Method for Cleaning Laser-Drilled Holes on Printed Wiring Boards by Plasma Treatment*

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We propose a new method for cleaning blind via holes after laser drilling of PWBs using oxygen plasma treatment. This report dealt with three kinds of PWB materials: epoxy resin and two kinds of aramid fiber reinforced plastics (AFRP: Technora or Kevlar fiber reinforcement). We observed the drilled holes after plasma treatment using both an optical and a scanning electric microscope (SEM). It was confirmed that adequate etching took place in the drilled holes by plasma treatment. We also compared the hole wall and hole bottom after plasma treatment with ones after chemical etching. It was clear that there was no damage to the aramid fiber tip on the hole wall, and that a smooth roughness of the hole wall was obtained by means of plasma treatment. As a result, we demonstrated that the plasma treatment is effective in cleaning the laser drilled holes of PWBs.

Key Words: Cleaning Method, Plasma Treatment, Blind via Hole, Laser Drilling, Printed Wiring Boards

1. Introduction

In the printed wiring board manufacturing sector, methods have been developed to improve circuit-packaging density since the electronics industry is currently progressing towards higher-density circuits. Laser drilling methods have been proposed for a new way to drill smaller diameter holes on the printed wiring boards (PWBs) to connect the circuits between circuit layers. We therefore have investigated laser drilling of blind via holes in multi-layer PWBs made of aramid fiber reinforced plastics (AFRP)⁽¹⁾. There have also been a few reports dealing with laser drilling of blind via holes in multi-layer PWBs made of glass fiber reinforced plastics (GFRP)⁽²⁾. Here, it is well known that a process of

cleaning holes after drilling is required because there are residual substances, for instance resin smears, on the blind hole bottom. A chemical etching process, wet process, is generally used to clean the holes drilled by a laser beam. At the present time, problems have emerged because the etching fluid flows are so poor in smaller diameter holes and because the fluid waste products negatively impact the environment.

There are some reports dealing with drilling smaller holes in PWBs and others concerned with resin smears on the drilled hole wall from the use of drilling tools⁽³⁾⁻⁽⁵⁾. However, there is no report dealing with resin smears in blind via holes after laser drilling. In the present report, we propose a new cleaning method for blind via holes after laser drilling of PWBs using an oxygen plasma treatment. Such a plasma treatment is considered an effective cleaning method for smaller diameter holes because it is a dry process involving no liquid chemicals.

* Received 14th October, 2003 (No. 03-4126)

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2. Production Processes of Multi-Layered PWBs

2.1 Built-up layer process and blind via holes by laser drilling

Figure 1 shows the steps involved in manufacturing multi-layer PWBs (for example, 4-circuit layers). First, circuit patterns are formed on the core plate. Second, built-up layers (e.g., an insulation layer) are pressed onto the core plate. This is called a built-up process. Third, blind via holes are drilled in the built-up layers by a CO₂ laser. Fourth, through-holes are made using drill tools. Fifth, cleaning and plating, procedures are performed. Finally, circuit patterns on both sides are formed by etching the plated copper. In the five steps, a chemical etching process (wet process) is generally used in cleaning the drilled holes by a laser beam. Figure 2 shows the types of holes formed by the laser beam. The insulation layer (built-up layer) is generally made of highly absorbent materials for a CO₂ laser beam. On the other hand, the copper foil of the circuit tends to strongly reflect a beam below the ablation threshold of copper. According to the energy input of the laser beam, three types of holes are produced, as shown in Fig. 2, namely, incomplete holes with low laser energy, complete blind via holes with adequate laser energy, and holes drilled through the copper foil with excessive laser energy.

Fig. 1 Steps in manufacturing of multi-layer PWBs

Fig. 2 Types of formed holes

2.2 Laser-drilled conditions

In the present report, the core material was a copper-clad laminate GFRP (glass woven cloth/epoxy composite) with a thickness of 0.8 mm with an 18 μ m thick copper foil for the circuits. The built-up layers were composed of three kinds of materials: two kinds of AFRPs (aramid fiber reinforced plastics; Technora fiber and Kevlar fiber reinforcements) and epoxy resin. These PWBs were made by Shin-Kobe Electric Machinery Co., Ltd. Laser beam machines (type 57-1-28 W and type 48-5-28 W, Synrad Co., Ltd.) with an output of 50 - 100 W were used to drill the blind via holes. The laser beam used was single mode with wave length of 10.6 μ m and light convergence was achieved by means of a ZnSe lens. The beam was focused on the upper surface of the work-piece, with a beam diameter of about 0.35 mm. N₂ was the gas used to facilitate drilling.

2.3 Residual substances on the copper foil of hole bottom

Figure 3 shows a cross section of the blind via hole formed by laser drilling in the AFRP (Technora reinforcement) layer. The complete blind via hole can be visually confirmed. However, it is well known that a process for cleaning these holes after drilling is required since there are residual substances (the resin smears) on the copper foil of the hole bottom as shown in Fig. 4. Chemical etching process, wet process, is generally used to remove the residual resin.

Fig. 3 Blind via hole in AFRP

Fig. 4 Resin smear on hole bottom

Problems have been emerged because the etching fluid flow is so ineffective in smaller diameter holes, and because of the negative impact of the fluid waste products on the environment.

