CU+ ION EXTRACTION FROM A MODIFIED BERNAS ION SOURCE IN A METAL-ION IMPLANTER

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An ion implanter, which can serve as a metal-ion supply, has been constructed and performance tested. Copper ions are generated and extracted from a Bernas ion source with a heating crucible that provides feed gases to sustain the plasma. Sable arc plasmas can be sustained in the ion source for a crucible temperature in excess of 350 °C. Stable extraction of the ions is possible for arc currents less than 0.3 A. Arc currents increase with the induced power of a block cathode and the transverse field in the ion source. Cu+ ions in the extracted beam are separated using a dipole magnet. A 20 μA Cu+ ion current can be extracted with a 0.2 A arc current. The ion current can support a dose of 10^{16} ions/ cm^2 over an area of 15 cm^2 within a few hours.

KEYWORDS : Ion Source, Copper, Metal Chloride, Ion Implanter

1. INTRODUCTION

Boron and phosphor ion implantation is often used in the fabrication of semi-conductors. Other applications include modification of surface irregularities stemming from erosion and corrosion, for example.

Usually, non-reactive metals (copper, silver, and gold, etc.) are used to produce dispersions of nanosized particles in dielectrics. These can be introduced via ion implantation, sol–gel techniques, pulsed laser deposition, and doping during growth processes [1,2]. Ion implantation techniques have several advantages. One of which overcomes thermo dynamical solubility restrictions in surface regions. Another provides for precise prediction of both the maximum range and concentration of the implanted species in a given solid. Cu+ ions especially can act as an antibacterial agent and wear behavior for some medical materials [3].

The *Proton Engineering Frontier Project* (PEFP) has developed a gas ion implanter to improve the surface properties of metals. It uses a duoPIGatron ion source. Typical ion implanters are limited to relatively *light* ions that can be produced from feed gases. We have fabricated a *metal*-ion implanter that can provide metal-ion beams. This paper demonstrates our metal-ion implanter and the Cu+ ion extraction thus realized .

2. MODIFIED BERNAS ION SOURCE IN THE METAL-ION IMPLANTER

Table 1. Metal-ion Implanter Specifications

Ion species	Cu
Maximum ion beam energy	120 keV Ion source : 20 keV Beam acceleration : 100 keV
Ion beam current	<0.1 mA
Type of the Ion source	Bernas ion source
Mass separation	90° bending using a dipole magnet
Beam acceleration	Electrostatics

The metal-ion implanter is involved in several stages of ion delivery: generation, separation, and acceleration. The ions are generated using a modified ion source originally proposed by Bernas [4-6]. Ions are mass-separated using variable voltage dipole magnets. The separated ions are passed through a high-voltage driven acceleration column. Detailed specifications and schematics of the metal-ion implanter we constructed are shown in Table 1 and Figure 1, respectively.

2.1 The Modified Bernas Ion Source

The ion source is responsible for gas supply, and plasma generation and extraction is shown in Figure 2.

