New Cathode Material for Air-Plasma Cutting (Report IV)†

—Direct Observation of Cathode Surface Erosion Process—

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Abstract

This paper describes the observation of cathode surface during arc discharge in various gas atmospheres. The sintered 80Ru-20Y_2O_3 electrode and Hf electrode are compared in Ar and Ar+20%O_2 gases. In consequence, in Ar shielding gas, the fusion area of cathode surface separated two regions of Ru and Y_2O_3 components and the molten particle was sputtered from Ru part. In Ar+20%O_2, the top of cathode surface was covered with the molten layer of Y_2O_3 and the plasma was stably sustained. From spectroscopy, the evaporation of cathode materials was increased with increasing oxygen content in shielding gas and arc current. Arc stability and life time of cathode is considered to be depended on the character of Y_2O_3 layer.

KEY WORDS: Air-Plasma Cutting, Ruthenium, Yttrium-Oxide, Hafnium, Evaporation, Erosion, Arc-Discharge, Cathode Phenomena

1. Introduction

From the previous study on the physical properties of cathode material[1,2], it was clarified that the sintered 80Ru-20Y_2O_3 electrode showed a good durability compared with Hf electrode due to having the high thermal and electric conductivity of 80Ru-20Y_2O_3 rather than those of Hf. It is necessary for making a durable cathode to increase a cooling gain of cathode itself by using the high thermal and electric conduction material.

This study is directed towards analyzing in aspect of cathode surface during arc discharge in order to investigate the effect of oxygen content in shielding gas on a arc stability and cathode erosion, why 80Ru-20Y_2O_3 electrode has good erosion resistance rather than Hf by the direct observation, EPMA, X-ray diffraction and spectral analysis method[3,4].

2. Experimental Procedure

2.1 Experimental materials

Materials used in this study are 80Ru-20Y_2O_3 electrode sintered at 2373k in H_2 with 2.4 mm in diameter, and Hf electrode produced by the molten process with 1.6 mm in diameter. And there are tapered at 45 degree of the top of cathode as shown in **Fig. 1.**

2.2 Direct observation method.

Fig. 1 shows the schematic illustration of direct observation system alignment used in this study. Xe lamp was focussed to cathode surface to overcome the effect of plasma light, then were observed by a streo-scope and a CCD camera.

2.3 Spectral analysis method

Figure 2 shows the schematic illustration of spectral analysis system used in this study. The evaporation of cathode materials was measured by using a

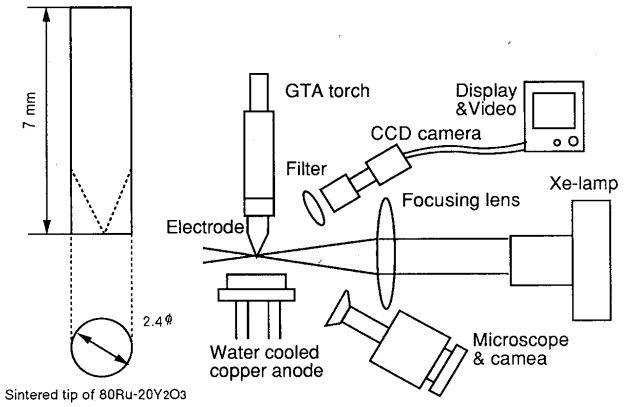

Fig. 1 Experimental alignment of direct observation method of the cathode surface during arc discharge.

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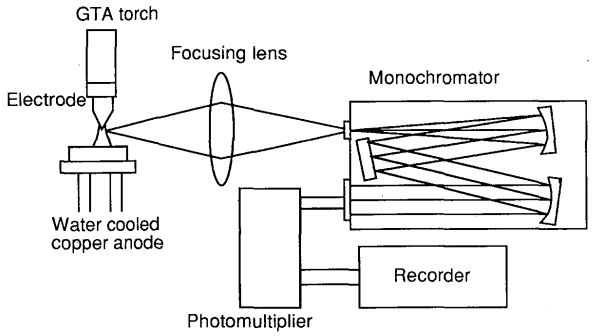

Fig. 2 Schematic illustration of spectral analysis method of cathode vapors.

monochromator(SHIMADZU,GE-50A).

