EXTENSION OF THE OPERATION REGIME OF AN ION SOURCE

Tar Ortiz[1], J. Pérez-Peraza[2,3], W. Calleja.[3]
1 Instituto Nacional de Investigaciones Nucleares, C.P. 18-1027, 11801, México, D.F.
2 Instituto de Geofísica, UNAM, 04510 C.U. México, D.F.
3 Instituto Nacional de Astrofísica, Optica y Electrónica, A.P. 51 y 216, 72000 Puebla, Pue. México.

Recibido: 25 de octubre de 1990 , Aceptado: 21 de noviembre de 1990.

RESUMEN

Se presenta un método para prolongar el régimen de operación de fuentes de iones acorde a las características del haz de partículas en diversos tipos de dispositivos que contengan una fuente de iones, tales como en aceleradores, generadores de plasma, implantadores de iones, inyectores de neutrones, tokomaks, etc.

ABSTRACT

We present in this work a method to lengthen the operation regime of ion sources, according to the peculiarities of the particle beam which is required by the user. This method can be applied to any kind of equipment containing an ion source, for instance, particle accelerators, plasma generators, ion implantators, tokomaks, neutron injectors, etc.

INTRODUCTION

Nowadays a great variety of scientific and industrial equipments require an ion source. Each one of such equipments employes ion beams of different characteristics. These peculiar properties depend on the purposes of each equipment. Though the ion source is only a component of the mentioned equipments, they are however of fundamental importance to reach the main goal of the research, or the production processes in consideration. Very often such researches or processes are delayed due to the natural erosion of the source electrodes of the ion source, after some time of continuos works. This erosion take place just at the level of the openings of electrodes to the passage of the ion beam. Therefore, the electrodes need to be replaced with a certain frecuency, which is not a complicated task, but implies however an interruption of the process, discontinuity of the required vaccum, etc. In order to reduce the frecuency of electrode replacements, it is of great importance to develop techniques for the prolongation of the adequate operation regime of ion sources with eroded electrodes.

THE EXTRACTION MODEL

The ion extraction model is based in previous works, with explicit consideration of the anode thickness (Ortíz, et al 1990) the opening of the extractor electrode (Ortíz, et al 1983) and the erosion effects (Ortíz et al 1986). Such a model is in fact based on the Popov's model (Popov, 1962), which allows for the determination of the distance from the plasma boundary to the extraction electrode. The original Popov's model does not consider the dependence on the extractor opening nor the effect of the anode thickness. For practical purposes, when an ion source and the corresponding extraction system is constructed, it is necessary to determine both the extractor opening and the anode thickness because the value of these parameters can modify the extraction regime.

The original Popov's expression starts with the Chil-Lagmuir's law (Langmuir, 1912)

$$I = 5.45 \times 10^{-8} \left(V^{3/2} S/d^{2} \sqrt{Z} \right) \qquad (1)$$

where I is the currente in amperes, V is the cathode-anode potential difference in volts, d is the distance between electrodes in cm, Z is the molecular weight of the carriers, and S is the emission area of the cathode (virtual cathode) in square centimeters. From this law, through a geometrical analysis of the arrangement of the electrodes on the extraction system (see Fig. 1), Popov deduces an expression for the distance from the extraction electrode to the plasma boundary:

$$d = \frac{3.7 \times 10^{-2} V^{3/4} D}{1 + 3.7 \times 10^{-2} V^{3/4} I^{1/2} (D - \Phi) l^{-1}} \qquad (2)$$

where d is the distance between the plasma boundary and the extraction electrode, D is the plasma cone cross-section diameter at the extraction electrode, Φ is the anode opening diameter, and l is the anode-extraction electrode distance.