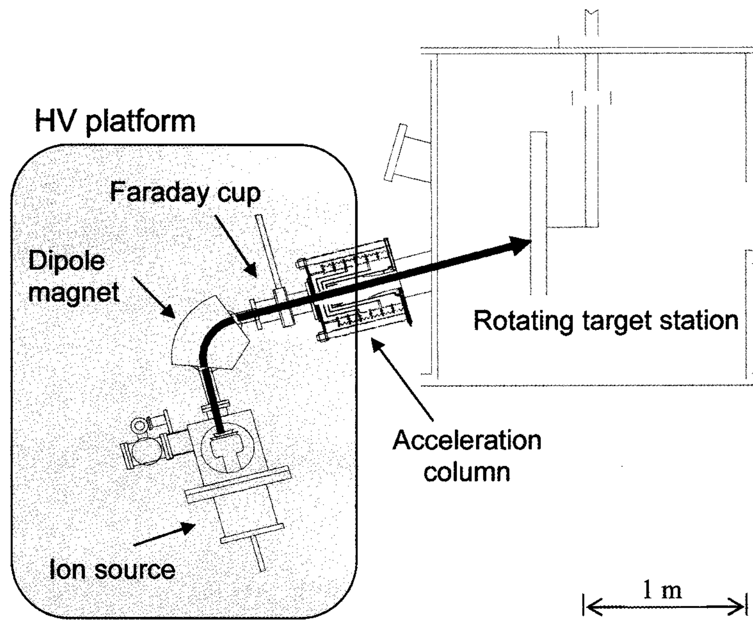

Fig. 1. Metal-ion Implanter Schematics

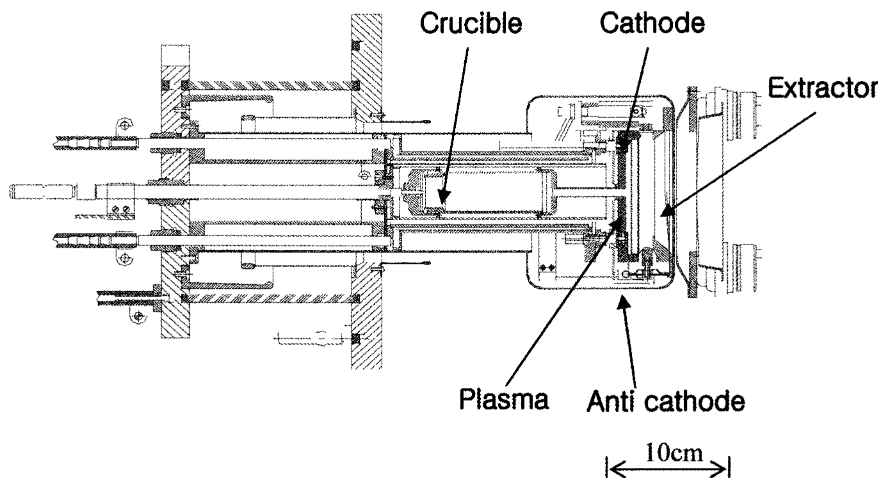

Fig. 2. The Bernas Ion Source

Also shown in that figure are the associated vacuum and power supplies. Power supply and ion source electrical schematics are shown in Figure 3. We modified the plasma chamber to enhance the filament life. A block-type cathode was used both to generate a plasma arc and to act as a heater.

2.1.1 Supplying an Ionization Vapor to the Metal Chloride

Heating elements are used to evaporate a chloride powder and thus provide neutrals atoms, which can later be ionized (Figure 2, center). Detailed material properties of the copper chloride are shown in Table 2. Heating elements made of stainless steel or alumina (Al_2O_3) cover the cylinder case (crucible) that contains the metal chloride powders. The crucible is surrounded by a cylindrical heater. The heating elements can heat the crucible to 600 °C using 500 W of electrical power. A thermocouple is used to measure the crucible temperature. For copper chloride (CuCl), the crucible can operate at less than 500 °C since the corresponding melting temperature is 430 °C

