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BEAM MEASUREMENT AND APPLICATION OF THE METAL VAPOR VACUUM ARC ION SOURCE AT KOMAC

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Abstract

The metal ion beam facility is developed including the metal vapor vacuum arc (MEVVA) ion source at the KOMAC (Korea multi-purpose accelerator complex). The MEVVA ion source has advantage that it can be extract almost metal ion species as well as high current ion beam. After the installation, we measured beam properties such as the beam profile and peak beam current depending on the operation condition, average charge state and cathode erosion rate. In addition, as one of the application fields, we irradiate the metal beam on the air electrode of the fuel cell and measured the performance. In this paper, the beam measurement results, are summarized and solid oxide fuel cell (SOFC) performances after metal beam irradiation are described.

BACKGROUND

The MEVVA ion source generates metal plasma through vacuum arc discharge between electrode [1]. This kind of ion source does not require gaseous operation to produce metal plasma, and uses bulk metallic cathode [2]. The arc current is concentration at a tiny spot on the cathode surface, it is called a cathode spot. This micro size spot is vaporized and ionized to metal plasma [3]. It can generate almost metal io species in Periodic table [4].

In this work, the possibility is studied that the (SOFC) efficiency improvement through the beam irradiation. Nobel metal ions are difficult to extract ion beam. They are extracted and irradiated on the SOFC. Before the irradiation beam properties are measured such as stability, peak beam current and beam profile. Then the average charge state is estimated to determine the total dose. From the above experimental process, beam properties are checked, and the irradiation condition is optimized to SOFC. The electrochemical performance of irradiated SOFC is analysed and compared through current density-voltage measurement and electrochemical impedance spectrometry (EIS) analysis.

METAL ION BEAM TEST

Stability

The metal ion beam facility is developed including the MEVVA ion source at KOMAC. It consists of the MEVVA ion source, the chamber for beam irradiation, power supplies, evacuation pump, the diagnostic system and remote controller. The integrity of ion beam facility was evaluated using chromium ion species, which is one of the universal species in MEVVA ion source, in previously study [5]. The extraction voltage is stable at the 3.75 kW of arc power. Experimental conditions were 4 Hz of repetition rate, 700 μs of the pulse width and 30 kV of the extraction voltage. When the silver and copper ion beam extract, the fluctuation of extraction voltage is 30.0±2.3% and 29.9±4.7%.

Properties

Beam properties of the silver and copper ion species are measured in the same process as before study. Irradiation parameters will be determined to improve the SOFC. Fig. 1 shows the peak beam current of the silver and copper depending on the arc power and the extraction voltage. The experimental conditions were 4 Hz of repetition rate and 900 μs of pulse width. The peak beam current of both ion species is increased as the arc power and extraction voltage increase.

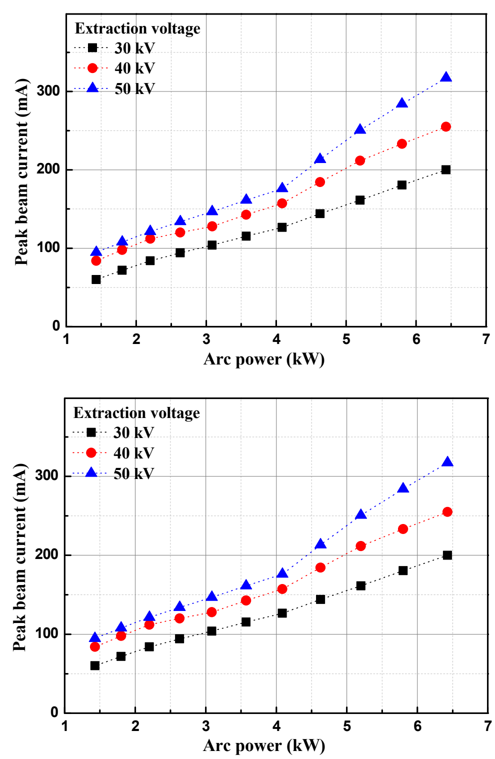

Figure 1: Peak beam current depending on the arc power and extraction voltage (a) silver (b) copper.

Figure 2 shows the beam profile and RMS radius depending on the arc power of silver and copper. The

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experimental conditions were 4 Hz of repetition rate, 700 µs of pulse width, 3.57 kW of the arc power and 30 kV of the extraction voltage due to the most stable extraction condition. The beam intensity of the silver is higher than the copper ion beam at the same extraction condition(Fig. 2(a)). The RMS radius gradually decreases and is the lowest at 3.57 kW(Fig. 2(b)). The radius of silver and copper ion beam is 69 mm and 56 mm, respectively.

