Study of Anodic Phenomena for Arc Plasma†

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Abstract

Analysis of gas-tungsten-arc plasma spectra has been made by the use of monochromator, and from the distribution of spectra the local thermodynamic equilibrium (LTE) of the plasma is discussed.

The spectral line of the anodic and cathodic elements were observed near the electrode. The line spectra of anodic element can be detected only near the anode.

The effect of polarity were also investigated. In case of electrode positive (EP) many spectral lines were observed even in plasma column. It is concluded that the electrode polarity has an important effect on the vaporization.

KEY WORDS : (Arc Plasma) (Anodic Phenomena) (Vaporization) (Spectroscopy) (Monochromator)

1. Introduction

Recently, the vaporization phenomena of anode material in arc discharge has been widely utilized in the field of fine particle production, extractive metallurgy, arc plasma CVD and so on. However, the anodic phenomena is not clearly understood yet[1,2].

A very thin boundary layer is formed on the anode surface. And it will be characterized by a high temperature gradient and extreme deviation from thermodynamic equilibrium state. The anodic phenomena is governed by physical and chemical state of the boundary layer and near it.

This work was thus directed towards analysing the anodic phenomena by the use of the spectral emission near the anode. Also from the spectral line distribution the local thermodynamic equilibrium (LTE) of above boundary layer region will be discussed. Particular attention was also paid to the effect of polarity and total pressure on the spectral line of anode and cathode materials.

2. Experimental Works

Figure 1 shows the experimental alignment for measuring the spectral line intensity by the use of monochromator. The power system was a conventional constant current type, in a negative polarity direct current arc discharge was applied with a copper water cooled anode, mainly. Mild steel, and SUS304 anode are also used. A variable arc length and torch orientation perpendicular to the anode were used throughout the series of tests. The rod electrodes use in this work were W-Y_2O_3 (2%), produced by the conventional powder metallurgy process with 3.2 mm diameter center less ground electrodes. The arc plasma light was focussed on the entrance of optical fiber connected to monochromator which has 500 mm focussing length. The dispersed light is then detected by means of a photomultiplier tube. In the measurement the wavelength ranging from 410 nm to 440 nm was mainly used, because in that region, the number of spectral line is not so much, there are few resonance line, and it is possible to avoid the error come from the second diffraction spectra.

To measure the effect of total pressure on spectral line in Ar or He atmosphere, a vacuum chamber was used. Noting that, there is no gas flow inside the chamber.

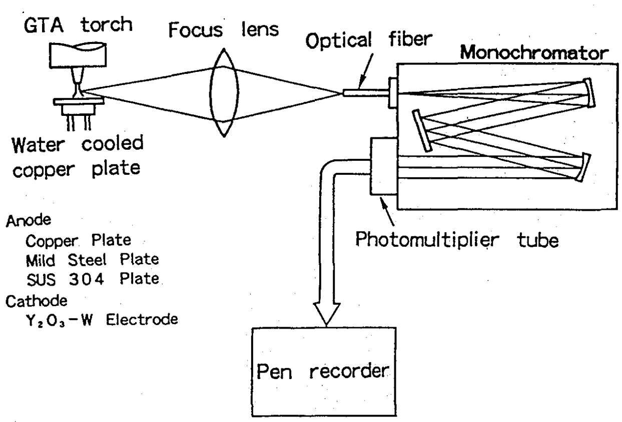

Fig. 1 Alignment of spectral emission measurement.