3. Experimental Results and Discussions

3.1 Macroscopic observation of cathode surface in oxidizing and non-oxidizing atmospheres

Figure 3 shows the changes in the cathode surface of 80Ru-20Y_2O_3 at 10 A in Ar and in Ar+20%O_2 shielding gases until 60 s in operating time. The cathode surface is molten in both Ar and Ar+20%O_2 shielding gases during discharge. This fused area in oxidizing atmosphere was extended rather than that in non-oxidizing atmosphere. In Ar shielding gas, the fused area of cathode surface separated two regions, but is hardly separated in Ar+20%O_2.

Figure 4 shows the changes in cathode surface of 80Ru-20Y_2O_3 at 60 A in both Ar and Ar+20%O_2 shielding gases. With increasing arc current from 10 A to 60 A, the fused area was widely extended and the top of cathode was roundly shaped after discharge. In Ar shielding gas, the fused area was distinctly separated in two regions of a dark part(A) and a bright part(B). And the argon arc plasma was unstable with sputtering of the molten particles from the dark part(A). It may be thought that the dark part(A) is a metal and the bright part(B) is an oxide from the direct observation.

On the other hand, in Ar+20%O_2 shielding gas, the fused area of cathode surface was hardly separated, and was covered only with the bright part(B) during discharge. After discharge, the metallic part appears immediately. This phenomenon is not clearly understood yet, but it may be considered because of the evaporation or the shrinkage of the oxide layer(B).

From the results of the direct observation, the states of 80Ru-20Y_2O_3 electrode in oxidizing and non-oxidizing atmospheres are considered as shown in the schematic

