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Development of High Flux Metal Ion Plasma Source for the Ion Implantation and Deposition

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Abstract

A high flux metal plasma pulse ion source, which can simultaneously perform ion implantation and deposition, was developed and tested to evaluate its performance using the prototype. Flux of ion source was measured to be 5 A and bi-polar pulse power supply with a peak voltage of 250 V, repetition of 20 Hz and width of 100 μs has an output current of 2 kA and average power of 2 kW. Trigger power supply is a high voltage pulse generator producing a peak voltage of 12 kV, peak current of 50 A and repetition rate of 20 Hz. The acceleration column for providing target energy up to ion implantation is carefully designed and compatible with UHV (ultra high vacuum) application. Prototype systems including various ion sources are fabricated for the performance test in the vacuum and evaluated to be more competitive than the existing equipments through repeated deposition experiments.

Keywords : ion source, ion implantation, ion deposition, metal plasma ion source

1. Introduction

Ion beam was at first discovered by Goldstein in 1886 [1] during the study of gas discharge at low pressures and subsequent investigation revealed that ion beam was generated from gas atoms in a discharge tube. In 1910, a practical ion source was produced from Neon with a long tubular electrode as anode. In general, ion sources showed that the ion energy was broadly spread at high voltage and the ion rate was very low and continuous discharge was not easily available. Since then advanced ion sources, which have large current and small energy variation, were developed by collision of atom-electron and surface ionization from collision and suitable to ionize atoms of solid or liquid state. Ion sources with an enhanced mean free path of ionizing electrons were newly introduced as an effective method to increase ion density in plasma of gas discharge. The ion sources with a hot or cold cathode ionizing gases by an electric oscillation in uniform or nonuniform magnetic field [2] or high frequency magnetic field [3] were also developed.

Broad ion beam sources were developed between the late 1950s and the early 1960s from the space exploration plan on electric propulsion [3]. Broad ion beam was commercially applied to Kaufman type. The research on the commercial applications was mostly performed in a field of etching or deposition with nonreactive ion beam in the 1970s. In the early 1980s many studies were made for the reactive process or material modification by chemical reaction [4]. Most of the present ion sources are applied to the instruments such as particle acceleration, mass separator, mass spectrometer and ion implantation.

Gas ion sources produce many ions by generating

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plasma from various nonreactive or reactive gases at room temperature or neutral gas including metal radical and are used in a wide range of applications. But, the ion sources have limits for applications of ion implantation or deposition since most material is not gas state at room temperature. The mechanism of metallic ion source is to change solid metal to gas or to produce ions directly from metal. Many methods based on evaporation by heating and ionization by RF discharges, by sputtering, or by vacuum arc have been developed to obtain gas or ion from solid or liquid metal. The MEVVA(metal vapor vacuum arc ion source) has been used as the strong metal ion source in field of ion implantation, limited to a few % duty cycles.[5]-[8] The MEVVA is suitable to synchrotron acceleration because of the low duty cycle and instant large current. The MEVVA can simply generate different ions by replacing with new cathode for a specific ion source. The MEVVA of methods generating metal plasma can produce the metallic ion source of large current and wide area and setup equipment is very simple. A pulse metal ion source can simultaneously perform ion implantation and deposition depending on pulse shape of acceleration power. Deposited films are much better than those of previous methods for deposition of thin films and etching of surfaces. For this reason the pulse ion sources become more popular as a new process in leading groups. The speed of deposition is high and deposition material is perfectly well ionized. No deposition systems except MEVVA could control the energy of ionization as required until now. As well, multiple cathodes metal arc ion source can deposit film of multi-layers and is expected to be a tool in creating multi-films of multiple functions.

In this work, we report on the development of metal ion sources for ion implantation and deposition; pulse type for both single cathode metal ion source and multi-cathodes metal ion sources. The basic performance of fabricated metal ion sources is evaluated and as a conclusion, expected to be widely applicable in various fields demanding thin films with better quality.

2. Principle of Metallic Plasma Production

Metal plasma can be obtained from arc discharge in a vacuum. An arc discharge is defined as discharge of high current and low voltage; electric potential of cathode materials or working gas decreases near ionization potential. As once arc discharge is formed on condition that power of high current and low voltage are applied between cathode and anode in a vacuum, a very tiny and bright spot called arcspot is generated and large arc-current flows at the spot. The moving arcspot evaporates cathode and generates ion plasma. Arcspots are generated at random, and the lifetime of a particular spot may be a sub-microsecond. The spot size is estimated to be in the range of 1-10 μm, and the current density at the spots is in the order of 10^6-10^8 A/cm^2.

To form an arcspot, an electrical impact so-called triggering is given at the cathode surface as large as metal molecules of cathode that come out of a vacuum. Electrons move to anode while the metal ions scatter and breakdown a vacuum between anode and cathode in a moment. Metal molecules between the cathode and anode electrodes are ionized via collisions with electrons. Cathode surface can be subsequently sputtered via back bombarding of some ionized metal molecules onto the cathode surface. It is called sputtering. Increasing movement of electron between anode and cathode keep the arc discharge. Cathode is etched by continuous ionization and collision of metal molecules. So, the arcspot is maintained.

