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Development and Test of Ion Source with Small Orifice Cold Cathode

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Abstract

The paper represents the results of the development and the test of "cold cathode" ion source model with 5 cm aperture where the glow discharge is utilized for generation of electrons in the cathode of the ion source. The results of probe measurements of the ion source are represented. The integral parameters such as electron energy distribution function(EEDF), electron density and mean electron energy, discharge voltage-current characteristics, and distribution of ion beam were studied.

1. Introduction

Cold cathode ion sources are now widely used in various ion beam technologies. The advantage of cold cathode ion sources is the utilization of the glow discharge for generation of electrons in the cathode of the ion source. This gives the opportunity to use chemically reactive gases as the working gases of the ion source contrary to filament [1] and "hot-hollow cathode" [1-3] ion sources that are very sensitive to the presence of oxygen, moisture and other contaminants. Several constructions of "cold cathode" ion sources are known nowadays [4-6]. Typically "cold cathode" ion source consists of cylindrical cathode and anode chambers connected through the orifice. In Ref. 6 it is reported that under condition of large orifice diameter(~1 - 8 cm) the ion current density extracted from the ion source could be doubly increased (from 1.5 mA/cm^2 to 3 mA/cm^2) by changing emission electrode potential from floating to cathode one. The disadvantage of the latter case is the fact that large potential difference between plasma and emission electrode makes the extraction of electrons with energy smaller than several keV nearly impossible. One more important result of Ref. 6 is the conclusion that the increase of the orifice diameter leads to the increase of ion beam uniformity near the emission electrode, the radius of the uniform spot being approximately equal to the radius of the orifice.

Most probably electrons generated in the cathode part of the ion source [6] penetrate to the anode chamber of the ion source where transversal motion of electrons is restricted by the longitudinal anode magnetic field. So electrons move towards emission electrode only in the central part of anode chamber originating from the orifice. Efficient ionization evidently takes place also only in the central part of the anode chamber. The energy of fast electrons coming from cathode part is higher than potential difference between floating emission electrode and plasma so a lot of electrons die at the emission electrode without producing ionization. This is the reason of low efficiency of the ion source under condition of floating emission electrode.

In order to avoid the disadvantages of the cold cathode ion source and develop the ion source with high efficiency in the range of both low (≤ 1 keV) and high ion energies,

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with increased reliability and resource, the new laboratory model of cold cathode ion source was designed and fabricated. The main physical idea of the model was to minimize the penetration of high energy electrons and cathode electric fields into the anode chamber by reducing the orifice diameter connecting cathode and anode chambers.

2. Fabrication of the ion source with cold cathode

Main consisting elements of cold cathode ion source are shown in Fig. 1. Cold cathode ion source consists of cathode 1 and anode 2 chambers, cathode magnetic system 3 and anode magnetic system 4, main 5 and additional 6 gas distributors and an ion extraction system 7. A cathode block 1 represents hollow cylinder 5 cm in diameter and 4.5 cm in length. On its lower end surface the gas distributor 5 is installed which is electrically insulated from the cathode block. On the upper end surface of cathode block a cone orifice 8 that connects cathode and anode blocks is attached. The diameters of orifices used are 2, 3 and 5 mm.

The anode block 2 represents hollow cylinder, where cylindrical anode, which has 9.5 cm diameter and 4.5 cm length, is installed in alignment. On the lower end surface of the anode block above the orifice connecting cathode and anode blocks a reflector of electrons as well as additional gas distributor 6 can be installed if necessary. On the upper end of anode block an ion-optical system 7 is assembled.

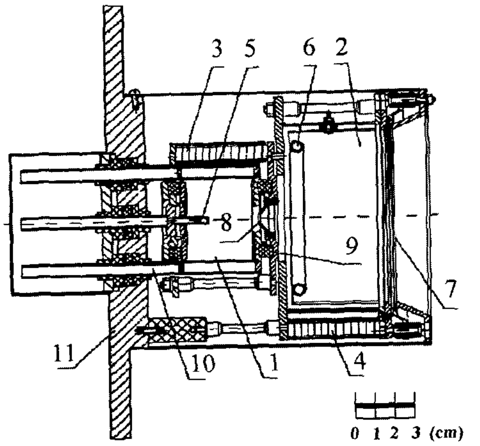


Fig. 1 The scheme of cold cathode ion source. (1,2) cathode and anode chambers ; (3,4) cathode and anode magnetic systems ; (5,6) main and additional gas distributors ; (7) ion extraction system ; (8) orifice ; (9) insulator, (10) coolant channel, (11) flange.

