Basic characteristics of thin wire arc plasma

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Abstract---- The plasma which was generated by the excessive electric current of a thin wire was investigated experimentally. By applying an electric current of about 50A to the copper wire of diameter 48 μ m in air, the plasma has been generated. A measuring means was time analyzed spontaneous emission spectra measurement and relative line intensity ratio method for the temperature determination was used. A degree of extension of the plasma was measured by the movable electrostatic probe which was put by the thin wire and electron density was estimated using the known mobility of electron. As a typical result, electron temperature was about 8000K. On the other hand, electron density tended to decrease with time from about 3 x10^{16}cm^{-3}.

1. Introduction

The discharge processes occurring in thin conductor wire explosion by the excess current flow are presently the subject of many investigations due to their importance in engineering application, and in plasma physics in general. In fact, the knowledge of the plasma characteristics of this kind of discharge is important to understand the workings of a fuse used for an excessive electric current interception. Furthermore, the thin wire explosion plasma has been used for the laser oscillation of metal atom and for the soft X-ray sources.

Recently, several experiments have been performed on the relatively high current thin wire discharge, and theoretical models have been developed to analyze the kinetic processes in such discharge[3]. In a recent paper [1], we have reported an investigation on the temperature and density of the low current thin wire discharge plasma in air for a pressure of atmospheric pressure and various current, as a function of discharge time. This experiment, however, has used single channel spectroscopic system to determine the temperature from relative line intensities of emission spectra. In this case, the reproducibility of the discharge becomes a problem.

In the present work, the plasma characteristics presented in [1] is improved by using multi-channel spectroscopic system. This leads to a considerable improvement in the reliability of the data. Further, in order to understand this kind of plasma we have measured many emission spectrum from molecules and atoms in the plasma simultaneously. It is considered these data contribute to a deeper physical insight into the thin wire discharge.

The organization of the paper is the following. Section 2 described the experiment; a summary of the apparatus and techniques used is given; and the diagnostics used for the measurements are described in detail. Section 3,4 presents a detailed experimental results and discussion. Finally, in Section 5 we present the conclusions of this work and discuss guideline for future research.

2. Experimental apparatus and method

The experimental study of the thin wire explosion plasma is performed in air. Diagnostics used in this experiment are multi-channel spectroscopic system and electrostatic probe. In spectroscopic measurement, we mainly determine the temperature of the plasma. The electrostatic probe is used for the determination of the plasma diameter.

A schematic diagram of the apparatus is represented in fig. 1. A thin wire explosion plasma is created between two electrode. The distance between two electrode is 5 mm and the thin wire is connected to the electrode by solder. The thin wire diameter is 48 μ m, and wire material is copper.

A capacitor is charged to proper voltage by power supply through resistance R and SW_1 before the discharge. The current start to flow by closing SW_2 and the plasma is created by evaporating the thin wire. Typical charged voltage of C is 200V, 160V, 80V.

The multi-channel spectroscopic measurement is performed by a system which is formed of a streak camera and a grating monochorometer. The emission of the plasma is defracted by defraction grating and introduced to the streak camera to record the time resolved emission spectra in this system. The temperature of the plasma is determined by the relative intensity ratio of copper atom emission lines ; 5105.54Å and 5218.20Å [2][4]. These data is stored and analyzed by PC.

The plasma diameter is determined by the electrostatic probe. The probe which applied bias voltage is installed at proper radial distance from the thin wire. The probe current is observed when the exploding plasma arrive to the probe. There is a time lag due to necessity time to arrive the plasma to the probe. We can determine the velocity of the expanding plasma using this time and the distance of the wire and probe. It is difficult to sweep probe voltage in a few msec. to measure probe V-I characteristics. We used the probe only to determine the diameter of the plasma. Electron density is roughly estimated by using the plasma diameter, mobility of the electron [5] and the discharge current by assumption uniform averaged current density in the plasma.

3. Plasma temperature

When one apply the current to the thin wire, the current maintain constant value during 0.3-2.0 msec depending upon the charge voltage. During this period the wire is heat upped to the melting point by joule heat, then the evaporation starts. The arc discharge occur at break point of the wire and the plasma which expands explosively due to the high temperature of the arc is created.

Figure 2 shows the typical emission spectra which measured by multi-channel spectroscopic system described previously. The spectra of vibration sequence nitrogen 2nd system bands, copper ion, copper atom and lead atom are observed. Nitrogen is the component of air, copper is the component of the thin wire and lead come from the component of the solder which used to connect wire and the electrode

The temperature of the plasma is determined by the measurement of emission spectra using this system. Figure 3 shows the time resolved spectra of copper (5105.54Å and 5218.20Å) atom which we used for the determination the temperature of the plasma. It is recognized that the arc discharge maintain for ≒100 μ sec in the condition of 80V charging voltage. In higher charging voltage , the discharge maintain fairly long period until the voltage of capacitor decrease to the minimal voltage which is necessary for arc discharge continuation.

