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Structure of ball grid array/permanent semi-elastomeric thermally conductive crumb rubber reinforced stencil/printed circuit board interconnects

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ABSTRACT

The aim of this paper is to investigate the structure of a BGA/Stencil/PCB interconnect, i.e. the structure produced when a permanent semi-elastomeric stencil is formed or placed within a usual BGA (Ball Grid Array) / PCB (Printed Circuit Board) interconnect. A permanent semi-elastomeric BGA stencil is a membrane that consists of arrays of perforations arranged in a grid manner. The membrane is produced from a thermally conductive material that is made by mixing synthetic rubber latex or styrene acrylic emulsion binders, conductive filler, and crumb rubber. The development of the new family of stencils transfers knowledge from the field of materials to the field of PCB manufacture/rework and may provide benefits to include increase in thermal conductivity, reinforcement with crumb rubber, inhibition of whisker formation/growth, protective coating to prevent the formation of corrosion products, and no need to use adhesives. The BGA/Stencil/PCB interconnects have the potential to extend the service life of a PCB and offer a more reliable operation, especially for PCBs used in high-risk applications (aviation, shipping and military applications). It is the first time that such materials are being used in highly sensitive electronic hardware applications.

KEYWORDS

BGA;
PCB;
Interconnects;
Semi-elastomeric;
Crumb rubber.

INTRODUCTION

The BGA is an electronic device that consists of copper pads (situated at the bottom side and that are) arranged in a grid manner onto which micro-balls (made from solder) are soldered, hence the name. On the PCB, onto which the BGA balls are resoldered, there is a matching set of copper lands. The BGA packages offer many advantages over other packages and as a result they are increasingly used for the manufacture of electronic circuits. BGAs are currently used extensively in mobile phones, computers, modems, handheld devices, office environment equipment, trucks and busses, and in aviation, shipping and military applications. A BGA component that is found to be faulty is removed from the PCB, cleared of the balls, cleaned and reballed, i.e. soldering a new set of matching balls onto the pads of the BGA. The BGA is then transferred to a rework (i.e. removal, repair and replacement) station and resoldered to the PCB[1]. In this work, the resoldering process could be carried out using a rework station and a permanent semi-elastomeric BGA stencil that is placed between the component and the PCB[1-3]. Alternatively, the stencil could be formed by casting after the resoldering process is completed, i.e. by the gravity-assisted liquid-stencil infiltration into the interstice of an ordinary BGA/PCB interconnect[4]. A BGA semi-elastomeric stencil is a perforated membrane (of thickness between 0.3-0.4 mm) which consists of arrays of perforations (micro-holes or apertures) arranged in a grid manner, i.e. a mirror image of the pads and lands patterns. The membrane is made from a semi-elastomeric material that in turn is made by mixing synthetic rubber latex or styrene acrylic emulsion binders, conductive filler and water treated crumb rubber powder. The stencil is permanently fixed between the micro-balls of the BGA and the PCB. The stencil can be produced from the membrane (i.e. thin sheets of the material) by laser cutting/drilling and does not require any cleaning processes. Alternatively, the stencil can be formed by casting, i.e. by the natural infiltration of the liquid-stencil between the BGA and the PCB. The stencil could be made to reduce the temperature of the BGA by transferring heat from the soldered joints to the heat-sink system of the application by monitoring the thermal conductivity of the material of the stencil. The material could therefore include up to 67% by weight of the neat binder of commercially available thermally conductive powder that can act as a conductive filler to enhance the thermal conductivity of the stencil. The stencil could also include up to 43% by weight of the neat binder of commercially available crumb rubber powder reinforcement produced from discarded car/truck tyres to increase the toughness. The stencil has the ability to render the use of corner/edge adhesives unnecessary. Adhesives are currently being used in the electronics manufacturing industry to act as BGA mechanical/thermal shock absorbers due to dropping/heating and to absorb flex due to PCB warping, and to inhibit whisker formation/growth by surrounding the solder joints[1]. The stencil, in addition, has the potential to inhibit whiskers formation and growth in the solder joints by surrounding and continuously compressing the joints[1-3]. The stencil can also act as a coating to prevent (or at least minimize) degradation of the interconnect by preventing corrosion.

