SMT Processing using Printed Anisotropic Conductive Epoxy for Direct Die Attach of Wire-bondable Chips on Flexible Additively Manufactured Electronics

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ABSTRACT
There are many options on the market for unpackaged, bare die with advanced capabilities, however these chips are often designed for wire bonding interconnection. This prevents them from being readily used in Flexible Hybrid Electronics (FHE) applications. Rigid boards are the substrate option for wire-bonded bare die attach, or wire-bonding of the die within a package for SMT assembly. This paper discusses three designs successfully transitioned from previously wire-bonded die to bare die direct-to-circuit attachment using standard SMT pick-and-place equipment. Work for one case was performed under a funded grant and the others were commercial customer requests. The bare die were attached using one interconnect material, a stencil-printed Anisotropic Conductive Epoxy (ACE) for flexible hybrid electronics (FHE).

Key words: Flexible electronics; Anisotropic conductive adhesive; Direct die attachment

INTRODUCTION
Implementation of a successful high throughput interconnection process for bare semiconductor die and support components on low temperature printed substrates offers significant advantages in cost, flexibility, and lower complexity. Attaching die, pads down, onto circuit connections with an anisotropic conductive adhesive requires fewer process steps than wire bonding, as the interconnect and underfill occur in the same process step. No solder bumping of the die is required, enabling a design alternative for direct attachment to thin, flexible substrates at ≤ 140°C with extremely thin bond lines (≤ 75 microns). The volume of the final product is significantly reduced through elimination of wire bonding (with design layout and additional processing steps). Direct die bonding with pressure-less conductive adhesive is also more amenable to thinner, less rigid, lower temperature and additively printed substrates for FHE. These advantages set the stage for mass produced inexpensive connected FHE tags, labels and sensors.

This Anisotropic Conductive Epoxy (ACE) material is composed of a binary epoxy resin loaded with ferromagnetic particles that have a high electrical conductivity coating. During the curing of the epoxy, as illustrated in Figures 1 and 2, a magnetic field is applied using a magnetic pallet, causing the ferromagnetic particles to align in columns forming a low electrical resistivity path through the thickness of the epoxy (and between the components and matching bonding pads), while maintaining very high electrical isolation laterally between pads. The epoxy upon cure also serves as an underfill eliminating the need for an additional process step. This method interconnects several circuits at once: eliminating the need for serial thermode processing. The thin bond line of conductive particles in an adhesive yields an extremely strong, yet flexible bond.

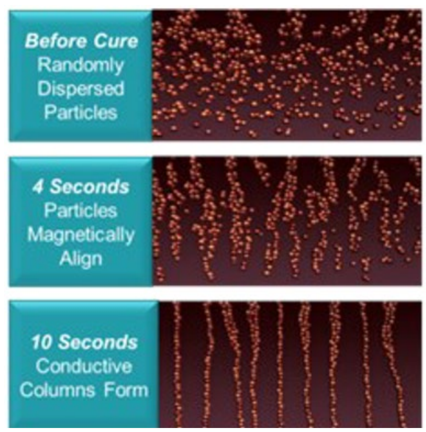

Figure 1. X-Ray photos of Z-axis magnetically aligned particles in the Anisotropic Conductive Epoxy (ACE)

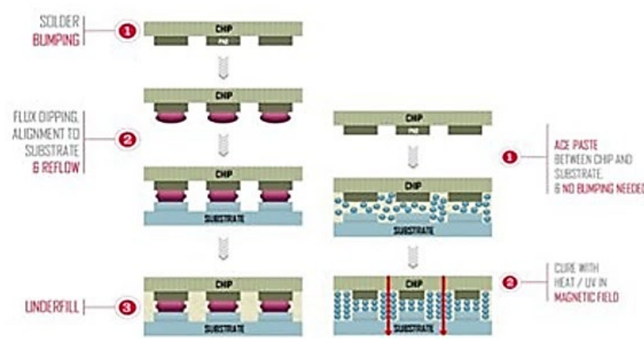

Figure 2. Flip Chip assembly comparisons: traditional solder balls & underfill attachment (Left); Die attach with z-axis magnetically aligned Adhesive Conductive Epoxy (Right)

DISCUSSION
Three different demonstration cases are described for the bare die direct-to-circuit attachments. This paper discusses the data results and the benefits of using this SMT-compatible ACE process as opposed to the current industry die bonding processes.