2.1.2 Seed-electron Emission for the Main Plasma

We modified the ion source seed electron supplying

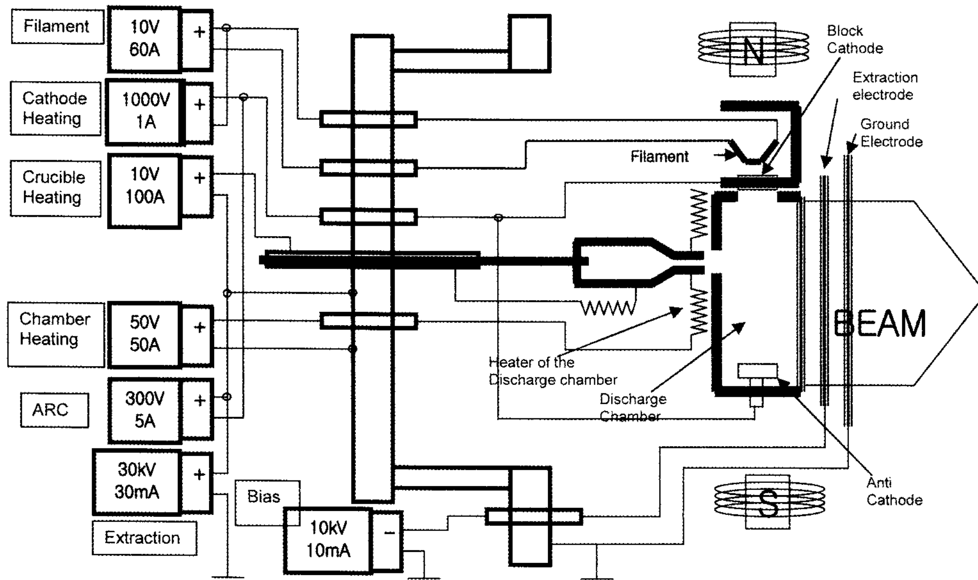

Fig. 3. Ion Source Power Supply Schematics

Table 2. Copper Chloride (Cucl) Material Properties

Material	CuCl
Melting temperature (°C)	430
Density (g/cm^3)	4.14
Temp.(°C) for given vapor pressure of the 10^{-4} torr	<500

structure to achieve a lifetime longer than typical Bernas ion sources which is used as a filament. Seed electron emission required for maintaining the plasma discharge is provided by an indirectly heated tungsten block cathode (5 mm x 5 mm x 8 mm) and not a filament, which is traditionally used. Thus, the filament is used to heat up the block cathode. It does not contact the plasma, so its lifetime is extended. The filament is made of a 1 mm diameter tungsten wire that includes 20% Re. The gap is 1 mm, and the induced voltage between the filament and block cathode is 700 V. Electrons emitted at the block cathode enter the discharge chamber through a carbon collimator. They then contribute to the main discharge. All components associated with electron emission are made of materials that have excellent mechanical properties at high temperatures, such as carbon for the structure, alumina for the insulators, and Mo for the electrodes.

2.1.3 Plasma Discharge Chamber

The carbon discharge chamber is composed of an anti-cathode, an ion extraction aperture, and a chamber heater. Its width, depth, and length are 20 mm, 20 mm, and 80 mm, respectively. To increase plasma confinement efficiency in the discharge chamber, we applied an external transverse magnetic field and negatively biased the anti-cathode—plasma electrons are thus reflected. The heater outside the chamber reduces re-condensation rate of vapor on the wall.

2.1.4 Ion Extraction System

Slit-type aperture extractors made of stainless steel were composed of 2 electrodes: one to drive ion extraction via a positive high voltage, and one to suppress back streaming of fast electrons via a negative high voltage. The aperture was 1 mm wide and a 60 mm long. Alumina was used to insulator the extraction electrodes. For a gap distance of 5 mm the aperture was able to operate spark-free at 20 kV.

2.1.5 Magnets for the Ion Source and Ion Mass Separation

Recall that both the ion source used to generate the high density plasma and the mass separation system used magnets. Both magnets were dipole magnets whose yokes were made of mild steel. Detailed magnet design parameters are shown in Table 3. The pole gap distance of the ion source magnet was 190 mm, and the designed maximum magnetic field was around 700 G. A yoke separating the magnet poles was installed with a distance of 190 mm in the ion source chamber. The resulting magnetic field increases linearly up to the 400 G field required to confine the plasma (Figure 4). Up to 4 A was required from the magnet power supply.

The mass separation magnet was a 90° dipole. It was used to select and accelerate the desired ions. Magnetic

Table 3. Mass Separation Magnet Design Parameters

Bending radius	400 mm
Bending angle	90°
Entrance angle	35°
Exit angle	20°
Pole gap	60 mm
Pole width	150 mm
Cross section of the return yoke	318 cm^2
Weight	900 kg

