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ABSTRACT

The production of beams of metallic ions from a cold cathode type penning discharge has been proposed for use with the Hilac and Omnitron. With the aid of a unique sputtering electrode, significant amounts of low charge state metallic ions have been analyzed and measured.

I INTRODUCTION

If it were possible to introduce sputtered atoms into an energetic, dense electron stream, at a point where extraction in ionic form were physically feasible, the problems associated with vaporizing materials at high temperature could be avoided. Such a scheme is feasible with the Penning, or oscillating electron discharge, and in particular, with the cold cathode type source used here. Since the periphery of the plasma column takes on a potential close to the most positive potential of the system^{1,2}), a negatively charged cylinder (dynode) made of the desired material may be inserted into the system (Fig. 1 and 2) and will be bombarded by those ions exiting the plasma boundary. These ions can be accelerated to full arc potential by electrically tying the dynode to the cathodes, or to some fraction of the arc potential.

These ions sputter close to their own number of the dynode material into the arc and in turn serve to counter balance the greater ion loss evident when the dynode is a cathode potential (negative). The metallic ions produced can be extracted from plasma potential by fitting the dynode with an exit slit.

II DESCRIPTION

All data shown with this ion source has been made within a 4 inch magnetic gap. Ions are analyzed and collected after a 180° shift in beam direction, in a faraday cup of extractor slit proportions. The dynode exit slit is $3/8$ " tall, .050" wide. Arc characteristics were studied at a field of 5500 gauss except when scanning for charge state distribution, in which case fields were kept about 4000 gauss. When the dynode is water cooled, duty factor and arc current may be chosen freely. Both arc and extractor are pulsed on for 3 ms. Arc current has been regulated under all conditions. Titanium cathodes are used and extractor voltages up to 15 kV are applied. Arc current, dynode current, cathode material, dynode

material, gas flow, and ion extraction energy are major parameters. No attempt to study the interdependence of all those parameters has been made.

The switch shown on Fig. 1, is a low internal impedance screen grid tube (4CX1000), used to isolate or connect the dynode from cathode potential on demand. (This switching feature has been helpful in identifying ions after extraction.) The voltage of a floating dynode, while not measurable, can be considered to be close to the anode potential. The effective electron current via the plasma and dynode is set by the value of R .

This arc will not strike without support gas. Should the minimum gas flow restriction be lowered with a negative dynode, the change in flow will be less than about 20%. Usually nitrogen or argon have been used except where these ions complicate the analysis. Support gas does contaminate the arc output and makes the identification of multiply charged ions difficult.

III RESULTS

For any given arc current there is an optimum value of dynode current (I_d), when peaking for a particular charge state metallic ion. In general the higher the arc current the greater should be I_d . The higher the charge state, the lower should be I_d . (For example: If arc current = 2.0 A, Al^{+1} peaks with $R \sim 1000 \pm 1000$ while Al^{3+} peaks when $R \sim 6000 \pm 200$). If I_d be made less than say 900 mA. under a given peaked operating condition, the arc would 'starve' for want of support gas. Should support gas be decreased slightly instead, the dynode current would have to be increased for sustaining the healthy arc.

If we examine the ratio of Be^{+1} to Be^{2+} we see a 10:1 reduction in beam intensity (Fig. 4) when the source is tuned for Be^{2+} . Support gas flow and

dynode current must be carefully adjusted for any Be^{2+} to be seen at all. No Be^{3+} has been detected. A plot of the support gas peaks is presented with the dynode floating close to anode potential. These measurements were made immediately after the beryllium data was taken. For further results see Table 1.

High charge state yield of the support gas is attenuated in proportion to dynode current. For example: With an aluminum dynode and neon as a support gas; if $R = 1800\Omega$, Ne^{3+} is one half the value it would have been when the dynode is floating, and is one tenth its value when $R \sim 0\Omega$, while Ne^{2+} is one fifth its full value when $R \sim 0\Omega$.

Total beam out of the ion source, measured by a calorimeter paddle just beyond the extractor, is found to be roughly proportional to arc power regardless of the current flow to the dynode.

Disadvantages inherent here are apparent. First, the increased flux of atoms in the discharge incurs a reduction in temperature and a constriction of the plasma is certain. In addition, metallic ions or atoms, once striking the dynode, are not returned to the arc in gaseous form, leading to poor 'gas efficiency'.