Cathode and anode blocks are electrically isolated with the insulator 9. The ion source is cooled by the coolant loop 10. The ion source is mounted to the vacuum chamber with the flange 11.

Magnetic field is created in the cathode block by means of the cathode magnetic system, consisting of magnets and magnetic conductors to simplify a discharge ignition and increase the efficiency of ion source operation. Anode magnetic system consists of permanent magnets and magnetic conductors too. Three types magnetic systems provided maximum values of magnetic field induction 17, 20, 25 mT in the cathode part and 4, 8 and 20 mT in the anode part respectively.

3. Experimental procedure

The operation of ion source is represented as follows. The air is used for the working gas of the ion source. The voltage is applied between cathode and main gas distributor that has the same potential as anode in order to ignite discharge. After ignition of the discharge, due to the voltage drop by the resistor in the electrical circuit connected to main gas distributor, the anode potential becomes higher than potential of the gas distributor. Then discharge is also started in the anode chamber. Emission electrode is under floating potential. The ion extraction system is composed of accelerating and decelerating electrodes as usual.

The integral parameters of ion source are measured. A computer is used for the control of power supplies of the ion source. Corresponding values of ignition, discharge and ion beam currents as well as discharge and grids voltages are measured and stored by the computer.

In order to measure the ion beam profiles the set of probes are installed in the vacuum chamber at the distance of 5 and 20 cm from the exit of the ion source (IS). All the probes are under negative potential in respect to the ground in order to reflect electrons available in the vacuum chamber.

Plasma parameters in the ion source are measured with the help of Langmuir probes 0.3 mm in diameter and 4 mm in length. The scheme of probe measurements is standard. Probe curves are measured in two planes separated from the emission electrode at the distances 30 and 15 mm at the axis r/R=0, at r/R=0.5 and near the wall at r/R=0.8, when R is the radius of anode. Electron energy distribution functions(EEDF) are calculated on the basis of probe Volt-Ampere characteristic with the help of regularization method [7]. Calculated EEDF are used for determination of electron density and mean electron energy.

4. Results of plasma and integral parameters measurements

The results of plasma parameter measurements for the model with 5 mm orifice are represented in Figs. 2-3. Measurements carried out in the cathode chamber show that there are lots of fast electrons, the mean electron energy is about 9.5 eV and the electron density is 3 (10^{10} cm^{-3}. The plasma there has potential close to one of gas distributor. To the contrary, plasma potential in the central part of anode chamber is much lower than potential of anode as shown in Fig. 3. This situation differs a lot from that existing in ion sources with filament or hot hollow cathodes [7]. The electron density in anode chamber is high only near the axis of the ion source. Most probably this situation is similar to that observed in Ref. 6. In the case of ion source model with 5 mm orifice, decrease of emission electrode potential will also result in the increase of the operation efficiency because a lot of fast electrons will be confined in the discharge.

Situation in the model with 3 mm orifice is quite different. The plasma potential in the anode chamber as shown in Fig. 4 is close to the anode potential.

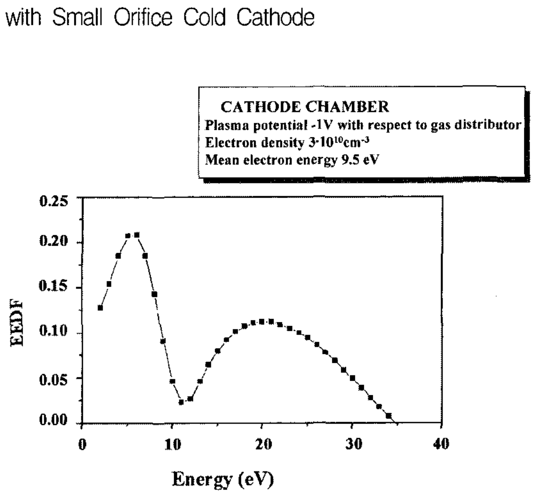


Fig. 2 EEDF in the cathode chamber of the ion source.

