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HIGH EFFICIENCY GLOW DISCHARGE ION SOURCE

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In this paper, design and investigation of new ion source characteristics working on the condition of the glow discharge has been carried out. The ion source is of self extraction type and is featured with its small size (length, l = 3.54 cm, width, h = 3.14 cm), easy operation and stable discharge. The best working conditions were found to be at discharge pressure in the range of 10^{-4} mbar and gap distance between the cathode and the anode = 5.5 mm. Internal and external operational characteristics have been studied at this optimum distance using hydrogen, nitrogen and argon gases.

Key words: *Glow discharge ion source, plasma sputtering, etching processes.*

INTRODUCTION

Glow discharges have been known for over 50 years as ion sources for atomic spectroscopy [1], mainly used in mass spectrometry [2] and optical emission spectrometry [3, 4]. Glow discharges are used in various applications such as deposition of thin films, etching and modification of surfaces in semiconductor industry and materials technology [5]. The glow discharge plasma [5] is created by applying a potential difference between two electrodes of certain distance apart in a partial vacuum. The potential difference is either constant in time (d.c. mode) or it can vary as a function of time (r.f. mode). The glow discharge owes its name to the fact that plasma is luminous [6]. Plasma is generated by supplying energy to a neutral gas causing the formation of charge carriers. Electrons and ions are produced when electrons with sufficient energy collide with the neutral atoms or molecules in the feed gas via electron impact ionization or photo ionization. The luminous glow is produced when the electrons have enough energy to generate visible light by excitation collisions. Since there is a continuous loss of electrons in the discharge, there must be an equal degree of simultaneous ionization to maintain a stable discharge. Additional electrons are produced by secondary emission from the cathode.

In glow discharge, there are three basic regions that are formed in the discharge, the cathode region, the glow region and the anode region. The plasma density at any point at the cathode remains constant, but the cathode area is not fully covered by the glow. The onset of the normal discharge is highly dependent on the shape, size and the material of the electrodes. After the negative glow fully covers the cathode area, a further increase of current results in a rise of the discharge voltage and thus in the plasma density.

Glow discharge plasmas are usually used in an abnormal glow regime for material processing, because in this operational mode the cathode is fully covered by the glow, which offers the possibility of uniform surface ion implantation by high energy ions [7]. In the last two decades, glow discharge devices have gained increasing interest in analytical spectrometry [8]. The use of a glow discharge for the mass spectrometric analysis of solids implies the understanding of three basic phenomena that determine the analytical performance of a glow discharge system, atomization and ionization of the sample material and ion extraction from the discharge. Atomization in a glow discharge is the result of cathode sputtering and depends on three experimental parameters such as, discharge current, discharge voltage and gas pressure.

In this paper, the design and construction of a compact glow discharge ion source are described. The discharge characteristics are measured at different pressures for various distances between the anode and the cathode using argon gas. From the discharge characteristics curves, we can determine the relation between the discharge voltage versus the gap distance between the anode and the cathode for different discharge currents at various gas pressures. The relation between the output ion beam current and the gap distance between the anode and the cathode is obtained with different measurements at different pressures using argon gas. Discharge and output ion beam characteristics have been investigated using hydrogen, nitrogen and argon gases to determination of the highest efficiency of the ion source.

EXPERIMENTAL SETUP

A schematic diagram of the high efficiency glow discharge ion source and its associated electrical circuit is shown in Fig.1. This ion source consists of aluminium Pierce shape anode with small aperture to confine the discharge and aluminium plane cathode. The anode has an internal diameter equal to 28 mm at the upper side and 10 mm diameter at the lower side and its length is 17 mm. The aluminium cathode has an aperture of diameter equal to 1.5 mm and length equal to 5 mm. Both the Pierce anode and the plane cathode are immersed in an insulator of Perspex material. The collector (Faraday cup) is situated at a distance of 5 cm from the ion exit aperture of the cathode and used to measure the output ion beam current. The working gas is admitted to the ion source through a hose fixed in a Perspex flange at the upper side of the anode. A 10 kV power supply is used for initiating the discharge (glow discharge) between the anode and the cathode.