The metal ions generated from arc discharge take a process of extraction and acceleration with designed electrodes and arrive at the target for ion implantation and deposition. The generated arc is composed of a stream of electrons moving from cathode to anode and metal ions ionized by these electrons. Some metal ions generate metal vapor, which will become a new ion by colliding with the cathode. The others go to the anode with the electron. A strong pressure gradient generated by the high current density of the arcspot forces the plasma to accelerate and move to the anode. A part of the plasma goes to the expansion region through the anode with holes. The expansion region is empty cylindrical metal of which the center keeps a line with center axis of cathode, and potential is the same with anode. Plasma density and beam diameter needed for extraction system was considered to calculate the size of expansion region. There are times when the magnetic field is applied to the expansion region by installing magnets for improvement of density or distribution of plasma.

Grids were installed at an end on the opposite side of the cathode of the expansion region and consisted of extraction and acceleration grids. The extraction grid extracts positive ions from the plasma and has a little or the same potential as compared with the cathode. Potential of the acceleration grid is lower than the cathode. This grid takes the extracted positive ions accelerates in the direction of the vacuum chamber and moves toward a target. Ion production process based on vacuum arcs was well investigated in detail by Kimblin [9]. In general metal ion source is pulsed to limit the power dissipation at the cathode. In most designs the duty cycle of a few percent can be reached and pulsed by a low repetition rate from one to several ten Hz. It is well known that about ten percent of arc currents are ionized and half of it is useful for ion beam. It means that about 10 A of metal ions are extracted under the optimized conditions. The metal ion source of the vacuum arc can be regarded as a suitable ion source in all ranges from formation of small metal ion beams for particle acceleration to beam emittance of large area for ion implantation and heavy capacity for deposition.

3. Design and Fabrication of MEVVA Systems

3.1 Overview

MEVVA system consists of cathode, trigger, anode, extraction grid, acceleration grid and acceleration column, etc.[10] The multi-cathode vacuum arc metal ion source has many cathodes and can be used for a process of deposition or ion implantation over multi layers of different kinds. The ion source has wide applications because deposition with the next cathode is possible without breaking high vacuum, since other cathodes can be installed if one cathode is exhausted, despite of depositing the same materials. The arc plasma expands through a hole in the anode into an expansion area that is usually connected to the anode. The extraction area is terminated with the extractor grid for ion beam extraction and the size of the expansion area and grid depends on the ion source application. The ion current is nearly constant during the lifetime of a cathode and also varies little from one cathode to the next. The total ion current increases linearly with an increase of arc current within the range of operation of the ion source, and is limited only by the saturation current for a given extraction voltage.

Vacuum arc can be initiated via triggering electrodes of a ring type isolated by aluminum or pipe from a cathode and the trigger electrode is connected to a power supply through feedthrough. Designed power supply can provide a peak current of 10~50 A as high voltage pulse with a peak voltage of 12 kV and a duration time of 30 μs. Main arc discharge can be produced by the energy from pulse power supply. The power supply consists of a pulse transformer with capacitors, resistances, IGBT switch and 250V DC power supply. Output of the pulse power supply is attached to both the cathode and anode through an optimized transmission line for pulse delivery. The volume of power supply and electric equipments for pulse generation varies with the pulse length and repetition rate of the vacuum arc ion source. Arcs are pulsed by every 0.1~1 ms and can be used up to 50 Hz as a design for ion source and material of the cathode. The drive time is an half hour at 1 Hz and pulse length 200 μs without changing the position of the cathode. The time is 24 hours for the opposite case.

3.2 Electrodes and Grids

3.2.1 Cathodes and trigger electrodes

Cathodes are distributed as circular types around rotation axis. One cathode was placed in the center of the anode for this research. Since the gap between the cathode and the trigger electrode is a key parameter for a reliable production of ion plasma, the size of the gaps should be correctly fitted by moving each cathode with a trigger electrode and as a result, the overall structure becomes complicated. So the insulator, which supports the trigger electrode and cathode, has the designed hole-structure for the insulation of each cathode. It is not possible for the cathode to move into the direction of the axis while driving. The cathode, however, can simply go toward the direction as being dissipated because the assemblages of cathodes can be easily divided by loosening four screws after driving.

In this design to supply one trigger electrode fixed at the cathodes lined with axis of anode with the pulse current from high pulse power for triggering, the trigger electrode and high voltage vacuum feedthrough can be connected to the point of contact in a selected position as the same type because each of the twelve cathodes has a trigger electrode. Each rotating cathode can be fitted to the axis of the anode in turn. A tungsten line of 0.8 mm used as a contact point was made from coil spring. It was not a serious problem to use even for a long time because tungsten has no elasticity change up to a temperature of 400 °C. The tungsten spring is passed through that and connected to the trigger electrode by making a U shaped hollow at the silica tube surrounding the assemblage of the cathode to protect the contact parts between the vacuum feedthrough and the spring. Cooling water moves around the cathode to control heat from used cathode of 7 mm. The cooling water passes through the assemblage of the cathodes and the center of the coaxial tube. Vacuum sealing is very important since the cathode should be not only rotated but also cooled. To rotate is very difficult once the cathodes are so strongly tightened for sealing. Leakage was prevented through an o-ring which support vacuum is inclined to one side even though it may be properly pushed down. Also, both sides of the axis were supported by a ball bearing not to move toward a direction of the axis.