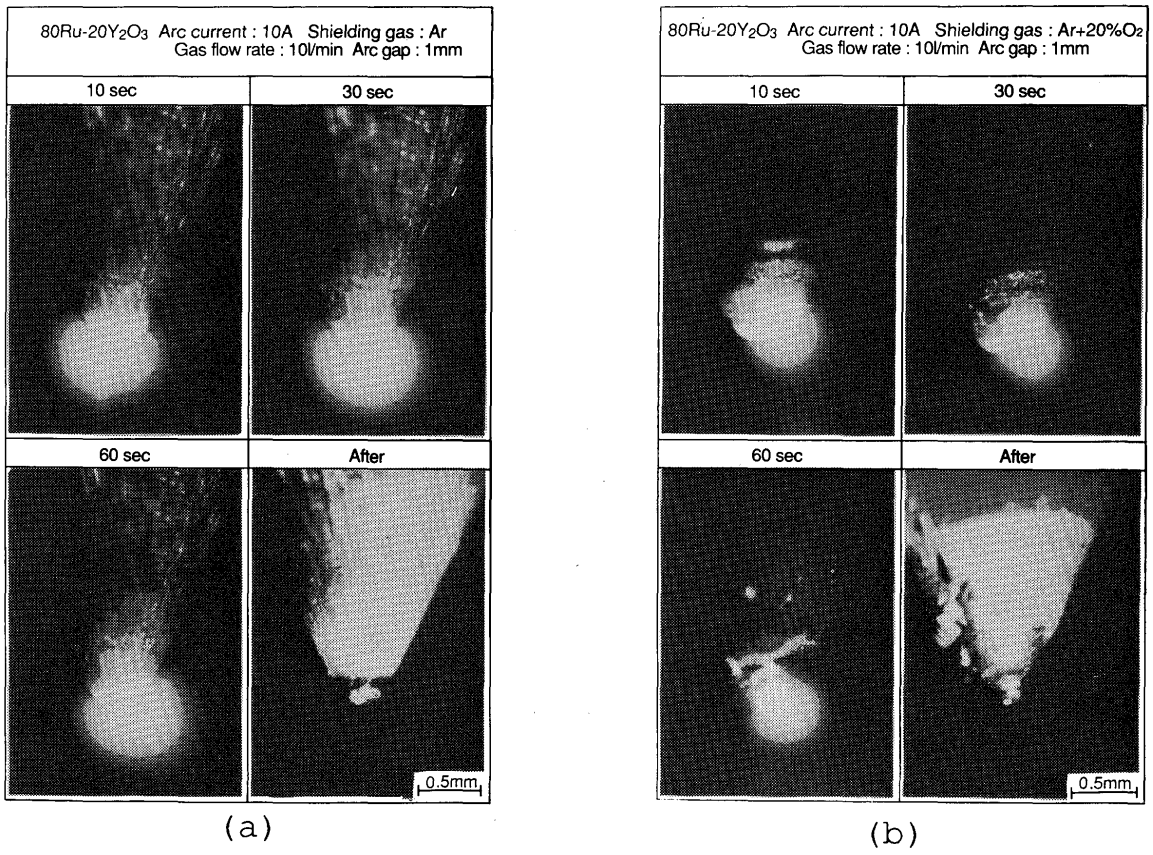

Fig. 3 Discharge state of 80Ru-20Y_2O_3 electrode at 10 A in arc current.(a): in Ar, (b): in Ar+20%O_2.

