Effect of Longitudinal Magnetic Field on a Simple Plasma Electron Source

A. H. Sari1,*; S. H. Mortazavi1; N. Bolouki1; M. Khoramabadi1; H. R. Ghomi2

1Plasma Physics Research Center, Science and Research Campus, Islamic Azad University, Tehran, Iran
2Laser Research Institute of Shahid Beheshti University, Evin 1983963113, Tehran, Iran

Received: 30 April 2008/Accepted: 30 May 2008 / Published: 1 June 2008

Abstract

In this paper new structure of a plasma electron source has been described. This electron source can produce a powerful and monochromatic electron beam by a simple obstructed discharge mechanism. The beam current and diode current has been measured for low pressure He discharges under the influence of an external longitudinal magnetic field. The magnetic field could vary from 0 to 45 mT. Voltage-current characteristics and Paschen curves has been obtained under mentioned conditions. The results show that by increasing of magnetic field, efficiency of the system significantly enhances but it decreases at higher magnetic field values.

PACS: 52.90.+z; 07.55.Db; 52.59.-f

Keywords: Electron beam; Cold Cathode; Obstructed Discharge; Magnetic field

Introduction

In the last decay the investigation of electron sources with cold cathodes working under secondary emission conditions in presence of electric and magnetic fields aroused considerable interests [1-6]. In these electron sources, where the conventional thermoionic cathode is replaced by a cold, secondary electron emitting electrode, electron emission is stimulated by bombarding the cathode with high energy ions, fast neutrals and photons in a glow discharge. The cathode fall in potential is necessary in order to maintain a cold cathode glow discharge and occurs over a distance, the cathode dark space (CDS), which is determined by the gas pressure, the current density, the cathode material and the gas species.

Generally, glow discharge electron gun can be divided into two groups: "hollow cathode" or internal plasma electron generation types and "front face emission" or secondary electron emission type. In a hollow cathode glow discharge electron gun, the plasma that developed inside the hollow cathode acts as a source of electrons for the electron beam. This type of electron gun, have two modes of operation. One mode is high impedance one in which the electron beam is produced, and the other is a low impedance mode where no electron beam is produced. Operation in beam mode occurs over a limited range of current and pressure [7, 8]. When these two parameters are not properly chosen the external dark space vanishes, production of electron beam ceases, and the discharge then operates in the low impedance mode. This is undesirable for stable operation of the electron gun. In contrast, secondary emission electron guns present only one mode of operation and, hence, represent a considerable practical advantage for stable electron beam operation.

The production of electron beam in our constructed device is in abnormal discharge regime. If the electrode separation is reduced so that the anode enters the normal CDS, then the sustaining voltage of the discharge increases such that the current is maintained. This operation regime is known as an “obstructed glow discharge” [9, 10]. An obstructed discharge may also be produced if the electrode separation is maintained constant and the pressure is decreased. Helium, in particular has anomalously large increase in sustaining voltage as the electrode separation is decreased. The obstructed discharge in low operating gas pressure produces a monochromatic beam owing to little interactions of electrons with neutrals [11]. Under the discharge condition in this mode, the potential exists over the whole A-C space. Therefore, an ion produced by electron – bombardment ionization is always accelerated toward the cathode by the potential gradient. On its way the ion suffers charge exchange with neutrals and then is converted into a neutral with the same energy as the ion possessed before and at the same time a cold ion remains. The cold ion is accelerated again and produces another energetic neutral repeatedly. As a result, an ion can make many fast neutrals before the charge arrives at the cathode. The fast neutrals collided with the cathode ballistically, are producing enough secondary electrons on the cathode to sustain the discharge.

Thus fast neutrals produced through the charge exchange between the neutral gas and the ions accelerated toward the cathode play an important role for sustaining of discharge [11]. The construction details have been previously reported by authors [12, 13]. In
this paper the effect of longitudinal magnetic field on electron beam is discussed.

**Experimental setup**

Schematic configuration of the electron source has been shown in figure 1. Both electrodes are in a Pyrex tube as vacuum chamber. The vacuum chamber is evacuated by a turbo molecular pump. All the vacuum seals are Viton O-rings. Pressure gauge is located at the top of the turbo molecular pump. The achievable end pressure is $10^{-3}$ Pa. The working gas is a high purity helium gas and is supplied through a needle valve into the chamber and system can operate in gas pressure from 1 to 10 Pa. The anode, conic intermediate electrode (floating electrode), the pumping duct are grounded and a negative DC high voltage is applied to a concave cathode up to $-20$ kV which determines electron energy.

The cathode face was made concave to focus the electron beam electrostatically. The aluminium works well to coverage the electron beam and reduces particle loss to the chamber wall. In this experiment, 80 mm curvature radius is used for concave cathode. The beam current is the current which is extracted at aluminium end section and the diode current is the total current which is consumed from DC power supply. So the diode current can be divided to the current which collides to conic intermediate anode and the beam current which pass through the anode hole. From gas species point of view, hydrogen and helium are more stable in sustaining discharge and works better for beam operation in comparison to argon and neon [11]. It is clear that, in order to obtain an electron beam, the electron current inside the chamber should converge on the tube axis without collision by anode.

In this study a solenoid coil was used to produce a uniform magnetic field (B) parallel to discharge axis (see fig. 1). The maximum strength of magnetic field is 45 mT. Experiments performed by low-pressure helium discharges under influence of this variable external longitudinal magnetic field.

In order to characterize the effect of magnetic field on discharge parameters, Paschen curve was obtained at different magnetic field values. In addition efficiency of electron beam production (the beam measured at target plate) under influence of mentioned external magnetic field obtained.

**Results and discussion**

Figure 2, shows the profile of breakdown voltage versus $Pd$ (where $P$ is Pressure and $d$ is anode-cathode distance) which is well-known as Pachen curve. This profile confirms that our device works at the left side of Pachen curve. As we can see in fig 2, by increasing of magnetic field, the slope of the curves enhance too, and the facility can work at lower value of $Pd$.

In order to obtain an efficiency profile to investigate the effect of magnetic field on beam performance, the division of beam current and diode current were considered. These profile obtained at a constant working pressure. Figure 3 shows on of these results. As it is clear in this graph, there is an optimum point for external magnetic field value which in this point we can obtain maximum beam current (maximum efficiency). This later result (fig 3), is an evidence which confirms the significant effect of such a magnetic field. We may come to this conclusion that the external magnetic field can play an important role on efficiency of any kind of plasma electron source.
in the Townsend regime is lengthened and their lateral diffusion is reduced. Thus electron losses to the walls decrease. When a magnetic field is applied to a discharge, electrons are trapped in circular paths. The effective path which is taken by an electron with an azimuthal velocity before reaching the anode becomes much longer than the distance between electrodes. Therefore collision probability of the electron also becomes higher. In addition, when an axial magnetic field is applied to such system, because of curvature of cathode surface, the $E \times B$ drift will increase the collision probability. So, by applying of axial magnetic field the trapping of electrons becomes efficient through the cyclotron motion.

By further increasing of magnetic field, a fall in efficiency is observed. When magnetic field rise, the larmor radius ($r_l$) is decreased and the electrons move in a semi straight line. Then electron effective paths become smaller, the collision probability reduce, so ionization rate decrease and recombination increase. The result would be the fall in efficiency profile.

**Acknowledgments**

The authors are grateful to Prof. M. Fukao (Dept. Electr & Electron. Engin. Shizuoke Univ., Hamamatsu, Japan) for his kind assistance with constructing the electron gun facility. The work was supported by Plasma Physics Research Center, Science and Research Campus of Islamic Azad University.

**References**