THE UNIVERSITY OF WARWICK

Fabrication of Polymer Electronic Boards by Ultrasonic Embossing and Welding

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Abstract: A method has been developed allowing fabrication of electronic boards from flexible polymer film by ultrasonic embossing and welding within seconds. A commercially available ultrasonic welding machine and micro patterned tools from aluminum are employed first to generate conductor paths on a flexible polymer film, in a further step, surface mounted devices (SMDs) are assembled and fixed on the flexible polymer film by a lid, and meanwhile electrical connected via a z axis conductive tape, both the molding of the lid and the bonding between the lid and electronic boards are implemented on an ultrasonic welding machine. Finally, the effectiveness of electrical interconnection is investigated at elevated temperature, humidity and bending load, exemplified by three simple circuit boards assembled with LEDs and resistors and capacitor separately, and the experimental results show that the electrical interconnection is effective, stable, and durable**.**

Key words: Polymer electronic boards; SMD; Polymer film; Ultrasonic embossing; Ultrasonic welding

1. Introduction

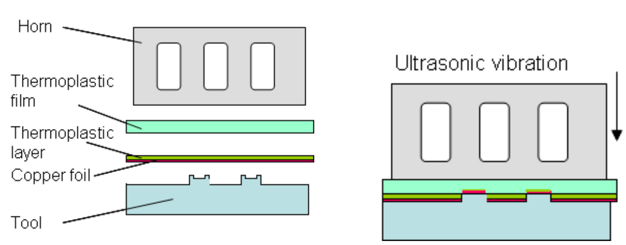
Electronic boards are usually realized as printed circuit boards (PCB). PCBs are fabricated by photolithography, electroplating, etching, mechanical drilling of via holes, etc.. In a subsequent process electronic elements are placed onto the PCB with a pick and place robot and electrical contacts are generated by reflow soldering [1, 2]. This fabrication nowadays is highly automated and well suited for mass production. However, toxic and hazardous substances are required for these processes and the sequence of all necessary production steps takes at least an hour.

In recent years, polymer materials are widely used in electronic boards in several capacities, such as substrate, structural thin film, adhesion and packaging, due to their advantages, including low cost, variety of mechanical properties, and easy processing [3]. Conductive adhesives were widely used to form the circuit paths on polymer substrates [4]; traditional lithography is applied to fabricate circuit paths on polymer substrates [5]. Three dimensional circuit boards based on Molded Interconnection Devices (3D MID) technology were developed by the processes of 2K shot injection molding technology [6] and laser direct structuring technology [7]; circuit pattern can also be replicated onto flat polymer films [8, 9].

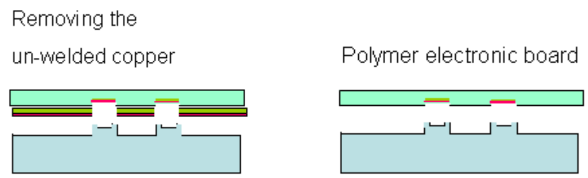
In this paper a process is introduced which allows fabrication of flexible electronic boards from thin polymer films by ultrasonic embossing and welding, and an approach for assembling and electrical interconnecting of SMDs is proposed to form a flexible electronic board. Finally, effectiveness, stability and durability of the electrical interconnection were investigated.

2. Fabrication of conductor paths

A conductor path is generated from a 20 µm thick copper foil on a flexible polymer substrate by embossing with an ultrasonic welding machine. The principle of the process is schematically shown in Fig. 1: A tool is fixed under the horn, the copper foil spin-coated with PLEXTOL B500 and one layer polymer film is placed on the tool. Then with suitable process parameters, including pressure and welding time, the sonotrode is pressed onto the polymer film, and heat is generated in the thermoplastic film due to molecules vibration and friction. Therefore, the circuit pattern is cut out by protruding bars on the tool and welded onto the thermoplastic film by pressure and heat. This way, after removing the un-welded copper foil, the conductor paths remain on the polymer substrate.