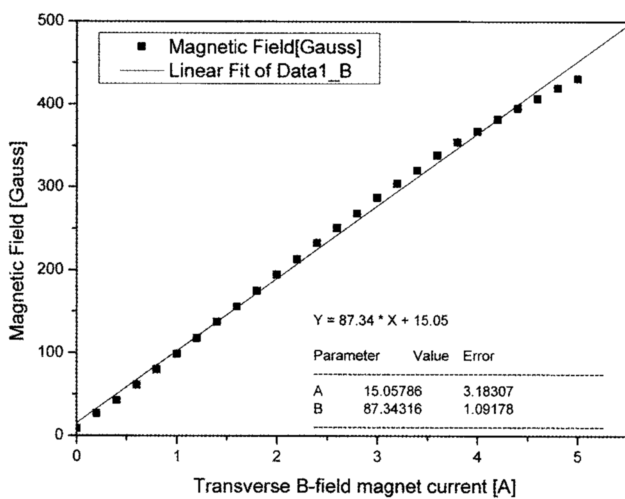

Fig. 4. Induced Magnetic Fields as a Function of Ion Source Current

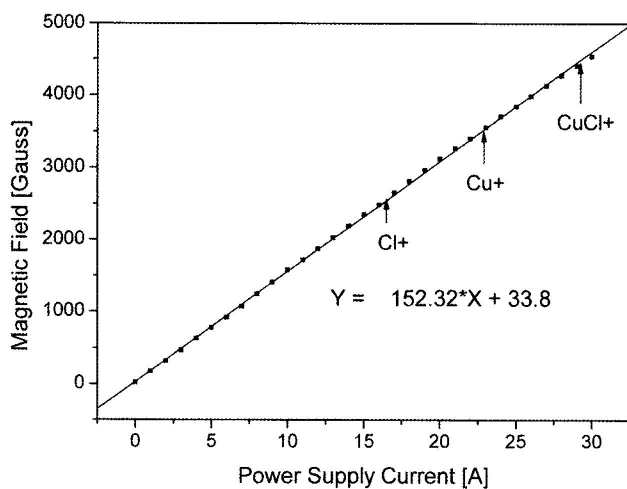

Fig. 5. Mass-analyzing Magnetic Fields for Separating and Extracting Ions: Current Dependence of the Power Supply

field intensity as a function of supply current is shown in Figure 5; this magnet can produce a field that can separate heavy metal-ions (up to 20 keV kinetic energy silver ions). The magnetic field is

$$B \approx \frac{1.44\times10^2\sqrt{EM}}{r}, \text{[G]} \quad (1)$$

where E is the ion bean energy in keV, M is the atomic mass unit and r is the dipole bending radius. From (1) the magnetic field was chosen to be 3515 G, 2627 G, and 4386 G for copper, chlorine, and copper chloride, respectively.

2.2 Plasma Arc Current of the Ion Source

This ion source had no extra feed gas except that which was provided by the heating crucible. Therefore, it required a long time to heat up to the 400°C evaporation temperature required in this work. Once this temperature was reached, we observed a slight increase in arc current. The arc current could not be measured before reaching this temperature. Arc current can be controlled by the heating power of the block cathode and the transverse magnetic field of the ion source.

2.2.1 Cathode Power Dependence

Arc plasmas can be sustained between the filament-heated block cathode and the chamber wall by using a CuCl vapor. Since the block cathode heater power is strongly correlated with filament power (Figure 6a), the block cathode heater filament has a linear electron emission curve. For a fixed arc voltage of 700 V and a magnetic field of 300 G, we can obtain stable arc plasmas. Arc currents increase with block cathode power. The currents can provide the plasma density necessary to extract the desired ions from the plasma chamber.

2.2.2 Magnetic Field Dependence

At a fixed power of around 320 W, with the block cathode, the magnetic field up to 400 G is adjusted. Arc current increases *slightly* with magnetic field up to 200 G (Figure 6b) and increases *abruptly* above for higher fields. Plasma confinement efficiency is enhanced above 200 G since it has the same seed electrons. Seed electrons emitted from the block cathode are drawn to the anode. They exhibit gyro-motion and are able to sustain the plasma. The gyro-radius of the seed electrons follows:

$$r_c \approx \frac{3.37\sqrt{E}}{B_0}, \text{[cm]} \quad (2)$$

where B_0 is the induced magnetic field in Gauss, and E is the electron energy in eV.