Figure 4 shows the time variation of the plasma temperature calculated from the data of fig.3. The temperature shows maximum value of ≒11500K immediately after the discharge initiation. A cause of the temperature which is relatively high is regarded as necessity on inonization for discharge channel formation. The reason why electric discharge stops it is regarded as decreasing of power supply voltage fell below an electric discharge maintenance limits.

4. Plasma density

The plasma diameter is measured by the electrostatic probe as described previously to calculate the electron density from discharge current. Figure 5 shows discharge current and probe current as a function of time. An initial value of the discharge current is 40A. The current flowing the wire rise like a step function when SW_2 is closed. After the period which need to heat up the wire to the melting point, arc discharge occur at the break point of the wire. This arc discharge heat up the wire further by the potential drop at the vicinity of the edge the broken wire and plasma expands explosively.

We observed the time-lag of the probe current compared with the arc discharge current. This time time-lag is regarded to be the time which is required that plasma reaches the probe. As shown in fig. 5, the time-lag increases with increasing the distance between the wire and the probe. The velocity of the expanding plasma is calculated from these data, and the sectional area of the plasma which changes time is determined. The probe current data whose distance is 4mm and 5mm frorm the wire show that the radius of the plasma once becomes long and becomes short afterward.

The time variation of the electron density which is calculated using probe data is shown in fig. 6. The electron density decreases with time as maximum value at $3\times10^{16}cm^{-3}$. When electric discharge initiation, since a metal wire vaporizes violently, plasma blows out in the direction of a radius. Afterward, it is thought in regard to an electric discharge channel of about radius 3mm.

5. Conclusion

We have conducted experimental investigations of the thin wire arc discharge at relatively low discharge current. The following conclusions are obtained.

a) The arc discharge maintain only ~100 μ sec at relatively lower charging voltage, and the discharge maintain for a long period at higher charging voltage.

b) The temperature of the plasma is about 11000~7000K.

c) The plasma density is determined by the observation of the plasma diameter using electrostatic probe, and the value of the density is about $3x10^{16}cm^{-3}$ at the initiation of the discharge and decreases with time.

To progress in the understanding of the kinetics more theoretical and experimental work is necessary. In particular, it should be interesting to study in more detail the plasma parameter variation with time and space. We will prepare a triple probe measurement system for this aim.

Reference

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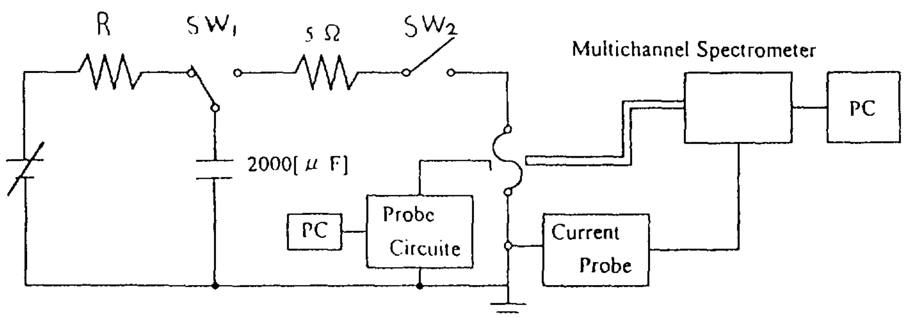


Fig.1 Experimental Apparatus

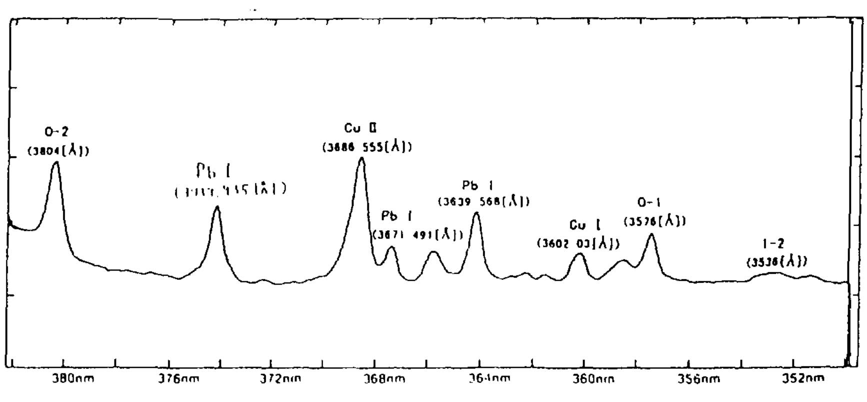


Fig.2 Emission spectra of thin wire arc discharge. Vc=200V.