EXPERIMENTAL

Materials

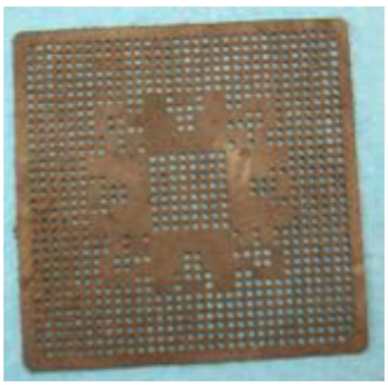
All basic materials used were commercially available. The semi-elastomeric materials were made from a 1-component cold-setting liquid synthetic rubber latex binder or a 1-component cold-setting styrene acrylic emulsion binder. The filler was a thermally conductive fine powder. The crumb rubber powder (produced by an ambient grinding process) was from car tyres (synthetic rubber) of 0-0.2 mm (200 μm maximum, 60 mesh) particle size.

Methods

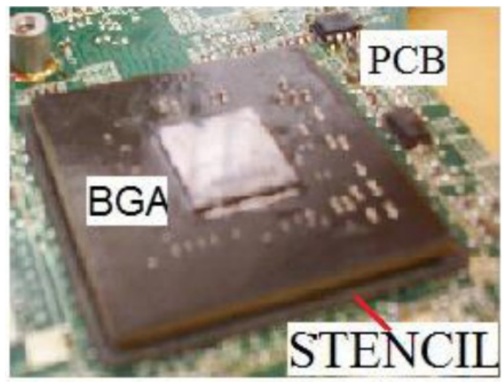
The crumb rubber powder was treated using the water activated method prior to mixing to enhance the binder/rubber/filler bond[1]. All mixing was carried out in plastic beakers by hand. The binders were mixed with various amounts of conductive filler and water treated crumb rubber powder. The mixtures were laid up on a flat surface. The flat surface was first cleaned and then coated with a thin layer of release agent (paste wax). It was found that sheets of the composites of thickness 0.3-0.4 mm were easily produced. It is claimed that the sheets produced here were made from a semi-elastomeric material in the sense that they are able to bend by a considerable amount without cracking. In fact, the sheets were found to be so flexible that they were able to fold over their side without any visual cracking[3]. In laboratory rework trial tests, BGA components were reballed using flux[1,3]. Then, they were transferred to a rework station, i.e. specifically built machines[1], to be soldered to a PCB. The soldering process was carried out in an infrared rework station using flux and also involved the use of a stencil that was placed between the BGA and the PCB[3]. Alternatively, the soldering process was carried out in a hot-air rework station using a continuous flow of a nitrogen-containing gas during the cooling stage[2]. The stencil was then formed by casting after the soldering process was completed. Factory produced (i.e. standard) BGA/PCB interconnects were modified by casting. Typical interconnects were split open using the hot-air rework station to produce cuts for structure examination. The stencil-reworked PCBs were next fitted into a laptop computer that was then switched on and its short-term functionality was assessed. Following this, stencil-reworked PCBs were put into the production line and their long-term functionality is being continuously monitored.

RESULTS AND DISCUSSION

Figure 1(a) is a photograph of a typical (laser cut/drilled) stencil (cross-sectional area 34x34 mm^2, 0.4 mm thickness and 0.6 mm aperture) produced by mixing the binder with 42% by weight of the neat binder of conductive filler and reinforced with 8% by weight of the neat binder of water treated crumb rubber powder.



(a)



(b)

Figure 1 : Typical stencil made with binder 42% conductive filler 8% water treated crumb rubber powder (a) and typical reworked BGA/PCB interconnect showing the BGA on top of the stencil (b).

Figure 1(b) is a photograph that shows a typical reworked BGA/Stencil/PCB interconnect in which the BGA (32x32 mm^2 and 1 mm thickness) was removed and then replaced using a stencil that can be seen underneath the BGA. Note that the stencil was purposely cut to a larger size to allow easy viewing to the reader.

Figure 2 are cuts from typical laboratory produced BGA/Stencil/PCB interconnects made using a constant flow of a nitrogen-containing gas and a hot-air rework station that shows cross-sections covered with the material (binder 50% conductive filler) formed by casting, on the BGA side (a and c) and on the PCB side (b and d).