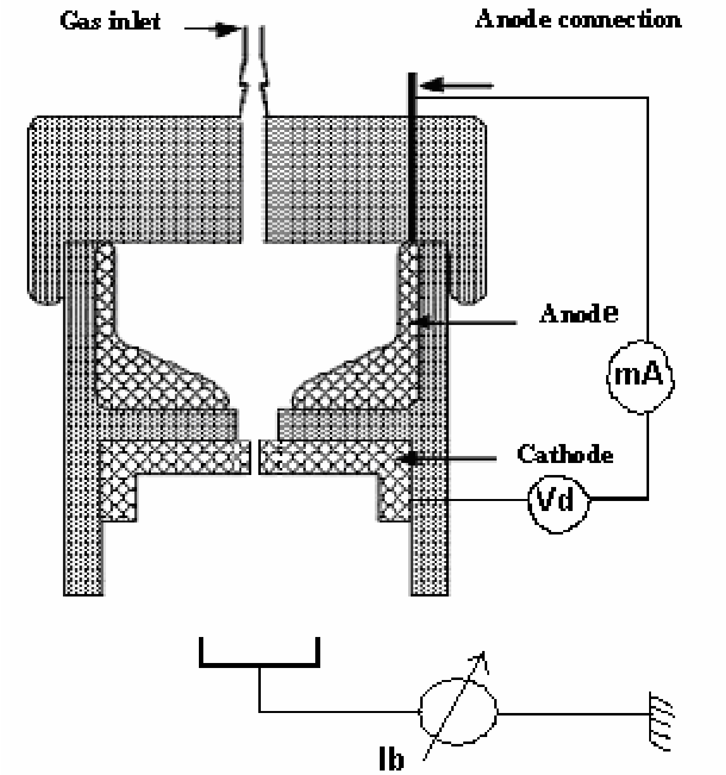

Figure 1. Schematic diagram of the ion source and its associated electrical circuit.

A complete vacuum system is used to evacuate the ion source chamber. It consists of stainless steel mercury diffusion pump of speed 270 l/s provided with electrical heater and backed by 450 l/min. rotary fore-line vacuum pump. The rotary pump is used to evacuate the system to pressure of 10^{-2} to 10^{-3} mbar, while the mercury oil diffusion pump is used to evacuate the ion source vacuum chamber to the order of 10^{-5} mbar. A liquid nitrogen trap is fixed between the ion source chamber and the mercury oil diffusion pump in order to prevent the mercury vapour from entering the ion source chamber. The working gas is transmitted to the ion source from a gas cylinder through a needle valve to regulate the rate of gas flow.

EXPERIMENTAL RESULTS AND DISCUSSION

Figures 2, 3, 4 and 5 show the discharge characteristics using argon gas, i.e. the relation between the discharge voltage, V_d, and the discharge current, I_d, at different gas pressures, p, for different values of gap distance, d, between the anode and the cathode equal to 5.5, 6.4, 9 and 11 mm, respectively. From these figures, it was found that an increase of the discharge voltage was accompanied by an increase of the discharge current, where the characteristics of such discharge is characterized by abnormal glow [9].

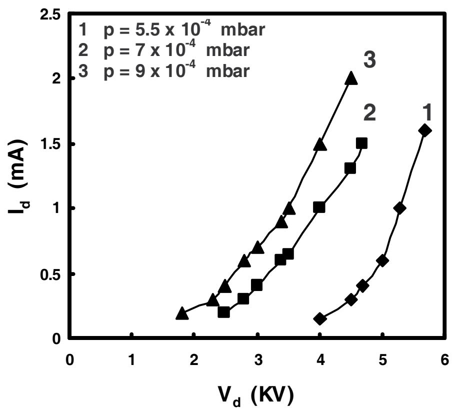

Figure 2. The discharge current versus discharge voltage at different gas pressures for the distance d between the anode and the cathode equal 5.5 mm using argon gas.

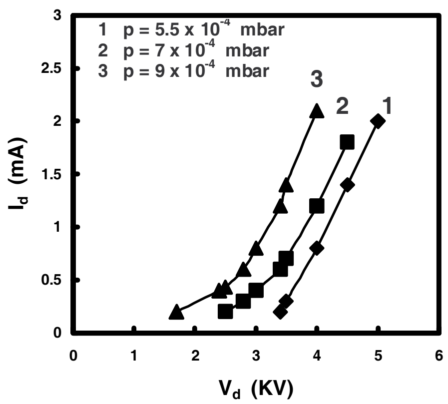

Figure 3. The same as in Figure 2 for d = 6.4 mm.

In this ion source, a self-extracted ion beam current is obtained. Figures 6, 7, 8 and 9 show the ion beam efficiency, i.e. the relation between the output ion beam current, I_b, and the discharge current, I_d, for different values of the gap distance between the anode and the cathode at various gas pressures using argon gas. From these figures, it is clear that, when the discharge current increases, the output ion beam current increases and reaches its maximum value at a gap distance equal to 5.5 mm for a pressure of 5.5 x 10^{-4} mbar. This ion source exhibits a favourite confined behaviour due to a mechanical constriction at the lower end of the anode and high electric field strength in the gap with a small gap.