In order to take into account the influence of the new parameters on the extraction system we start with the Chil-Lagmuir modified law by introducing an effective distance (Semaschko, 1981)

$$I = 5.45 \times 10^{-8} (V^{3/2} S/d_{\mathrm{eff}}^{2} \sqrt{Z}) \qquad (3)$$

where $d_{\mathrm{eff}} = d + r + \delta$, r is the radius of the extraction electrode aperture, and δ is the anode thickness. In this case, to derive an expression for the distance from the extraction electrode to the plasma boundary, through a geometrical analysis of the arrangement of the electrodes on the extraction system, we note that is necessary also to introduce an effective diameter D_{eff} which corresponds to the effective distante l_{eff} (Ortíz and Vazquez, 1983). From Fig. 1 it follows that the expression for l_{eff} and D_{eff} are

$$l_{\mathrm{eff}} = 1 + (r + \delta) \qquad (4)$$

$$D_{\mathrm{eff}} = D \left[1 + \frac{(r + \delta)}{l} \right] - \frac{(r + \delta)}{l} \qquad (5)$$

By introducing these changes, the distance between the plasma boundary and the extraction electrode is

$$d = \frac{3.7 \times 10^{-2} D V^{3/4} I^{-1/2} - (r + \delta)}{1 + 3.7 \times 10^{-2} (D - \Phi) l^{-1} V^{3/4} I^{-1/2}} \qquad (6)$$

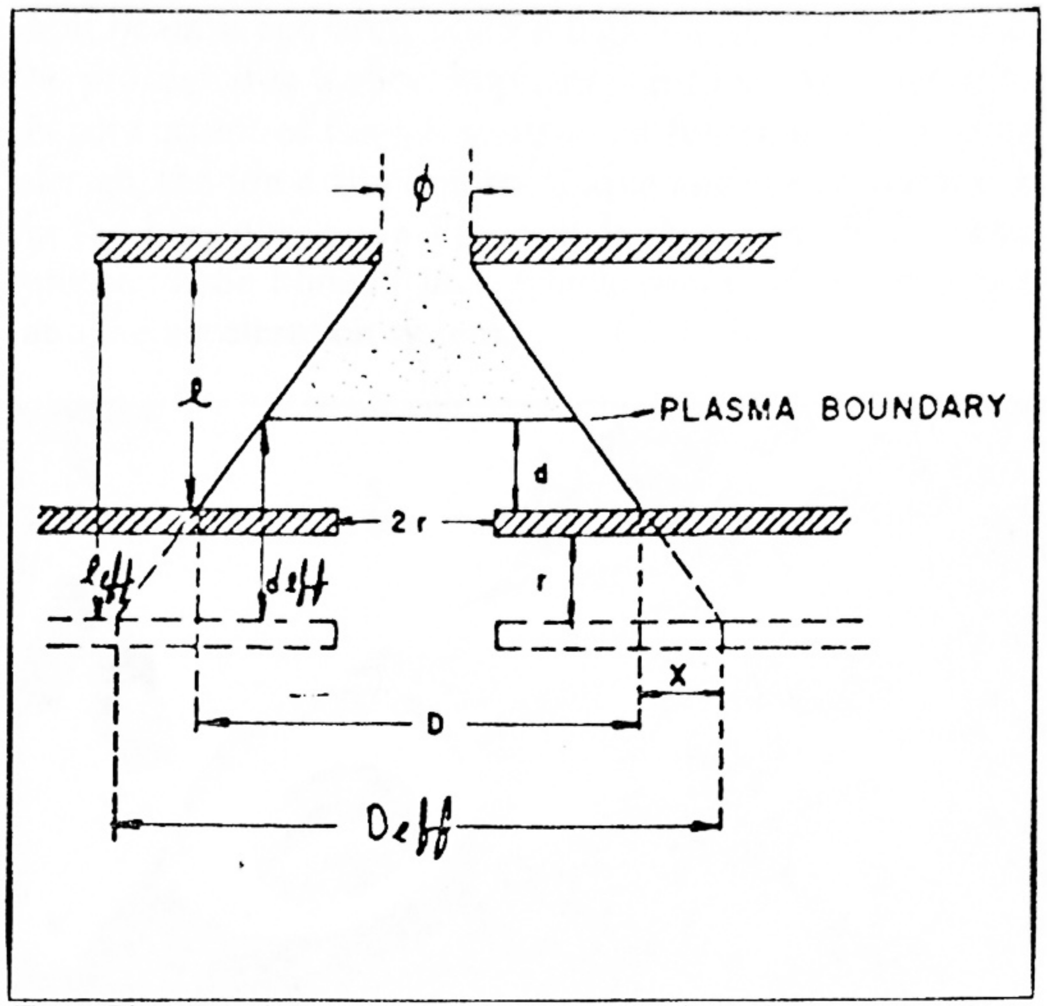

Fig. 1 Diagram of the electrode arrangement in an ion source extraction system.

where V is the extraction potential in kV; I is the output ion current in amperes; D, Φ, r and δ are given in cm. The expression allows us to calculate the extraction electrode-plasma boundary distance as a function of all geometrical parameters of the extraction system. The distance d includes the effect of the extraction electrode opening, as well as the effect of the anode thickness.

