Transactions of the Korean Nuclear Society Virtual Autumn Meeting
December 17-18

The multiple Ion Charge State Measurement of the Metal Vapor Vacuum Arc Ion Source at the KOMAC

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1. Introduction

The metal vapor vacuum arc (MEVVA) ion source can extract high current metal ion beam using the vacuum arc discharge. The vacuum arc discharge occurs between cathode and anode in the MEVVA ion source, the arc current is concentrated on the cathode surface with small spot. And the cathode surface is melted by concentrated arc current, therefore cathode is heated, vaporized, and ionized into the plasma state [1]. For these principles, the MEVVA ion source can also extract wide metallic ion species such as the high melting temperature materials (tungsten, graphite), pure semi-conductor materials (silicon, germanium) into ion beam [2]. And the MEVVA ion source generates the metal plasma of the multiple charge state [3]. The MEVVA ion source was installed on to the vertical ion beam facility at the Korea Multi-purpose Accelerator Complex (KOMAC). So, the metal ion beam is directly irradiated by the vertical direction from top site (ion source) to bottom site (sample) and the metal ion beam can irradiate large area. Therefore, the metal plasma of the multiple charge state is directly extracted and accelerated by the extraction grid. In these reasons, the metal ion beam has energy distribution [4]. In this study, we conduct the analysis of the metal ion beam charge state with the nickel cathode. The metal ion beam was irradiated by silicon wafer at the same condition, and it is analyzed by the Dynamic Secondary Mass Spectrometry(D-SIMS). Finally, we measure the metal ion charge distribution.

2. Experimental and Results

In this section, some of the ion beam facilities and methods used the experiment are described. The ion beam facilities include the ion source, vacuum chamber, high voltage power supply and the vacuum system.

2.1 The Metal vapor vacuum arc ion source

Fig. 1 shows the vertical ion beam facility and the MEVVA ion source at the KOMAC. The MEVVA ion source is purchased from Plasma Technology Limited (PTL, Hongkong). The MEVVA ion source is installed on the vacuum chamber and the metal ion bema is directly irradiated to sample. The vacuum pump is connected with the vacuum chamber and these consists of the turbo molecular pump and scroll pump. The pressure is decreased from atmospheric pressure to the high vacuum. So, the MEVVA ion source is operated in the 10^{-6} Torr. Behind of the vacuum chamber, the high voltage power supply is installed and these have four power supply; the trigger power supply, the arc power voltage supply, the extraction power supply and the suppress power supply. The trigger power supply initiates the arc discharge by applying high voltage near the cathode. And then arc discharge is maintained by the arc power supply between the cathode and the anode, it is lower than the trigger power supply. Finally, the metal ion beam is extracted by the extraction power supply. The MEVVA ion source is operated in the pulse mode, and repetition rate and pulse width can be adjusted up to 20 Hz and 1500 usec. And it can be extracted up to 80 kV. The MEVVA ion source generates multiple charge state metal plasma; therefore, the metal ion beam has energy distribution according to the ion charge state [5].

Fig. 1. The vertical ion beam facility and the MEVVA ion source.

2.2 The cathode for the MEVVA ion source

In case of the MEVVA ion source, the solid type cathode is used for plasma generation. The cathode is cylindrical and it has 10 mm diameter and 30 mm length (Goodfellow, United Kingdom) and the arc discharge occurs on the cross section of the cathode surface. The cathode was fabricated by casting method, first it is 100 mm length and cut to 31 mm. The cross section where the discharge occurred was machined again because this is an important factor in arc discharge.