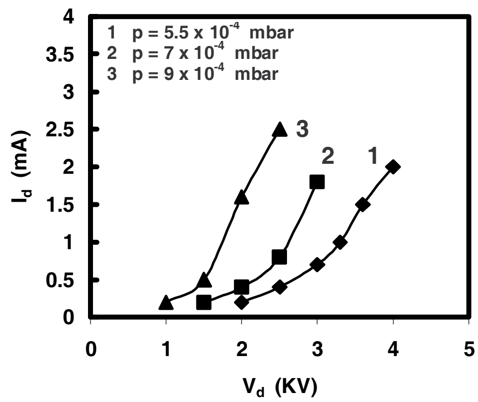

Figure 4. The same as in Figure 2 for d = 9 mm.

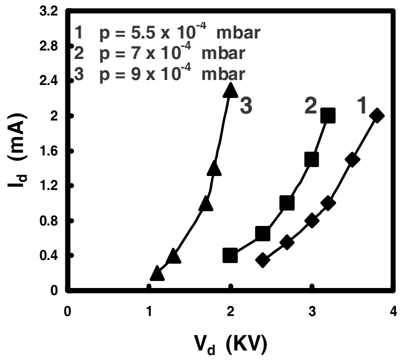

Figure 5. The same as in Figure 2 for d = 11 mm.

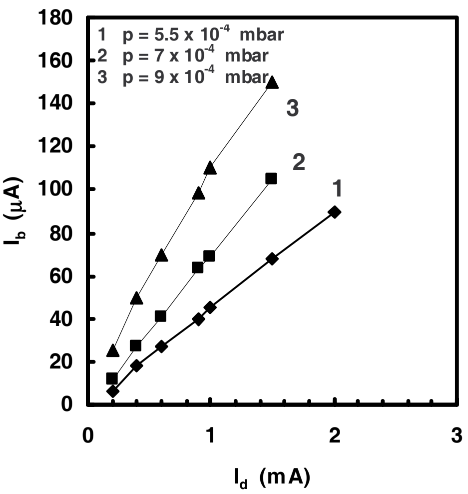

Figure 6: The output ion beam current versus the discharge current at different gas pressures for the distance d between the anode and the cathode equal to 5.5 mm using argon gas.

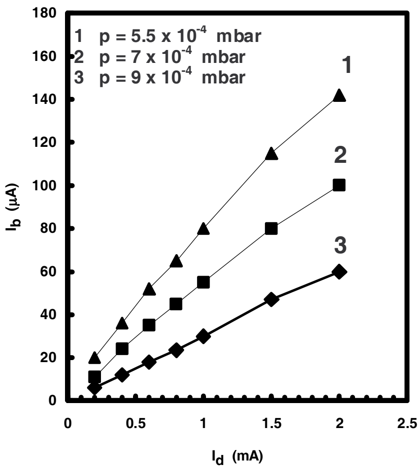

Figure 7. The same as in Figure 6 for d = 6.4 mm.

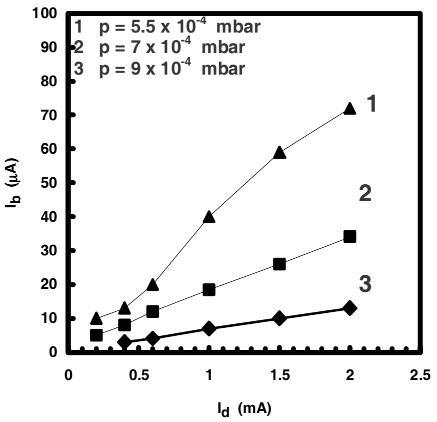

Figure 8. The same as in Figure 6 for d = 9 mm using argon gas.

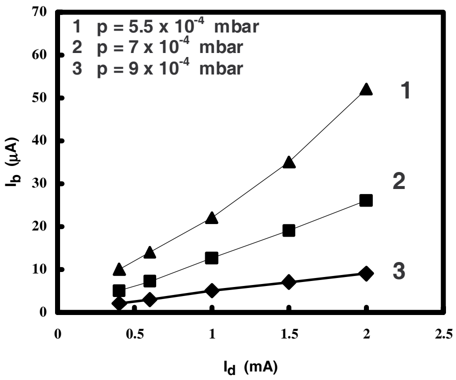

Figure 9. The same as in Figure 6 for d = 11 mm.