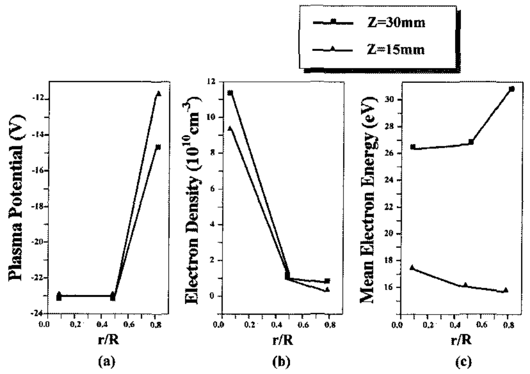


Fig 3. Spatial distribution of plasma potential (a), electron density (b) and mean electron energy (c) in case of ion source with 5 mm orifice. Horizontal axis are r/R

EEDFs at several points(r/R=0, 0.5 and 0.8 for z=15 and 30 mm each) in the anode chamber are presented in Fig. 5. They are similar to that observed in common ion sources [7]. Probe measurements show that plasma potential in the central part of cathode block is close to the potential of ignition electrode while plasma potential in the anode chamber is close to the anode potential. That means the potential difference between gas distributor and anode is concentrated in a small transitional region between the cathode and the anode chamber. The potential drop at this area helps to extract electrons from cathode to anode part of the ion source. On the contrary potential drop between anode plasma and emission electrode is small, so low energy ion beam can be easily extracted

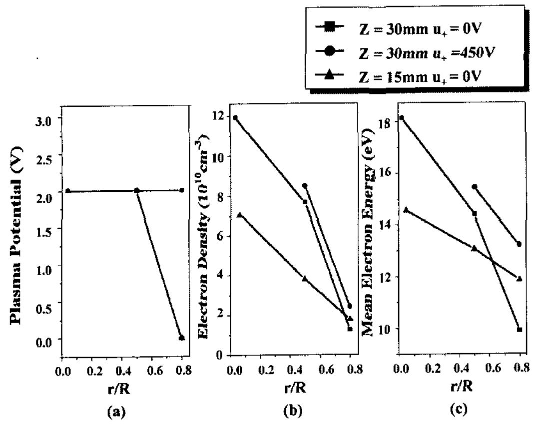


Fig. 4 Spatial distribution of plasma potential (a) electron density (b) and mean electron energy (c) with and without extraction voltage U+. Case of ion source with 3 mm orifice

from the ion source. The numbers of fast electrons are increased with the increase of ion extraction voltage. The number of fast electrons increased with the increase of the extraction voltage can be shown in Fig. 6.

The decrease of the orifice diameter till 2 mm shows that in this case all discharge current is close to main gas distributor and ion beam current is negligible.

When the increasing discharge voltage controlled by a computer reaches to some value which is the function of pressure, ignition of discharge takes place, discharge current appears and discharge voltage is reduced in its value. Then approximately in 200s after obtaining stable mode of operation, discharge voltage, ignition, discharge and ion beam currents are measured. Such a procedure of measurements is very useful for studying characteristics