THE ION IMPLANTATOR

Ion implantators are commonly employed for the introduction of impurities in the semiconductor materials that are used, for instance, in the production of complementary MOS integrated circuits (Calleja, 1989). In general, an ion implantator consists of an ion source, an extraction system,

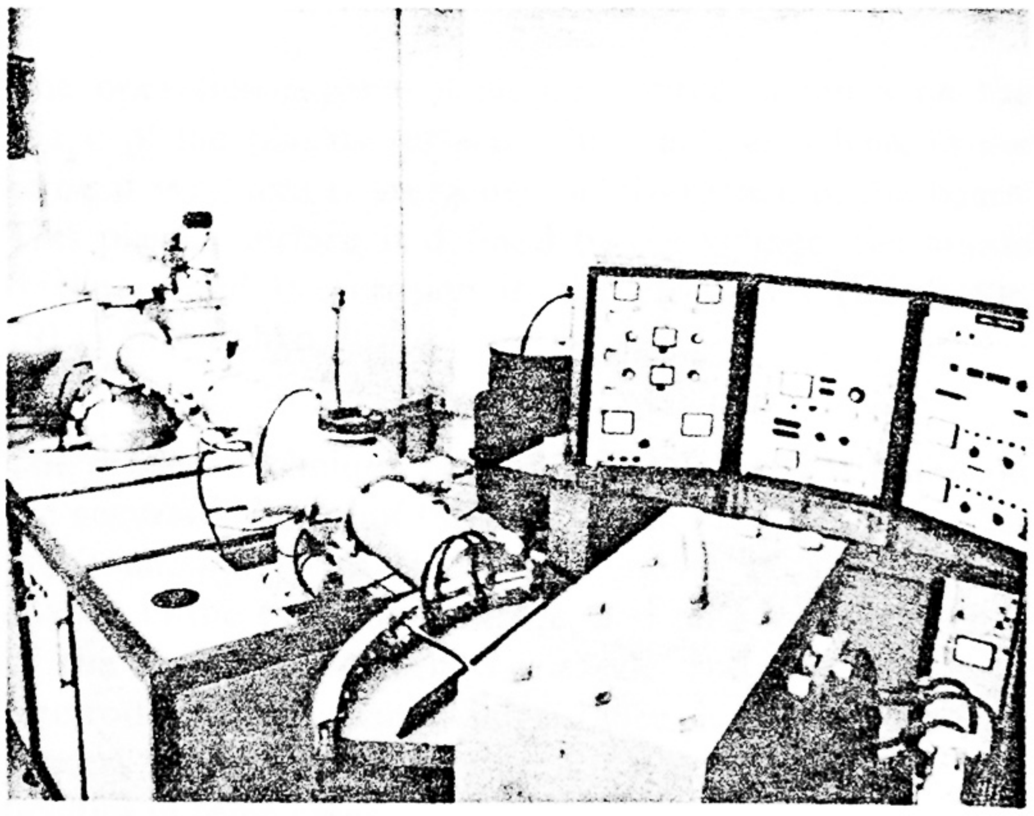

Fig. 2 General view of the Ion Implantator for the MOS processes at INAOE.