3.2.2 Anodes and expansion area

The anode with a hole of 20 mm in diameter at the center has a disc shape and the edge has a 230 mm flange made of stainless steel. One side of the flange is connected to the acceleration column and the other side is attached to the cathode system through the electric insulating flange. Vacuum sealing has o-ring and insulating flange is MC ring of 230 mm outer diameter, 176 mm inner diameter and 76 mm length. It has ten penetrating holes and ten M8 tabs of 60 mm in depth at the edge. The expansion region is established in surrounding 20 mm hole at center of flange; 12 permanent AlNiCo5 cylindrical magnets with a 62 mm diameter, 73 mm length inside, 8.5 mm diameter and 70 mm length outside are assembled as the same gap on the circumference of the outside and has a field of 430 G magnitude. Composed of rubber or organic material, a lot of heats were produced both at the anode and at the cathode because of the maintained arcspot and cooling water was used for part fixing and insulating the anode.

3.2.3 Grid

Grid has many holes as thin board of disc type extracts ions from plasma and accelerates the extracted ions. An extraction-acceleration would be a normal arrangement for the fabrication of a simple and effective grid. The grid was set on a position where expansion of the plasma plume is expected. The initial grid is the extraction grid nearest from the plasma. Ions can be extracted by having the same potential with the cathode. Few KV would be applied to the acceleration grid maintained at negative with respect to the cathode. A high positive voltage is applied to a part forming plasma and voltage of acceleration column is properly distributed. The extraction grid was made of molybdenum of 104 mm in diameter and 0.3 mm thick, and the region of 64 mm in diameter is filled up by tight hole of 2.3 m in diameter. The extraction and acceleration grids were placed to correctly fit on each other and the gap was 2.4 mm.

Plasma matching which apply an appropriate voltage to the grid for a high quality beam from the ion source would be required. Maximum current of produced beam would be affected not by the plasma source but by the grid. Therefore, the design of the grid is particularly important, and the current limit is also determined by that factor.

3.3 Power Supply

3.3.1 Bi-polar pulse power supply [11]

A bi-polar pulse power is the main equipment for the generation and maintaining of the arc current. The performance of the metal ion source largely depends on its ability. IGBT is a suitable device to use for output and this has been shown by the results of repeated experiments. Thyratron Spark gap SCR turns on in giving to gate signal but does not turn off by gate signal. It was difficult to generate a pulse shape of perfect rectangular waveform. To control the width of a pulse was not easy since it depends on the electric charge of the capacitor. Because vacuum tube is highly expensive and the peripheral circuit is too complicated, the fabrication of pulse wave with IGBT is rather profitable, if possible.

The termination of the circuit was designed by the emitter follower method as shown in Fig. 1. The capacitor C_1 is charged through resistance R_1 from the DC power supply. When the pulse input signal is triggered from the pulse generator determining driving conditions, IGBT turns on and large instant currents would be initiated in a matching condition with load impedance. As pulse input signal is cut off, no current can occur due to the turning off of the IGBT.

Capacitor C_1 of 7.84 mF is composed of 14 chemical

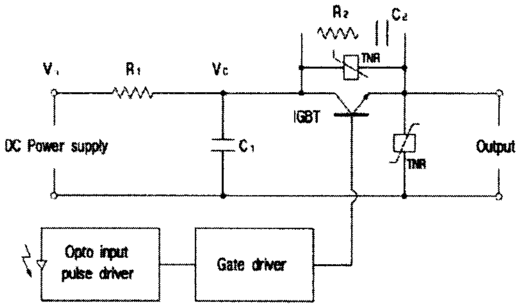


Fig. 1. A circuit of main switching part for bi-polar pulse power supply.

capacitors of 400 V and 560 μF in parallel by using a copper plate of 1 mm in thickness. To reduce the length, the capacitors were connected as two lines of seven pieces. A discharge resistance of 100 $k\Omega$ is connected to the chemical capacitors so that charges of the capacitor may not remain when not in use. R_2 and C_2 as a snubber are adjoined to the collector and emitter of IGBT in parallel with the IGBT to protect the breakdown during operation. Two resistances of 10 $k\Omega$ and 150 W in parallel are used for R_2. Oil capacitor of 100 V and 2 μF is used for C_2. Pulse output wiring takes a fast rise and fall repeatedly. Few kV high current flows over the wire without losing the pulse. The copper plate of 0.1 mm in thickness has a dimension of 50 mm in width and 1800 mm in length. Both ends of the overlapped ten pieces are soldered and 0.05 mm mica is put into the gap of each piece. Finally, the heat contraction tube is covered. Each of

