The Effect of Lamination on Printed Silver Tracks for Plastic Circuits

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ABSTRACT

Circuits in Plastic (CiP) is an electronic systems manufacturing technology with cost and environmental advantages. Flexible and CiP circuits both require conductive tracks on plastic. In CiP silver tracks are screen-printed on thin film, thermally cured and the film is hot laminated to a plastic substrate with components to form the circuit. As both the curing step and the lamination step requires elevated temperatures, the option of using a single temperature step for both processes was investigated. Standard length tracks of varying widths were printed on a 1.6 mm thick polycarbonate substrate with a SMT resistor. The circuit was sealed by laminating a 0.1 mm thick cover sheet using controlled temperature and pressure. Dog-bone tensile tests were used to assess the reliability and limits of connections. The electrical contacts on the substrate and components remained intact until the specimens were extended beyond 3%. This has proved to be a robust circuit manufacturing technique.

Keywords: printed plastic circuits, circuits in plastic, strain, flexible circuits, silver ink.

1 INTRODUCTION

To combat the global e-waste crisis, there is an urgent need to develop a technology where environmental pollution from electronics, their manufacturing and product end of life is minimized through recycling and re-use. The management of waste electrical and electronic equipment (WEEE) or e-waste is a major environmental issue as around 20–50 million tons of such waste is generated worldwide. The increase is a higher rate than other solid waste streams [1]. Electrical and electronic equipment (EEE) contains over 1,000 materials of which brominated flame retardants (BFRs) such as polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) have been the target of the regulators forcing manufacturers to adopt halogen-free flame retardants.

Many developed countries have been sending their unwanted e-waste to developing and under developed countries for recycling and disposal. Wires, cables, components and printed circuit boards are incinerated to recover metals. This releases toxic gases creating air pollution, health risks and associated environmental damage. Plastic enclosures used for packaging electronic circuits is shredded. Some e-waste is landfilled and other is recycled to some degree. The landfill disposal of electronic products can result in chemical leaching into the soil and water table. When the water is used for human needs or for agriculture, toxic components may end in human systems with significant negative health implications. For example children born in these areas are known to have birth defects and abnormalities caused by this polution [2]. This hazard can be minimised through efficient recycling, however, the fabrication of circuits without toxic components has been legislated [3, 4].

Alternatively, new circuit fabrication strategies based on screen printed conductive tracks have been suggested [5]. The circuits in plastic (CiP) technology has electronic components embedded in a plastic substrate with a screen printed conductive ink printed on a thin sheet and laminated onto the substrate containing the components. A number of issues related to this technology have been investigated.

(a) Screen printing was used to form electrically conductive patterns on flexible substrates [6]. The samples were subjected to tensile loads and proved that the conductor could be strained up to 75% without breaking. The resistance of the screenprinted conductive track increased only slightly as a function of strain. It is possible to produce highly stretchable and flexible conductors for use in printable electronics applications.

(b) Merilampi et al [7] investigated screen printing of conductive ink films on stretchable PVC. The structures maintained their conductivity under large strain levels and they can thus be integrated into clothes, where strains are applied. The resistance of the structures increased as a function of strain. In addition to ink selection, it is possible to control the strain sensitivity as well as the recovery of the structures by the selection of different substrate materials.

(c) Henning [8] conducted a study of screen printing conductive inks on polycarbonate, polystyrene and polyester. He also investigated the effect of temperature, relative humidity and electrical resistance. It was reported that the conductive track resistance increases with higher temperatures and the resistance decreases, when exposing the track for a long time to humid conditions. Similarly conductive tracks were printed on 100 micron film then subjected to tensile loads. The tracks remained conductive until a significant lateral contraction of the plastic substrate ("necking") was observed. The track resistance increased monotonically with the extension of the substrates.

(d) Two major reliability investigations relating to the CiP manufacturing technique – mechanical/electrical connections and thermal properties were reported [9]. The first investigation demonstrated experimentally that with appropriate ink selection, the circuit connectivity was maintained under dog-bone tensile tests. The second investigation was a thermal modeling exercise which demonstrated that the heat lost from a sealed plastic circuit was almost identical to a traditional mounted gull-wing, surface mounted (SMT) circuit.

2 PRINTED CIRCUIT BOARD TECHNOLOGY

Printed circuit board technology has seen significant improvements over the 60 to 70 years since adoption. The steps involved in fabricating a printed circuit include copper plating and etching an epoxy resin, fiber board. The components are mounted using solder paste and a high temperature solder step. The assembled board is placed into an enclosure for enviornmental protection and ease of use. This manufacturing process presents challenges in materials and chemical use, the process steps involved, the recovery of copper from the chemical etchant and the disposal of the remaining chemical solvents. End of life product management issues due to rapid product development, the number of new electronics devices available, their use and their end of life management is also a major concern worldwide. The volume of obsolete working electronics continues to increase as new products are introduced with better functions, performance and aesthetics.