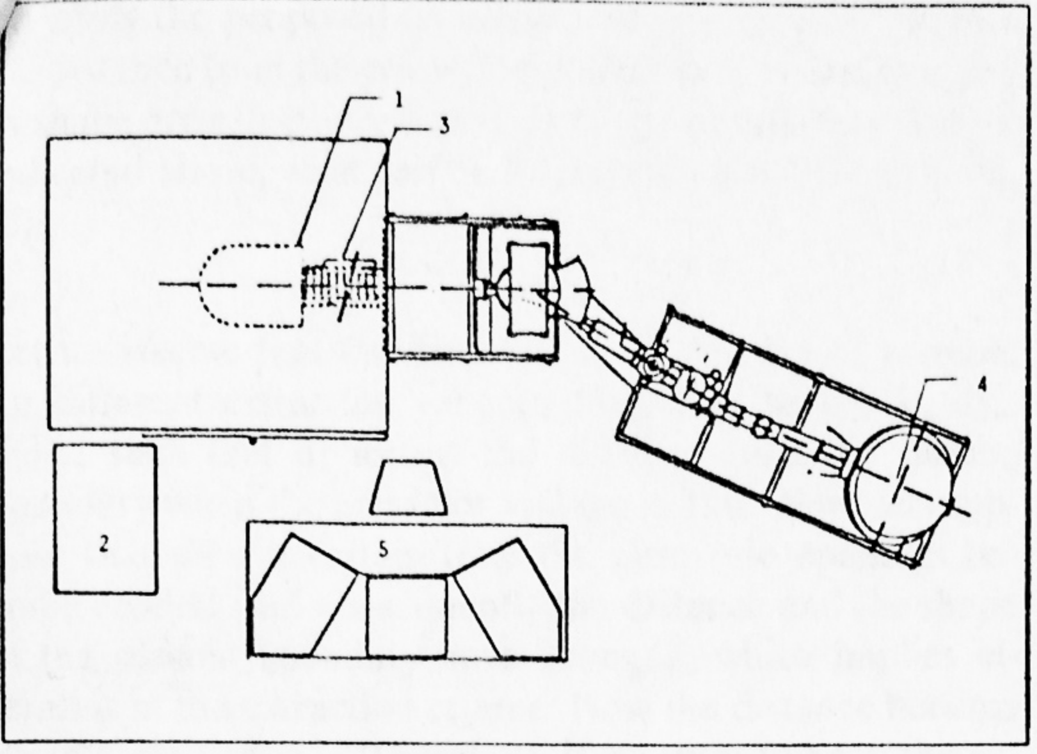

Fig. 3. Diagram of the implantator of ions type MPB 202: 1.ion source, 2.voltaje unit, 3.extraction system, 4.implantation chamber, 5.control desk.

and an acceleration and sweeping system for the uniform distribution of ions on the substrate. In Fig. 2 and Fig. 3 it is shown respectively a general view and schematic diagram of the ion implantator MPB-202 which is employed at INAOE for MOS processes (Calleja, 1989).

The system MPB-202 has an ion source which is able to operate with a wide variety of materials. It is often more convenient the use of gaseous materials, since in this way it is avoided the employement of a vaporization chamber, as with solid materials. The MPB-202 of INAOE is at present working with: Boron Trifluoride (BF_3), Phosphorus Pentafloride (PF_5) and Arsenic Trifluorure (AsF_3), in order to implante positive ions of Boron, phospurus and arsenic respectively (Calleja, 1989).

The effectiveness of an ion source is measured in terms of the ion current intensity which is delivered to the accelerator and finally implanted in the sustrate. A high current beam is required when a high amount of wafers must be processed in a short implantation time. In practice the beam current of the ion source is a function of the system design, the ion extraction technique and the material used in the ion source. In Fig. 4, it is shown the high voltage unit, and the blinded unit, which contains the ion source and the acceleration system.

