Generation of Electron Beams by Plasma Cathode Electron Guns under Fore Pump Pressure Range[1]

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Abstract – Results on investigation and design of plasma cathode electron gun for electron beams generation in pressure range 1–10 Pa are presented. Several specific problems appear at these pressures. Main of them are: high probability for electrical breakdown of accelerating gap, great influence of back ion stream both on emission electrode and emitting plasma, secondary plasma appearance in beam propagation area and intensive beam-plasma interaction, leading to broadening of beam energetic spectra and beam defocusing. Specific peculiarities take place in case of generation of ribbon type electron beams. They are local maximums in current density distribution across the beam.

1. Introduction

Necessity in electron beams in fore-pump pressures is defined by possibility of their application in such scientific and technological areas as material melting and evaporation in atmosphere of oxygen or other active gases, plasma generation for plasma chemical aims, thermal treatment of material surfaces and others. All this requires research and design of guns, which are able to generate electron beams in bad vacuum conditions. As may be concluded from literature [1, 2], earlier efforts were directed to guarantee as little pressure in regions of electron acceleration and propagation as possible. At such conditions main problem was to secure stable discharge for emitting plasma formation. Present work is manly devoted to investigation of special effects, which take place in electron beam formation directly in bad vacuum.

2. Effects, observed in electron beam generation in bad vacuum

Many types of discharges, and discharge with hollow cathode in that number, certainly exist in pressure range 1–10 Pa. If discharge is applied for plasma cathode formation, problems are: maintaining of stable emitting plasma boundary, electrons acceleration and electron beam formation. As it was shown earlier, stable plasma boundary exists only if emission electrode is performed as metal mesh or perforated plate. In both cases dimensions of mesh cells or holes have to be comparable with ion sheath thickness [3]. This thickness principally depends on what electrode is used as emission electrode. In our electron gun emission holes are displaced in anode. And because potential difference between plasma and electrode is several volts, sheath thickness is about one tenth of mm and mostly determined by plasma density, i.e. discharge current. In above named pressure range plasma density and therefore sheath thickness greatly depends also on back ion stream from accelerating gap to emitting plasma. Obviously, the greater gas pressure and emission current density, the more this influence. Dramatic consequences take place, if sheath thickness becomes much less than mesh cell size. In this case plasma penetrates into accelerating gap, discharge develops in this gap between hollow cathode and accelerating electrode, and further electron acceleration becomes impossible [4]. This effect is usually named as breakdown.

Another possibility of electrical strength loss is connected with secondary plasma formation in the region near accelerating electrode. Distance between this plasma and emission electrode is formed in agreement with Child-Langmuir Law and, if plasma density is high enough, this distance becomes much less than inter-electrode gap. At constant accelerating voltage it causes electric field intensity growth near emission electrode. Dramatic consequences in this case are explosive centers formation and arc spots appearance on the electrode surface. Development of arc discharge with simultaneous voltage drop may also be qualified as another type of breakdown. At last, back ion stream may cause great heating (to red lighting) of emission electrode. It makes non-effective mesh application in emission electrode, if emission current densities are more ~10 mA/cm^2.

Back ion stream may have also positive effect because of its possible application for discharge generation. Procedure of discharge initiation has two steps. First – application of several kilovolts voltage to accelerating gap, second – fluent ascent of discharge voltage. Physical mechanism looks as following. First step causes high voltage low current glow discharge in accelerating gap and back ion stream to

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hollow cathode. These ions cause electron emission from walls of hollow and therefore lighten initiation of discharge with hollow cathode.

