Continuous Roll-to-Roll Circuit Fabrication by Ink Jet Printing Process

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Abstract

Flexible substrates are becoming more important in the printed circuit board industry. The flexible circuit boards can be thinner and lighter than rigid board, and can be flexibly and easily assembled into high level electronic product. In this paper, we developed the ink jet printing technique to form the copper metal wire on flexible substrate. It combines the self-assembled polyelectrolyte as surface treatment, the ink jet printing of catalyst, and electroless plating processes into one continuous roll-to-roll system. Specially, the working surface of the substrate is kept out of contact with each transmitting roller to avoid the pollution in this continuous roll-to-roll circuit fabrication system by ink-jet printing. This design is important for modular process flow. To avoid the elongation and alignment deviation of flexible substrate, this continuous roll-to-roll system also has a robust tension control to guarantee the position accuracy of about ±10μm. In this study, all the process flow are tabulated and discussed, especially in the arbitration between the ink-jet patterning step and other processes.

Introduction

The novel process is developed in ITRI OES to form metal wires, includes the steps of appropriately treating the surface properties of the substrate to improve the adhesion between the metal and substrate; microdispensing the catalytic pattern for forming metal film, and depositing metal on the catalytic pattern on the surface of the substrate by an electroless plating process. These technologies offer the potential for low cost materials-efficient deposition of metal. Inkjet printing, as a derivative of direct-write processing, offers the additional advantages of low capitalization, very high materials efficiency, elimination of photolithography processes. The substrate treatment processes provided good adhesion between metal film and substrate, and are suitable for multiple substrates, including rigid substrate and flexible substrate applied in the printed circuited board and flat display industry.

Flexible substrates are new and important applications in circuited board and flat display industry. The flexible substrates are produced by “roll” type, and these are long, thin and flexible material. Employing the roll-to-roll manufacturing method in flexible circuit board or flexible display process can save the men power, material cost and apparatus cost. There are economic advantages to making a product long because it can be manufacturing continuously instead of in batches.

But there are special technology requirements for the ink jet printing roll-to-roll manufacturing process. These are different from the traditional roll-to-roll manufacturing process. First, the working surface of the substrate must always keep out of contact with each transmitting roller to avoid the pollution in circuit pattern. No matter which process is used, it should satisfy single side surface contact requirement. The working surface pollution in the self-assembled polyelectrolyte process influences the uniformity of the surface property. The contact angle between ink and the substrate will change as the pollution occurs. Consequently, the line width and line width variation qualities are hard to control. If pollution happened in the ink-jet printing process, the printed circuit pattern would contain defects. In this study, we develop the continuous single side contact system to combine all the production processes of combining the self-assembled polyelectrolyte step, ink-jet printing of catalyst, and electroless plating step.

High accuracy control of the tension, nip and edge position for the ink jet fabrication are tremendously important to reduce defect. To ensure this requirement, the control law constructs three main feedback loop included in this roll-to-roll manufacturing apparatus. The first is the on-line tension feedback loop, the second is the on-line position feedback loop, and the last one is velocity compensation loop. Tension control is very important for web manufacturing and process setting. If the tension is too low, the web will tend to flop and flutter and will tend to shift and the path will wander sideways going through the machine and may lose traction on rollers. Conversely, if the tension is too high, portion of the web may be damaged due to local yielding, or web breaks may increase if the material is brittle. Tension also affects geometry such as changes in length, width and registration, curl and flat. So, roll-to-roll handling requires knowledge and control of substrate stresses at every point in a machine, as well as at all time. Accuracy and response time are very important for our roll-to-roll system. That’s a new challenge for mechanism and control rate design.[1]

Detail of Modules

As mentioned before, to avoid working surface pollution, the surface for processing needs to keep out of contact with each transmitting roller. OES developed a new flexible substrate delivery design for the metal film ink jet printing process (Fig. 1). The substrate on the delivery path always keeps one side surface contact with all transmitting roller. The design is modularized and flexible. We arranged the rollers position to reach the one side contact requirement. Each module has the same in/out delivery passage, and is easily to combine with different processes, e.g. dipping, flushing, baking, curing, and printing. Look at the stream flow, all the roll-to-roll circuit fabrication processes include dipping, flushing, baking for the SAM process, micro-dispensing the catalyst for forming metal film pattern, and dipping for metal plating, respectively (see Fig. 2).