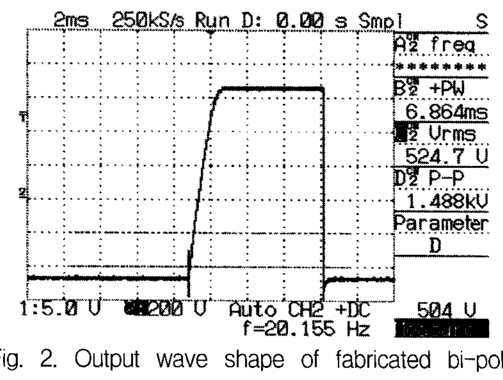


Fig. 2. Output wave shape of fabricated bi-polar pulse power supply.

the negative and positive output cables is fabricated for wiring. The measured output waveform from bi-polar pulse power supply is shown as in Fig. 2.

3.3.2 Trigger power supply

Trigger pulse power generates a weak arc between trigger and cathode by creating a momentary high current. [12] Main arc discharge can be formed by insulation breakdown of space between the anode and cathode. This equipment is a HV power supply of 10 kV and 50 A current. The power supply was designed with SCR which can manage large peak current and a maximum instant current of 50 A can be easily produced by employing the pulse source with a peak voltage of 12 kV, pulse width 40 μs and maximum repetition rate 20 Hz with a help of transformer to amplify the voltage. Fig. 3 shows a block diagram for the main switch of trigger pulse power supply. In operation, SCR_1 turns on and filled charge of C_1 and C_2 is move to C_1 and C_3, if gate of SCR_1 is given trigger pulse when both SCR_1 and SCR_2 turn off, therefore the current continuously flows until the electric potential of C_1 and C_3 will be the same. SCR_1 turns off automatically at that time. The next time when the trigger pulse is supplied for SCR_2, SCR_2 turns on and charge of the C_3 passes through SCR_2. The strong pulse current is generated at primary of T_1. No current occur any more, and turns off automatically when the whole C_3 is discharged. C_1 and C_2 are charged up to the maximum while SCR_1 is turned off. Trigger pulse is applied to the gate of SRC_1. Then, the C_3 is filled with the charges of C_1 and C_2. SCR_2 turns off after charging. The process is performed continuously. A period limit of repetition working depends on the charging time of C_3. A gate pulse generator must be designed as the type that it receives the synchronization signal from the bi-polar pulse power supply and outputs gate pulse on SCR_2 with a rising signal and generates gate pulse on SCR_1 in controllable random time. In this research the pulse to control pulse of output and controlling time difference is generated with 74LS123 of TTL IC. The waveform is examined with oscilloscope on operation of power. That is measured as high voltage probe at the point where the C_3 and the cathode of SCR_1 were coupled.

Fig. 4 corresponds to the charged wave shape of capacitor C_1 of pulse power supply displaying a rising and falling wave signal of charge and discharge. The wave measured at both electrodes of Tr_1 transformer is shown in Fig. 5. The pulse signal of peak-to-peak

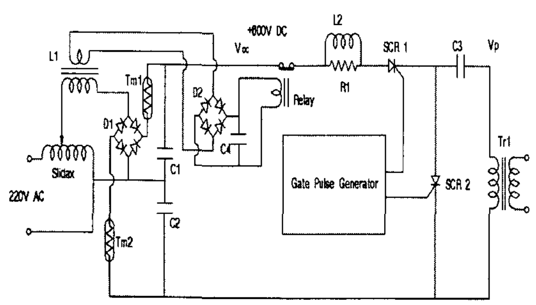


Fig. 3. Main switch of trigger pulse power supply.

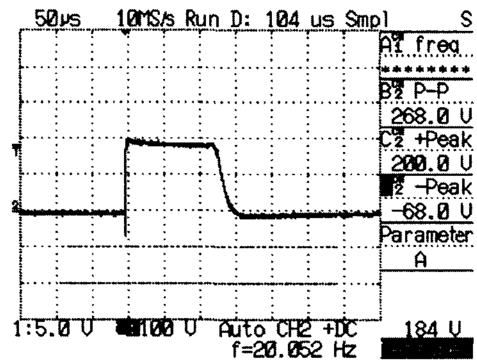


Fig. 4. Charged wave shape of C1

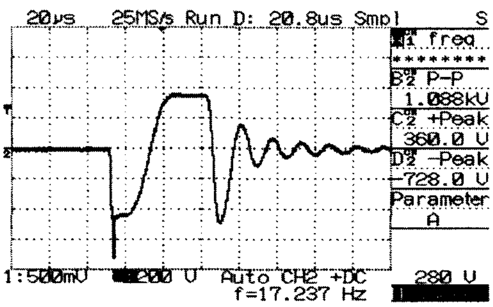


Fig. 5. Wave shape of Tr1 electrode

voltage, 1 kV is applied and the approximate output was expected to be 20 kV when unloaded.

