Pramāṇa. Vol. 2, No. 1, 1974, pp 46–50. Printed in India.

Characteristics of electrostatic charged particle oscillator ion sources

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MS received 29 October 1973

Abstract. Two ion sources of the charged particle oscillator type are described. The discharge chamber consists of an outer cylinder as cathode and an axial wire or a pair of wires along the axis as the anode. The energy spectra and ionic composition of the ion beam have been measured with a double focusing mass spectrometer of the Mattauch–Herzog design constructed in the laboratory. A high percentage of dissociated ions and multiply charged ions has been observed in the ion beam. A brief description of the mass spectrometer is also given.

Keywords. Mass spectrometry; ion sources; gas discharge.

1. Introduction

In recent years, a new method of obtaining gas discharges at low pressures has been developed, using the confinement of charged particles by electrostatic fields. A radial electrostatic field caused by an axial anode enclosed by a cylindrical cathode provides a long oscillatory path for electrons, which can therefore cause ionization of a large number of gas molecules before being finally collected by the anode. Two slightly different configurations have been employed, one by McClure (1963) involving a single fine wire as the anode situated along the axis of a surrounding cathode cylinder, and the other by McIlraith (1966) involving two fine wires at the same potential as the anode situated parallel to but symmetrically displaced on either side of the axis of the surrounding cylindrical cathode. Both the configurations provide stable discharges at low gas pressures without the need for a magnetic field and have wide applications as ion pumps, ion gauges and ion sources. Fitch *et al* (1970) first used the two wire anode design as an ion source and measured the variation of positive ion current with the collector position along the radial and axial directions. Mukherjee and Bhattacharya (1972) have measured the variation of discharge current and ion current with the anode potential at different gas pressures. Fitch *et al* (1971) have used the discharge device also as an ion gauge using an external heated filament for electron emission and found that the gauge has a very high sensitivity of the order of 70000 $Torr^{-1}$ and a linear response in the pressure range of 20 μTorr to 0·2 nTorr. The McClure design has also been used for an ion gauge of the orbitron type with external electron injection and is found to have a high sensitivity (Fitch *et al* 1969, Fitch and Rushton 1970 a).

These ion sources provide very intense ion beams and are therefore suitable for the purposes of ion implantation, specimen thinning and etching. Also the simplicity of design and the operation at low pressures suggest use of these ion sources for mass spectrometric analysis. However, data regarding the energy spectra and ionic composition of the ion beams produced by such sources do not appear to be available in the literature. We present here the results of investigations on these characteristics of the ion sources. Preliminary studies on the McClure type source were reported by us earlier (Swaminathan and Venkatasubramanian 1972).

2. Experimental

The two designs of the ion source are shown schematically in figure 1. In the McClure design, the cathode is a stainless steel cylinder of length 25 mm and internal diameter 25 mm, to whose ends are fixed end plates with a central aperture of 6 mm diameter, held at the same potential as the cathode. The anode, which is a tungsten wire of 0·1 mm diameter, is situated along the axis of the cylinder and passes through the apertures in the end plates. The two ends of the anode are fixed to porcelain insulators and the anode wire is maintained taut by springs mounted at the ends. The cathode cylinder has a 1 mm slit along its length to allow extraction of positive ions in the radial direction. The extraction voltage is applied between a pair of electrodes mounted in front of the slit in the cathode, one of them being the defining slit of width 0·6 mm.

In the ion source of the McIlraith design, the cathode has an identical geometry and an identical configuration of extraction electrodes is employed. However, the anode consists of a pair of tungsten wires 0·1 mm diameter and 3 mm apart, situated parallel to the axis of the cylinder such that the plane of the wires is perpendicular to the direction of ion extraction.

Studies on the energy spectrum of the ion beam extracted from the ion sources and its ionic composition have been carried out using a double focusing mass spectrometer of the Mattauch–Herzog design, constructed in the laboratory. The mass spectrometer has a magnetic analyser housing composed of mild steel side plates separated by 6 mm spacers. To this is brazed a tube of 10 cm inner diameter to hold the electrostatic analyser. The electrostatic analyser is of the cylindrical condenser type with a mean radius of 10 cm and a sector angle of 31° 50′ and is

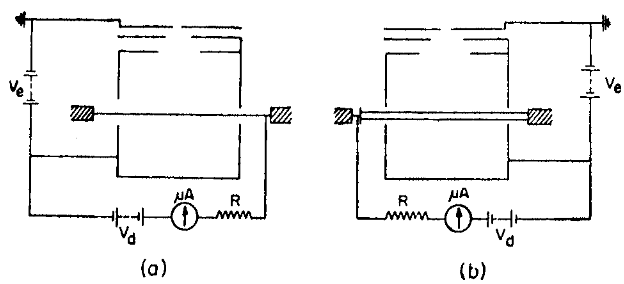

Figure 1. Schematic diagram of the ion sources (*a*) McClure design and (*b*) McIlraith design

mounted on a flange resting on the tube, being supported on threaded insulating pillars. A β-slit is provided 5 cm away from the exit of the electrostatic analyser and there is a monitor electrode behind the β-slit. Ions after mass resolution are collected by a Faraday cage at a radius of 10 cm. The mass spectra are obtained by scanning the magnetic field, while the energy spectrum is obtained by noting the monitor current as a function of the electrostatic analyser voltage.