Figure 3 are cuts from typical factory produced BGA/PCB interconnects that show cross-sections covered with the material (binder 50% conductive filler) formed by casting, on the BGA side (a and c) and on the PCB side (b and d).

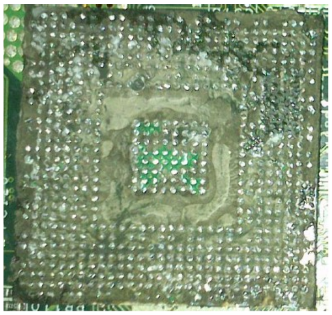
Figure 4 is a cut from a typical factory produced BGA/PCB interconnect that shows cross-sections covered with the material (binder 46% conductive filler 4% water treated crumb rubber powder) formed by casting, on the BGA side (a) and on the PCB side (b).

Figure 5 are cuts from typical factory produced BGA/PCB interconnects that show cross-sections covered with the material (binder 42% conductive filler 8% water treated crumb rubber powder) formed by casting, on the BGA side (a and c) and on the PCB side (b and d).

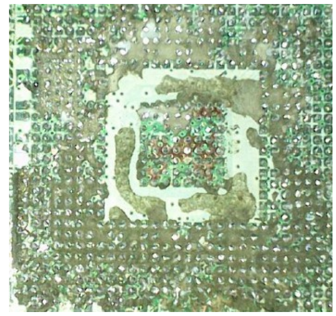
Figure 6 are cuts from typical laboratory produced BGA/Stencil/PCB interconnects made using flux and an infrared rework station that show cross-sections covered with the (laser cut/drilled) stencil (binder 42% conductive filler 8% water treated crumb rubber powder), on the BGA side (a and c) and on the PCB side (b and d).

Figures 2-6 are photographs that show the structure of BGA/Stencil/PCB interconnects and confirm the function of the stencil, which is to surround and hold the micro-balls firmly within its apertures. These figures confirm the claims made that the stencil has the potential to inhibit whiskers formation and growth in the solder joints by applying a continuous compressive stress via the semi-elastomeric stencil to the solder joints[1]. These figures demonstrate the good adhesion and robustness (i.e. the material appears to be compact) of the stencil and confirm claims made that another advantage of using the new stencil could come from its natural ability to absorb flex due to PCB warping and mechanical shock due to dropping, thus rendering the use of corner/edge adhesives unnecessary[1].

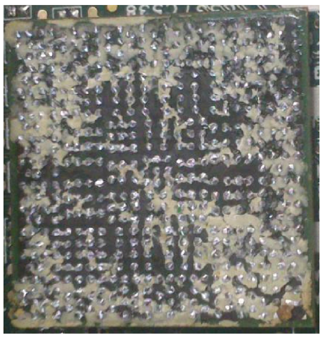
The method of measurement of the thermal con-



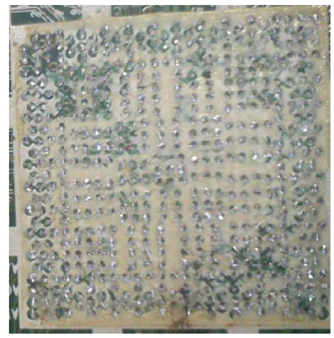
(a)



(b)

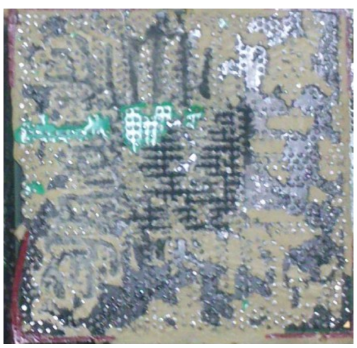


(c)



(d)

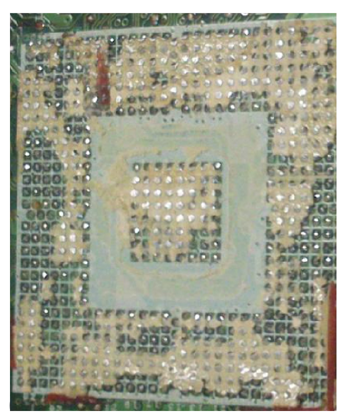
Figure 2 : Typical home produced BGA/Stencil/PCB interconnects made using a nitrogen-containing gas and a hot-air rework station showing cross-sections covered with the material (binder 50% conductive filler) formed by casting on the BGA side (a and c) and on the PCB side (b and d).