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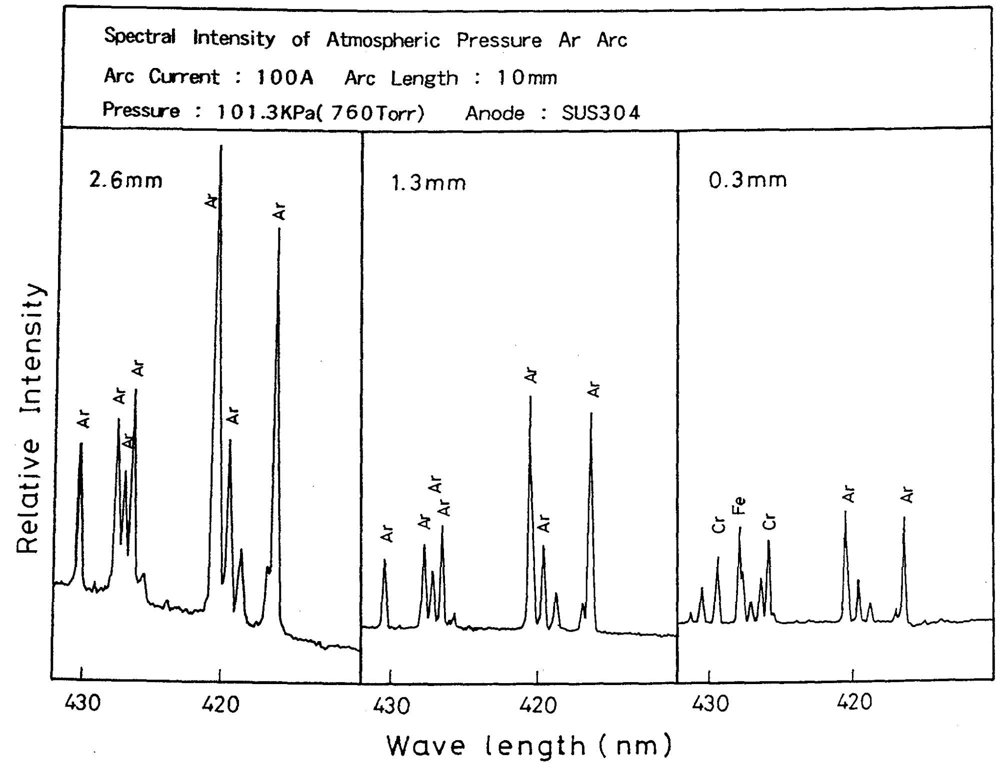

Fig. 2 The relationship between the relative intensity and the distance from the anode at the atmospheric pressure Ar.

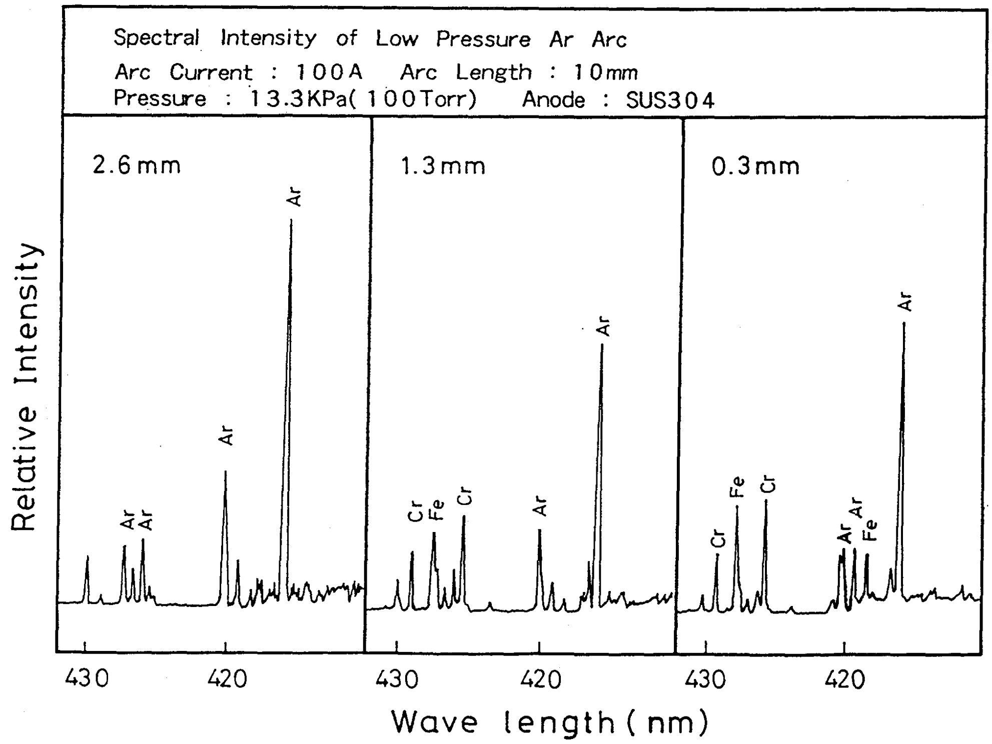

Fig. 3 The relationship between the relative intensity and the distance from the anode at the low pressure Ar.