The European Union directives RoHS and WEEE [3, 4] relate to recycling and minimal toxicity and the Basel Convention prohibits the international movement of toxic waste. Highly efficient and environmentally benign recycling plants are not available in almost all nations. It is in this legislation environment that the electronics industry is looking for alternative manufacturing and recycling technologies [9].

3 CIRCUITS IN PLASTIC TECHNOLOGY

Circuits in Plastic technology has been developed to reduce the number of process steps involved in electronics manufacturing, to reduce chemical usage and to encourage end of life recycling and reuse of recovered raw materials. The idea is to emphasise "cradle to cradle" technologies instead of "cradle to grave" so that all raw materials can be fed back into the manufacture of new products.

Two methods are used in manufacturing CiP circuits. Method one involves creating voids in a thermoplastic sheet. The electronic components are placed in the voids and heat pressed so they are flush with the surface of the substrate. Conductive silver ink is screen printed directly on the components embossed to complete the electronic circuit. A thin film of thickness around 100 microns of similar material is used to heat seal the circuit to protect from the environment.

Method two involves creating voids in a thermoplastic sheet. The components are placed in the voids and heat pressed so they are flush to the substrate surface. Conductive silver ink is screen printed on a separate thin film. It is aligned with the components in a base substrate and heat pressed using a hot embossing machine so the connections from the printed film and components are made. It also enables the circuit to be sealed from the enviroment. The sealing process helps prevent mechancial, environmental and chemical damage of the conductive tracks.

4 PRINTED CONDUCTORS

The important characteristics for new electronic manufacturing technologies include low cost, environmentally sustainable production methods, recyclability, lower energy consumption and high production efficiency. This can be achieved, in part, by the integration of electronics as a part of the outer structure. One of the promising manufacturing techniques for electronics production is the printing of conductive tracks.

Printed electronics is gaining momentum due to the ease of printing, the availability of equipment, the lower temperature requirements and high speed. Different printing techniques are used to print conductive patterns, passive components and passive microwave circuits. Screen printing and ink jet printing are examples of printing technologies under investigation. Silver and carbon nano-materials show promise, however a thermal annealing step is required.

5 TENSILE TEST

Using CiP technology, tensile test dogbone structures were constructed (see Figure 1). Polycarbonate sheet was machined to the dogbone design for tensile testing. The substrate thickness was 1.6mm. Two different sized (1206 and 2512) 10Ω resistors were positioned in the centre of the dog-bone. The resistors were heat pressed into polycarbonate to be flush with the top surface. Conductive silver ink (Electrodag 479SS) was screenprinted on the plastic substrate and component contact pads. For the large resistor, the track width was 5mm and for the small resistor the width was 2mm. The track lengths were 55 mm and 52 mm for the large and small resistor circuits respectively. A polycarbonate film of 100μm thickness was heat sealed (laminated) to the substrate using heat and pressure from a computer controlled semi-automatic hot embossing machine. This sealed most of the circuit from the environment and also cured the silver ink in one thermal step. The two ends of the circuit were left exposed to allow external connections.

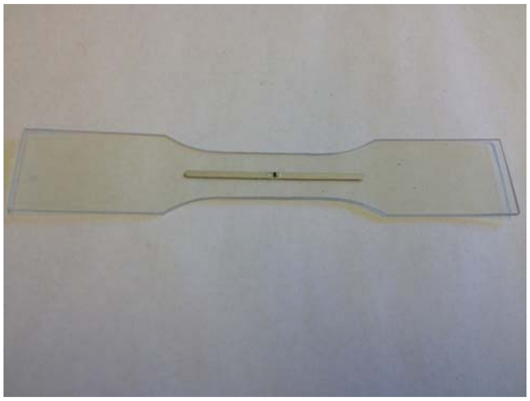

Figure 1: Dogbone structure with resistor hot embossed and screen-printed with conductive ink

A CircuitWorks CW2400 conductive two part epoxy glue was used to connect wires to the ends of the track. A benchtop Instron tensile testing machine T-Slot table (Figures 2 and 3), with a maximum force of 50 kN was used. The speed and extension of the sample were set by software. Machine parameters are adjusted using the software so that the extension, load, strain, tensile stress and time were recorded. The resistance of the circuit was logged during the tensile test using a digital resistance meter.

The mechanical load was applied at 1mm per minute and the extension range was limited to 10mm. A total 10 samples were tested. The circuits failed (open circuit) when the specimens were extended beyond 0.03 mm/mm (maximum was 0.04 mm/mm) which is equivalent to a strain of 3%.