(a) (b)



(c) (d)

Fig. 1 Principle of ultrasonic embossing and welding of a flexible polymer circuit board substrate: (a) Placing polymer films, copper foil spin coated with polymer on the tool; (b) Pressing the sonotrode onto the tool, applying ultrasound, and cooling down; (c) Removing the un-welded copper foil; (d) Flexible polymer circuit board substrate.

The copper foil, 20 μm in thickness, used to from the conductor path has a rough bottom surface, on which a layer of liquid polymer (PLEXTOL B500 from Symantec), 20 μm in thickness, is spin-coated. Then the copper foil is dried and cured at 35℃ in oven for 20 minutes. After that, the polymer layer is used as an adhesive to bond the copper foil and polymer film.

The aluminum tool with the desired pattern is fabricated on a micro-milling machine. The dimension of the protruding micro structure is, as shown in Fig. 2, 100 µm in height and 100 µm in width. This is designed to cut circuit paths out of the copper foil. The distance from the top of the protruding bar to the surface of the tool and circuit track zone in the middle of the protruding bars are 300 µm and 200 µm, respectively. It is designed according to the thickness of the polymer film, 250 µm were used in this paper. This way, the pressure and energy are focused onto the circuit track area to strengthen the sticking strength between the copper and polymer film. The un-welded copper foil afterwards can be removed easily by adhesive tape.

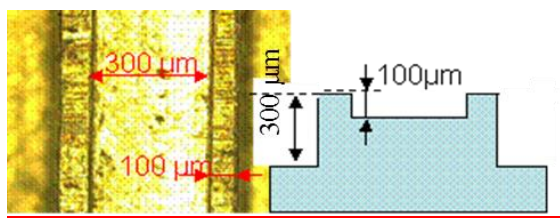


Fig.2 Dimensions of the micro structures on the tool.

In this paper, the polymer film polyvinylidene fluoride (PVDF), 250 μm in thickness, was chosen as the substrate of the electronic board; other polymer films such as PVC and PE are also suitable as substrates of electronic boards.

For the entire processes only the special treated copper, tools with the desired patterns, polymer films, and an ultrasonic machine are needed. The whole process just lasts a few seconds, and is low cost and highly efficient. Fig. 3 shows a flexible electronic board and a view of a cut through a conductor path.

(a) (b)

Fig. 4 (a) Polymer based flexible electronic board with a single layer of conductor path; (b) View of a cut through the electronic board.

3. Interconnection and assembling of the SMD

The reliability and effectiveness of the electrical and mechanical interconnection between conductive path and surface mounted devices (SMDs) are crucial factors for the flexible polymer electronic board. In the traditional process for printed circuit board (PCB), the SMDs are assembled and interconnected on the PCB by soldering or conductive adhesive, compared to rigid PCB, the interconnection on flexible polymer electronic boards need to bear extra strain and stress, so a new assembling method is proposed and conducted by the process of ultrasonic molding and welding.

3.1 Assembling of electronic elements

The SMDs are fixed and assembled through bonding between the flexible polymer electronic board and a polymer lid by ultrasonic embossing and welding. The principle is shown schematically in Fig.5: In the first step, a special designed tool is fixed on the working plate, the cavity in this tool is designed according the dimension of the SMD, taking for example a capacitor here, and the protruding margin is used to form the brim of the lid. Then, two layers of polymer films are placed on the tool, and a capacitor is placed on the polymer films aligned to the corner of the cavity, with suitable process parameters the capacitor and the polymer films are pressed into the cavity. Subsequently in the second step, a layer of Z axis conductive tape is placed on the capacitor, and the substrate of the circuit board is placed on the z axis conductive tape. Finally, with suitable parameters the substrate of circuit board, z axis conductive tape and the capacitor are bonded together by the vibration of the sonotrode. So the brim of the polymer lid is welded on the polymer substrate at relatively high temperature, after cooling, the residual stress in the lid due to the change of temperature will fix the SMDs on the substrate tightly.