Besides, consideration of the time lag for each step, in this design, a buffer mechanism was design to matching each process in this continuous system. By add more module or just the distance between the rollers, one can tune the needed processing time (see Fig. 3).

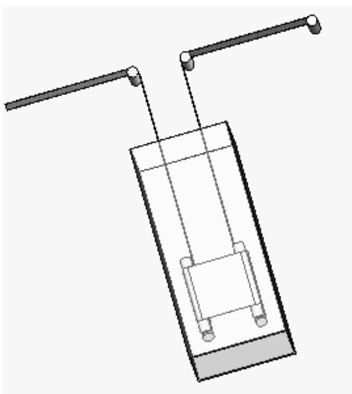

Figure 1. The flexible substrate delivery design.

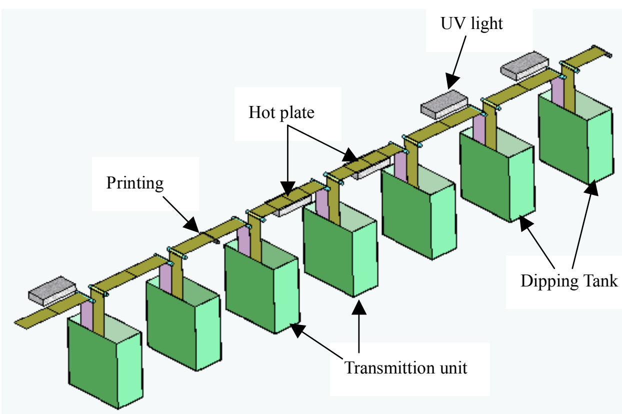

Figure 2. The continuous roll-to-roll system.

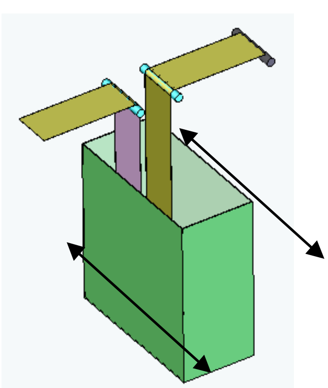

Figure 3. The process compatibility tuning.

Batch Process

The process is developed to form metal wires on the flexible substrate, includes the steps of appropriately treating the surface properties of the substrate to improve the adhesion between the metal and substrate; micro dispensing the catalytic pattern for forming metal film, and depositing metal on the catalytic pattern on the surface of the substrate by an electroless plating process.

Self-assembling monolayer (SAM) films have been used as building units for constructing multilayer structures and as modifiers of surface properties. Such surface modification, for example, can be used to promote adhesion and wettability, prevent corrosion, modify the electrical and optical properties of the material or create electro active monolayers suitable for various optical and electronic sensors and devices.[2-6]

SAMs are prepared by selective absorption of compounds at solid fluid interfaces to construct organized oriented compact monolayers of good quality and having a thickness ranging from about 1 nanometer to about 3 nanometers. The molecular self-assembly process takes place as a layer-to-layer process, which is based on the spontaneous absorption of either nonionic polymers, polyanions or polycations from dilute aqueous solutions onto surfaces that carry a functional group or a charge opposite to that of the depositing polymer. Selective absorption of these polyelectrolytes is alternated to form a bilayer assembly and leads to the formation of multilayer assemblies. The molecules are typically used for constructing the first monolayer have a terminal polar group and a non-polar functional group at either the other end of the molecule or somewhere within it.[7]

Following the SAM treatment is the catalyst printing step by Cheng et al.[8] The printing pattern can accord to the input of image data. When dried, the catalyst will be adhere onto the substrate surface, and diffuse onto the monolayer of poly (allylamine hydrochloride) (PAH). It makes a pattern on the substrate as a result.