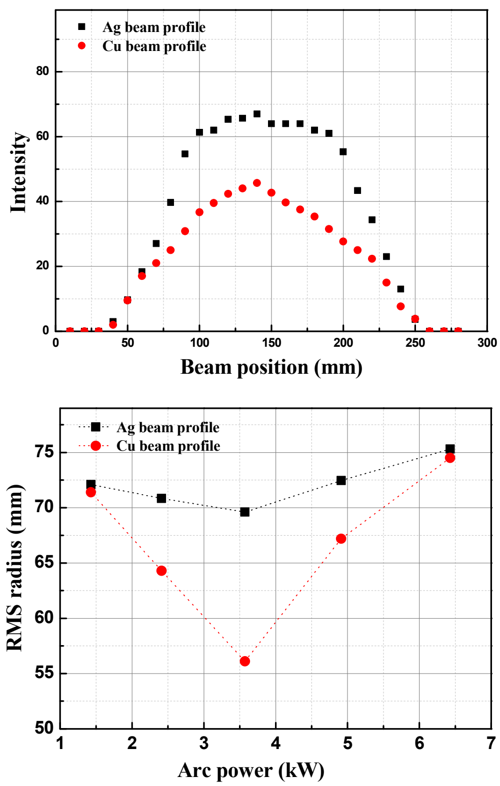

Figure 2: silver and copper beam profile results (a) beam profile (b) RMS radius depending on the arc power.

Figure 3 shows the charge distribution of silver and copper by the dynamic secondary mass spectrometry. Each charge state peak is fitted using the SRIM simulation data in order to analyse the depth profile result. The average charge state of silver and copper is 1.7 and 2.0, respectively. This result is compared with other previous studies as shown in the Table 1 [6,7].

As above experimental study, the beam properties of the silver and copper ion species were measured. In the operation region, the peak beam current of both metal ion species is similar, approximately 200 mA at 30 kV of the extraction voltage. On the other hand, there is difference in the RMS radius that 69 mm of silver and 56 mm of copper, respectively. From these results, the SOFC is installed at the RMS radius for irradiation experiment. The metal ion beam is extracted under the matching condition, the lowest RMS radius extraction condition, and a mask is cover on the SOFC to irradiate only air electrode. The total dose of ion beam is estimated by using current density of a small faraday cup and the average charge state.

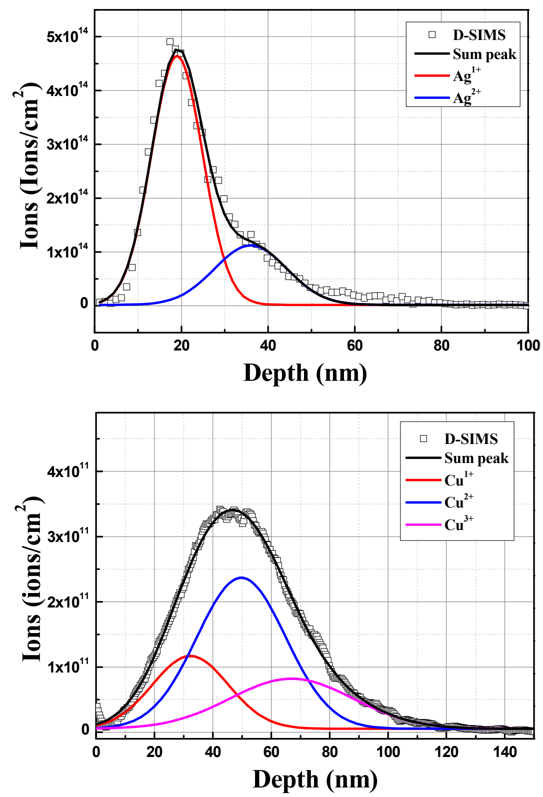

Figure 3: Results of depth profile analysis and fitting. (a) silver (b) copper.

Table 1: Average Charge State

Ions \Institute	KAERI	LBNL	IHCH
Silver	1.7	2.1	2.1
Copper	2.0	2.0	2.0

BEAM IRRADIATION

The electrochemical performance of SOFC is measured after the metal ion beam irradiation. Fig. 4 shows the current density-voltage measurement result. The experimental conditions are 3 Hz of repetition rate, 900 µs of pulse width, 3.70 kW of the arc power and 30 kV of the extraction voltage. Fig. 4(a) shows the voltage with current density depending on the metal ion species. The total dose is 3×1016 ions/cm2. As results of the ion beam irradiation of the silver and copper, the power density of SOFC is 1119.3 mW/cm2, 1087 mW/cm2, respectively. It is improved by 20% and 15% compared to the reference SOFC before beam irradiation. There is no difference in the activation energy loss in the initial current density increases. On the other hand, the electrochemical performance is improved because the slope is reduced in ohmic resistance and concentration resistance. When the current density is over 2000 mA/cm2, the concentration loss is improved. Therefore, power density is increased after the metal ion beam irradiation.

Noble metals are well known as excellent electrochemical catalyst for improving fuel cell performance. Among

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them, silver has a good oxygen reduction reaction rate than copper. Thereby, the power density of silver ion beam irradiated SOFC is higher than the copper ion beam irradiated SOFC at the same total dose(Fig. 4(a)). An increase of total dose means an increase of total amount of catalyst. The power density is increased depending on the silver ion beam total dose, as in shown in Fig. 4(b). The total dose of silver ion beam is 1, 3 and 5×1016 ions/cm2, and the power density improves 2, 20 and 23% compared to reference SOFC.