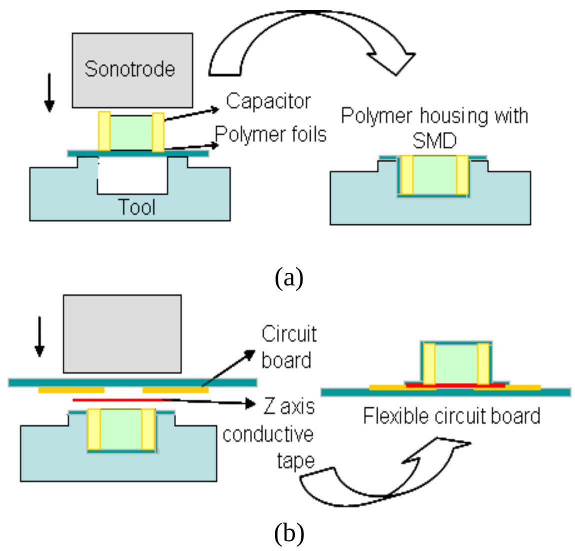


Fig. 5 (a) Molding of the housing of electronic elements; (b) Assembling and interconnection of electronic elements and conductor paths.

3.2 Joining of conductor paths and SMDs

The electrical joining of conductor paths and SMDs is realized through the z-conductive polymer layer, which is only conductive in z axis direction when compressed during assembling of the SMDs as shown in Fig. 5. A z-conductive polymer layer is placed between the electronic element and conductor pads, after the process of ultrasonic embossing and welding, the polymer lid is welded on the polymer substrate due to the pressure and heat. After the bonding area got cooled, the polymer's shrink will strengthen the tightness of encapsulation, meanwhile, it will ensure the effectiveness and stability of the electrical interconnection between the conductor paths and SMDs.

4. Test

To verify the effectiveness of mechanical and electrical interconnection between conductor path and SMDs, experiments were conducted at different conditions such as elevated temperature, humidity, and various cycles of bending loads.

4.1 Electrical interconnection of LED

Fig. 6 shows a flexible LED electronic board assembled with the above mentioned method, under the voltage excitation of a multi-meter, the LED's working proves the effectiveness of electrical interconnection.

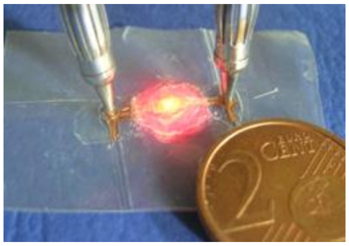
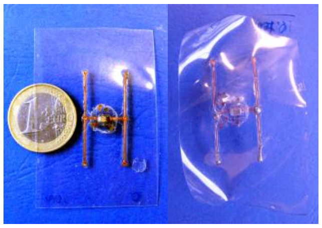


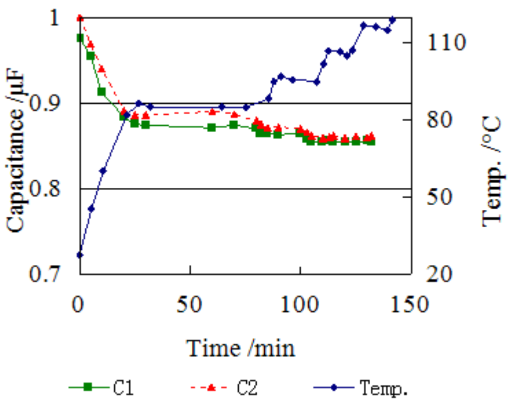
Fig. 6 LED electronic board

4.2 Influence of the high temperature on capacitance

Two simple PVC based flexible electronic boards assembled with capacitors (C1 and C2) were put in an oven with various temperatures from 25 ℃ to 105 ℃ for two hours, the flexible electronic boards before and after the treatment at various temperatures are shown in Fig.7 (a), duo to the thermal treatment the flexible electronic board got deformed from to plane board (left) to a distorted film. However, the capacitances did not change much. The capacitance of the two capacitors declined from 0.99 μF to 0.86 μF, when the temperature rose up to 110 ℃, as shown in Fig.7 (b), correspondingly the capacitance change rate was nearly 13%.