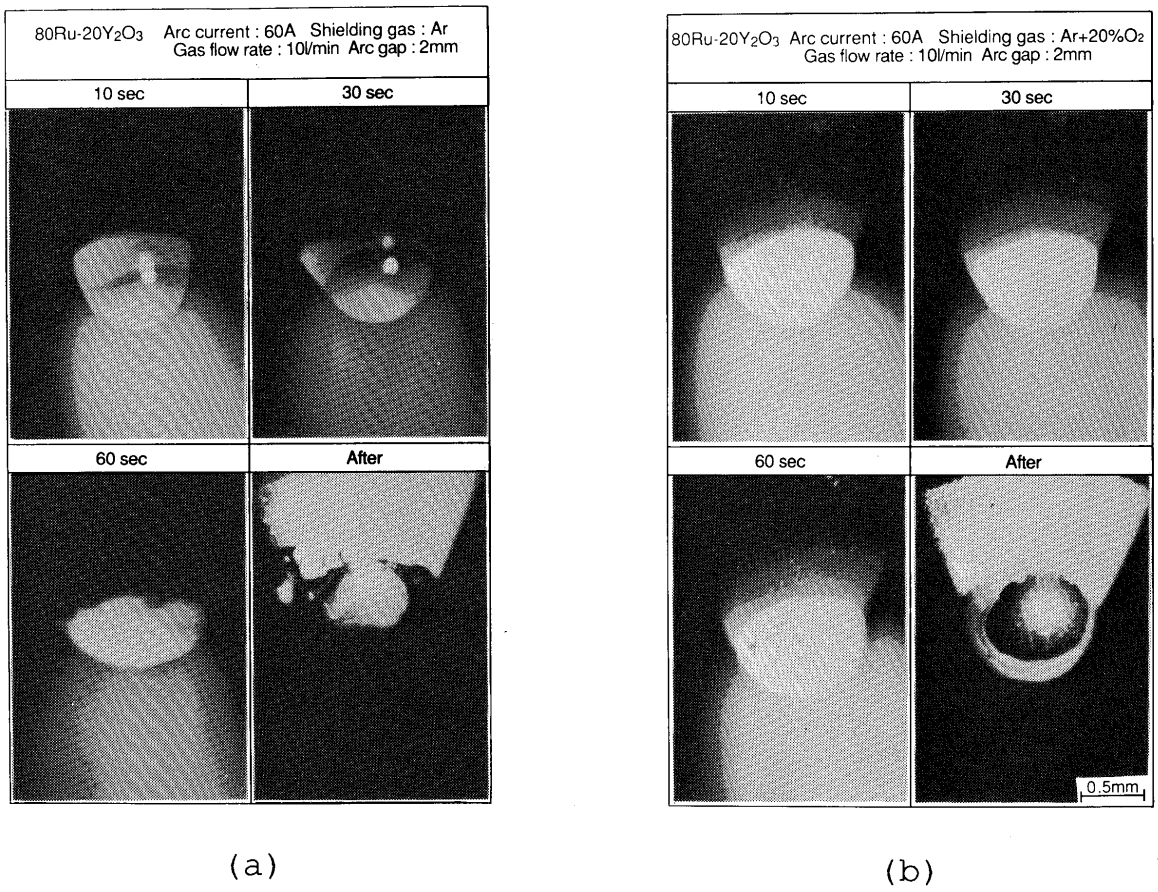

Fig. 4 Discharge state of 80Ru-20Y_2O_3 electrode at 60 A in arc current.(a): in Ar, (b): in Ar+20%0_2.

illustration of **Fig. 5.**

Figure 6 shows the changes in cathode surface of Hf electrode at 10 A in Ar and Ar+20%0_2 shielding gases. The top of cathode surface during arc discharge was molten like as in gas metal arc welding, and this fused area was widely extended more than that of 80Ru-20Y_2O_3 one in the both of Ar and Ar+20%O_2 shielding gases under the same arc current(10A). Especially, in Ar+20%O_2 shielding gas, the fused area was more wide and Hafnium oxide

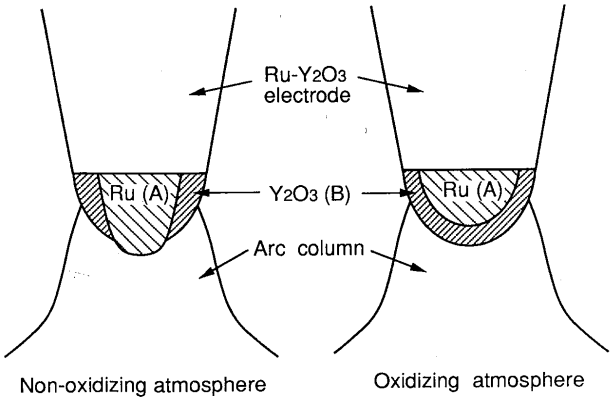

Fig. 5 Schematic illustration of discharge state for sintered 80Ru-20Y_2O_3 electrode in Ar and in Ar+20%O_2.

(HfO_2) was formed on the molten cathode surface. This severe fusion of Hf electrode will be related to the lower thermal conductivity and the strong oxidation at high temperature.

3.2 Analysis of cathode surface after discharge

Analysis of the fused area of cathode surface after discharge was made by using EPMA and micro X-ray diffractmeter. The diffraction pattern was obtained under 50kV-120mA, 100μm in the beam spot diameter and 600s in detect duration by using Cu$K\alpha$

Figure 7 shows the microstructure and EPMA results of the top of the cathode surface of 80Ru-20Y_2O_3 after discharge at 60 A in Ar+20%O_2 shielding gas. The top of cathode was clearly separated into two components of Ru and Y.

Figure 8 shows the X-ray diffraction pattern of the fused area of 80Ru-20Y_2O_3 cathode after discharge at 90 A in Ar+20%O_2 shielding gas. In consequence, it can be seen that A part shows mainly Ruthenium (Ru) and Ruthenium oxide (RuO_2), and B part shows only Yttrium oxide (Y_2O_3).

Figure 9 shows the EPMA results of the cross section of Hf electrode at 30 A for 10 s in Ar and Ar+20%O_2

