Metal plating removal from insulator substrate using pulsed arc discharge

K Imasaka¹, S Gnapowski² and H Akiyama²

¹ Department of Electrical Engineering and Information Technology, Kyushu Sangyo University, 2-3-1 Matsukadai, Higashi-ku Fukuoka, 813-8503, Japan
² Institute of Pulsed Power Science, Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto, 860-8555, Japan

E-mail: imasaka@te.kyusan-u.ac.jp

Abstract. Removal technique of metal materials from a metal plating insulator substrate using a pulsed arc discharge was proposed and its fundamental characteristics were investigated. The metal plating substrate with three metal-layers structure (copper, nickel and gold layers) is used as the sample substrate. Repetitive pulsed arc discharge plasma is generated using three types of electrode systems. Effects of the electrode systems on the metal plating removal from the insulator substrate were investigated. The metal plating was removed by the pulsed arc discharge between the electrode and substrate surface. A part of the gold layer, which is the topmost metal layer on the insulator substrate is vaporized and removed by the repetitive pulsed arc discharges.

1. Introduction

Environmental destruction and depletion of resources has become a problem due to the economic growth of recent years on a global scale. Therefore, the conversion to sustainable and recycling-oriented society utilizing 3R (Reduce, Reuse and Recycle) from the traditional mass disposal type society is demanded. There is recycle of printed circuit board for mounting electronic circuit components with respect to the 3R. In order to recycle the printed circuit board, it is necessary to remove and separate the metal plating materials from the insulator substrate such as the plastics.

Printed circuit boards composed of the multilayer metal plating and the insulator substrate are widely used. In general, copper (Cu), nickel (Ni), gold (Au) and chromium (Cr) are utilized as the multilayer metal plating materials. As you know, Ni and Cr are rare metals and also Au is one of the high additional value metals. Therefore, it is important and useful to remove and separate these metal plating materials from the printed circuit boards concerning to 3R. Pulsed power technology seems to be one of promising methods for it. Early works related to the recycle of the printed circuit board using pulsed power technology showed that it was possible to separate electronic circuit components such as resistor, capacitor and soldered metallic wires from the board by its fragmentation into small pieces using the shock waves which was generated by the pulsed discharge [1-3]. However, these studies could not remove the metal plating materials from the board.
The final purpose of this study is to develop the recycle technology to remove and separate the metal plating material from the insulator substrate using the pulsed arc discharge. In this work, basic phenomena of the metal plating removal from the substrate by the proposed method were investigated.

2. Experimental setup

Schematic diagram of the metal plating insulator substrate used in this experiment is shown in figure 1. The substrate has a structure in which three metal plating layers were formed on an insulator substrate made of a fiber-glass reinforced plastic (FRP). Materials of the three metal-layers are composed of Cu, Ni and Au, respectively. This metal plating substrate is widely used for the printed circuit boards.

On the other hand, it is reported that a thin metal wire or rod electrode covered with an insulator such as a ceramic tube is effective electrode system as an electrode system for the removal of metal plating by the pulsed arc discharge [4-6]. Therefore, the similar electrode system was also used in this study. In the previous studies [4-6], however, only one type of electrode system was used and the metal plating substrate was composed of Cu, Ni and Cr in electroplating on an acrylonitrile butadiene styrene (ABS) used as the plastic substrate, which was different one from this study. In this study, three types of electrode system (Type-A, Type-B and Type-C) were used to investigate effects of the relative positional relationship between the electrode system and the surface of metal plating layers on the removal of metal plating materials. These electrode systems were shown in figure 2.

<Type-A> This electrode system was same as one used in the previous studies [4-6]. Rod electrodes made of tungsten inserted into the ceramic tubes were used as the high voltage and ground electrode, respectively. Both electrodes were set up above the metal plating substrate at the angle of 45 degrees. In this case, we defined the separation between two electrodes and the distance from the substrate as \(d\) and \(g\), respectively.

![Figure 1. Metal plating substrate.](image1)

![Figure 2. Configuration of electrode systems.](image2)

![Figure 3. Experimental setup.](image3)
<Type-B> The tungsten rod electrode inserted into the ceramic tube and the metal plated substrate were used as the high voltage and ground electrode, respectively. The rod electrode was set up at the distance of $g$ from the surface of metal plating substrate, which was used as the ground electrode. Angle of the rod and substrate was 45 degrees.  