The gyro radius of 700 eV electrons in a 200 G magnetic

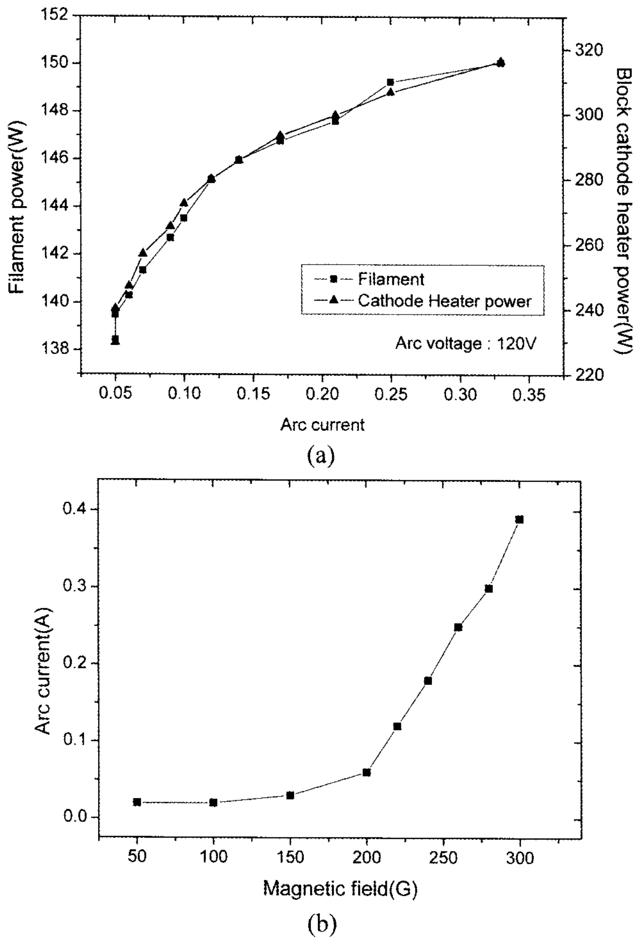

Fig. 6. Arc Current Dependence on Power of the Filament and Block Cathode (a) and the Transverse Magnetic Field of the Ion Source (b)

