure are the anodes of the discharge cells; elements 3, 5 and 7 - cathodes. A voltage is applied between the electrodes 7 and 8, which accelerates the ions to the energy of the sputtering ions required by the technology. At the same time, in this gap (between electrodes 7 and 8), the deceleration of the electron beam accelerated between electrodes 2 and 3 is carried out.



1, 5, 7 – cathodes; 2, 4, 6 –anodes; 3 – accelerating electrode (electrons); 8 – accelerating electrode (ions)

Figure 1. – Schematic electrode structure of a multi-discharge system

Conclusion. The proposed concept of the source shows the possibility of creating multi-discharge panels that allow solving urgent problems of forming technologically combined electron and ion beams for the implementation of electron-beam assistance to plasma-chemical processes or combined exposure to electron and ion beams. Sources of this type can become a unique universal tool for applying film coatings for various purposes. Such systems can be of interest both as separate sources and as cells of a multi-discharge source for the formation of an impact on large areas.

REFERENCES

1. Барченко, В.Т. Физика и технология плазменных эмиссионных систем / В.Т. Барченко. – Санкт-Петербург: Изд-во СПбГЭТУ «ЛЭТИ», 2014. - 286 с.
2. Кузьмичёв, А. И. Магнетронные распылительные системы. Кн. 1. Введение в физику и технику магнетронного распыления / А.И. Кузьмичёв. – Киев: Аверс, 2008. – 244 с.
3. Penning FM. Coating by Cathode Disintegration. US Patent 2,146,025; N.V. Philips, Gloeilampenfabrieken, Eindhoven, The Netherlands; 1939
4. Москалев, Б.И. Разряд с полым катодом / Б.И. Москалёв. – Москва: Энергия, 1969. – 184 с.
5. Крейндель, Ю.Е. Плазменные источники электронов / Ю.Е. Крейндель. – Москва: Атомиздат, 1977. – 145 с.
6. Алямовский, И.В. Электронные пучки и электронные пушки / И.В. Алямовский. – Москва: Советское Радио, 1966. – 454 с.
7. Груздев, В.А. О механизме возникновения электрического поля в плазме при эмиссии электронов / В.А. Груздев, В.Г. Залесский // Вестник Полоц. гос. ун-та. Сер. С, Фундаментальные науки. – 2014. – № 4. – С. 103–108.
8. Груздев, В.А. Формирование эмиссионного тока в плазменных эмиттерах электронов. / В.А. Груздев, В.Г. Залесский // Прикладная физика. – 2009. – № 5. – С. 82–90.

9. Gruzdev, V.A. Electron-optical characteristics of the beam generated by the electron plasma sources / V.A Gruzdev, V.G. Zalesski // Electrotechnica and electronica (Bulgaria). – 2014 – V. 49, № 5-6. – P. 264–268.
10. Gruzdev V.A. Emission current formation in plasma electron emitters / V.A. Gruzdev, V.G. Zaleski // Plasma Physics Reports. – 2010. – №36. – p. 1191-1198
11. Залесский, В. Г. Эмиссионные и электронно-оптические системы плазменных источников электронов : дис. ... д-ра физ.-мат. наук : 01.04.04 / В. Г. Залесский. – Минск, 2015. – 316 с.
12. Gruzdev V.A. Universal plasma electron source / V.A. Gruzdev, V.G. Zaleski, D.A. Antonovich, Y.P. Golubev // Vacuum. – 2005. – №77. – p. 399-405.
13. Zaleski V.G. Peculiarities of plasma electron sources operation at high pressures / V.G. Zaleski, D.A. Antonovich // Journal of Physics D: Applied Physics. – 2007. – №40. – p.7771-7777.