(a)

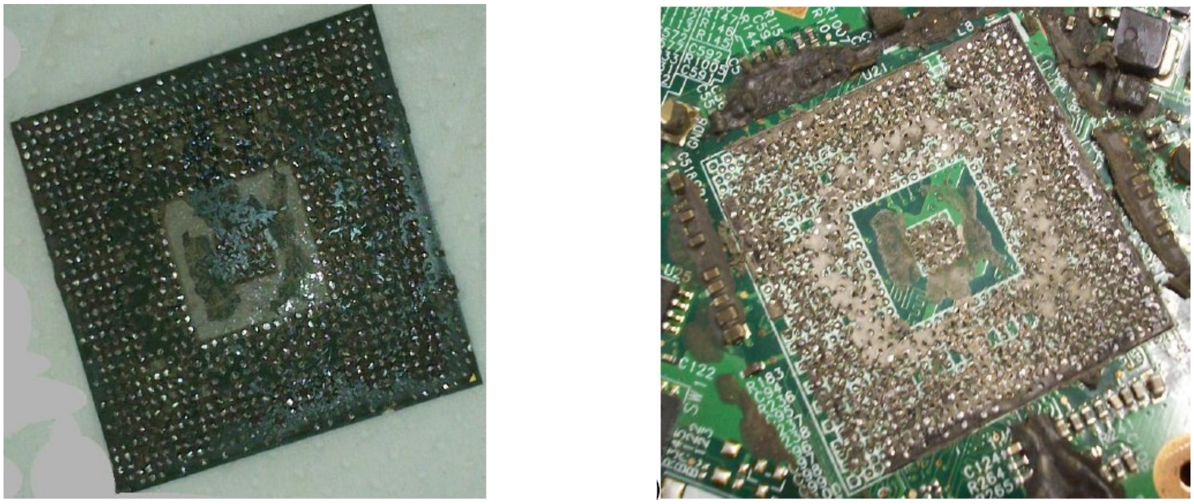
(b)

(c)



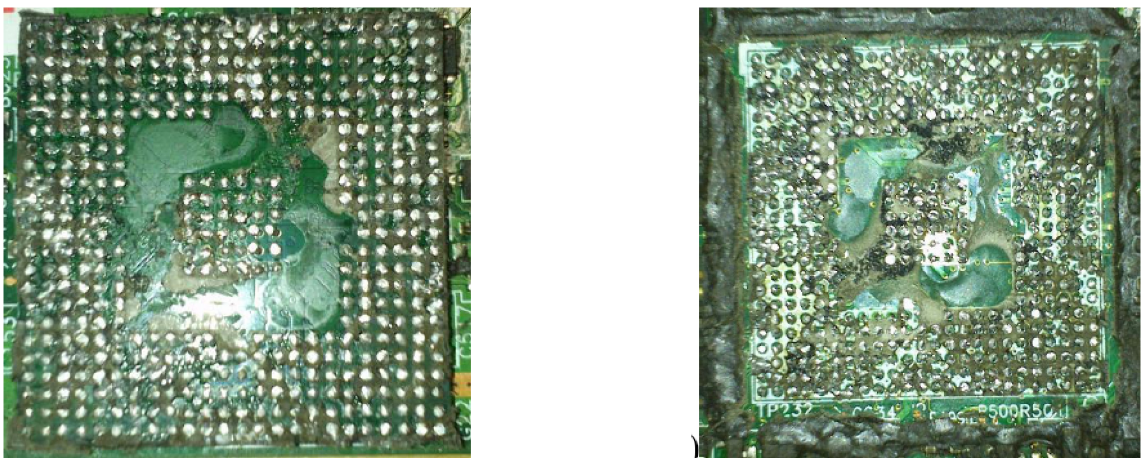
(d)

Figure 3 : Typical factory produced BGA/PCB interconnects showing cross-sections covered with the material (binder 50% conductive filler) formed by casting on the BGA side (a and c) and on the PCB side (b and d).