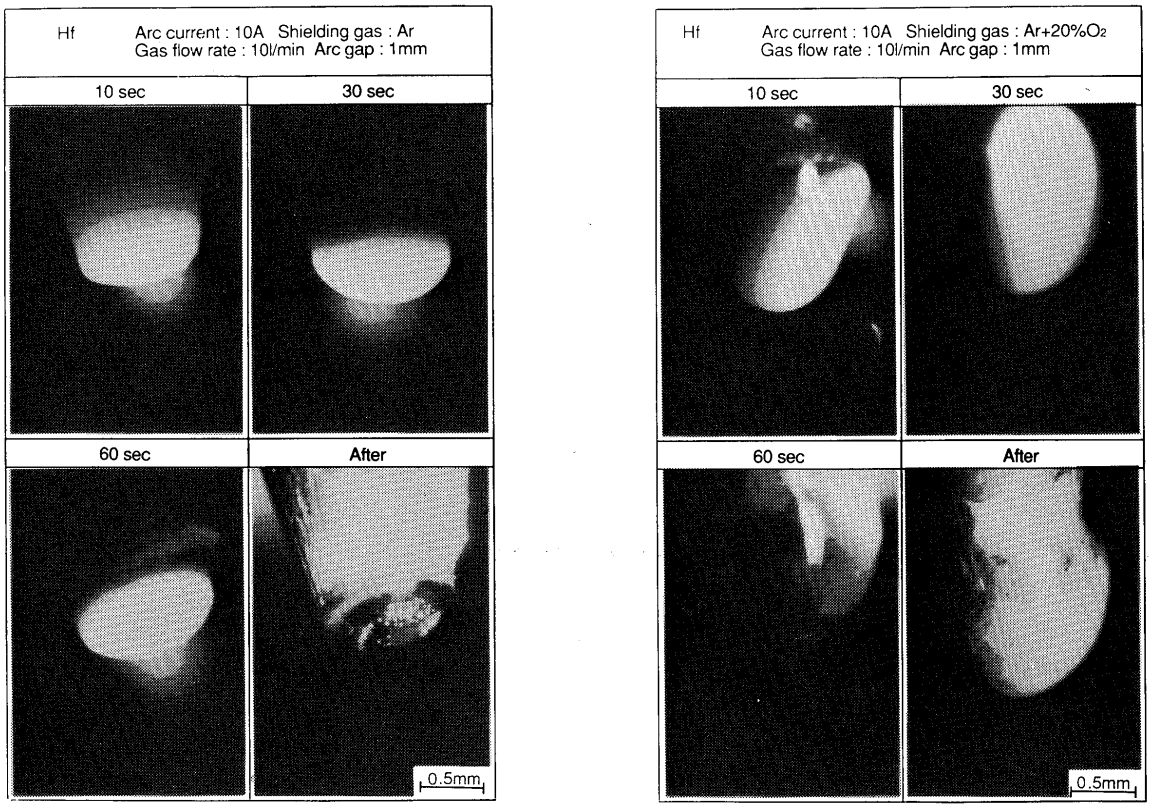

Fig. 6 Discharge state of Hf electrode at 10 A in Ar and in Ar+20%O_2.

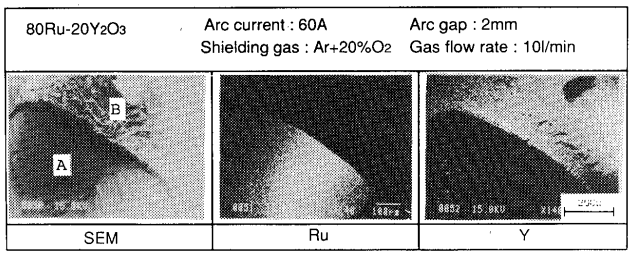

Fig. 7 EPMA analysis results of cathode surface of 80Ru-20Y_2O_3 electrode after discharge in Ar+20%O_2 shielding gas.

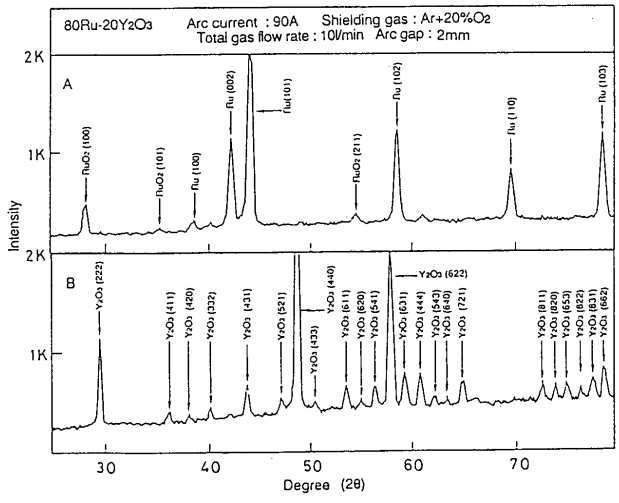

Fig. 8 X-ray diffraction pattern of cathode surface of 80Ru-20Y_2O_3 electrode after discharge in Ar+20%O_2 shielding gas.