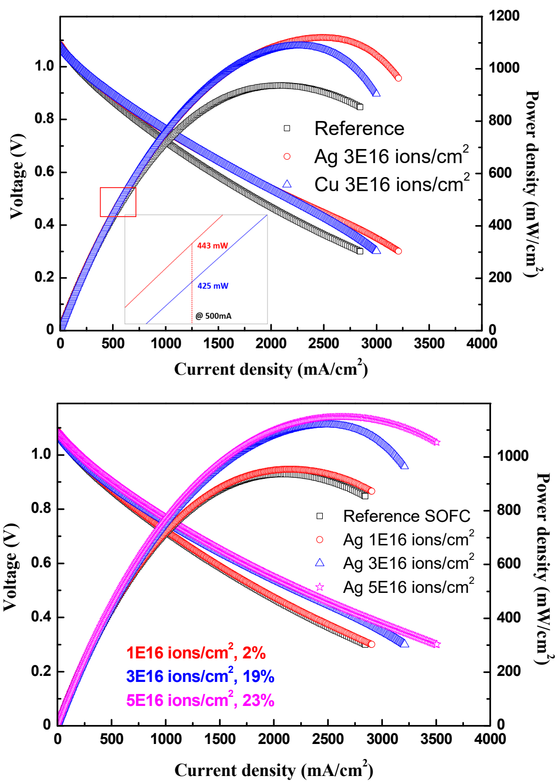

Figure 4: Current density-voltage measurement results of irradiated SOFC (a) comparison with silver and copper ion beam at total dose 3×10^{16} ions/cm^2 (b) depending on the silver ion beam total dose.

Figure 5 shows the EIS results of irradiated SOFC. These figures are presented based on the Nyquist plot. The Nyquist plot shows the semi-circle, it means the area specific resistance(ASR) of SOFC electrode. Rs, R1 and R2 mean the electrolyte resistance, fuel electrode resistance and the air electrode resistance, respectively. Fig. 5(a) shows the total ASR depending on the ion species. After ion beam irradiation of silver and copper, the total ASR is reduced with 2.77, 2.51 and 2.18 ohm-cm^2, respectively. Among the ASR, R2 significantly is reduced with 25, 29% compared to the reference SOFC. Fig. 5(b) shows the total ASR depending on the total dose of silver ion beam. When the total dose increases, the total ASR is reduced. Also, R2 is reduced approximately 46% as total dose is 5×10^{16} ions/cm^2.

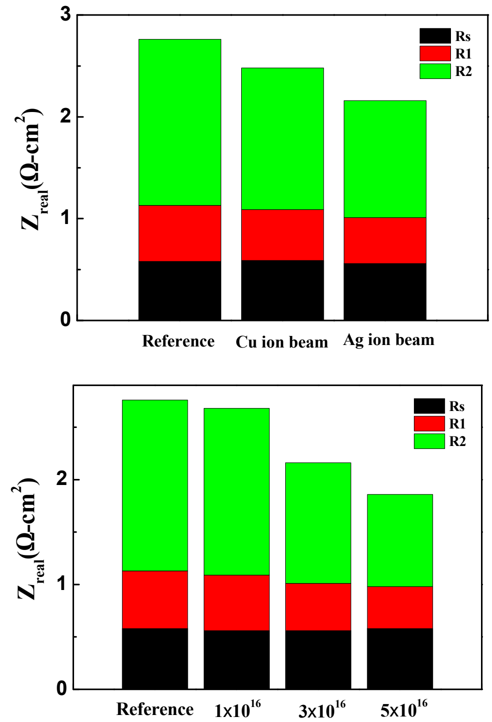

Figure 5: EIS analysis result of irradiated SOFC, Rs is electrolyte ASR, R1 is fuel electrode ASR and R2 is air electrode ASR (a) comparison with silver and copper ion beam at total dose 3×10^{16} ions/cm^2 (b) depending on the silver ion beam total dose.

SUMMARY

In this study, silver and copper ion beams were extracted by using the MEVVA ion source. Beam properties were measured such as stability, peak beam current, beam profile and average charge state. The maximum peak beam current of both metal ion species is approximately 200 mA at 30 kV of extraction voltage, and RMS radius is 69 mm and 56 mm, respectively. The beam match condition with the lower RMS radius is 3.90 kW of are power. The average charge state is 1.7 of silver and 2.0 of copper, there are similar results in other previous study. The optimization condition was determined. The metal ion beam was irradiated on the SOFC air electrode, depending on the metal ion species and total dose. After irradiation, the electrochemical performance was measured by current density-voltage measurement and EIS. The concentration loss is reduced by ion beam irradiation, and the power density is improved. Among the ASR, R2 is significantly reduced. This study shows that it is possible to improve the electrochemical performance of SOFC by using metal ion beam irradiation due to the improvement electrochemical reaction at air electrode.

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