Developments of saddle field ion sources and their applications

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ABSTRACT

Ion sources should have different performance parameters according to the various applications for which they are used, ranging from ion beam production to high energy ion implanters. There are many kinds of ion sources, which produce different ion beams with different characteristics. This paper deals with the developments and applications of some saddle field ion sources which were designed and constructed in our lab. Theory of operation and types of saddle field ion sources are discussed in details. Some experimental results are given. The saddle field ion sources operate at low gas pressure and require neither magnetic field nor filament. This type of ion sources is used for many different applications as ion beam machining, sputtering, cleaning and profiling for surface analysis etc.

Keywords: Saddle field ion sources/ sputtering process / self-extraction ion source.

INTRODUCTION

During the past decade, a clear progress has been made in the advancement of the technologies of ion sources. Applications range of ion sources from providing beams of hundreds of amperes for fusion applications, nano–amperes for microprobe trace analysis, broad beams for ion implantation, space thrusters, industrial polymerisation, food sterilisation, to medical, military and accelerator applications [1]. At present a lot of companies, research institutes over the world create and develop different kinds of ion sources.

These are the duoplasmotrons, Kauffmann ion sources, Hall accelerators, Penning sources, saddle-field ion sources, radio frequency ion sources, electron resonance ion sources and others [2], [3]. Part of them is used mainly for research and special purposes.

Saddle field ion sources are advanced compact ion and fast atom sources for use in a wide range of applications [4], [5], [6], where small size and high beam intensity are required. Applications include small-scale substrate cleaning and etching, ion beam sputtering of thin films, transmission electron microscope, specimen thinning, fast ion bombardment for mass spectrometry and secondary ion mass spectrometry. In this paper, a review of the researches and developments on the saddle field ion sources is given and a description of various types that have been developed.
A. Theory of saddle field ion sources

The discharge is produced by the electrons oscillation between two cold cathodes in a saddle field which possesses a single saddle point. In the saddle field ion sources (Cold cathode oscillating electron ion source), the discharge mechanism (plasma production) [7], [8] is initiated by the primary electrons which are essentially comes from the cosmic rays. To produce and intensify the plasma, the electrons must have long path lengths and this can be achieved by allowing the electrons to have an oscillatory motion. This discharge depends on the oscillatory motion between the cathodes separated by the anode using electric fields. The discharge mechanism of the source is very simple, where it has the advantageous behaviour of the penning source without magnetic field. Saddle field ion sources may be evaluated by the high degree of ionization, the small gas consumption, the small energy spread of the beam and the large ion current.

B. Types of saddle field ion sources

Saddle field ion sources have been passed by many types of developments and modifications since their existence in 1966 [9]. Developments have been branched into three types as, the cylindrical symmetry saddle field ion sources, the spherical symmetry saddle field ion source and the plane symmetry saddle field ion sources.

B1 Cylindrical symmetry saddle field ion sources

This kind of ion sources was first described by Mcilraith [7]. Its major advantages are that it produces an intense beam of energetic ions at low pressures without the assistance of a magnetic field or thermionic source of electrons. This type of ions sources consists essentially of a cylindrical cathode surrounding two anode wires which are arranged about the cylinder axis (Fig.1). Positive ions produced from this source can be extracted radially outwards towards the collector.

![Diagram of Cylindrical Symmetry Saddle Field Ion Source](image)

**Fig.1:** First version of cylindrical symmetry saddle field ion source [7].
A cylindrical symmetry saddle field ion source [10,11] shown in Fig.2 has been constructed and optimized at the Accelerators and Ion Sources Department, Nuclear Research Center, Atomic Energy Authority. It consists of two copper anode rods surrounded by a stainless steel cylindrical cathode. A ceramic hollow cylinder with two opposite holes is placed inside the stainless steel cylindrical cathode to confine the discharge between the two anode rods and the cathode.

A focusing electrode is placed at 5 mm from the ion source and a Faraday cup is placed at 1.5 cm from it. A ceramic hollow cylinder with two opposite holes each of diameter 5 mm is placed inside the stainless steel cylindrical cathode to confine the discharge in the central zone between the two anode rods and the stainless steel cylindrical cathode. The output ion beam current is extracted from an exit aperture of 1 mm diameter in the stainless steel cylindrical cathode. A Faraday cup is placed at a distance of 1 cm from the ion exit aperture.

**Fig.2:** The cylindrical symmetry saddle field ion source [10,11].

**Fig.3:** The experimental investigation of the relation between the breakdown voltage, \( V_b \), between the anode and the cathode and the value of separation distance \( d \) at different pressures using nitrogen gas [10,11].
The measurements showed that the optimum distance between the two anode rods is equal to 7 mm and higher ion beam current can be obtained. This ion sources can be used for etching, thinning and micro machining applications. It is featured by its higher efficiency with respect to lower gas consumption and has a long life time of operation.

**B2 The spherical symmetry oscillating electron ion source**

Franks [6] designed the spherical geometry electrostatic ion source and observe that, the saddle field configuration can be achieved. The developed spherical saddle field electrostatic oscillator ion source [8] is based on the efficient ionization produced by oscillating electrons in a saddle field. A high ionized plasma can be produced at low initial gas pressures, due to the long path length of electrons. Fig.4 shows the schematic diagram of the spherical type electrostatic ion source. The anode is made from stainless steel of thickness 2 mm and a central hole of 5 mm diameter.

Two hemispherical aluminum cathodes of radius 11 mm are used. Two identical ion beams can emerge, supposing that the dimensions of the two ion exit aperture are the same. One of these two ion beams is monitored continuously while the other beam can be used for various applications. The spherical ion source is very suitable for ion thinning and machining applications.

**Fig.4: The spherical ion source and its associated electrical circuit.**

**B3 The plane symmetry oscillating electron ion source**

Recently an electrostatic plane symmetry ion source has been studied and designed [12,13]. This ion source consists of stainless steel annular anode, two annular screens of inner hole diameters 5 mm and 9 mm respectively. Two disc cathodes, one with 1 mm hole diameter for inserting the gas and the other with 2 mm hole diameter for ion beam extraction.
The main parts of the plane symmetry oscillating electron ion source\(^{(11)}\) is shown in Fig.5. A stainless steel cylindrical tube ended by two brass flanges forming the body of the source. An aperture is made in one of the brass flanges for gas inlet and the other as an ion beam exit aperture, this brass flange acts as a cathode. At the middle of the cylindrical tube, a circular stainless steel disc with a central hole of 5 mm diameter.

Two brass screens have the same shape as the anode but with central hole of 9 mm. The two brass screen are placed on both sides of the anode and isolated from it by ceramic insulators. A Faraday cup is used to measure the output ion beam current. On the top of Faraday cup, a negatively biased (-120V) copper ring is placed to prevent secondary emission from the Faraday cup due to ion beam bombardment. The anode is connected to high power supply varies from 0 to 10 KV via a high ohmic resistance to protect the power supply when the breakdown occurs. Each of the cylindrical tube, screens and the two cathodes are connected to earth. This type of saddle field ion sources can be used for surface cleaning, ion thining, ion etching and micro-machining.

**CONCLUSION**

In this article, a quick review has been achieved for different types of saddle field ion sources, their principle, their operation and finally applications in various fields. The advantages of the saddle field ion sources, can operate at low pressure \((10^{-3} - 10^{-4} \text{ Torr})\), long life operation due to the absence of filament, compact and simple design and low power consumption.
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