Effect of Electroplating Current on Surface Morphology and Thickness of Plated-Through Hole (PTH) in Multilayer Printed Circuit Board (PCB)

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Abstract. Multilayer printed circuit board (PCB) consists of many layers in PCB. In order to connect one layer to other layers is needed plated-through-hole (PTH). PTH is commonly formed from the copper metal using some methods such as electroplating or electroless plating. Electroplating is method which there is adhering process the copper metal using the electrical current. This method is easy and cheap in PCB manufacture. One of the important part of electroplating result is surface morphology and thickness of PTH in multilayer PCB. The objective of this study is to im the electroplating current in electroplating process to learn more about the effect of electroplating current against the surface morphology and thickness of PTH.. The electroplating current applied in this experiment is at 5 A, 10 A, 15 A, and 20 A. In this research is also used Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) to characterize the formed PTH in multilayer PCB. The results shows that the PTH was successfully formed in through hole of multilayer PCB. The thickest PTH is about 37.8 μm for the applied current 20A and the smoothest morphology of PTH cross section is at the electroplating current 15 A.

Keywords: electroplating current, PTH thickness, multilayer PCB.

1. Introduction
One of the hardest surface adjustment technologies that it is applied for pre-treatment product is the electroplating process. The electroplating process generally utilizes the electrochemical reaction principle [1], so the electric current also is applied in this process to make metal coating. Some metal materials which they are used in this electroplating process are copper, tin, silver, gold, chromium, nickel, and so on [2]. The electronic product coated by metal using electroplating process has many advantages such as lower resistivity, better anti-electromigration ability, higher thermal exchange rate [3], corrosion prevention, aesthetic finishes, and coating component [4]. Furthermore, surface smooth, copper grain, and resistivity of coated metal using the electroplating process are affected by many parameters such as the electric current density, the electric field distribution, the stirring style, and
temperature [5,6]. This electroplating process is widely used in aerospace, electronics, automotive, and so on [3]. One of important part in electronic products utilizing the electroplating process is printed circuit board (PCB). Copper is metal which it is commonly used as coating material in manufacturing printed circuit board (PCB) [7,8].

An important technology to manufacture multifunctional electronic products is the high-density interconnection (HDI) of printed circuit board (PCB), so making multi-layered PCB is substantial to be the high-density interconnection (HDI) [9]. One of parts on multilayer PCB is plated-through hole (PTH) [9,10]. PTH has the purpose to connect one layer to other layers in multilayer PCB [11-13]. Therefore, PTH is essential part in multilayer PCB. The objective of this study is to learn more about the effect of electroplating current against the surface morphology and thickness of PTH. The optimal electroplating current can increase the PTH performance in A4 size PCB. The high PTH performance can improve the connection between one layer and other layers in multilayer PCB as well as the adhesiveness between PTH and component.

2. Experimental Method
In order to form PTH in multilayer PCB is needed some steps such as designing, preparing material, pressing the FR-4 materials, drilling, brushing, cleaning, immersing in the conductive carbon solution (black hole solution), drying, electroplating process, cleaning, drying, testing and characterization [14]. Some steps was conducted sequentially from designing till characterization to obtain the good PTH in multilayer PCB.

The first steps is started by designing PTH in A4 size PCB using Altium Designer. The next step is preparing material. The materials include FR-4 materials (A4 size), conductive carbon solution (black hole solution), distilled water, ethanol 98%, and copper (II) sulphate pentahydrate (CuSO$_4$.5H$_2$O, meltex). Making the PCB stack from three FR-4 materials was conducted when preparing material was complete. The PCB stack was made by gluing the FR-4 materials using solid glue (A4 size) and pressing them to make the four layers of PCB. The pressing process was conducted with the constant pressure 12 bar and temperature 170 $^\circ$C for 30 minutes. The next process is the drilling process. The drilling process is to make the holes in multilayer PCB with hole diameter 0.6 mm [13] and it works following the PCB design. Brushing and cleaning were conducted to clean the drilled PCB. The distilled water was used during brushing and cleaning. The next step is immersing the PCB surface in the conductive carbon solution for 5 minutes and drying at temperature 80 $^\circ$C for 10 minutes. The next process is the electroplating. The electroplating process was conducted for four multilayer PCBs, but the electroplating current was different for each multilayer PCB in which the electroplating currents were 5 A, 10 A, 15 A, and 20 A. Each electroplating process needed about 45 minutes. Cleaning and drying of multilayer PCB were done after the electroplating process was finished. The formed PTH in multilayer PCB is characterized using Energy Dispersive Spectroscopy X-Ray (EDS) and Scanning Electron Microscopy (SEM) (Phenom ProX Desktop SEM).