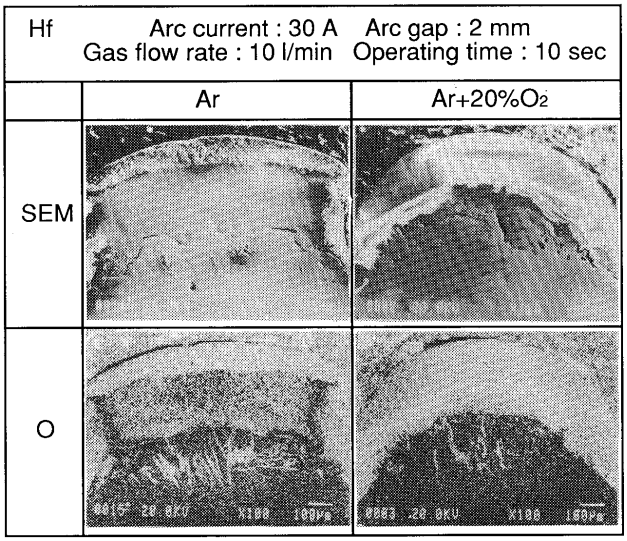

Fig. 9 EPMA analysis results of cathode surface of Hf electrode after discharge in Ar and in Ar+20%O_2 shielding gases.

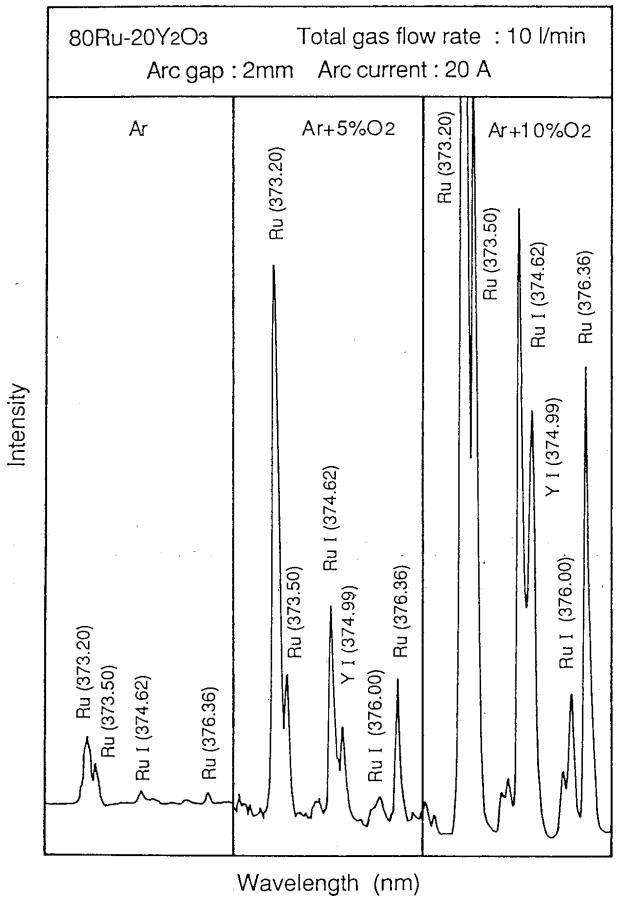

Fig. 10 Spectral analysis results of 80Ru-20Y_2O_3 cathode as a function of oxygen content in Ar.