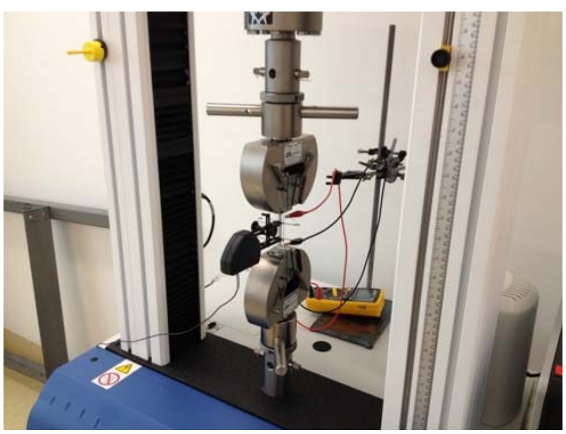

Figure 2: Dogbone circuit specimen mounted on the tensile testing machine with connections to the wireless multimeter

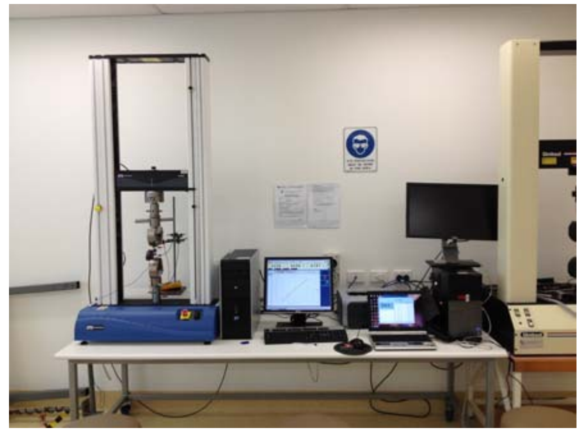

Figure 3: Tensile testing machine setup – Machine, USB multimeter and computers to log test data and resistance

6 RESULTS AND DISCUSSION

Tensile tests are commonly used to measure the strength and maximum extension of materials. Throughout the tensile test, the ink remained electrically conductive until a significant crack formed between the component and the conductive track. Over this range, the adhesion of the ink and the laminate to the substrate was strong enough to follow the extension of the whole sample. The conductive epoxy glue used to connect the track to the resistance meter did not fail.

The resistance of the circuits (silver conductive track and resistor) measured during the tensile test was plotted as a function of elongation in Figures 5 and 6. The resistance increased slightly with extension due to a decrease in silver particle to particle interconnections within the track and contact. The measured resistances varied slightly between samples.

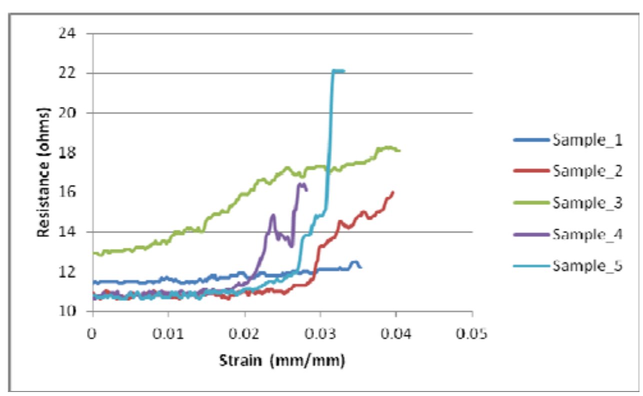

Figure 5: Resistance variation of silver printed tracks on polycarbonate and embedded 1206 resistor. The sample was sealed by polycarbonate film.

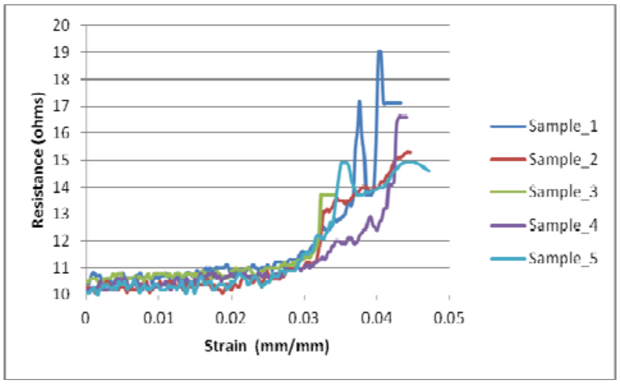

Figure 6: Resistance variation of silver printed tracks on polycarbonate and embedded 2512 resistor. The sample was sealed by polycarbonate film.

In Figure 5, for strains less than 0.02 mm/mm, the plots are relatively linear. The linear part of Figure 5 has a slope of 100Ω/mm/mm and in Figure 6, the slope is 40Ω/mm/mm. The increased track and component thickness reduces the resistance change for the same strain values. The thicker track also exhibited a larger strain value at break-down. Note that Sample 3 in Figure 5 is very different to all other curves and has a very high initial value. This suggests that the initial contact with the circuit element was poor. A thicker substrate will greatly reduce the strain and so improve the robustness of the circuit when subjected to strain, as, for example, might occur when the substrate is flexed.

7 CONCLUSION

The main aim of the experiment was to assess the use of CiP technology when only one thermal step was used. This heat/pressure step proved that both hot embossing and lamination of electrical connections was possible simultaneously. The tensile tests carried using two differently sized resistors was used to check the effect of track thickness. The tests involved a dogbone structure containing the resistor, screenprinted conductor and laminated by polycarbonate film. It was demonstrated that the electrical contacts on the substrate and the components did not fail for both large and small size resistors until the specimens were extended beyond 3%.

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