3.3.3 Beam power and acceleration power

The role of beam and acceleration power was firstly to extract and secondary to accelerate ions from metal plasma while bi-polar and trigger pulse power supply was producing metal plasma. Beam power determines the potential energy of formed metal plasma and acceleration power extracts metal ion from metal plasma of any potential energy and feeds the ions into the acceleration column with a uniform magnetic field. Maximum voltage for acceleration was designed as 40 kV because of needed beam power, which can simultaneously perform the ion implantation and deposition. The system supplies sufficient current to the capacitor as charged power during generating metal plasma by applying DC high voltage power to the resistor and capacitor. The resistor prevents DC high power supply from being out of order because of excessive current and large entry current from flowing over the capacitor. That is a winding resistor of 30 $k\Omega$ and 3000 W. The current can be generated less than the limit by the existence of resistance in early time of charging since the resistance has individually inductance parameter. The capacitor is composed of 5 ceramic capacitors of 10 nF and 50 kV in parallel and 50 nF capacitor is connected. DC high voltage power supply of 10 kW can deliver a 40 kV and 250 mA using a HV 20-250R model of VOLTRONICS. A power of -5 kV and 100 mA was used for the acceleration of extracted ions.

3.4 Vacuum and pumping system

High vacuum system was designed and fabricated using stainless steel in a cylinder structure with a diameter of 550 mm and a height of 450 mm. That is surrounded by five cooling water flanges and has windows by attaching a rectangular flange. The source holder was set for installation of source inside the chamber and can be rotated. It takes twenty minutes for the vacuum chamber to reach a working pressure of 1×10^{-6} torr by oil diffusion pump with a pumping speed of 100 *l/sec*. The water baffle was placed on the gap between chamber and diffusion pump to prevent oil back streaming. Gate valve is installed in the space between the water baffle and gate valve. Pirani and penning gauges were used to measure pressure of main chamber and roughing line connected to the rotary pump of 550 *l/min*.

3.5 Acceleration column

Metal arc ion source was designed to accelerate naturally and collide with a source by raising the potential of place generating plasma up to a few kV. Most of metal ion sources were made up a part including plasma generation by arc and acceleration column. However, the best way to increase the potential of the metal ion source over several ten kV is to isolate and hold between the vacuum chamber and the metal ion source by using a separated acceleration column. By using the separated acceleration column, optimized conditions for acceleration of the extracted ion were definitive because of no distortion of the electric field or no charging up to high voltage over 100 kV. Thus, the acceleration column was carefully designed as a structure coupled by ceramic rings and metal rings in this research. Nine ceramic rings in the center were made from the alumina of high purity as thin ring of 170 mm in outer diameter and 130 mm in inner diameter and both plates were metalized. Two ceramic rings of both columns have the same size of inner and outer diameter with a thickness of 10 mm and only one side was metalized. The metal ring was made form a chemical electroplating of the Ni after cutting a 0.5 mm thick plate of Kovar with a similar thermal expansion constant with aluminum. It has a size of 180 mm in outer diameter and 120 mm in inner diameter, respectively. Ceramic ring and metal ring were coupled by brazing process at high temperature and high vacuum.

The electrode in the column was designed to prevent the metal particle from being coated on the insulator surface of the acceleration column and breakdown column. By this the weak force of direction toward the center was given for undesirable impurities not to produce by sputtering so as for the metal ion to collide with the electrode of acceleration. The same resistances were placed on each column outside the acceleration column from high voltage to ground and uniform magnetic field was applied. This resistance 300 $M\Omega$ and capacitor of 100 pF and 15 kV are attached to provide an instant current in parallel. To apply high voltage bias to the cathode of the metal ion source the chamber and metal ion source were firmly insulated through the acceleration column. Each column of nine acceleration electrodes can be applied up to 15 kV and the maximum bias voltage was 135 kV and a 40 kV was applied up to a maximum of 49 kV DC power supply in the this research. The negative line of DC power supply, negative line of bi-polar pulse power supply and negative line of trigger pulse power was united and loaded on this potential. The above AC input lines have the same potential by insulating the transformer.

4. Experimental Results and Discussion

After about 30 min pumping with the rotary and diffusion pump, a working pressure of 1×10^{-6} torr was obtained low enough to operate the metal plasma ion source. A pressure during operating time is also important for the clean process of ion source. The measured pressure was 1×10^{-5} torr during the operation of the ion source under optimized conditions of deposition through repeated experiments. It means that metal plasma ion source is generally a clean process technique.

A flux of ion beam can be produced as a beam current extracted from plasma while bi-polar pulse so-called peak ion current is applied. It is reasonable because of the negligible differences between them although the ion current varies with charged state. The average ion current I_a can be described as follows;

$$I_a = I_n \times R_d \tag{1}$$

where the I_n is a peak ion current and the R_d is a duty ratio. Current integration accuracy is defined as variation difference of average current during long time measure without the change of processing conditions. To measure the arc current under operation was difficult but can be approximately calculated with average current of DC power supply by duty ratio. Average current of DC power supply was measured as 1.3 A for a 100 V bi-polar pulse power with a duty ratio of 0.3 % and peak current of 433 A. On this condition, during the deposition of cobalt films with a 20 nm thick, the average flux was calculated for the processing parameters of pulse repetition 15 Hz, pulse width 200 μs, beam voltage 200 eV, and acceleration voltage 100 V. Beam voltage is not so high to avoid the generation of huge heat during the deposition of relatively thick films.