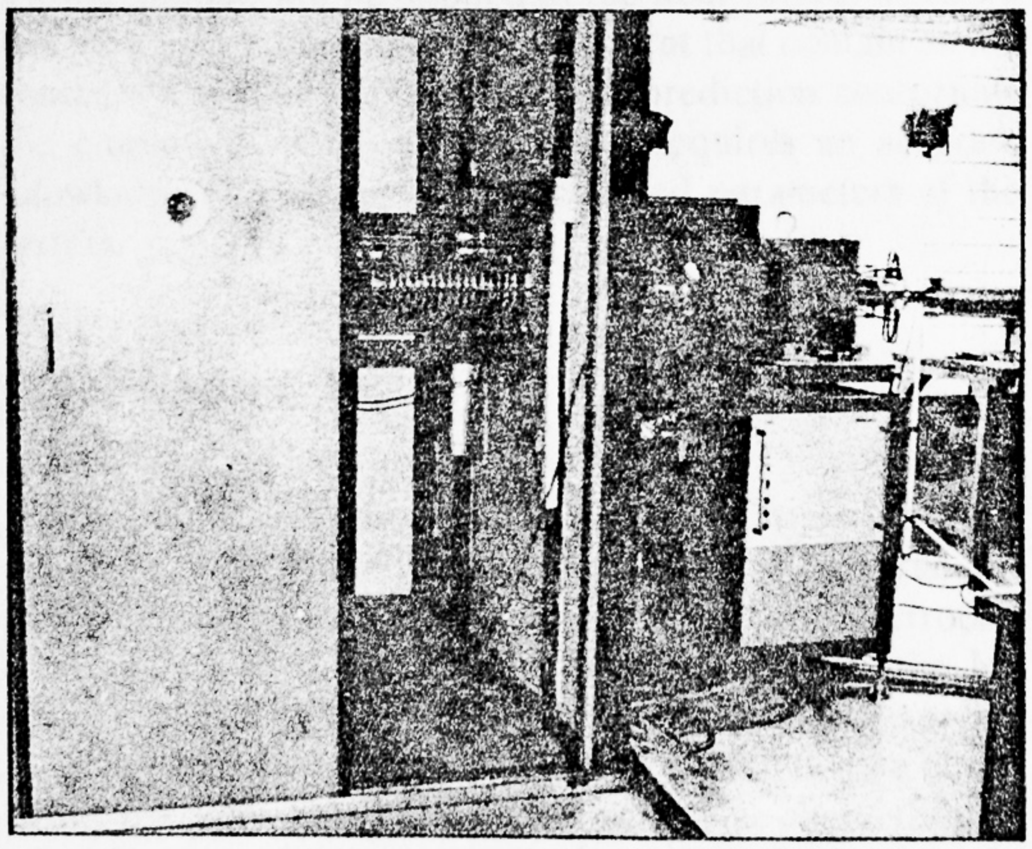

Fig. 4. The high voltage unit and the blinded unit with lead.

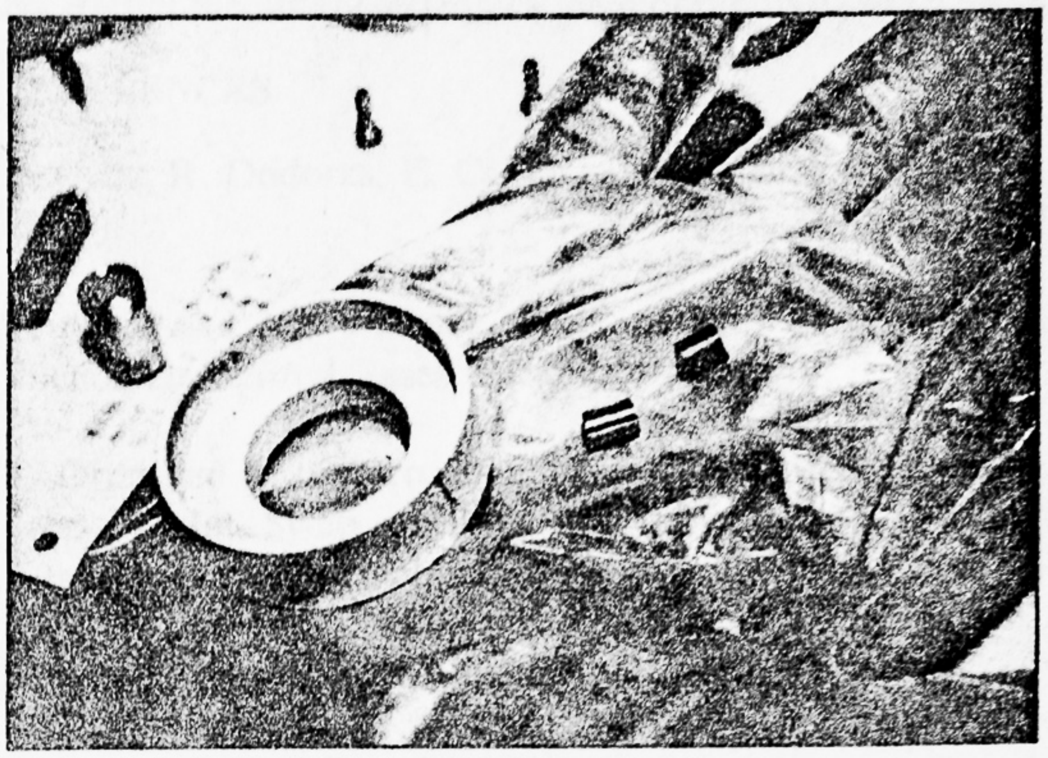

Fig. 5 View of the electrode replacement.