Figure10 shows the relation between the output ion beam current with gap distance between the anode and cathode at a discharge current of 1.5 mA and a pressure equal to 5.5 x 10^{-4} mbar using argon gas. It is clear from this figure that, an increase of the output ion beam current by decreasing the gap distance from 11 mm to 5.5 mm. It was found experimentally that the discharge is unstable for d < 5.5 mm, so the optimum gap distance between the anode and the cathode in our experimental device is 5.5 mm.

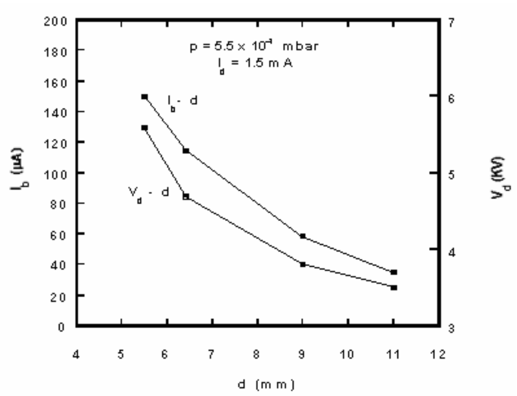

Figure 10. The output ion beam current and the discharge voltage versus the gap distance between the anode and cathode using argon gas.

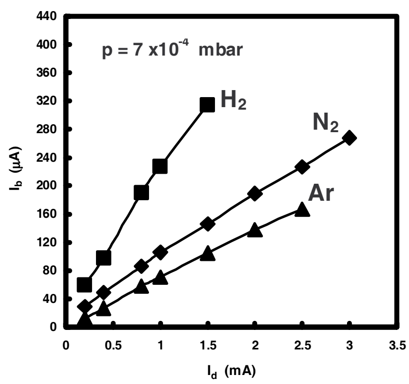

Figure 11. The output ion beam current versus the discharge current using various gases at d = 5.5 mm.

Figure 11 shows the relation between the output ion beam current and the discharge current at gas pressure equal to 7 x 10^{-4} mbar. From this figure, it is clear that, at discharge current equal to 1.5 mA, and gap distance equal to 5.5 mm, the output ion beam current of hydrogen, nitrogen and argon gases are 315, 145 and 105 μA respectively. This is due to the difference in mass and ionization efficiency.

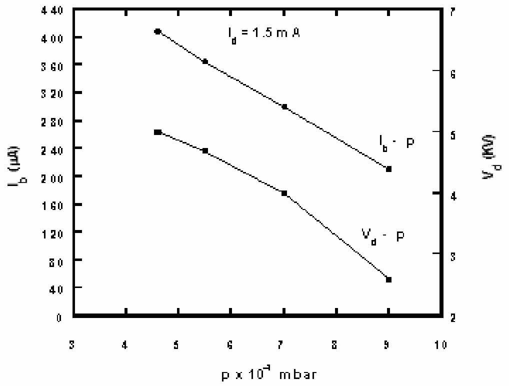

Figure 12. The output ion beam current versus the pressure using hydrogen gas at d = 5.5 mm.

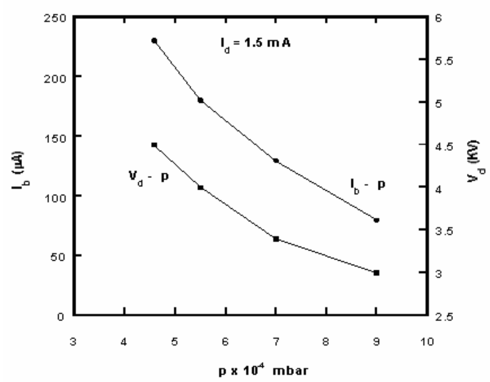

Figure 13. The output ion beam current versus the pressure using nitrogen gas at d = 5.5 mm.

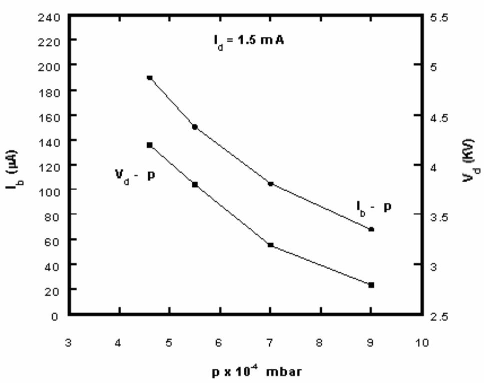

Figure 14. The output ion beam current versus the pressure using argon gas at d = 5.5 mm.