IV DISCUSSION

When the dynode was lined with calcium, and nitrogen used as support gas, the following data has been taken. A simplified schematic is given on Fig. 4 (insert).

By monitoring the current through r_d and knowing the full arc voltage as well as the value of R , the potential difference (ΔV) between anode and dynode can be calculated and plotted against dynode current. (With R very large, nearly full arc potential appears across the series resistance R ; i.e., small (ΔV). Assuming periphery plasma potential to be close to anode potential, + 10V, ΔV may be considered to be about 10V less than the sheath potential at

the dynode. As the dynode current is made to increase, ΔV increases, accompanied by a decrease in power at the cathodes and a proportionate increase in power at the dynode. Fig. 4 resembles a Langmuir-type probe plot with a cutoff point of about + 50V, and Fig. 5 presents the shift of arc power from cathodes to dynode. Note that power may be conserved since the anode return is current regulated. Arc potential is free to vary and does when peaking for ion output, but for the duration of this data collection, remained constant.

Choosing typical operating conditions for a Be^{+1} ion beam, with 2000 series resistance, and a regulated arc current of 1.25 amperes, 820 ma. of electrons are measured flowing to the dynode and 430 ma. to the cathodes, totaling 1.25 amperes anode drain. Since the dynode sheath current is ionic,* a flux of electrons equal to the ion loss at the dynode, less the number of electrons removed from metallic atoms, will be removed at the anode and should lead to a constriction of the plasma. It appears that the atom vs. ion yield must be small (<2) since the large ion drain implies a high partial metal pressure ($>1000\mu$). Perhaps dynode pumping serves to lessen this effect. It is not surprising then that we find high charge state peaking with minimal dynode current.

V CONCLUSION

By controlling the dynode current, the sheath potential drop can be adjusted. This in turn sets the sputtering ratio (atoms/ion) and the metallic

* Secondary electron current is likely to be less than one quarter the total sheath current. In view of the high magnetic field and the EXB geometry, speculation about this current will be passed by.

atom concentration in the arc. An increasing sheath potential drop also allows for greater incident ion current density. These two effects interrelate for ion peaking effects and can allow for less than the usual minimum gas flow rates for a given arc power consumption.

High support gas flow rates encountered here are detrimental to high charge state production and need to be minimized. If the dynode lining were allowed to run hot (self heating is easily accomplished), greater utilization of metallic atoms would be allowed, and a consequent reduction in support gas should be realized.

Table I

	Be	Al	Ca	Ti	Nb	Au
+1	500 μ a	550	270	130	-	24
2+	25	300	150	66	40	9
3+	-	25	72	20	20	4
4+	-	-	12	10	11	2
5+	-	-	2(?)	-	3(?)	-

All readings in μ a. 15 kV extraction potential. Arc currents less than 2 amperes, 8% duty factor.

REFERENCES

- * This work was done under the auspices of the U.S. Atomic Energy Commission
- 1) Guthrie and Wakerling, Characteristics of Electrical Discharges in Magnetic Fields, Chap. 2 and 3, McGraw-Hill Book Co., New York, (1944)
 - 2) J. Kistemaker and J. Sneider, Physica 19, 950 (1953)

FIGURE CAPTION

- Fig. 1 Cross section drawing of the cold cathode ion source with dynode and associated electronic equipment.
- Fig. 2 Photograph of assembly with water cooled dynode. Dynode insert is beryllium.
- Fig. 3 Metallic ion current versus magnet field strength. Arc current 2 amperes, duty factor 8%. Extraction voltage 9.2kV. Support gas argon, dynode insert beryllium.
- Fig. 4 Dynode current versus potential difference (ΔV) between anodes and dynode. ΔV approximate sheath potential drop at the anode. Arc current 1.3 amperes, arc voltage 1500V, duty factor 6%. Support gas argon, calcium insert.
- Fig. 5 Peak pulsed power versus series resistance, R. Arc current 1.3 amperes, arc voltage 1500(± 100 V). Peak power 1.95 kW. Nitrogen support gas, calcium insert.

Fig. 1

XBL-682-4475

XBB 682-701

Fig. 2

Fig. 3

XBL-682-4476

Fig. 4

XBL-682-4477

XBL 682 4478

Fig. 5

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