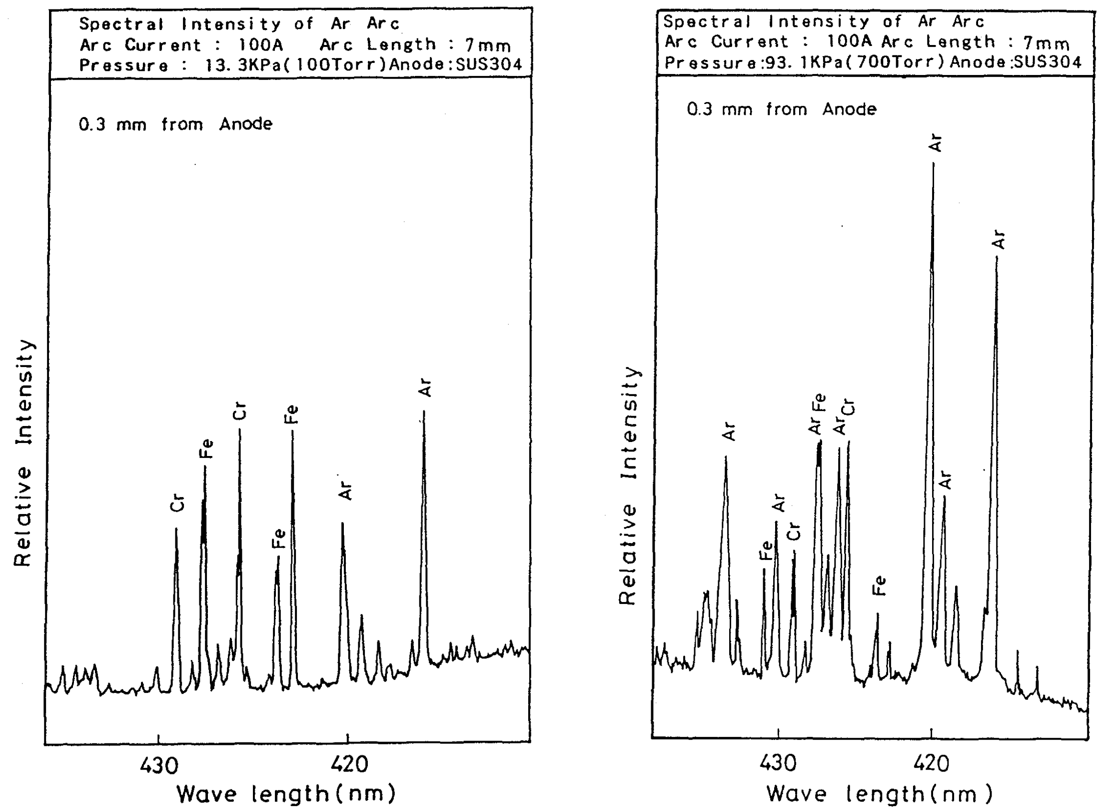

Fig. 4 The effect of total pressure for relative intensity in Ar arc.