<Type-C> Type-C electrode system was similar that of Type-B, however, Angle of the rod and substrate in the Type-C was 90 degrees.  

Several diameters of the tungsten wire or rod and the ceramic tube were paired and used. The diameters of tungsten, $\phi_e$ were 0.1, 0.3, 0.7 and 3.0 mm. Outer and inner diameters of the ceramic tube, $\phi_{out}$ and $\phi_{in}$, respectively were $\phi_{out}/\phi_{in} = 2.0/1.0, 2.5/1.3, 6.0/3.5$ mm.  

Experimental apparatus was shown in figure 3. A pulsed power generator was used to generate the pulsed arc discharge on the metal plating substrate. The specifications of the generator were maximum output voltage of 120 kV, discharge repetition rate of 40 pps and the energy of 40 J/shot. A feature of this generator is higher repetition rate of discharge in comparison with the previous studies [4-6] in which a generator has the repetition rate of 6 pps. Output voltage and current were measured with a high voltage probe (Pulse electronics co. ltd, EP-100K) and Rogowski coil (Pearson electronics, Inc, Model101). A high-speed microscope (Keyence co., VW-6000) was used to observe the surface condition of the metal plating substrate and behavior of the repetitive pulsed arc discharges. An electron probe microanalyser (Shimazu co, EPMA-1720) was employed in order to analyze the material elements of the metal plating layers.

3. Results and discussion  

3.1. Effects of electrode systems on the removal of metal plating  

Figure 4 shows the surface condition of the metal plating substrate after the pulsed arc discharge generated in the three types of electrode systems. Settings of the output voltage, repetition rate and the number of shots of the pulsed power generator were 100%, 40 pps and 200 shots, respectively. Details of the typical results for each electrode system are as follows.  

<Type-A> Pulsed arc discharge was generated between electrodes through the metal plating surface by applying the pulsed high voltage between electrodes. After the discharge of 200 shots, two removed regions were formed on the metal plating layer just below the high voltage and ground electrode. Size of the removed region was several mm in diameter. The removed region tended to become larger as increasing the number of shots and output voltage setting value. However, the removal regions were formed at only two positions below the each electrode and it was difficult to...
remove the metal plating from the substrate efficiently between electrodes as a whole.

<Type-B> When the repetitive pulsed high voltage was applied to the tungsten electrode, pulsed arc discharge was generated between electrodes and the metal plating was removed. The removed region was formed on the metal plating below the tungsten electrode. Size of the removed region was increased to approximately 10 mm in diameter in comparison with that of the Type-A.

<Type-C> The metal plating on the substrate below the tungsten electrode was removed by the repetitive pulsed arc discharge. Size of the removed region was approximately 10 mm in diameter, which was almost same size in case of the Type-B electrode system. However, ring-shaped arc discharge spots were formed in the removed region. It was different from the result of the Type-A and Type-B electrode systems.

Figure 5 shows a relationship between the removed area of the metal plating and the 3-types of electrode systems in which the experiments were performed by changing the combination of parameters such as $\phi_e$, $\phi_{out}$, $\phi_{in}$, $d$ and $g$. These parameters for each electrode system are shown in Table 1. The combination of $\phi_e$, $\phi_{out}$, and $\phi_{in}$ is all the same for the three electrode systems. The $d$ and $g$ was changed in 3.0 mm and 2.0 mm or less, respectively. Settings of the output voltage, repetition rate and the number of shots of the pulsed power generator were 100 %, 40 pps and 200 shots, respectively. All of the removed area generated by the pulsed arc discharge under these experimental conditions for each electrode system was summarized in figure 5. It should be noticed that figure 5 shows only the ranges of diameters without statistical viewpoint because the diameters were obtained under many different experimental conditions. The removed area was evaluated by its diameter. Diameter of the removed area formed in the Type-A electrode system was widely varied from about 0.5 to 6.0 mm. Meanwhile, Diameter of the removed area formed by using the Type-B or Type-C electrode system was increased to about 2 times compare to that of the Type-A. From figure 5, it was also found that the Type-C electrode system was more effective to the removal of the metal plating in this experiment. In particular, the characteristic ring-shaped discharge region was formed in the Type-C electrode system as shown in figure 4. Therefore, then we investigated relationship between the removed region and the discharge phenomena by using the Type-C electrode system.