3. Results and discussion
Plated-Through Hole (PTH) in multilayer PCB is generally formed using electroplating method [11]. In this electroplating method is needed some materials such as copper plate as anode, FR-4 material as cathode, copper (II) sulphate pentahydrate (CuSO$_4$.5H$_2$O) solution, and solution chamber. In this electroplating process is also applied the direct current (DC). The illustration of electroplating process for multilayer PCB is as shown in figure 1. There is an oxidation-reduction reaction or redox reaction when the DC current is applied in this electroplating process.

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\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \quad \text{(reduction in cathode)}
\]

\[
\text{Cu} \rightarrow \text{Cu}^{2+} + 2e^- \quad \text{(oxidation in anode)}
\]
Figure 1. The illustration of electroplating process for multilayer PCB.

Figure 2. SEM images of PTH cross section in multilayer PCB for electroplating current at (a) 5 A, (b) 10 A, (c) 15 A, and (d) 20 A.

Plated-through holes (PTHs) were successfully formed using the electroplating method. The SEM results show that the copper metal adhered on the hole surface of multilayer PCB as shown in figure 2. The copper metal adhered on hole surface of multilayer PCB was formed by applying the electroplating current at 5 A, 10 A, 15 A, and 20 A for each multilayer PCB. Further, the SEM images exhibit that copper metal of PTH attached and bonded with FR-4 material. The copper metal of PTH also connect one conductive layer to other conductive layers of multilayer PCB. The SEM images also show the morphology of PTH cross section. The morphology of PTH cross section for electroplating current at 15 A is seen smoother than others.

Figure 3. EDS results of PTH
The element contents of PTH are characterized by using Energy Dispersive X-Ray Spectroscopy (EDS). The EDS results show that the major content of PTH is copper as shown in figure 3. The copper content of PTH is more than 73 %. The copper contents of PTH for the electroplating current at 5 A, 10 A, 15 A, and 15 A are 74.2 %, 86.2 %, 73.3 %, and 80.6 %, respectively. These results show that the formed PTH in multilayer PCB has the copper content more than 73 %. It indicates that the electrical conductivity of formed PTH is good because the copper is one of metals which own the high electrical conductivity. The high electrical conductivity of PTH is one of the criteria for the good PTH. The higher electrical conductivity of PTH, the better PTH in multilayer PCB.

The thickness of PTH is measured by using Phenom ProX Desktop SEM. The results show that the thickness of PTH is 12.15 μm, 21.20 μm, 30.90 μm, and 37.38 μm for the electroplating current at 5 A, 10 A, 15 A, and 20 A, respectively. This results show that the thickest PTH is obtained at applied current 20 A about 37.38 μm whereas the PTH thickness at 20 A is the thickest about 37.38 μm as shown in figure 4.

4. Conclusion
PTH was successfully formed in multilayer PCB using electroplating method. The copper contents of PTH are more than 73 %. These copper contents of PTH show that PTH has the good electrical conductive which it allows the current flowing from one layer to other layers well. The SEM images show that the thickness of PTH is 12.15 μm, 21.20 μm, 30.90 μm, and 37.38 μm for the electroplating current at 5 A, 10 A, 15 A, and 20 A, respectively. This results show that the thickest PTH is obtained at applied current 20 A about 37.38 μm as well as the smoothest morphology of PTH cross section is at the electroplating current 15 A. So, the electroplating current affected the morphology and thickness of PTH.

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