The uniformity of the substrate surface property is very important; it strongly influence the quality of the product. These pictures showed the defect of the SAM film (Fig. 4). Observation found if the flexible substrate wrinkles or widens, the monolayers are hardly to build uniformly. Also, in case a little pollution occurs in the working surface, the defect would occur. Figure 5 shown the defect of the metal line due to pollution on working surface during not appropriate delivery.

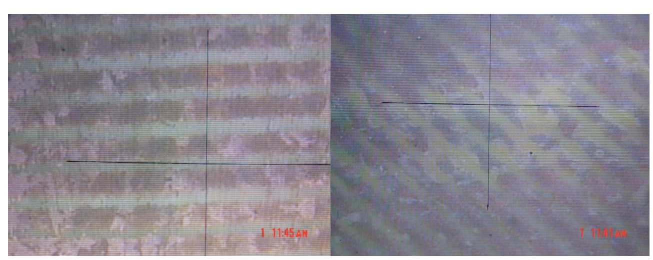

Figure 4. The defect of the SAM film.

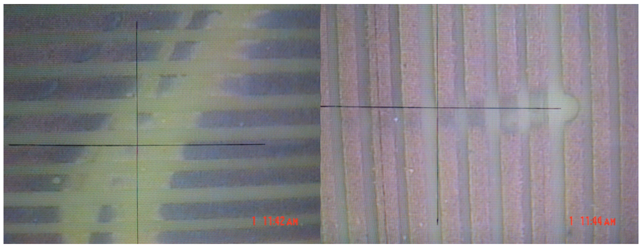

Figure 5. The defect due to substrate pollution.

The copper plating bath was based on the prior formulation.[8] All of the reagents were dissolved in DI water at room temperature and stirred. To keep the solution stable, a bubble generator with air was used in the plating bath. The pH of the bath was monitored in specific pH value, and the copper deposition carried out at room temperature. Immersion time and temperature are two key factors to control the wire thickness. After removal from the plating solution, the samples were rinsed with DI water to remove loose copper and plating solution and then set aside to dry.

In experimental observation, the plating thickness and its growth rate both are related with the stirring condition. The layout of the bubble generator in the electroless plating tank will influence the quality of the metal film, more uniform and smaller bubbles are prefer. However, if the bubble directly contact the working surface (the side of ink-jet printing of catalyst), then the cavitation phenomenon would happen. To avoid this situation, the bubble generator was combined with the transmitting roller. So the bubbles generate from roller won't touch the working surface to avoid the cavitation defect (see Fig. 6).

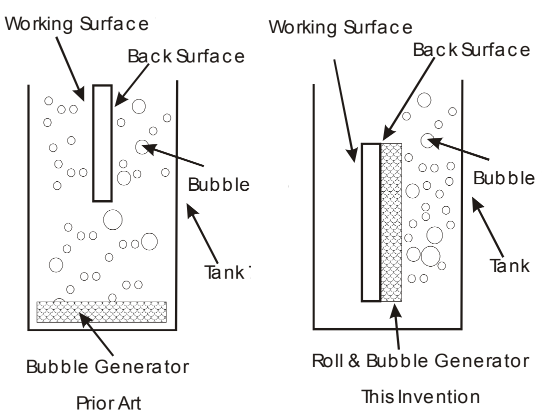

Figure 6. Electroless plating tank design.

Conclusion

In this paper, an all ink-jet fabrication process has disclosed. We demonstrated the patterning flow of electric circuits on flexible substrates via combining three technologies: the self-assembly of polyelectrolytes, the ink-jet printing of catalyst and the electroless metal plating. This continuous ink jet printing roll-to-roll system was used to realize the metal film on flexible substrate. The specialty is on the design of single side contact, modular structure, time lag tuning mechanism, and the stirring mechanism. To get high accuracy control, the control law consists of three major feedback loop, the tension, position, and velocity loop, respectively. This design for circuit board printing IJP process has demo prototype in OES. Further study will improve on designing the feedback time and the mechanism necessary to meet the strict requirement for HDI products.

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