The first example was work performed under an Army FPSSI contract W5170124C0063, "Advanced Electronic Interconnects for Robust Fine-Pitch Microelectronic Sensor Systems". The die, a Pixel Array, has 2-sides of perimeter Input-Output (I/O) bond pads. In the traditional assembly the die is back-side bonded to the circuit, with wire bonds connecting the perimeter I/O from the top face of the die to surrounding bond pads on the circuit. The wire-bonded die circuit subassembly is next placed into a traditional 25.4 mm x 50.8 mm metal package with side-wall feedthroughs, and the subassembly is wire-bonded to the feedthroughs. In total, approximately 140 wire bonds are needed. An optical lid seals the housing. This package is then placed into a connecting mounting socket for use.

This z-axis interconnect SMT process was demonstrated using an ACE magnetic pallet for column formation during the cure cycle, to mechanically and electrically attach the peripheral edges of the bare die Pixel Array face-down to the printed circuit (PCB). Die bond pads were 127 microns x 127 microns, on 500 microns pitch. The ACE was deposited onto the PCB using a 0.1 mm thick stencil. Cure conditions were 135°C for 25 minutes. The imaging portion of the Array faced through a slot in the circuit board. An optical cover would be placed directly on the opposite side of the PCB.

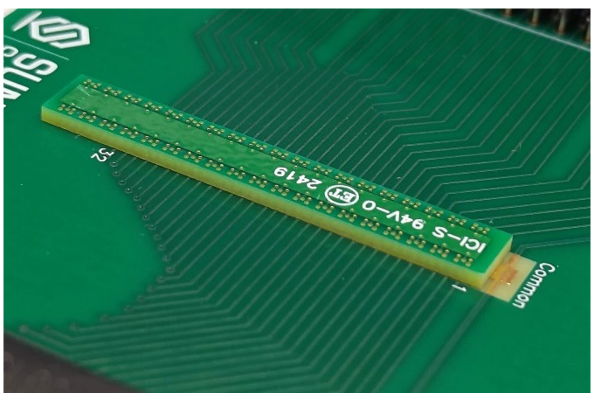

Figure 3. FR4 Replica of Pixel Array Die on Test Board

The photo in Figure 3 is an FR4 physical replica (6 mm x 40 mm x 0.5 mm) of the 64-pin array die, used early in the project to develop the initial ACE connectivity process. The replica board was quickly replaced by the Pixel Array die (not shared as is proprietary). Figure 4 is the test PCB used for both circuit connection and the package, as the optical cover would be placed on the far side.

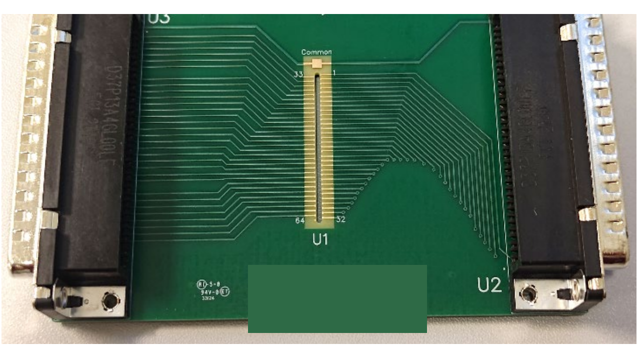

Figure 4. Test Board with bond side footprint and optical opening for bare die image sensor

This approach enabled z-axis miniaturization, reducing the package height by 20%. In addition, 140 wire bonds were eliminated, and a secondary circuit board inside the 25.4 mm x 50.8 mm metal package. Initial focus was to demonstrate the ACE bonding of the bare die versus product miniaturization. The next generation can be envisioned, with improvements in product size, weight, performance and cost reductions (SWaP-C). For example, if the design advanced from a rigid PCB to say a 0.25 mm thick flex, close to a 50% reduction in package thickness could be achieved, along with less packaging materials and fewer process steps.

The second example involves an imaging device for an automotive camera module. As in the previous case the imaging portion of the bare die can be placed face down through a "window" and attached with ACE on the perimeter bond pads. The bare die can be accommodated without requiring a redesign.