Fig. 6 shows the RBS spectrum of cobalt (Co) film deposited on the single crystal silicon substrate by employing a single cobalt cathode. A distinct peak was newly observed near the 650-760 channel range and confirmed to be a pure Co layer. In experiment, deposited area was about 100 cm^2 and the thickness was evaluated to be 143 nm from the least square

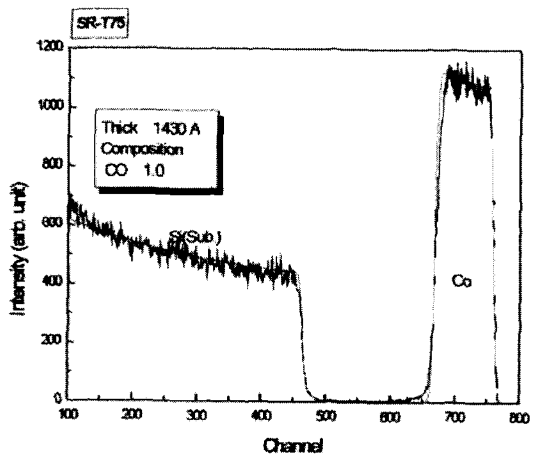


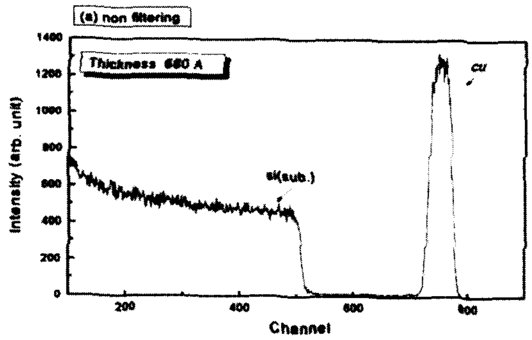
Fig. 6. RBS spectra for Co thin film deposited on Si substarte by our MEVVA system.

fitting of the RBS result. Beam Flux was about 1000 mA during the deposition.

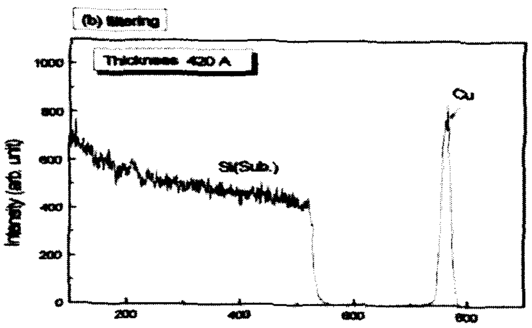
Fig. 7 shows the RBS results of Cu films deposited on the single crystal Si substrate to test the effects of ion beam filtering by using an electromagnetic lens system. Both spectra of Cu samples prepared (a) without and (b) with filtering process display a well-isolated peak near the channel range of 730-780 confirmed due to Cu atoms. From the sharpness of the Cu peak, the filtered-beam sample has thinner Cu layer than the unfiltered sample. In analysis, the film thickness of Cu on Si was 680 Å for unfiltered sample and 420 Å for filtered-beam sample under the same deposition period, respectively.

The surface of Cu thin film prepared without filtering process was much rough compared to the Cu film surface prepared with filtering process. Since macro particle was emitted over 60° from axis direction, particles are mostly filtered at extraction region at the end of the cylinder. Some of the macro particles passed trough the extraction area were directly deposited and resulted in a rough surface. In respect, the particles passed through two extra grids were becoming more uniform and resulted in a smooth Cu surface.

Fig. 8 and 9 display SEM photographs of Cu samples prepared without and with beam filtering process, respectively. Some of macro particles were observed for the surface of both Cu thin films but much larger particles from unfiltered sample compared to the filtered-beam sample. The cross-section of both samples also clearly indicated that unfiltered sample has much larger size of Cu grains. The observed film thickness of both samples was in a good agreement with the previous estimation by RBS modeling.