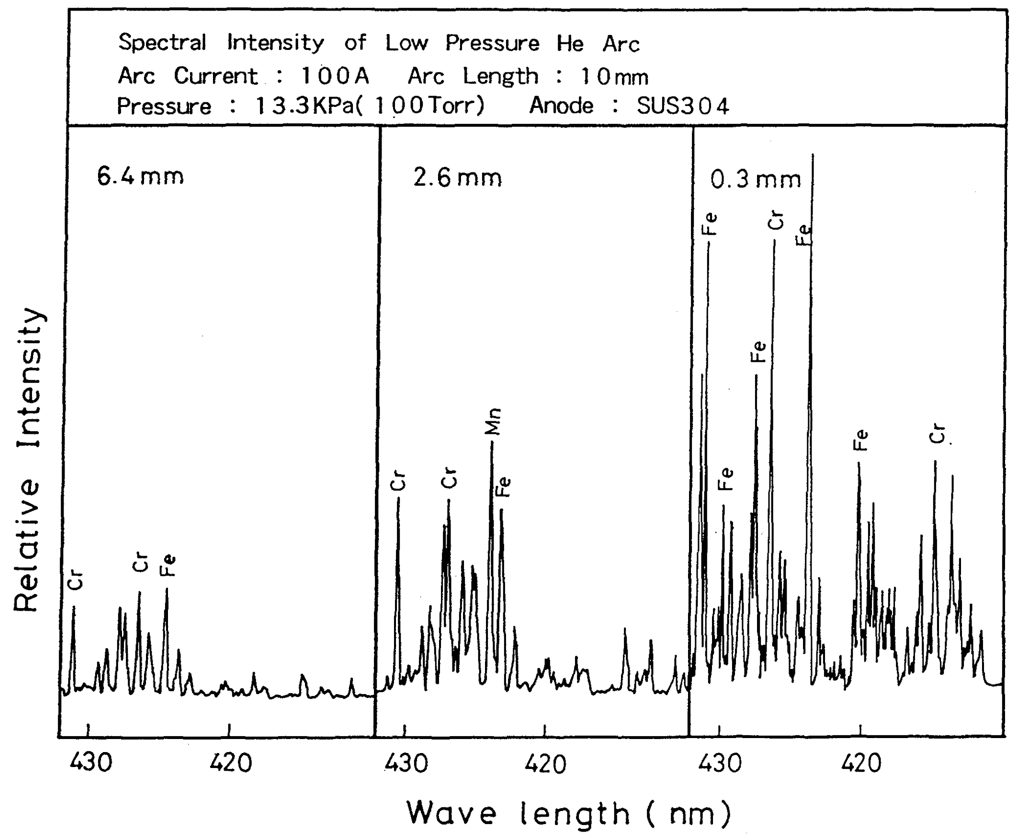

Fig. 5 The relationship between the relative intensity and the distance from the anode at the low pressure He.

3. Result and Discussion

3.1 Effect of total pressure and shielding gas

Figure 2 shows the relationship between the spectral wavelength and the relative intensity at the atmospheric pressure discharge, in case of SUS 304 as anode at 100A in pure argon. The spectral line intensity of anode material was measured at several points from the anode. Generally, near the anode the spectral line of Fe and Cr can be identified (0.3 mm), but far from the anode (1.3 mm and 2.6 mm) the spectral line of anode metal can not be detected. It could be said that, the arc column is free from the vaporized anode materials.

Moreover, the same phenomena was also observed in the case of arcing in pure Ar at low pressure (13.3 KPa) as shown in **Fig. 3**. Noting that, here, at 1.3 mm from the anode the spectral lines of Fe and Cr were detected while at 2.6 mm are not detectable. That was attributed to the effect of reducing the total pressure.

To have clear understanding on the effect of total pressure on vaporization of anode material, the same test was carried out at 93.1 KPa and 13.3 KPa in Ar atmosphere at 0.3 mm from anode and the results are shown in **Fig. 4**. It is clearly observed that with slightly decrease of total pressure, 93.1 KPa, the spectral line intensity of the vaporized anode metal increase compared with Ar. However, at lower pressure (13.3 KPa) the spectral line intensity of Ar decreased while the spectral line intensity of the vaporized anode metal increased.