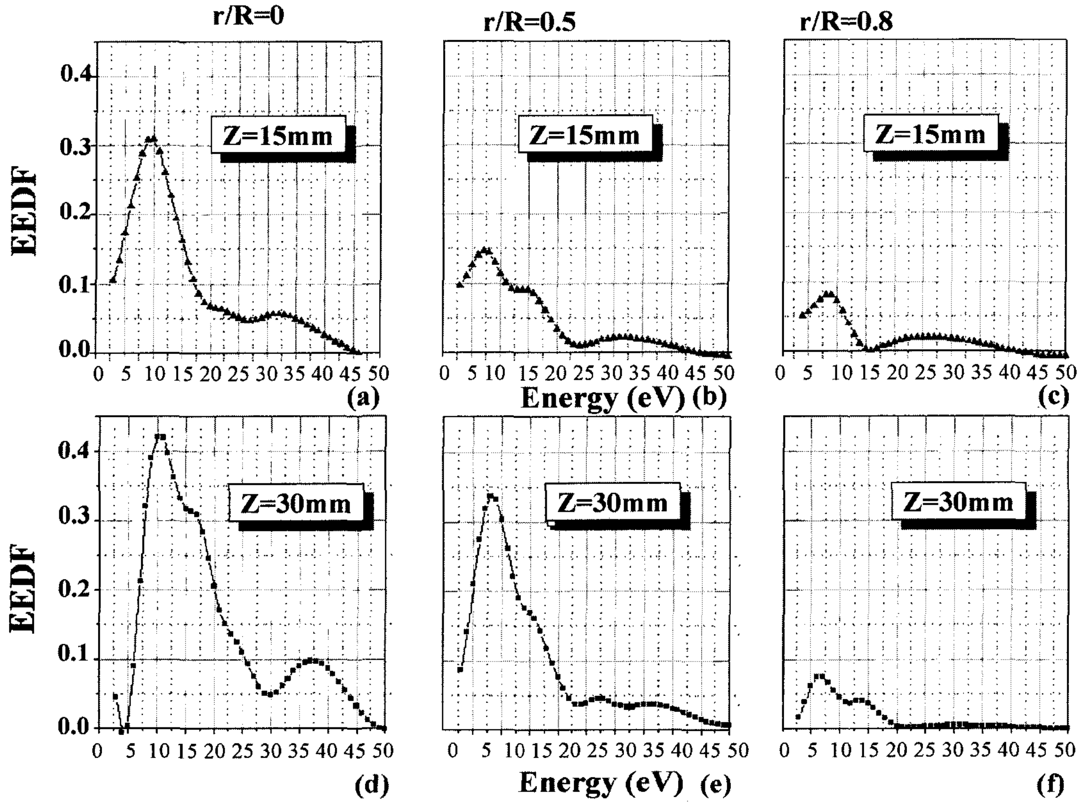


Fig. 5 Calculated EEDF in case of ion source with 3 mm orifice without extraction voltage at differnt locations. Axial position at 15 mm from emission electrode and radial position at r/R=0 (a), same axial position and at r/R=0.5 (b), same axial position and at r/R=0.8 (c), axial position at 30 mm from emission electrode and r/R=0 (d), same axial position and at r/R=0.5 (e), and same axial position and at r/R=0.8 (f)

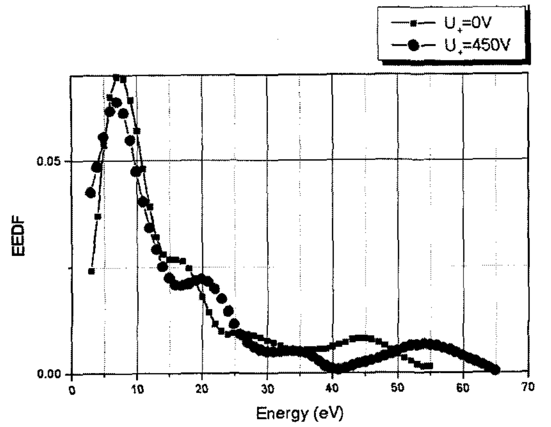


Fig. 6 Comparison of EEDF with and without extraction voltage.

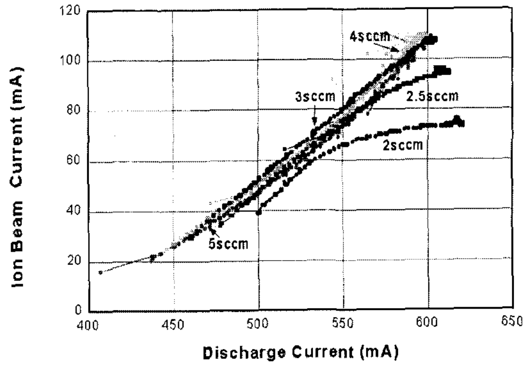


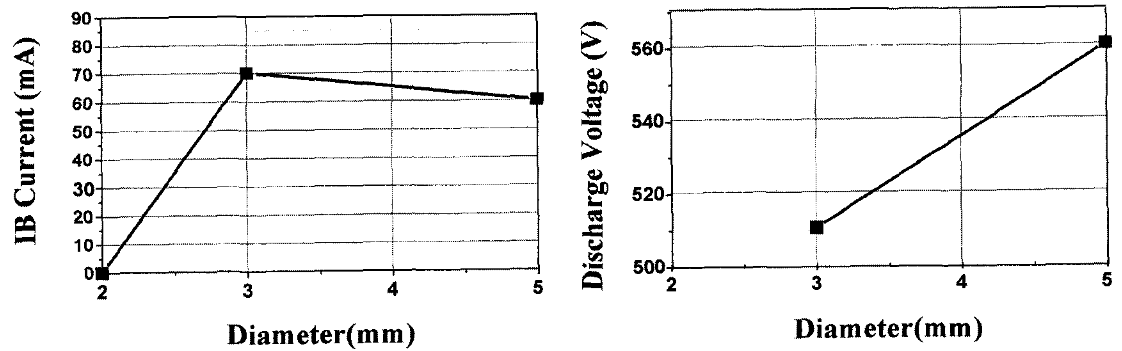
Fig. 7 Dependence of ion beam current on discharge current.