Figure 5 shows a cross section of the blind via hole after laser drilling in the epoxy resin layer. Figure 6 shows a blind via hole after cleaning by chemical etching. Comparing Fig. 5 with Fig. 6, it can be seen that the chemical etching cleans not only the hole bottom but also the hole wall. Figure 7 shows the delamination between the epoxy resin layer and the circuit copper foil on the hole bottom after chemical etching. Figure 8 shows a cross section of that hole after copper plating. Inferior plating can be seen at the hole bottom. In this case, chemical etching reduces the ultimate reliability of the circuit connection.

2.4 Influence of chemical etching on surface quality of AFRP drilled holes

Figure 9(a) and (b) show the hole wall of a Technora fiber-reinforced plastic layer after laser drilling and chemical etching, respectively. A rough surface is observed in Fig. 9(b), confirming that a epoxy resin has only been etched to protrude the Technora fibers. Figure 10(a) and (b) show the hole wall of a Kevlar fiber-reinforced plastic layer after laser drilling and chemical etching, respectively. In this case, a rougher surface is still observed after chemical etching as shown in Fig. 10(b). Addition-

ally, chemical etching has fibrillated the tips of the Kevlar fiber which has poor chemical resistance against it.

Figure 11(a) and (b) show cross sections of a drilled hole and chemically etched hole after plating, respectively. Comparing these figures in regard to the blind via holes of the AFRP layer, the surface roughness of the hole wall has worsened after chemical etching. Moreover, there is a risk of reducing the reliability of the circuit connection between the layers when copper plating, since it is generally considered that any increase in surface roughness causes a decrease in the copper-plating quality.

3. Proposal for a New Method of Cleaning Blind via Holes

3.1 Cleaning the hole bottom by plasma treatment

From the above results, poor hole quality can be seen in other parts except for the bottom when the traditional cleaning method is used at a sufficient strength to remove the resin smears on the copper foil of the hole bottom. Therefore, we propose a new cleaning method of selectively removing the resin smear on the copper foil of the hole bottom by plasma treatment. Figure 12 shows the experimental equipment needed for this method. The printed wiring

Fig. 5 Blind via hole in epoxy resin

Fig. 6 Blind via hole after chemical etching

Fig. 7 Delamination after chemical etching

Fig. 8 Cross section of hole after plating

(a) After drilling

(b) After chemical etching

Fig. 9 Hole wall of Technora fiber reinforcement

(a) After drilling

(b) After chemical etching

Fig. 10 Hole wall of Kevlar fiber reinforcement

(a) After drilling

(b) After chemical etching

Fig. 11 Cross sections of a drilled hole of Technora fiber reinforcement after plating

boards are held in place halfway between two electrodes 100 mm apart. The plasma is introduced via an audio frequency from a 40 kHz power source (100 W) under Oxygen gas. The treatment pressure is 10 Pa, and the treatment time is 1 h.

The Oxygen plasma (O^*) affects the epoxy resin as follows according to Eq. (1).

The plasma decomposes the epoxy resin into CO_2 and H_2O . Furthermore, only the copper foil surface of the hole bottom can be affected by controlling an electric field direction.

Fig. 12 Experimental equipment of plasma treatment

3.2 Blind via hole cleaned by plasma treatment

Figure 13(a) and (b) show the hole bottoms after laser drilling and after plasma cleaning, respectively. Comparing these figures, it can be confirmed that an appropriate degree of plasma etching occurs to remove the resin smear on the hole bottom.

Figure 14 shows a cross section of the blind via hole of an epoxy resin layer after plasma treatment. Little evidence of etching can be seen on the drilled hole wall compared to that in Fig. 6.

3.3 Comparing the chemical process with plasma treatment

Figure 15 shows the relationship in epoxy layer drilling between the number of pulses when laser drilling is used and the increase in hole diameter after the etching process. A smaller increase in diameter by

(a) After laser drilling

(b) After plasma cleaning

Fig. 13 Hole bottoms

Fig. 14 Blind via hole in epoxy resin after plasma treatment

Fig. 16 Variation of surface roughness

Fig. 15 Increase in hole diameter

plasma treatment can be seen compared to the wet process (chemical etching), making it clear that there is little effect on the drilled hole wall from the plasma.

Figure 16 shows the relationship between the irradiation time length during laser drilling and the surface roughness of the hole wall after cleaning of an AFRP (Technora fiber-reinforcement) layer drilling. It is clear from Fig. 16 that the surface roughness after plasma treatment is markedly less value than that after chemical etching. It is thus confirmed that adequate etching takes place by means of plasma treatment when cleaning the blind via holes formed by laser drilling.

4. Conclusion

(1) In the traditional chemical fluid process used to clean blind via holes, etching simultaneously occurs on both the copper foil surface of the hole bottom and on the hole wall. Therefore, except for the hole bottom, poor hole quality can be observed elsewhere when this method is used at a sufficient strength to remove the resin smear from the copper foil of the hole bottom.

(2) As to the blind via holes of AFRP layers, rough surfaces are observed after the chemical process, because the epoxy resin is only randomly etched comparing to Technora fiber and Kevlar fiber. Additionally, the tips of Kevlar fiber are also fibrillated by chemical etching, since that fiber shows poor chemical resistance.

(3) It can be confirmed that sufficient etching occurs to remove resin smears from the hole bottom by means of the proposed plasma treatment without affecting hole-wall quality. The plasma treatment is considered to be effective in cleaning the smaller blind via holes formed by a laser beam in the printed wiring board manufacturing sector.

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