(a) (b)

Figure 4 : Typical factory produced BGA/PCB interconnect showing cross-sections covered with the material (binder 46% conductive filler 4% water treated crumb rubber powder) formed by casting on the BGA side (a) and on the PCB side (b).



(a) (b)

(c) (d)

Figure 5 : Typical factory produced BGA/PCB interconnects showing cross-sections covered with the material (binder 42% conductive filler 8% water treated crumb rubber powder) formed by casting on the BGA side (a and c) and on the PCB side (b and d).

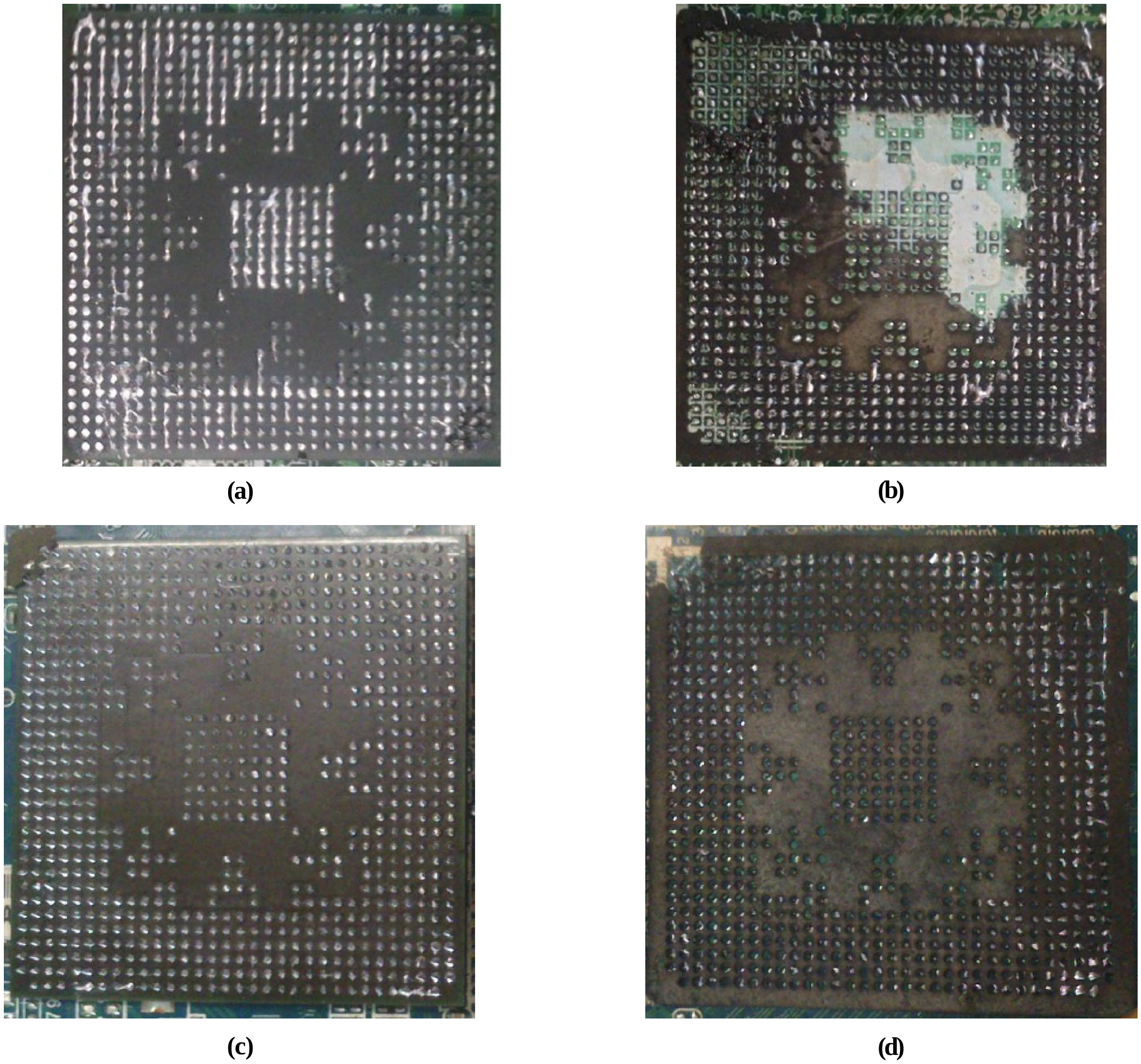


Figure 6 : Typical home produced BGA/Stencil/PCB interconnects made using flux and an infrared rework station showing cross-sections covered with the (laser cut/drilled) stencil (binder 42% conductive filler 8% water treated crumb rubber powder) on the BGA side (a and c) and on the PCB side (b and d).

ductivity (K) of the material developed previously[3] yielded a similar range of values of the thermal conductivity of the material of the stencil developed here and showed a material with considerable increase in K suitable for use in electronic applications.