Specific peculiarities are observed for guns, producing narrow focusing beams and beams of great cross-section. First of them generate beams with high current densities (≥100 mA/cm^2). This level may be reached, as a rule, if electron emission is realized through single hole (channel) in emission electrode. It begets, as minimum, two specific problems. One of them is plasma boundary stabilization in this channel. As our investigations showed, plasma propagation in anode channel [5] is distinguished from one in cathode channel, because in second case restriction of propagation length is due to ion sheath growth, and limitation of propagation in anode channel is connected with plasma breaking owing to electron losses to channel walls. The other problem is electron beam interaction with secondary plasma, which is produced by beam in the area of its transportation [6]. This interaction has form of beam-plasma discharge (BPD). Confirmations of it are: abrupt plasma density growth at beam current increasing, changes of plasma lighting color from weak violate to bright white and broadening of beam energetic spectra. Result of it is breaking of conditions for beam focusing and lowering of beam current density. Therefore appearance of BPD is undesirable effect for beam transportation from electron gun to target. BPD is appeared, as a rule, in beam crossover, i.e. decisive parameter for its existence is current density. Another important parameter is beam electron energy. Growth of this energy reduces probability of BPD. One of the ways to avoid BPD and simultaneously to increase total beam current is electron extraction from plasma through not single, but multiple emission holes. This allowed raising of total beam current. Current density rising is possible also if special form of emission electrode is employed. However at these conditions emission area is high enough (usually ~1 cm^2) and beam brightness is falling down.

Second type guns are predestinated for ribbon electron beam generation by electron extraction from discharge with extended hollow cathode. Main problem is current uniformity along beam cross section. This problem appears if trying to increase current density by narrowing hollow cathode split. In this case ribbon beam transforms in several narrow beams, which positions may change during generation. Physical reason of this effect is plasma redistribution in hollow due to local thinning of ion sheath in cathode split aperture.

3. Electron guns

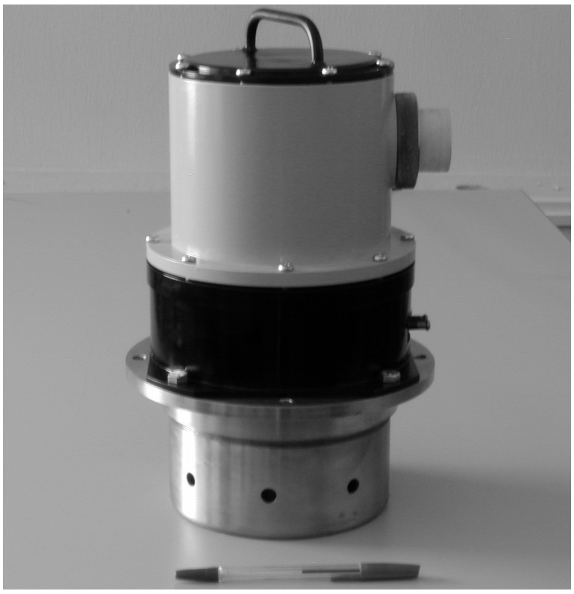
Nowadays three types of electron guns have been designed for generation of cylindrical, narrow focusing and ribbon like beams. Parameters of beams are presented in table. Photos of electron guns are shown at Fig. 1, *a*, *b*). Power supplies based on reorganizing technique are designed for all types of electron guns.

Conclusion

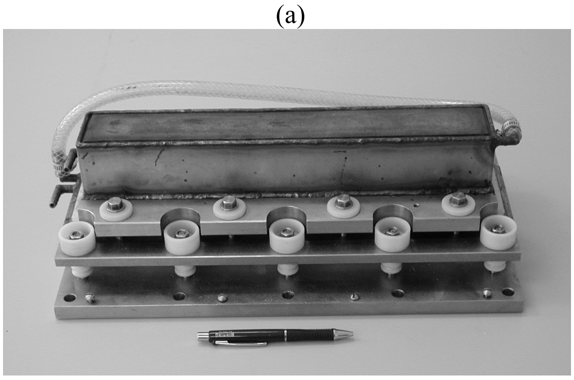
A number of effects, taking place in plasma sources, which generate electron beams in pressure range 1–10 Pa, were investigated. On the base of these results the row of guns, generating different configurations beams were designed. One of peculiarities is, these guns work without gas feeding and do not require complex system for gas control.

Table. Electron beams parameters

Type	Cross-section, mm^2	Energy, keV	Current, A	Pressure, Pa
Cylindrical	10–100	5–15	0–0,3	2–10
Focusing	1	15 –20	0,01–0,1	3–8
Ribbon	10×300	2–8	0,1–1	3–13



(a)



(b)

Fig. 1. View of electron guns, generating cylindrical or focusing beams (a) and ribbon like beam (b)

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