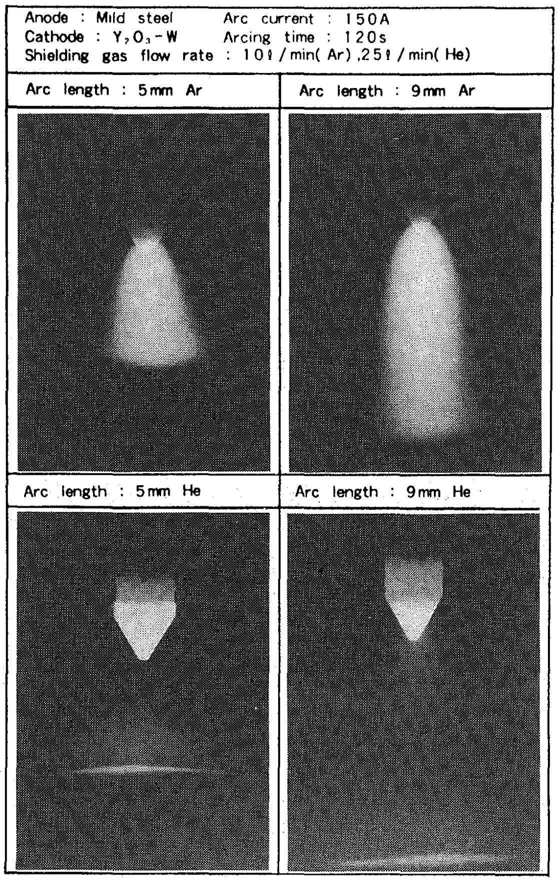

Fig. 6 Direct observation of Ar and He arc.

In case of arcing in pure He atmosphere at lower pressure (13.3 KPa) the situation is quite different. As shown in **Fig. 5**, the spectral line intensity of vaporized anode metal becomes higher while the He spectral line can not be detected in this range of wavelength. Noting that even if the measuring point was shifted to the point of 6.4 mm from the anode there is a possibility to find some of the vaporized anode metal in the arc column. That was related to the following:

(1) The higher heat input in case of pure He arcing which promote the vaporization of anode metal.
(2) The plasma flow is weak. Thus the metal vapor can easily diffuse to the arc column.
(3) The gradient of electric field is high, then the anode metal vapor is easily excited.

To observe clearly these differences between arcing in pure Ar and in pure He, the arc is observed directly at 150 A in both cases of Ar and He shielding gas at 5 mm and 9 mm of arc length respectively at atmospheric pressure, and the results are shown in **Fig. 6**. Apparently, the color of the arc column is not changed in case of arcing in pure Ar. But in case of pure He, the color of anode region is different from the other arc column region. In other words, in case of arcing in pure He, it is easy to differentiate the anode region from the other arc column region because of the existence of vaporized anode metal on this region. Thus it is easy to find the vaporized anode metal with high amount in arc column in case of low pressure.

3.2 Effect of polarity

Figure 7 shows the effect of arc polarity on the spectral line intensity and the element of vaporized metal. The arc current is 100 A at EN, and 50 A at EP, to avoid the severe melting of the electrode. The anode metal is mild steel and the arc length is 6 mm. The spectral line is measured at the center of the arc column. In case of EN only the spectral line of the vaporized metals were detected, with many of unknown spectral lines. This is attributed to the effect of cold cathode phenomena.

3.3 Theoretical calculation of arc temperature

By using the assumption of LTE, the plasma temperature can be measured. Assuming the pressure of plasma in LTE, thus each atom excited must follow the Boltzmann's distribution law, and the spectral intensity can be expressed as follows:

$$I_k = A_{ki} h \nu_k n_o \frac{g_k}{Z(T)} \exp\left(-\frac{E_k}{\kappa T}\right) \qquad (1)$$