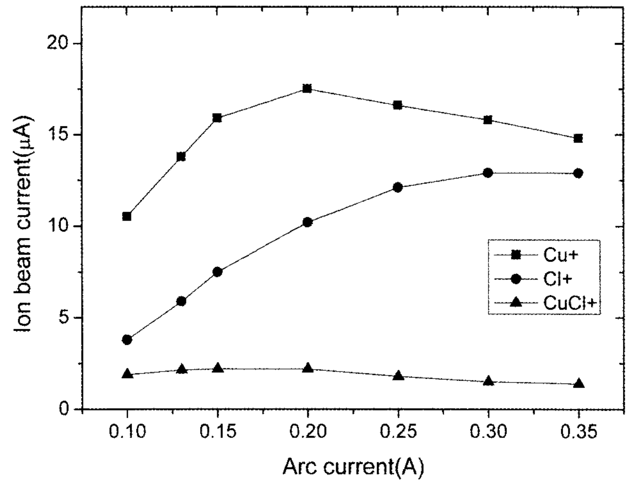

Fig. 7. Ion Beam Currents as a Function of ARC Current

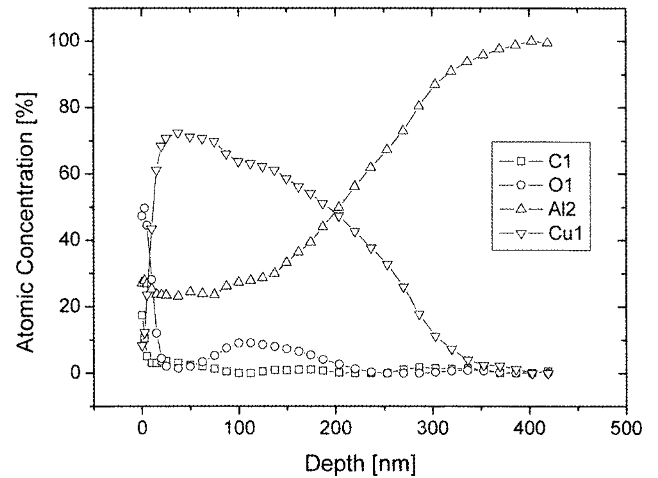

Fig. 7. AES of Al Irradiated by 115keV Cu+

field is around 4.5mm. This is less than the 20 mm width of the discharge chamber. Since electrons emitted from the block cathode in a magnetic field less than 200 G have a relatively large gyro-radius, only these emitted electrons contribute to the discharging of the plasma near the block cathode. Magnetic fields in excess of 200 G can confine more electrons; this extends the plasma generation region. Electrons confined by a transverse magnetic field can generate and extend efficient arc plasmas in the entire plasma chamber.

2.3 Cu^+ Ions Extraction of the Ion Source

Ions are extracted from the ion source using a 15 kV extraction voltage after a sustained stable plasma is achieved. We can measure the desired ion extraction current using a Faraday cup by adjusting the magnet fields of the mass separation magnet. Since copper, chlorine, and copper chloride ions have different bending radii, we can measure each beam current near the calculated bending magnetic field. Due to a residual magnetic field, the desired ions were measured in a field 100 G higher than the calculated field. Each peak current with a step of 15 G which is equivalent to 0.05 atomic mass units was found to be dependent on the current resolution of the power supply.

Cu+, Cl+, and CuCl+ ion beam current as a function of arc current are shown in Figure 7. The Cu+ ion current is higher than both the Cl+ and CuCl+ currents. Other ions such as Cl_2+ and Cu++ could not be observed. This implies that relatively more Cu+ ions, with their relatively low reaction rate as compared to electrons and neutrals, survive and reach the extractor. The Cl+ ions, on the other hand, are more likely to convert to neutrals and negative

ions before extraction. Cu+ ion current increases for arc currents up to 0.2 A. Above this, it decreases slightly. Cl+ ion arc current increases steadily with arc current. The reason may be that the ions have a different beam profile. For the Cu+ ions, the beam optics may be optimal at a 0.2 A arc current. The Cu+ ions may be diverging above this extracted current. Cl+ ions have an optimal arc current of at 0.3 A—it seems to be saturated.

In order to confirm successful copper ion implantation in a sample, a pure Al sample was irradiated. Over 2 hours implantation time, 15 keV extracted ions were accelerated up to 100 kV for a final energy of 115 keV. The depth profile of the Cu+ implanted sample was measured using auger electron spectroscopy (AES). Figure 8 shows the atomic concentration of the AES with a variance of the Al depth. Clearly, copper ions have penetrated the Al sample. AES reveals impurities such as carbon and oxygen except for copper and aluminum. The carbon on the surface may have come from the diffusion oil pump, and the oxygen may come from the Al oxidation before prior to irradiation.

3. CONCLUSION

We have successfully obtained a Cu+ ion beam by evaporating a CuCl powder and obtaining the associated plasma discharge in the ion source from a metal-ion implanter. Arc plasmas that include Cu ions can be sustained in the ion source discharge chamber by heating the block cathode and by using a transverse magnetic field. Cu+ ion currents can be extracted up to 20 μA for a 15 kV extraction voltage. Cu+ and Cl+ ions were the main ions extracted from this ion source. Higher ions currents are extracted for Cu+ than for Cl+ at this extraction voltage. Cu+ ion implantation was confirmed through AES. Block cathode has extended the ion source time with an environment of a chemical reaction of the chlorine vapor and plasma. It operated fault-free for one year, even after sustaining some damage. The major limiting component for this ion source is the block cathode heating filament and the insulators which may be contaminated by vapor deposition.

ACKNOWLEDGEMENTS

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