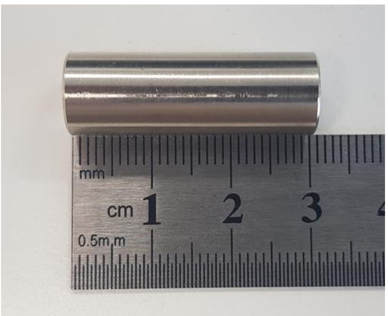

Fig. 2. The cathode for MEVVA ion source

2.3 Measurement of the multiple charge state

The ion charge state of the nickel cathode is measurement using D-SIMS. For analysis, the nickel ion beam was irradiated on the silicon wafer. The irradiation conditions are 4 Hz reputation rate, 900 usec pulse width, 30 kV extraction voltage and total ion beam dose is 9.79×10^{16} ions/cm^2 for 3 hours. Despite being extraction to 30 kV, ion beam has an energy distribution due to the ion charge state. These are 30 keV, 60 keV, 90 keV, 120 keV. Fig. 1 shows the results of D-SIMS analysis and it is sum peak. Therefore, we conduct the peak fitting. First, the penetration depth was calculated using SRIM software in order to determine the stopping energy according to the energy distribution of the nickel ion beam in the silicon wafer. Each penetration depth is 29.0 nm, 51.7 nm, 74.7 nm, 98.9 nm depending on the energy. In the Fig. 1, these have 5 peaks. The ion charge state of the nickel has four states from 1+ to 4+. And penetration depth of the D-SIMS results is similar to the SRIM calculated data. However, it can be seen that there is a peak at the 17.41 nm in the Fig. 1. This is the peak due to the nickel oxide layer on the cathode surface. In the cathode fabrication process for MEVVA ion source, a thin oxide layer was formed and it is extracted with the pure nickel ion beam during the initial plasma discharge [6].

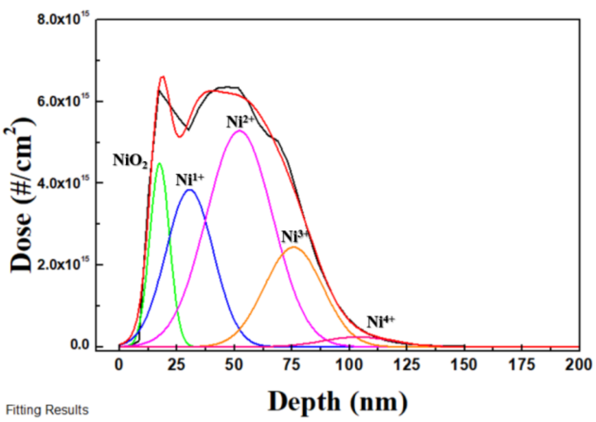

Fig. 3. D-SIMS data and fitting results of the Ni ion beam.

Table I: Results of the Ni ion beam analysis

	SRIM (nm)	D-SIMS (nm)	Area	%
NiO_2	-	17.41	4.48×10^{15}	11.3
Ni^{1+}	29.0	30.47	3.84×10^{15}	23.4
Ni^{2+}	51.7	52.13	5.28×10^{15}	44.9
Ni^{3+}	74.7	75.64	2.44×10^{15}	18.2
Ni^{4+}	98.3	103.73	2.43×10^{14}	2.2

And peak area and percentage are also calculated each ion charge state. The area percentage is 23.4 %, 44.9 %, 18.2 % and 2.2 % from 1+ to 4+, so Ni^{2+} has large area about 44.9%. Therefore, the average charge state of the nickel cathode is 1.77.

3. Conclusions

In this study, the ion charge state of the nickel cathode is experimentally measured by the D-SIMS analysis. Initially, there is an oxide layer on the cathode surface. Therefore, the nickel oxide peak is included in the D-SIMS data, and the ion charge state distribution is compared with the SRIM data.

REFERENCES

[1] I. Brown, Vacuum arc ion sources: Recent Developments and Applications, arXiv
[2] I. Brown, Vacuum arc ion source, Review of Scientific Instruments, Vol 65, 1993
[3] I. Brown, Cathode Erosion Rate in Vacuum-Arc Discharge, IEEE Transactions on Plasma Science, Vol 18, 1990
[4] C. W. Kimblin, Erosion and ionization in the cathode spot regions of vacuum arcs, Journal of Applied Physics, Vol 44, 1973
[5] S. H. Lee, Y. S. Cho, H. S. Kim, H. J. Kwon, Cathode erosion rate measurement of MEVVA ion source, Transactions of the Korean Nuclear Society Virtual Spring Meeting, 2020
[6] L, Torrisi, F. Caridi, D. Margarone, L. Giuffrida, Nickel Plasma Produced by 532-nm and 1064-nm Pulsed Laser Ablation, Plasma Physics Reports, 2008