Differential pumping is employed between the source and analyser regions, the pressures being measured by Penning gauges. The discharge gas is let into the cathode cylinder from the gas reservoir by a needle valve through a glass capillary tube. For studying the energy spectrum argon was used as the discharge gas, while various gases were used to study the pattern of dissociation in the discharge.

The ion sources were operated at anode voltages of the order of 2 kV and pressures in the range of 10^{-4} to 10^{-5} Torr. Stable discharges were obtained under these conditions with discharge currents of 10–100 μA for the McClure source and 50–250 μA for the McIlraith source. With an ion extraction voltage of 1 kV, resolved ion currents were obtained in the range of 10^{-9} A.

3. Results and Discussion

The energy spectra of positive ions extracted from the two sources are shown in figure 2. In both cases the anode voltage was 2 kV and the extraction voltage was 1 kV. It is found that in the McClure source, the mean energy of the ions is greater than the extractor voltage by about 700 V. Kingdon (1923) has shown that for the electrostatic configuration as in the McClure design, the electrons execute repeated oscillations in the vicinity of the anode and cause ionization of a large number of gas molecules. The positive ions are extracted from the positive ion sheath as it is pushed away from the anode. A value for the mean energy, intermediate between the extractor voltage and the sum of the anode and

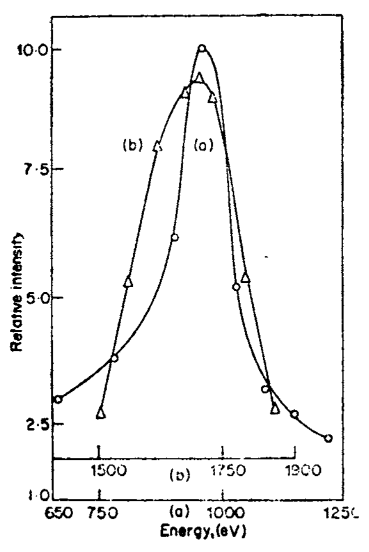

Figure 2. Energy spectra of the ion beams from the two sources (*a*) McIlraith source and (*b*) McClure source

Table 1. Dissociation pattern for different gases

Gas	Ion species	Relative Intensity		
		EB source	McClure source	McIlraith source
Hydrogen	H_2^+	..	..	100·0
	H^+	..	..	15·3
Nitrogen	N_2^+	100·0	100·0	100·0
	N^+	7·0	25·3	92·0
Oxygen	O_2^+	100·0	100·0	100·0
	O^+	11·0	32·2	26·4
Carbon dioxide	CO_2^+	100·0	100·0	100·0
	CO^+	11·5	35·0	82·2
	C^+	6·0	10·0	6·7
Argon	A^+	100·0	100·0	100·0
	A^{2+}	10·0	7·0	24·6

extractor voltages, is probably indicative of the sheath as being the major source of ionization. In the McIlraith source, however, the ions do not seem to gain much energy from the discharge, suggesting the saddle-point region between the anode wires as the source of ion production. The full widths at half the maximum for the spectra are respectively 150 V for the McIlraith source and 300 V for the McClure source.

The fragmentation pattern of gases in the two sources, as deduced from the mass spectra of the extracted ions, is shown in table 1. Both the sources produce a high percentage of dissociated ions of the molecular gases, as is often observed in glow discharges. It should also be noted that there is a large fraction of A^{2+} ions produced in argon discharge in the McIlraith source. Further, the CO^+ ion intensity in CO_2 discharge and N^+ ion intensity in N_2 discharge are only a little less than the corresponding molecular ion intensities, indicating that dissociation and multiple ionization are more predominant in the McIlraith source than in the McClure source. The intensity of O^+ ions in O_2 discharge in the McIlraith source is comparatively less, probably due to charge exchange reactions present in oxygen discharges (Dickinson and Sayers 1960, Knewstubb *et al* 1963). Dissociative recombination appears to play a plausible role under the conditions of operation of these sources and can make an effective contribution to the higher abundance of atomic ions compared to the electron bombardment source, for which data obtained with a commercial mass spectrometer (AEI MS10) are also presented in table 1. The larger ion currents produced in the McIlraith source indicate a more efficient trapping of electrons and a higher ionization efficiency, supporting McIlraith's observation that the electrons in this design have a mean free path about 40 times larger than in the McClure design (McIlraith 1966). The two principal modes of operation of the discharge in the McIlraith design, *viz.*, the oscillating mode and the orbiting mode (Fitch and Rushton 1970 b) are likely to coexist in the discharge current regime investigated in the present work.

4. Conclusion

Both the ion sources, being similar in design and operational characteristics, have significant advantages over Penning and glow discharge sources in that they operate at low pressures without the need for a magnetic field. The sources and their associated electrical circuits are very simple in design and the sources can deliver very intense ion beams.

Acknowledgements

One of us (S S) thanks the University Grants Commission, New Delhi, for financial assistance.

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