Transactions of the Korean Nuclear Society Virtual Spring Meeting
July 9-10, 2020

Cathode erosion rate measurement of MEVVA ion source

Seung Ho Lee [a, c], Yong-Sub Cho [b, c], Han Sung Kim [a, c], Hyeok-Jung Kwon [a*, c]
[a]*Accelerator Development and Operation Division, Korea Atomic Energy Research Institute, Korea*
[b]*Nuclear Physics Application Research Division, Korea Atomic Energy Research Institute, Korea*
[c]*Department of Accelerator and Nuclear Fusion Physical Engineering, University of Science and Technology*
[*]*Corresponding author: hjkwon@kaeri.re.kr*

1. Introduction

MEVVA (Metal Vapor Vacuum Arc) ion source is device for extraction of metal ion beam using vacuum arc discharge. Because MEVVA ion source uses vacuum arc discharge, it can extract not only high melting temperature materials such as tungsten and graphite but also pure semiconductor materials such as silicon and germanium an ion beam. Therefore, MEVVA ion source has the advantage that various metal ion beam can extract than the conventional ion source[1]. In addition, MEVVA ion source can extract high-current and large-area metal ion beam. Recently Korea Multi-purpose Accelerator Complex (KOMAC) has constructed MEVVA ion source with maximum voltage of 80 kV and beam current of 5 mA and it is under pre-liminary test. Also, MEVVA ion source received facility inspection from the Korea institute of nuclear safety (KINS) and it is licensed for use. In this study, we report the measurement results of the cathode erosion rate of MEVVA ion source.

2. Experimental and Results

2.1 Configuration of MEVVA ion source

Fig. 1 shows the constructed MEVVA ion source at KOMAC. In the fig. 1, MEVVA ion source is located top site and irradiation chamber is located bottom site. Metal ion beam is irradiated in the vertical direction. And behind of the irradiation chamber, high voltage power supply for ion beam acceleration is located and vacuum in the chamber is pumped by two TMP and scroll pump.

Fig. 1 The MEVVA ion beam facility at the KOMAC

MEVVA ion source can apply extraction voltage of 80 kV and beam current of 5 mA. MEVVA ion source is operated in repetitive pulse mode, and repetition rate and pulse width can be adjusted up to 20 Hz and 1500 usec. In order to occur vacuum arc discharge, the trigger electrode surrounds the cathode coaxially with insulator. When the high voltage of 23 kV is applied the trigger electrode, vacuum is breakdown between cathode and anode and arc discharge will be occur[2]. After that, the generated metal ion beam is accelerated and extracted with extraction grid.

2.2 Passage of the facility inspection

Recently, MEVVA ion source received facility inspection from the KINS and it is licensed for use. In order to the facility inspection, safety system is prepared such as remote controller of ion source, door and RMS interlock and operation status indication light.

Fig. 2 MEVVA ion source safety system at control room

Fig. 2 shows safety system of MEVVA ion source. First, remote controller of MEVVA ion source is able to remote control such as ion source power, plasma generation and ion beam extraction. Remote control and ion source are separated into a control room and a laboratory and there is a thick concrete wall between them. Second, operation status indication light is divided into green, orange and red. This indicates ion source status externally and the red light turns on during the ion beam extraction for access restriction in laboratory. Third, door and RMS interlock automatically shuts off the ion source power when laboratory door is opened or radiation dose in control room increases during ion beam extraction. Finally, it is possible to safely operate MEVVA ion source from radiation during ion beam extraction through this safety system.

2.3 Cathode Spot

Metal plasma is generated by vacuum arc discharge between cathode and anode. When the vacuum arc discharge occurs, current is concentrated at a small number of tiny, discrete sites on the cathode surface, it is called cathode spot. Cathode spot move around cathode surface, and its diameter is micrometer, current density is 10^6 ~ 10^8 Acm^{-2} and lifetime are microseconds. The current density of cathode spot is extremely high, cathode spot is heated, vaporized and ionized into the plasma state[1~2].

2.4 Cathode erosion rate

Cathode of MEVVA ion source is gradually decreased due to cathode spot and erosion. In this section, erosion rate is measured experimentally and compared depending on the materials characteristics. Cathodes of MEVVA ion source are prepared to measure erosion rate such as chromium, titanium, tungsten and copper and it is extracted by metal ion beam. After experiment, weight change of cathode is measured to calculate the erosion rate. All cathodes have same cylindrical shape and it there are diameter 10 mm and length of 30 mm[4].

Table I: Characteristics of MEVVA ion source

Elements	Tm (K)	Ma	Qa (C)
Cr	2180	51.99	2.1
Ti	1941	47.86	2.1
W	3695	183.84	3.1
Cu	1357	63.54	2

Table I shows the characteristics of cathodes used in the experiment, Tm is melting temperature, Ma is atomic mass unit and Qa is average charge. During the experiment, the arc current of chromium and titanium cathodes are 142.85 A, 166.67 A, respectively and arc current of tungsten and copper are 107.14 A. In case of the total arc current, it is assumed that only one cathode spot per pulse is occur. Table II shows the experimental erosion rate by measuring the weight before and after the metal ion beam extraction experiment.

Table II: Experimental erosion rate with Cr, Ti, W, Cu

Elements	Arc current (A)	Total Arc time (sec)	Erosion (mg)	Erosion rate (ug/C)
Cr	142.85	90.72	420.2	32.42
Ti	166.66	17.28	110.0	38.19
W	107.14	30.24	222.8	68.76
Cu	107.14	30.24	115.5	35.64

As shown in Table II, erosion rate of titanium is higher than Cr, even if total arc time if titanium is small. There are two reasons. First, the arc current of titanium is higher than chromium. This means that the cathode spot has melted more cathode surface and erosion is fast. And Tm of titanium is lower than chromium. Also, this causes more cathode erosion at the same arc current. For this reason, erosion rate of titanium has higher than chromium. Next, arc current and total arc time of tungsten and copper are same. Although tungsten has a higher Tm, Ma of tungsten is significantly bigger than copper. At the results, erosion rate of tungsten is higher.

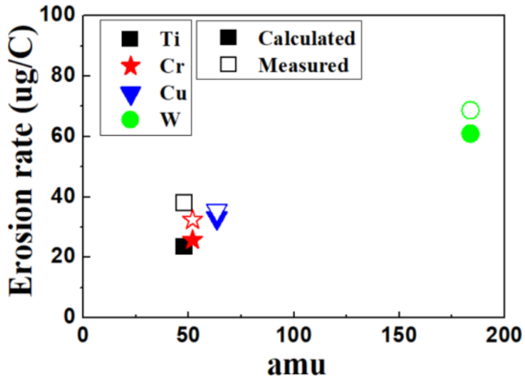

Fig. 3 Comparison of calculated and measred erosion rate

Fig. 3 shows the comparison of the calculated by ref [3] and experimentally measured erosion rate. Ian Brown calculated the erosion rate through Ma and Qa of cathode. It is confirmed that the calculated erosion rate has approximate value to the experimental value. However, the applied formula has no Tm of cathode. Therefore, it is error for all data.

3. Conclusions

In this study, the erosion rate of cathodes with different characteristics cathode are experimentally measured. Then, the measured erosion rate is compared with calculated erosion rate. As a result of comparison, it is confirmed that the cathode erosion rate is related to Tm and Ma.

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