(a)

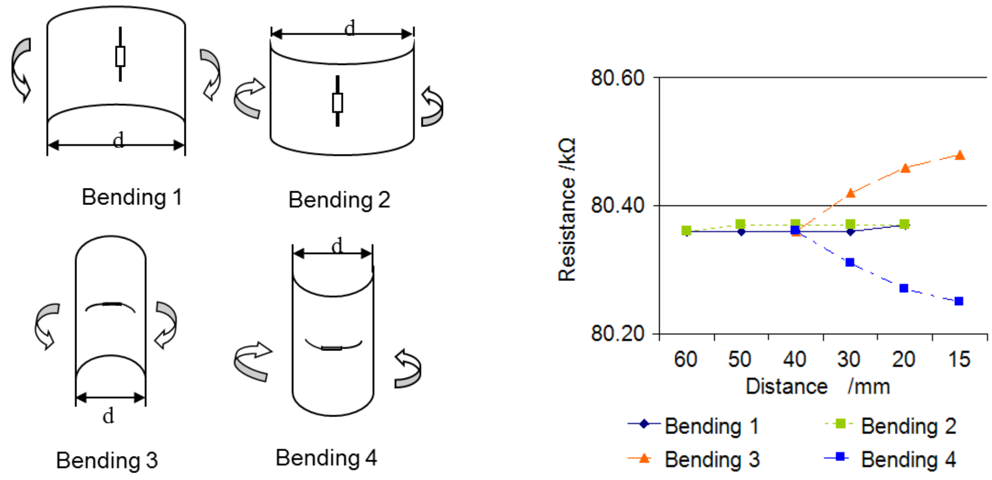


(b)

Fig.7 (a) Polymer electronic board assembled resistor before (left) and after (right) thermal treatment; (b) Capacitance change during the thermal treatment.

4.3 Influence of bending load on resistance

To investigate the effectiveness of interconnection of flexible electronic boards when stressed, a 6 cm ×4 cm flexible polymer electronic board assembled with a resistor was bent along the long side from 60 mm to 20 mm and along the short side from 40 mm to 15 mm, and in the up and down direction as well, meanwhile the resistance was recorded online, so there were four bending styles as shown in Fig. 8 (a). The resistance at each bending step is shown in Fig. 8 (b). A resistor with initial resistance of 80.36 kΩ is selected as experimental sample, the maximum and minimum resistance changes, 80.48 kΩ and 80.25 kΩ, happened when d equals 15 mm in bending 3 and bending 4 respectively, so the resistance change rates were 0.15% and 0.14%.



(a) (b)

Fig. 8 (a) Four bending load styles and (b) the experimental results

5. Conclusion

In this paper, a flexible electronic board fabricated by ultrasonic embossing and welding from a flexible polymer film is introduced. The conductor pattern is punched out from a copper foil, 20 µm in thickness, and welded on a polymer substrate. The whole process is finished in 1-2 s.

A polymer lid embossed by ultrasound is used to assemble the SMDs, and a layer z axis conductive tape placed between conductor path and SMD is applied to realize the electrically interconnection. After the polymer lid is bonded on the electronic board, the bonding strength and polymer's shrink will ensure the effectiveness of the z axis conductive tape.

To verify the effectiveness of mechanical and electrical interconnection between conductor path and SMD, experiments under different conditions are conducted. The experiments showed only resistance changes of less than 0.15% due to bending load and elevated temperatures.

Polymer electronic boards fabricated by ultrasonic hot embossing and welding may have a wide potential in industrial applications because of the low cost and quick process. In the following time, more complicated circuits will be realized and applied in MEMS devices such as sensors and actuators.

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