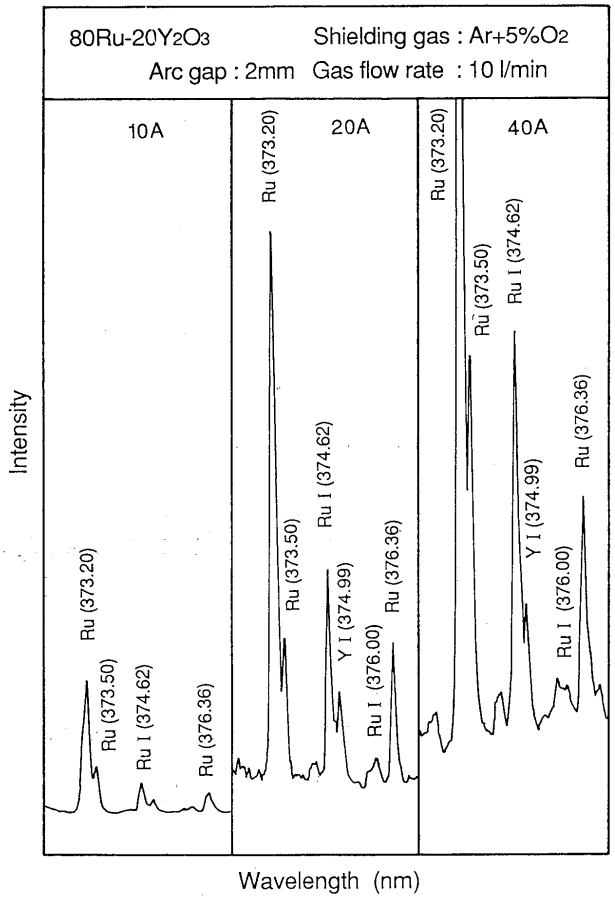

Fig. 11 Spectral analysis results of 80Ru-20Y_2O_3 cathode as a function of arc current.

shielding gases. The molten part of cathode surface was covered with the thick layer of oxide in both Ar and Ar+ 20%O_2. This oxide was Hafnium oxide(HfO_2) from micro X-ray diffraction pattern.

From the direct observation, EPMA and X-ray analysis of the fusion area of cathode surface of 80Ru-20Y_2O_3 electrode, the arc root is formed on the molten layer of Y_2O_3 covered on the cathode surface during discharge in oxidizing atmosphere.

3.3 Spectroscopy of cathode material vapors

Spectral analysis was carried out to determine the effect of the oxygen in shielding gas and the arc current on the evaporation of cathode material by using a monochromator. **Figure 10** shows the effect of the oxygen content in Ar shielding gas on the relative intensity of spectral lines emitted from the evaporated atom at 20 A in arc current. In non-oxidizing atmosphere, only Ru lines could be detected and its intensity showed very low. On the other hand, Ru and Y appear in oxidizing atmosphere and the intensity of Ru and Y increased remarkably with increasing oxygen content in Ar. Though it is difficult to determine the vapor specie quantitatively, particularly at the cathode surface boundary the evaporation rate of Ru should be increased with increasing oxygen in Ar shielding gas. Because Ruthenium oxide reacted easily with oxygen and its product like RuO_2 was easily evaporated upon 1237 K.

Figure 11 shows the effect of the arc current on the spectral intensities of Ru and Y in Ar+5%O_2 shielding gas. The evaporation rate of Ru and Y shall be increased with increasing from 10 A to 40 A in arc current. This is due to the fused area of emitting surface was extended with increasing the arc current.

4. Conclusions

The main conclusions drawn from this study are as follows:

(1) In Ar shielding gas, the fused area of 80Ru-20Y_2O_3 electrode was distinctly separated two regions; Ru and Y_2O_3 during discharge. And the arc was unstable and sputtering of the molten particle from Ru part occurred.

(2) In Ar+20%O_2 shielding gas, the fused area of cathode surface was hardly separated, was coverd with the molten Y_2O_3 layer. And the arc was stable due to emitting a thermionic electron from the Y_2O_3 layer.
(3) From the spectral analysis of cathode vapor during arc discharge, the evaporation is considered to increase with increasing the oxygen content in shielding gas and the arc current.

Acknowledgements

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