Nitrogen (N_2) is often used to reduce the metal oxides formed during the soldering of the BGA onto the PCB. In this work, some solder joints were produced (i.e. a successful electrical connection was achieved) in the laboratory by the application of a continuous flow of a nitrogen-containing gas during the cooling stage using a hot-air rework station. The continuous flow of the nitrogen-containing gas is achieved in ambient air conditions from a supply tube via a tapered nozzle across the width of the PCB area that contains the lands at a rate approximately 0.02 $m^3\,sec^{-1}$[2]. The flow of the nitrogen-containing gas is maintained for a very short period (2 minutes). The use of a controlled continuous flow of the nitrogen-containing gas in ambient air conditions provides an environment that virtually results in the deposition of a gas film on top of the PCB area that contains the lands that displaces the ambient air and hence results in the establishment of N_2 conditions that allow the bonding of the solder balls onto the lands[2]. Similar techniques of forming bonds under special conditions have been reported in the literature[5,6]. The stencil was then formed by casting. The stencils were found to adhere well to both the BGA and the PCB surfaces and therefore they can also act as a protective coating preventing degradation of the interconnects by preventing corrosion. Preliminary water diffusion tests[7,8] indicated that the material absorbed no water at any time, contrary to resins[8]. Most metals corrode with time (i.e. recombine with corrosive agents in the environment like oxygen, chlorine, sulfur, fluorine etc.) in an attempt to return to their natural state. Since these corrosion products interfere with the passage of electrical current across an interconnect, then the contact surfaces can be coated to prevent or at least minimize the formation of corrosion products[9].

CONCLUSIONS

The work reported here relates to the development of permanent stencils, i.e. a family of materials that can be used for the production of BGA/PCB interconnects during the manufacture of a PCB (Printed Circuit Board) or the rework (removal, repair and replacement) of a BGA (Ball Grid Array) component that can be found on a PCB. The stencils could be made from a semi-elastomeric sheet of a material that in turn could be made from synthetic rubber latex or styrene acrylic emulsion binders, thermally conductive fillers and crumb rubber powders. The stencils are then produced by laser cutting/ drilling. Alternatively, the stencil can be formed by casting after the BGA is soldered onto the PCB. Visual examination of the structure produced when the stencil is formed or placed within a common (i.e. standard or rework laboratory produced) BGA/PCB interconnect confirms the functions of the stencil which are (i) to surround and hold the micro-balls firmly within its apertures, (ii) it has the potential to inhibit whiskers formation/growth in the solder joints by the application of a continuous compressive stress via the semi-elastomeric stencil to the solder joints, (iii) its natural ability to absorb flex due to PCB warping and mechanical shock due to dropping, and (iv) it can act as a coating to prevent or minimize degradation of the interconnect by preventing corrosion. Other benefits include (v) the elimination of stencil cleaning processes, (vi) ability to increase the thermal conductivity that gives the advantage of temperature balance underneath the BGA in addition to reducing the temperature of the BGA by transferring heat from the soldered joints to the heat-sink system of the application, (vii) reinforcement with crumb rubber, (viii) non-toxic and thus environmental friendly, and (ix) low cost. A disadvantage may be the setting time of the material within the interconnects (about 24 hours). The development of the family of stencils and the subsequent BGA/Stencil/PCB interconnects, transfers knowledge from the field of materials to the field of PCB manufacture/rework. It is envisaged that millions-upon-millions of discarded laptops could be back from the brink of being hauled to a dump and reused bringing extra benefits to owners. PCBs used in high-risk applications (aviation, shipping and military applications) could be manufactured/reworked using the low cost permanent stencils to extend the service life and offer a more reliable operation.

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