Green Ink-Jet Technology for Fabrication of Multilayer Flexible Circuit Part I: System Construction & Fabrication Process

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Abstract

Printed circuit boards (PCB) are being widely applied for related electronic produces in industry. The trend in the future is toward narrower metal line, tiny via hole, and complex multilayer manufacture processed. The challenge is therefore for the difficulty of producing excellent metal thickness on substrate surface and inner surrounding of holes for high level application. This study proposed an improving method on electroless plating, and combined with the ink-jet printing of catalyst to form a high aspect ratio of metal thickness for the substrate surface and hole inner wall. This study laminated the flow direction by dynamic pressure control and modulated the velocity at divergence along the substrate surface and hole inner wall. Meanwhile, the stabilization of electroless plating was tuned by an inner flow circulation, to reduce of cavity defect in metal forming. By this system improving, high performance circuit at full reliability was made on multilayer flexible substrate with holes, the variation of aspect ratio of thickness can control within 13%, and further reduce up to 2% with the hole diameter decrease.

Introduction

With the development of electronic devices, printed circuit boards (PCBs) have been toward for high density packaging and ultra-multilayers design. Board in 10-20 layers with a typical line / spacing of 100um are minimum request for applications [1,2]. Sequential build-up technologies in fabrication have been rapidly developing to achieve such high density multilayer printed circuit boards [3,4,5,6,7]. However, the difficulty is in the fabrication of connecting hole between layers, the proportion of via-hole diameter to layer thickness (via-hole length) decreases thereby forming high electrics resistance due to the deterioration of metal film around the via wall. It is because that the electrolyte of electro-plating can not flow pass through via-hole well and uniform.

Some prior researches proposed mechanical disturbing method to improve the uniformity within the wall of via-hole. ISHII NARIMITSU et al. [9] disclosed a spray device, to pour electrolyte as the substrate moving up and down. KUKANSKIS PETER E; DONLON EDWARD T et al. [10] placed a vibration source within the chamber of electro plating, to periodic circulate the plating flow. This article shows a totally different approach aim to solve the hard penetration problem in tiny via-hole. After an ink-jet printing of catalyst in pre-determined pattern on a substrate with tiny via-holes, a close chamber system drives the electro plating flow into the via-holes by modulating the pressure ratio of upstream and downstream. The flow velocity difference along the substrate surface and along the wall of via-hole will dominate the forming metal thickness. Experiments shown this design will improve the connecting quality for via-holes on multi-layers board. Also, it was found during this design process, the accumulation of metal is tight and effectively prevents metal crack on board. This design provides efficiency flow circulation passing through via-holes and presented excellent reliability.

Description of System Design

This system was consisted of several key components. First, the flexible substrate is fixed inside the chamber to divide the space into two parts, as a separation membrane. It constrains the electrolyte flow only has the outlet from one side to another side by via-holes. A pressure generating device and a pressure regulator are connected to this chamber at different sides, to control the flowing condition, where the pressure generating device is for pumping the plating solution flow parallel to the surface of the substrate, and the pressure regulator is for controlling the pressure differences between the two sides of the substrate. In this design, the plating solution flow parallel to the surface of the substrate and into via-holes will be significant different and could be controlled by the pressure generating rate and pressure regulator.

The mechanical detail described in Fig.1. It consisted of a sealed chamber 10, a substrate 20 that have a plurality of through holes 21 inserted within the chamber 10 and well sealed. A upstream flow element 11 and a downstream flow element 12 had standard Swagelok plug on chamber. Where the pressure generator 30 pumped electrolyte solution into chamber, and the pressure regulator 36 at downstream tuning the outlet pressure to control the velocity passing through via holes. The pressure difference between the two sides of the substrate 20 was controlled through adjusting ratio of pressure generator and pressure regulator. It was notable that the velocity tuner 34, function as a gap (W) adjusting, to change the boundary condition of flow on substrate, and affect its boundary layer thickness and flow velocity. As shown in Fig.2.