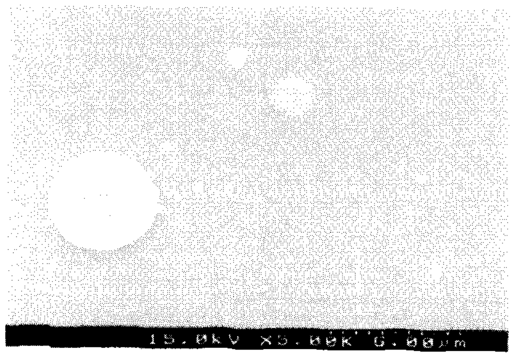


(a)

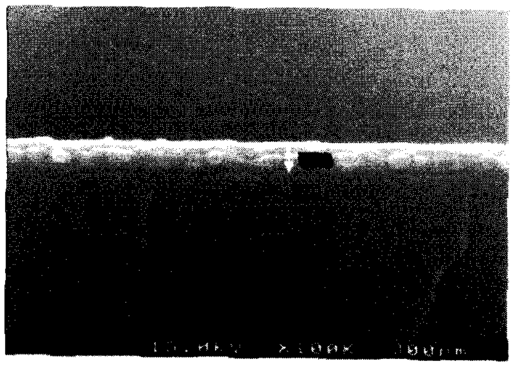


(b)

Fig. 7. RBS results of Cu thin films deposited on Si (a) without filtering and (b) with filtering.

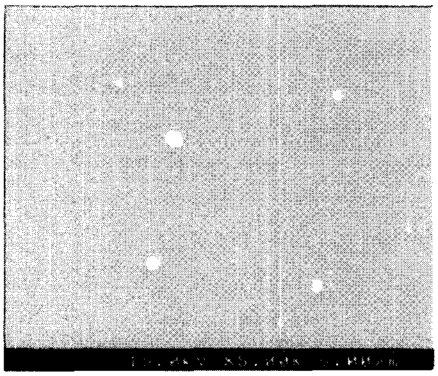


(a)

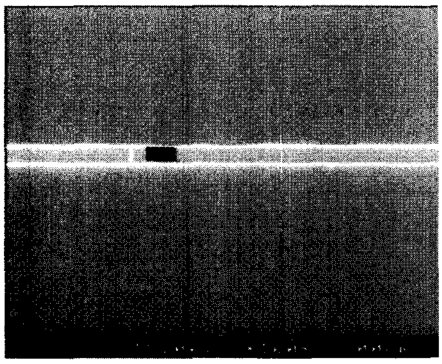


(b)

Fig. 8. SEM photographs of Cu thin film prepared without beam filtering process: (a) surface morphology and (b) cross sectional view.



(a)



(b)

Fig. 9. SEM photographs of Cu thin film prepared with filtered-beam process: (a) surface morphology and (b) cross sectional view.

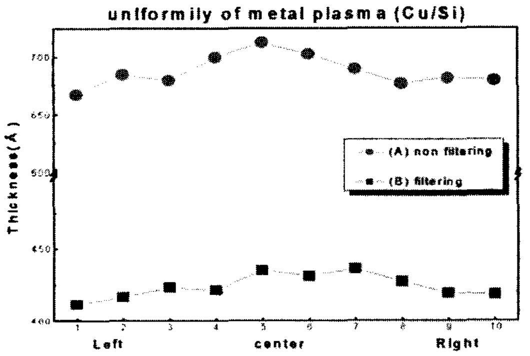


Fig. 10. Measurement of uniformity of Cu/Si thin film by metal ion source.

Fig. 10 shows the variation of measured thickness for a Si wafer with a deposited Cu surface area of 100 cm^2 from the center to both ends by a gap of 1 cm.

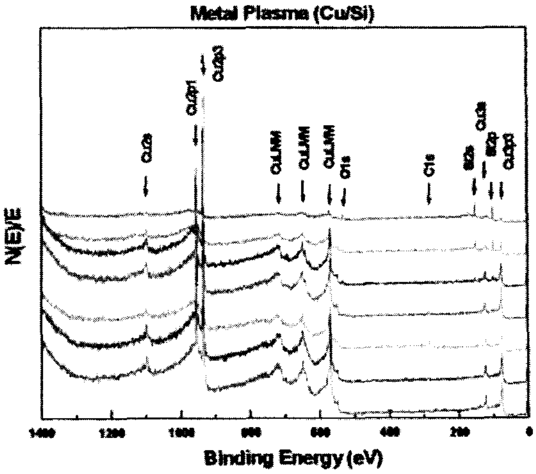


Fig. 11. A series of XPS spectra of Cu thin film deposited on Si substrate with a gradual removing of film by sputtering.

The deposited Cu thin films were estimated to have a lateral thickness uniformity of about 5 %.

The X-ray photo-electron spectroscopy was used to perform a qualitative analysis for the high purity thin film prepared by a filtered-metal ion of Cu^+ and a typical result is shown in Fig. 11 illustrating a progressive reduction of Cu signals due to the sputtering of Cu film. The XPS spectra were recorded for the sample with a deposited dimension of 3 mm×3 mm on Si substrate with sputtering by Ar^+ ions of 3 keV. The X-ray source was well focused on the sample area of 400 μm^2. In addition to the main Cu core and Auger peaks, Fig. 11 also shows a small C1s peak near the binding energy of 300 eV and O1s peak near the binding energy of 550 V during the sputtering. Except the small oxygen peak observed only near the Cu/Si interface due to the oxidized Si top surface and the C1s peak appeared once a while in the middle of the Cu film, the occurrence of clear Cu $2p_{1/2}$ and Cu $2p_{3/2}$ peaks near the binding energy of about 950 eV indicates a successful preparation of high purity and single-phased Cu films by metallic ion-beam deposition technique. The pulse metal arc ion source can effectively change kinetic energy by varying beam power and increase an adhesion by increasing the kinetic energy of ions. The prepared thin films were confirmed to have an excellent adhesion between metal and Si substrate by tape peel-up and wheel test due to the formation of ion beam intermixed layers.