APPLICATION

As we stated before, a frecuent problem in the employement of ion sources is the erosion of the electrode opening. This erosion results in a change of the boundary between the plasma and the extractor (see eq. 6), which in turn is translated in alterations in the operation regime of the ion sources. For this reason it is necessary to change periodically the eroded electrodes (see Fig. 5).

The operation regime of an ion source depends on the shape of the plasma surface, which acts as a lens, in the sense it produces convergence or divergence of the beam. This plasma surface is defined by the voltage, the anode thickness and the erosion in the electrodes (Langmuir, 1912 y Semaschko, 1981).

The original technique proposed in this work is based on the accurate control of the position and shape of the plasma boundary. This is done by means of an adequate change in the extraction voltage, and an adequate change of the distance between the anode and the extraction electrode. This change in distance is not an obvious process in every ion source, and it may present some difficulties in some cases.

o apply the proposed technique we begin by testing that he distance from the plasma boundary to the extractor and its shape are effectively functions of the parameters that we indicated above, what can be directly done by means of eq. (6).

Let us assume that the distance, d, in absence of erosion, for different extraction voltages (kv), may be d_1, d_2, d_3... d_{10}...., such that d_1 means the distance from the plasma boundary when the extractor voltage is 1kv. Now, lets suppose that after a certain time the electrode openings become eroded, and consequently the distance and the shape of the plasma boundary have changed, which implies alteratins in the extraction regime. Now the distance become d'_1, d'_2, d'_3 ... d'_{10},.... Therefore, if we want to keep the extraction regime with a constant current, after the electrodes have been substantially eroded, we need to keep the distance of the plasma boundary to the extractor and the plasma boundary shape constant; that means, we need that $d_1 = d'_1$, $d_2 = d'_2$ ...$d_{10} = d'_{10}$. From this conditions, we see in eq. 6 that it is necessary to vary the voltage and/or the distance among electrodes (depending on the particular case), according to the following expressions:

$$V = \left[\frac{d + r}{M \left[1 - (D - \Phi) \right] l^{-1} D^{-1} d} \right]^{4/3} \tag{7}$$

$$l = \frac{d M (D - \Phi) V^{3/4}}{D \left[M V^{-3/4} - (d + r) \right]} \tag{8}$$

where $M = 3.7 \times 10^{-2} DI^{-1/2}$

This technique will be applied in the near future, when we will have easy access to some equipment that contain an ion source. It can be realized that any prediction concerning the employement of this technique requires an accurate knowledge of each one of the involved parameters of the system.

CONCLUSIONS

A new technique is proposed to extend the mean life of the adequate operation of ion sources, by controlling variations in the extraction voltage V, and distance among electrodes, l, according to the particular characteristics of the ion beam required by the user. This technique may be applied to any system containing an ion source. The degree of difficulty to apply it depends on the particular characteristics of each system, but in general it is a relatively simple technique. We will begin to apply it on the MPB-202 ion implantation system at INAOE.

ACKNOWLEDGEMENTS

We want to extend our thanks, to the research and technical staff of the microelectronics team of the INAOE.

REFERENCES

T. Ortiz, R. Ondorza, E. Camps, Rev. Scien. Inst. **61**, 653 (1990).

T. Ortiz and M. Vazquez, Proc. of XVI Int. Conf. of Phenom. in Ionized Gases, Düsseldorf, 1983.

T. Ortiz and M. Castro, Proc. of XIII Yugoslav Summer School & Int. Symp. on Phys. of Ionized Gases, Sibenik, Yugoslavia, 1986.

S.N. Popov, Soviet Physics Technical Phys. **6**, 1047 (1962).

J. Sangmuir, Phys. Rev. **2**, 450 (1912).

N.N. Semaschko, "*Inzhektory Buistri Atomov Vodorada*", Energoisdat, Moscow (1981) (In Russian).

W. Calleja, "Technology for ion implantation in MOS processes", Internal Technical Report of INAOE, Tonantzintla, Pue., MEXICO, 1989 (in Spanish).