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Study on Extra-Fine Metallic Wire Annealing using Atmospheric Pressure Plasma Jet
大気圧プラズマジェットによる極細線アニーリングの検討

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Annealing and cleaning processes for metallic thin wires are simultaneously carried out irradiated by atmospheric pressure plasma.The system expects amaintainable and simple thin wire production device. However, breaking wire at direct irradiation of atmospheric pressure plasma occurs in the case of extra-fine metallic wires annealing. To improve annealing process of extra-fine metallic wires with atmospheric pressure plasma, we developed a long plasma jet reactor. The height and length of plasma jet were 1 mm and 250 mm, respectively. Annealing effect for extra-fine wires by using the plasma jet was also examined.

1. Introduction

Production procedure of metallic thin wires consists of stretching, annealing and cleaning processes. In the previous studies, copper thin wires of 200 μm in diameter are simultaneously carried out annealing and cleaning processes irradiated by atmospheric pressure plasma [1,2]. Therefore, a maintainable and simple thin wire production device with atmospheric plasma is expected. However, breaking wire at direct irradiation of atmospheric pressure plasma occurs in the case of extra-fine metallic wires annealing.It indicated that the cause of the breaking wire is the electric field in the atmospheric pressure plasma.

To improve an extra-fine metallic wire annealing with atmospheric pressure plasma, we developed a long plasma jet reactor. The plasma jet can mitigate the effect of breaking wire because of small electric field in the plasma jet.Annealing effect for extra-fine wires by using the plasma jet was also examined.

2. Experimental method

Figure 1 shows a conceptual diagram of a plasma jet reactor. The plasma jet reactor consists of a cylindrical electrodecovered with dielectric tube, plate electrodes, and an acrylic reactor. To obtain the plasma jet, the slit is set on the reactor. The discharge gap, which is the distance between a plate electrode and cylindrical dielectric, is 11.4 mm. The material of the dielectric is an acrylic resin and Al_2O_3. Plate electrodes were set on the top outside of the reactor.

Experimental equipment consists of plasma reactor, inverter power supply, and gas tank. Inverter power supply is possible to control the output voltage and frequency. In this experiment, frequency of inverter power supply is fixed as 45 kHz. The plasma jet is generated with a dielectric barrier discharge (DBD) by applying an inverter power supply. The plasma jet is pushed out from the slit by helium gas.

To confirm the annealing effect, the extra-fine wire of 20 μm in the diameter of copper was set at 1 mm from the slit. The elongation rate of extra-fine wires was measured with the tensile testing machine. The elongation rate ε is given as [3],

$$\varepsilon = \left(\frac{L_1 - L_0}{L_0}\right) \times 100[\%] \tag{1}$$

where, L_0 is the initial length of thin wire, and L_1 is the elongated length before breaking wire.

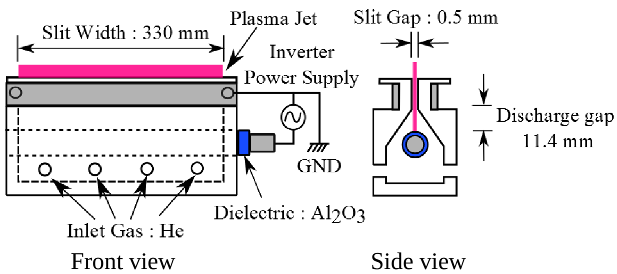

Fig.1. Conceptual diagram of the plasma jet reactor

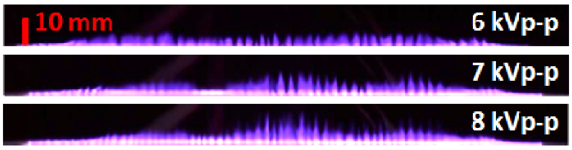

Fig.2. Photograph of the plasma jet at 100 L/min of flow rate of helium

3. Experimental results

3.1 Behaviors of the plasma jet

Figure 2 shows a photograph of the plasma jet at 100 L/min of flow rate forhelium. The plasma jet was not generated under 6 $kV_{p\text{-}p}$ of the applied voltage. The jet length of the plasma increases with the increase of the applied voltage. To irradiate the plasma jet for the extra-fine wires, the jet length is required to be over 1 mm. The jet width is estimated to be more than 250 mm. These results indicate that the plasma jet satisfies the measurable length for the elongation rate.

3.2 Influence of the input power for elongation rate

The input power of the plasma is estimated from the voltage and current waveforms. Figure 3 shows the typical time evolution of voltage and current waveforms in the plasma jet reactor ($V_{p\text{-}p}$:8 kV, helium gas flow rate:100 L/min).Equivalent circuit for atmospheric pressure plasma can be expressed by serialconnection of the capacitance C in the DBD and the resistance Rin the plasma. It is necessary to derive the resistance R to calculate the input power as,

$$R = \frac{V_{eq} - \frac{1}{C}\int I_{ob}(t)\mathrm{d}t}{I_{ob}(t)} \tag{3}$$

where, V_{eq} is the calculated voltage from the equivalent circuit and I_{ob} is the observed current. Input power and average input power in the plasma are estimated as follows.

$$P(t) = R \cdot Iob(t)^2 [\mathrm{W}] \tag{4}$$

$$P_{\mathrm{average}} = \int_0^T P(t)\mathrm{d}t \cdot f \ [\mathrm{W}] \tag{5}$$

Figure 4 shows the relation of average input power and elongation for 30 sec of irradiation time. The results show that the elongation rate was not improved by increasing average input power of the plasma.

The elongation rate of extra-fine wires is required to be more than 3 % [4]. The annealing effect of extra-fine wire has not been obtained. It is necessary to improve the energy transfer from the input power to the thermal input of extra-fine wire.

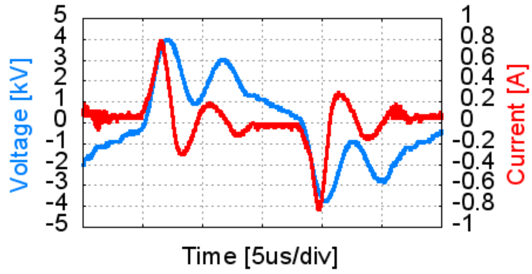

Fig.3. Typical time evolution of voltage and current waveforms in plasma jet reactor

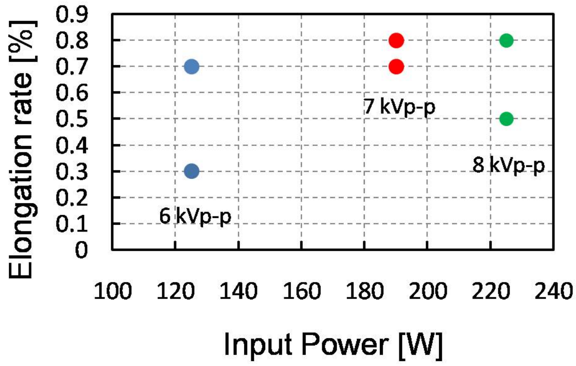

Fig.4. Relationbetweenelongation rate and input power

4. Conclusion

To demonstrate extra-fine wire annealing, we have developed the long plasma jet reactor. These results indicate that the plasma jet satisfies measuring elongation rate of extra-fine wire. It also indicates that the jet length of the plasma increases with the increase of the applied voltage.

Elongation rate of extra-fine wire as a function of input power was measured. It shows that the elongation rate does not improve by the increase of input power. It suggests that the conversion efficiency from the input power to the thermal input of extra-fine wire should improve the system.

Acknowledgments

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