Pulse stability was measured to be near 100 % by the oscilloscope test of the pulse. Recovery equipment was installed at pulse power supply to radically prevent the system stopping during the deposition and so pulse stability was greatly increased. The pulse did not stop over 5 min during the deposition. Even when the generated trigger pulse was applied to trigger electrode, main discharge was not happened until a sufficient current for arc discharge was obtained. Otherwise, the arc discharge was not stable because of incorrect gap between the trigger and cathode electrodes. For measurement of trigger ratio discharge current was recorded by applying pulse to trigger voltage during 20 min with a cycle of 1 Hz and then, a formation of triggered metal plasma was observable through the glass windows. The failure of arch discharge was observed once a while. Experimental current integration from discharge current and duty ratio was highly compatible with the RBS results within a 10 % error. Ion beam of 1.5 Å could be obtained at 100 V and 2.4 A bi-polar DC power of Cu plasma cathode and 0.3 % duty ratio. The accuracy rate of 90 % could be specified through the repeated experiments by RBS analysis. Therefore, current integration indirectly from discharge current and duty ratio would be then reliable required for the estimation of process conditions in case of stable operation of metal plasma.

Fig. 12 shows the RBS spectra for multi-layer samples prepared by subsequently depositing 2600 Å NiCr layer after the deposition of 600 Å Cu layer on silicon substrate. The deposition and ion implantation was simultaneously performed by 20 kV beam power. The pure Cu rod was used for deposition of Cu layer and an alloy rod of 23 % Cr and 77 % Ni was used to deposit NiCr layer. It could be confirmed that the deposition was well defined as the same composition

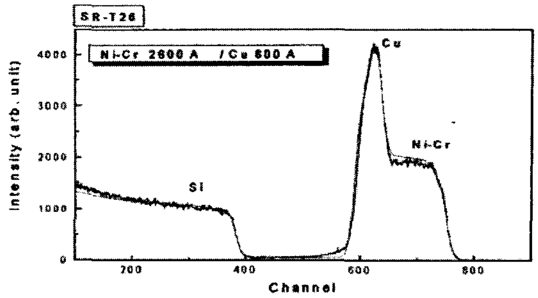


Fig. 12. RBS spectra for Cu/Ni-Cr multi layer thin film deposited on Si substrate by multi cathode arc ion source.

ratio with material used as ion source from RBS simulation result. The red solid line represents the simulation result and the black line corresponds to the real RBS data.

The lower channel of the Cu peak was not in a perfect concordance with the simulation. This deviation can be understood as a result of Cu atom penetration into the silicon substrate via an initial implantation process by 20 kV bias applied to ion beam. The same phenomena were expected for the subsequent deposition of NiCr layer on Cu. The energy of metal ion beam varies with the voltage and current of the anode applied between the vacuum and the generating arc. The ionic species of Cu atoms were estimated consisted of about 20-30 % for Cu^{1+} state, 40-55 % for Cu^{2+} state and 20 % over Cu^{3+} states. Thus, ion energy for the 20 kV bias was expected enough for the implantation of Cu^{2+} and over Cu^{3+} states ranging from 20 to 60 keV.

5. Conclusion

Single and multi-cathode vacuum arc metal ion sources were designed and fabricated for the deposition or ion implantation of multi layers without breaking high vacuum. The ion current was nearly constant during the lifetime of a cathode and increased linearly with an increase of arc current within the range of operation of the ion source. Under optimized conditions with a consideration of heated substrate by acceleration voltage, the ion flux was estimated to be over 1000 mA resulting in a highly controllable deposition rate by varying pulse duty ratio. Beam uniformity was confirmed to be within 95 % by RBS thickness analysis and cross sectional SEM measurement.

It was proved by SEM measurement that the macro particles of Cu ion beam were largely filtered by the operation of grids. The adhesion on single crystal Si substrate was increased with the increase of beam power. The ion was implanted on the source deposited by Ni-Cr as the same energy to change the cathode after depositing Cu on Si substrate as 20 kV. Ion plasma deposition of metallic films was a clean process to prepare high purity thin film with a very uniform thickness by excluding most of macro particles. As a result of the peel-up test, metal thin film with a strong adhesion was deposited on SiO_2, dielectric, poly-imide and polymer substrate with a help of ion implantation to some extents. The main advantage of our high flux metal plasma pulse ion source is simpler design and cheaper cost than the previous system for the ion deposition and possibly implantation of metal sources. For this reason our ion source will be adequate not only for the various academic research works but also for the industrial fabrication. The prototype was suitable for the research of metal ion implantation used for milling of metal, ceramic, semiconductor, super semiconductor, glass and polymer and the ion deposition of small area and volume in the mass production.

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