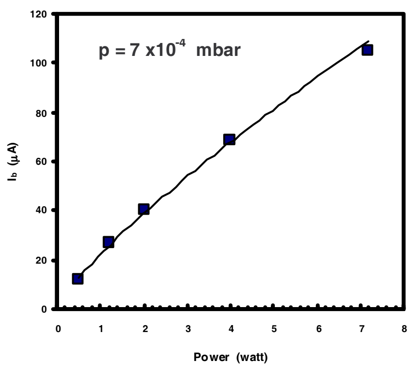

Figure 15. The output ion beam current versus the power using argon gas at d = 5.5 mm.

Figures 12, 13 and 14 show the relation between the output ion beam current and discharge voltage with gas pressure at discharge current, I_d = 1.5 mA and at the optimum gap distance between the anode and the cathode using hydrogen, nitrogen and argon gases respectively. It is clear that both the output ion beam current and discharge voltage increase by decreasing the pressure, i.e. the rate of etching of any specimen exposed to the output ion beam of any gas increases by decreasing the pressure [10]. It is also clear that the maximum output ion beam current and discharge voltage were obtained at an optimum pressure equal to 4.6 x 10^{-4} mbar where the etching rate is maximum due to the ion beam current extracted from a stable discharge.

Figure 15. shows the relation between the output ion beam current versus the power using argon gas at gap distance equal to 5.5 mm. It was found that an increase of power was accompanied by an increase of the output ion beam current, consequently, the efficiency of the ion source increased.

CONCLUSION

Design and construction of a glow discharge ion source with high output ion beam current have been made in the department of Accelerators and Ion Sources, Atomic Energy Authority, Egypt. This ion source has compact size and is featured by easy and long stable operation using hydrogen, nitrogen and argon gases. To maximize the output ion beam current produced by the source, the gap distance between the anode and the cathode must have an optimum value. The optimum gap distance between the anode and the cathode was found to be 5.5 mm, where a stable discharge current could be obtained with maximum output ion beam current and energy. When the mechanical geometry, the plasma and the operational parameters are matched, the beam divergence is minimum. This ion source can be used for etching, sputtering and micro-machining applications.

REFERENCES

[1] Pisonero, J., et. al., *J. Anal. At. Spectrum* **16**, 1253-1258(2001).
[2] "*Glow Discharge Spectroscopes*", Ed. Marcus, R.K., Pleunm Press, New York, 1993.
[3] Qayyum, A., et al, *Plasma Chemistry and Plasma Processing* **25**, 551–565(2005)
[4] Dreyfus, R.W., et al, *Pure & Appl. Chem.* **57**, 1265–1276(1985).
[5] Bogaerts, A., et al, *Surf. Interface Anal.* **35**, 593–603(2003).
[6] Conrads, H., et al, *Plasma Sources Sci. Technol.* **9**, 441–454(2000).
[7] Qayyum, A., et al, *Plasma Devices and Operations* **14**, 61-70(2006).
[8] Budtz-Jorgensen, C.V., "*Studies of Electrical Plasma Discharges*", Ph.D. Thesis, Faculty of Science, Aarhus University, Denmark (2001).

[9] Vertes, A., et al., *Mass Spectrometry Reviews* **9**, 71-113(1990).

[10] Wilson, R.G., and Brewer, G.R., *Ion Beam with Applications to Ion Implantation*, John Willy and Sons, New York, 1973.

مصدر الأيونات ذو التفريغ الكهربي المتوهج عالي الكفاءة

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في هذا البحث، تم تصميم و دراسة خصائص مصدر أيونات جديد و الذي يعمل باستخدام التفريغ الكهربي المتوهج. يعتبر مصدر الأيونات الجديد ذاتي الاستخراج ، و يتميز بصغر حجمه (طول = ٣,٥٤ سم ، عرض = ٣,١٤ سم) ، سهل التشغيل ، و ذو تفريغ كهربي متوهج مستقر. و قد وجد أن أفضل ظروف تشغيل عند ضغط في حدود $١٠^{-٤}$ تورشيللى و مسافة الفجوة بين المصعد و المهبط = ٥,٥ مم. عند هذه المسافة المفضلة ، تم دراسة خواص التشغيل الداخلية و الخارجية لهذا المصدر الجديد و ذلك باستخدام غازات الهيدروجين و النيتروجين و الأرجون.