A key process is the stability of electrolyte which dominates the uniformity and quality of metal circuit. The electrolyte stabilizing device 31 is a stirring device to promote the mixing of electrolyte flow input and oxygen synchronously, and it can contain a extra bubble generator if necessary, Generally, to speed up the growth rate of metal while ion change between Pd-nuclear of catalyst and electrolyte, higher temperature is preferred. In this consideration, temperature controller 33 followed after a laminar flow stabilizing device 32, to transfer laminar electrolyte at setting temperature into chamber 10. Thus, an optimal reaction temperature is achieved, and got excellent growth rate in expectative metal thickness. In choosing the laminar device, it needs to know that the screen size will depend on the operation of pressure range. Here we adopted porous plate to get a full developed velocity profile before flowing into chamber. The full developed flow will further modulate its velocity and boundary layer thickness along the substrate surface by velocity tuner 34, to avoid flow separation occurrence. Flow separation will deteriorate the uniformity of metal formation, and generally created defects like cavity shape. Typically, the gap between the substrate and chamber boundary at 1 mm was preferred. The velocity tuner 34 is a rigid plate body moving relative to the substrate 20 to adjust the gap space W. Also, the growth rate can further enhance by an electric field controller 35, immersed in electrolyte and the positive and negative electrode located on the different side of the substrate 20 respectively, to accelerate the ion exchange rate. But it should be carefully that over driving the electric current will form bad metal profile and loose grain metal particle, and worse electric performance was presented.

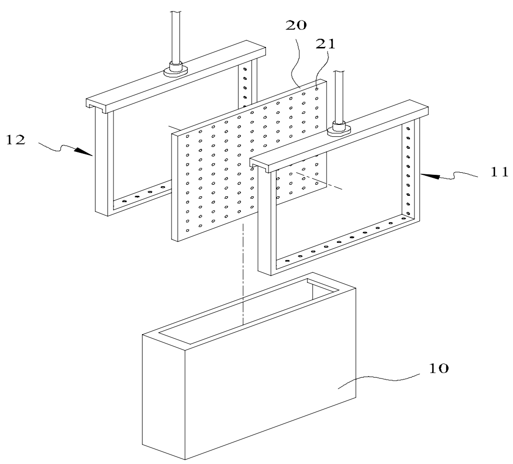


Fig.1 The chamber body of flow circulation system.

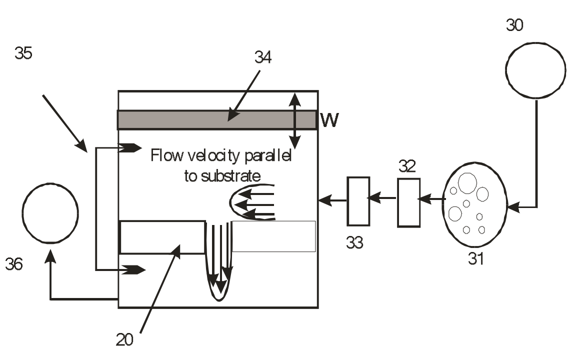


Fig.2 Layout and its control component for flow circulation

The processes of forming metal circuit are depicted in Fig.3.It comprised a base frame 1, a moving stage 2, and plurality of electrolyte tanks A-I. Each tank is fill different solution to certain purpose, where A-E is for the surface treatment before ink-jet printing of catalyst, included the two ion water tanks, and self-assembled polyelectrolyte solution of PAH (Poly(allylamine hydrochloride)), PAA (Poly(acrylic acid)) and PAH (Poly (allylamine hydrochloride)) / PSS (sodium styrenesulfonate) [11]. After forming polymer film on the surface and inner holes, an ink-jet printing of catalyst to pattern on substrate was operated [8]. F-H is related to the electroless plating, included one accelerator solution, activator solution, reducer solution and electroless solution.