of ion source operation. One can sometimes see the appearance of pulsed mode of ion source operation under small gas consumptions. In pulsed mode operation, the discharge is periodically restricted to the main gas distributor by the instability. As a result the anode discharge current decreases and discharge voltage increases that leads to the closing of discharge to the anode, then the process is repeated. Ion beam current is much larger under situation that the discharge current is closed to the anode.

The dependency of discharge voltage on discharge and ignition current is measured. At high gas consumption (m≥4 sccm) it is found that the normal mode of glow discharge exists in the cold cathode ion source. The decrease of the flow rate leads to the transition of the discharge to abnormal mode first in the realm of high discharge currents Id and then in the all considered ranges of Id. The transition of the discharge to the abnormal mode leads to the significant increase of the discharge voltage necessary for the extraction of the meaningful values of ion beam currents.

The dependency of ion beam current on the discharge current is shown in Fig. 7. At high gas consumption (m≥3 sccm), the ion beam current increases linearly with the increase of discharge current. At lower gas flow rate, the ion beam current is saturated with the increase of discharge current. The maximum ion beam current obtained at the discharge current of 600 mA is 110 mA when the gas flow rate is above 3 sccm.

By the comparison of the IS parameters obtained with different diameter of orifice, the IS with 3 mm orifice is optimum(see Fig. 8).



(a) (b)

Fig. 8 Dependence of ion beam current (a), and discharge voltage (b) on diameter of the orifice for the gas flow rate of 4 sccm.

5. Results of the ion beam profile measurements

The results of the ion beam profiles measurements in case of model with 3 mm orifice are represented on Fig. 9. The measurements carried out at small(5 cm) distance from the ion source show that at the discharge currents higher than 150 mA ion beam profiles and consequently ion beam profiles at the exit of the ion source practically do not depend on the discharge current. Ion beam profiles are also similar at gas flow rates higher than 3.5 sccm. Comparison of the ion beam profiles obtained with models with different magnetic systems showed that in the case of magnetic systems that provides stronger magnetic field in the anode part ion beam profiles are slightly narrow most probably due to the alignment of electrons motion by longitudinal magnetic field. The increase of the distance between ion source and probes leads to the extension of the ion beam profile. The size of the uniformity in the 5 % range spot here is 4cm. This result is valid for all considered discharge currents.

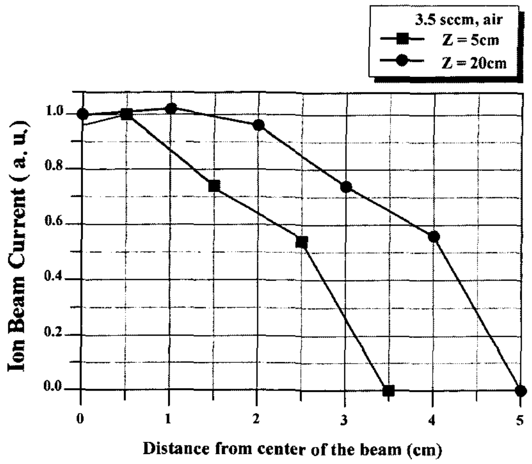


Fig. 9 Ion beam profiles at 5 cm and 20 cm from the ion source with 3 mm orifice.

6. Conclusion

The cold cathode ion source is developed and the characteristics including EEDF are studied. The floating emission electrode scheme is adopted to increase the emission of electrons. To increase the efficiency of the ion source, the orifice diameter connecting cathode and anode chamber is reduced. By reducing the orifice diameter, the inflow of high energy electrons from the cathode chamber and the effect of cathode chamber potential on the anode chamber can be reduced. When the dimensions of cathode and anode chamber are 5 cm in diameter and 4.5 cm in length, the optimum orifice diameter is 3 mm compared to 2 mm and 5 mm. In this case the plasma potential in anode chamber is close to the anode potential itself. The operation of the ion source is stable with the high air gas flow rate above 3.5 sccm and maximum beam current obtained is 110 mA.

The optimization of the ion source dimensions, especially the length of anode chamber has to be studied further because it affects the ionization efficiency of the elctron.

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