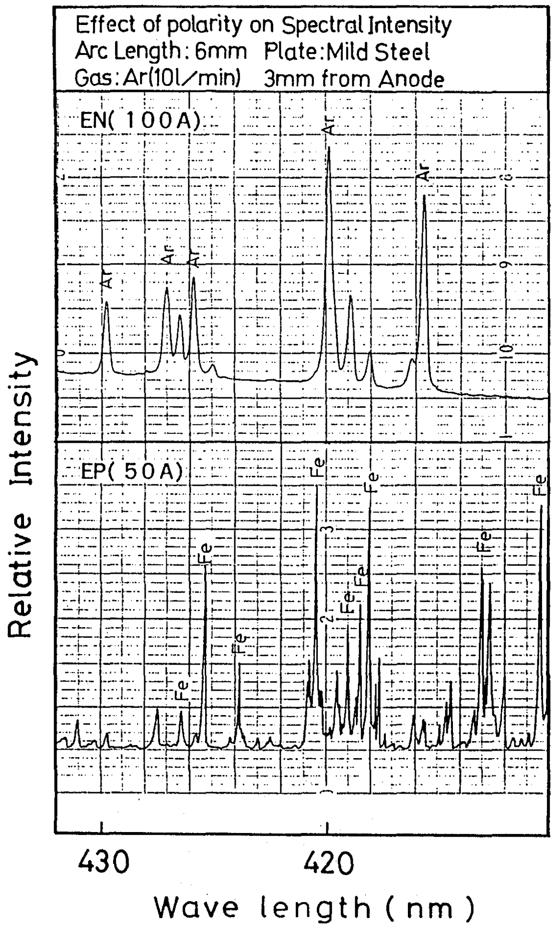

Fig. 7 The effect of polarity in atmospheric Ar arc.

where n_o is the number density

$Z(T)$ is the partition function

h is the Planck constant

κ is the Boltzmann constant.

The upper and lower bound states involved in the transition are denoted by k and i, respectively. g_k is the statistical weight of the upper state. E_k is the energy of the upper state with respect to the ground state. A_{ki} is the transition probability, and ν_k is the frequency. Eq. (1) is rewritten as

$$\log \frac{I_k \lambda_k}{A_{ki} g_k} = -\frac{5040}{T} E_k + \log \frac{n_o hc}{Z(T)} \qquad (2)$$

the logarithms of the measured emission intensities plotted versus E_k fall along a straight line whose slope is $-5040/T$. From the slope the temperature of plasma is calculated.

From the experimental results which measured at 4 mm from anode at 13.3 KPa, 101.3 KPa, 160 KPa respectively, the Boltzmann plot of LTE was calculated and showed in **Fig. 8**. Noting that with increasing the total pressure the deviation of this plot become smaller. From this calculation the temperature of plasma in this case is about 9000 K. Due to the incomplete equilibrium near anode region, there is a large deviation from Boltzmann distribution.

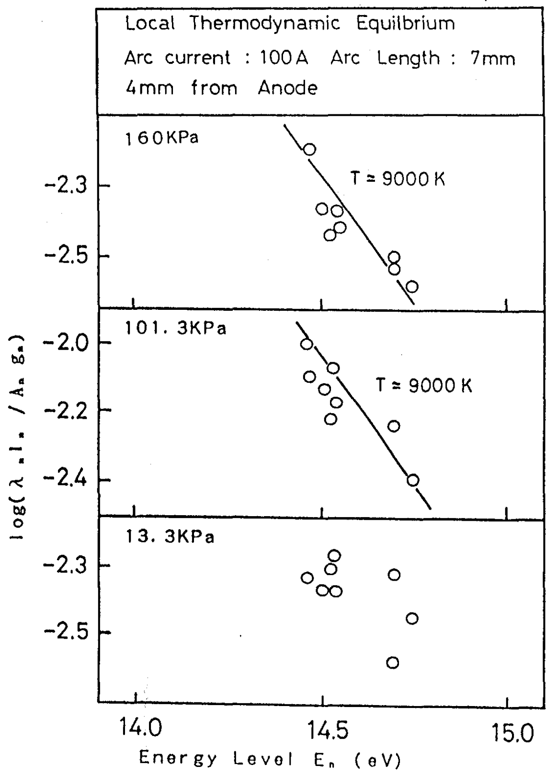

Fig. 8 The effect of total pressure in Boltzmann plots.

4. Conclusion

The main conclusion drawn from this study are as follows:

(1) In case of arcing in pure Ar the vaporized anode metal can be observed only very near to the anode region. While in case of arcing in pure He the vaporized anode metal is diffused to the arc column.

(2) In case of EP polarity, many spectral line were detected in arc column even in the low current. It means intense evaporation in this polarity due to the cold cathode phenomena.

(3) At low pressure, the arc is not in LTE state, but at 1 atm or over the LTE become effective.

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2) N. A. Sanders and E. Phender, J. Appl. Phys, Vol. 55, p714-722