![Figure 5](image)

**Figure 5.** Dependency of diameter of removal area on 3-types of electrode systems.

### Table 1. The parameters $\phi_e$, $\phi_{out}$, $\phi_{in}$, $d$ and $g$ for each electrode system.

|          | $\phi_e$ (mm) | $\phi_{out}$ (mm) | $\phi_{in}$ (mm) | $g$ (mm) | $d$ (mm) |
|----------|---------------|-------------------|------------------|---------|---------|
| Type-A   | 0.1, 0.3      | 2.0               | 1.0              | 0, 1.0, 3.0 | 0, 1.0, 2.0 |
|          | 0.7           | 2.5               | 1.3              | 0, 1.0, 3.0 | 0, 1.0, 2.0 |
|          | 3.0           | 6.0               | 3.5              | 0, 1.0, 3.0 | 0, 1.0, 2.0 |
| Type-B and Type-C | 0.1, 0.3   | 2.0               | 1.0              | 1.0, 3.0   | -       |
|          | 0.7           | 2.5               | 1.3              | 1.0, 3.0   | -       |
|          | 3.0           | 6.0               | 3.5              | 1.0, 3.0   | -       |
3.2. Relationship between removed area of metal plating and discharge phenomena

Figure 6 shows the metal removal region and the pulsed arc discharge phenomena by changing the output voltage setting value from 10% to 100% in case of the Type-C electrode system. Repetition rate of the discharge and the number of shots were 40 pps and 400 shots, respectively. It was found that the removed region of the metal plating by the discharge tended to become larger as increasing the voltage setting value and the ring-shaped discharge region was clearly formed at the output voltage setting value of 50%. The high-speed microscope observation revealed that the formation of the ring-shaped discharge region was due to the behavior of the repetitive pulsed arc discharge. The repetitive discharge plasma channels were produced between electrodes shot to shot and these plasma channels were moved in the shape of the ring between the tungsten rod and the inner space of ceramic tube.

Output voltage and current waveforms were also shown in figure 6. The peak output voltage and current value for 1 shot discharge at the voltage setting value of 10% was 6kV and 400A, respectively. When the voltage setting value was increased to 100%, the peak output voltage was almost same because the gap distance between electrodes was same as 5mm in both cases but the current was increased to 800A. As increasing the number of discharge shots up to 400 the peak current value was decreased to 700A. The decrease of current was thought to be due the increase of impedance between electrodes because of the removal of metal plating from the substrate.

![Output voltage and current waveforms](image)

**Figure 6.** Effects of pulsed arc discharge on metal removable (Top: photos of pulsed arc discharge, middle: surface condition after discharge, bottom: output voltage and current waveforms).

3.3. Surface analysis of the metal-plated substrate after the discharge

Figure 7 shows the material element analysis of the metal plating layers after the repetitive pulsed arc discharge. The metal plating layers were composed of Cu, Ni and Au. Material of the topmost surface of the layers was Au and the middle layer material was Ni. It was found from figure 7 that the Au layer was removed by the repetitive pulsed arc discharge. However, the Ni layer could not be removed by the discharge. This result suggest that the Au layer was evaporated and removed by the pulsed arc discharge but the Ni and Cu layers could not be removed from the substrate. Although the reason for this result was under consideration, one of the possible reasons for it was thought that not only
4. Conclusions
The removal method of the metal plating layers from the insulator substrate by the repetitive pulsed arc discharge was proposed and the characteristics were basically investigated. Obtained results were summarized below.

1. The rod electrode inserted into ceramic tube to plane electrode system (Type-C) was effective to the removal of metal plating.
2. The metal plating was removed by the repetitive pulsed arc discharge, which formed the ring-shaped discharge region.
3. Au layer, which was the topmost material of the metal plating layers could be evaporated and removed by the pulsed arc discharge.

In the future experiment, we will try to investigate the relationship between the discharge phenomena and the mechanism of metal plating removal in more detail by using an optical emission spectrometer and other metal plating substrates.

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