In this instance the die was bonded on 4 sides. A flexible substrate replaced the rigid PCB version. The improvements can be seen in the photos of Figure 5.

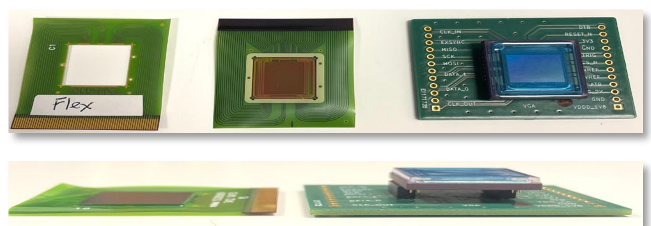

Figure 5. Camera module comparison of ACE direct die attach (Left) to standard wire bonded packaging (Right)

After assembly, third party testing confirmed no signal or general performance loss moving to direct die attach, yet much was gained by reductions in weight, size and cost.

The third example of direct die attachment with this ACE involved an RFID tag. The end user had several requirements. First preference was to reduce the number of processing steps to an alternative solution with low resistance connections, with a path for scalability. The proposed solution was elimination of the wire-bonding, dam and fill processing on a rigid PCB for a flexible substrate solution. Moving to a lower cost PET would provide flexibility, lighter weight and a thinner product but in doing so required a lower temperature bonding solution. As before, the customer die could be used without redesign, and transition from a wire-bonded assembly to direct die attach.
It was necessary to print a new circuit as the die would be connected face down. The FHE circuit was Ag-printed ink on 0.13 mm thick PET, with an antenna and bond pads for the microcontroller die. Figure 6 below illustrates the assembly.

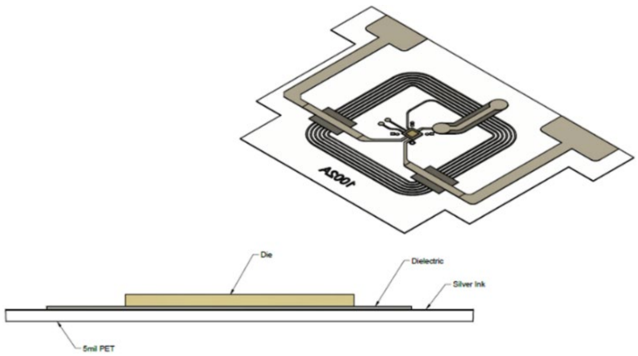

Figure 6. Third demonstration of direct die attach with ACE, a flexible RFID tag

The die pitch was 100 microns. The bare die were placed with an SMT Pick-and-Place machine. 114 circuits were fabricated in the prototype run, demonstrating early scalability with 16 RFID tags per sheet and producing 60 assemblies per hour. Contact resistance of 0.007-0.020 Ω^{cm} was measured. 98% bond yield was achieved with the ACE after 0.5” diameter mandrel bend testing and 85°C/85RH for 1000 hours.

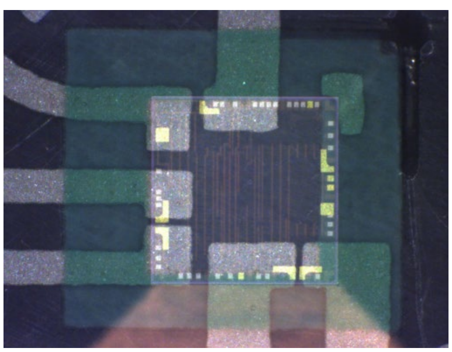

Figure 7. Die attach, wire-bonding, dam and fill - replaced with one process step ACE bond at 135°C

CONCLUSIONS

The Anisotropic Conductive Epoxy and ease of use advances current FHE packaging. Lower profile component attachment on flexible substrates enables smart labels not limited by rigidity and thickness. This emerging ACE is compatible with SMT lines’ sheet-to-sheet (S2S) processing. The case studies presented share the results of transitioning an existing wire-bonded product design to an FHE system using Anisotropic Conductive Epoxy on existing SMT infrastructure, with potential 50% reduction in thickness, reduced area, and higher throughput. With additional process development, this approach of enabling manufacture of enhanced capability IoT systems using existing die and SMT infrastructure could be made widely available to US contract manufacturers.