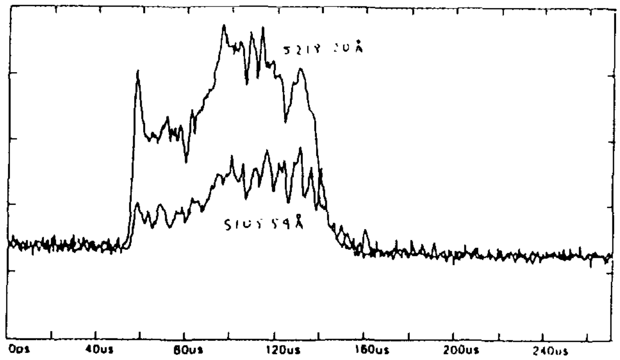


Fig.3 Time resolved spectra of Cu atom. Vc=80V.

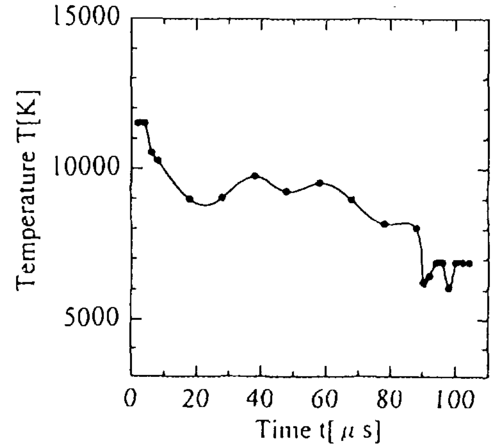
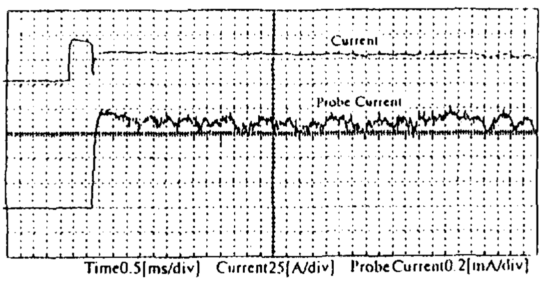
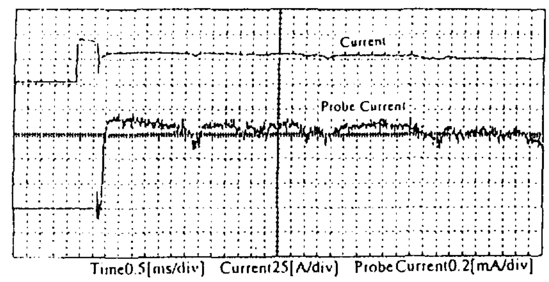


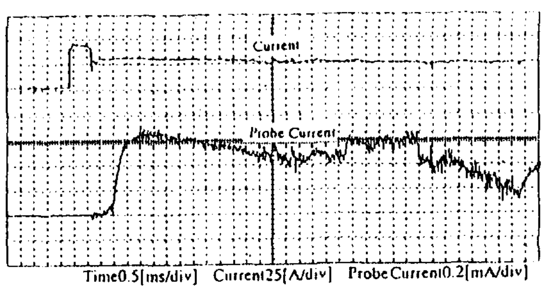
Fig.4 Time variation of temperature. Vc=80V.



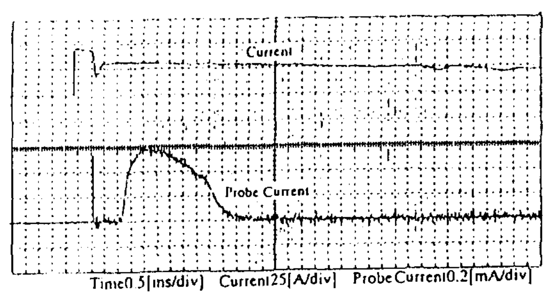
(a) Wire - Probe distance 1mm.



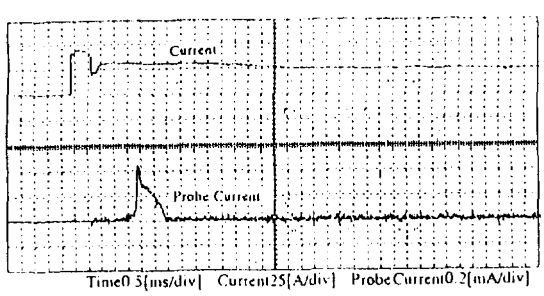
(b) Wire - Probe distance 2mm.



(c) Wire - Probe distance 3mm.



(d) Wire - Probe distance 4mm.



(e) Wire - Probe distance 5mm.

Fig.5 Time variation of discharge current and probe current for various probe position.

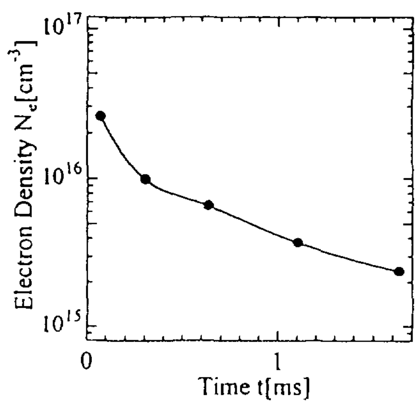


Fig.6 Electron density variation.