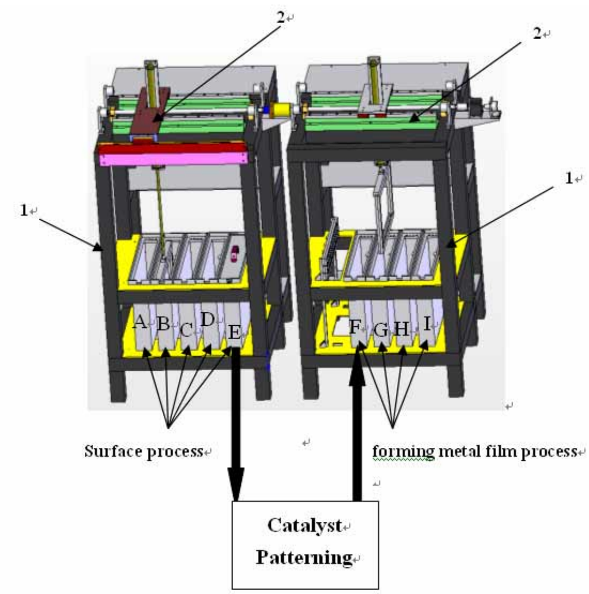
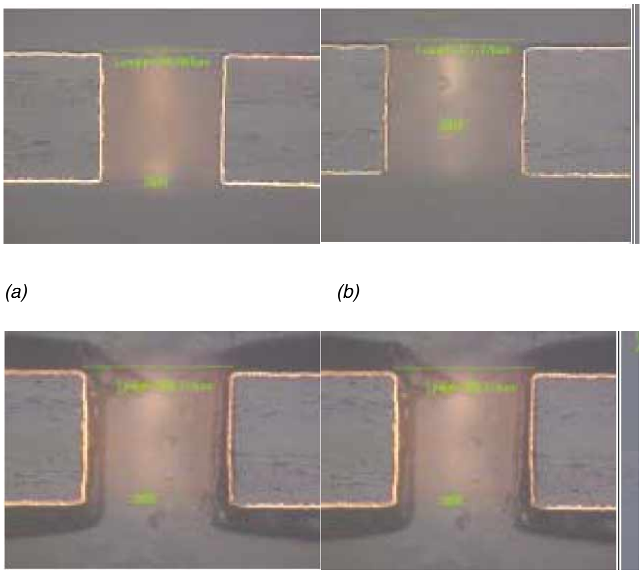


Fig.3 The processes of metal film forming

Discussion and Conclusion

Experimental results shown several samples with growth metal circuit on FR-4 substrate of different via-hole diameter, to compare the variation at same flow circulation control. Fig 4(a)-(d) was a cross-section image by SEM (Scanning Electron Microscopy). It is obvious that the metal thickness on the substrate surface and on the wall of via-hole was perfectly at same magnitude. Compare with classic printed circuit board process, in a thickness ratio (surface thickness / wall thickness) of 3, this flow circulation method substantially improved the ratio to near ideal value of 1. The measured via-hole diameter was range from 200 um to 300 um, and its aspect ratio (substrate thickness / via-hole diameter) is from 0.66 to 1.25, as shown in Table.1. Experiments proved that the trend of less variation for the thickness difference between substrate surface and inner wall of via-hole with the decrease of via-hole diameter. By this system improving, high performance circuit was made on multilayer flexible substrate with via-holes, and the variation of aspect ratio of thickness can control within 13%, and further reduce up to 2% with the via-hole diameter decrease.



(a) (b) (c) (d)

Fig.4 The difference of cross-section of through hole

Table 1:Test pattern value and result

section	(a)	(b)	(c)	(d)
hole dimension (mm)	0.2	0.25	0.3	0.35
aspect ratio	1.25	1.25	0.89	0.66
The thickness of surface(1) (um)	5.52	3.38	10.29	12.72
The thickness of inner hole(2) (um)	5.65	3.85	12.56	11.02
(2)/(1)	1.02	1.13	1.22	0.86

In this paper, a novel ink-jet fabrication process with a flow circulation in following electoless plating for meatl circuit was disclosed. We proposed improving method on electroless plating, to form perfect metal thickness for the substrate surface and via-hole inner wall. By this system improving, high performance circuit was made on multilayer flexible substrate with via-holes, and the variation of aspect ratio of thickness can control within 13%, and further reduce up to 2% with the via-hole diameter decrease.

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Biography

Jie-Kai Chang received his Master degree in Mechanical Engineering from National Chung Hsing University in 2001. He is now a system integration engineer in the Printing Technology Division, Display Technology Center of Industrial Technology Research Institute at Taiwan. His work has primarily focused on the industrial ink-jet printing processes development, especially in color filter, PWB, MEMS device fabrication by ink-jet printing.