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ALTERNATIVES TO SOLDER IN INTERCONNECT, PACKAGING, AND ASSEMBLY

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ABSTRACT

Solder plays a special role in the world of electronics manufacturing as evidenced by the disruptive nature of the lead-free movement. The intense search for attractive lead-free solders reveals the preeminent importance of solder to the industry. In fact, solder consumes so much attention that solder-less alternatives are often overlooked.

Material-based alternatives to solder include conductive adhesives and transient-phase compounds. Developments in nanotechnology spawned a virtual renaissance in conductive adhesives and other solder-less joining materials.

As a complement to the solder-less materials developments, embedded assemblies use conventional materials in novel ways to improve performance by cutting interconnect parasitics and increase reliability gains by eliminating wire-bonds and solder-bumps. Freescale, Imbera, GE, Verdant, and many others develop and employ diverse approaches to embedding active devices.

Particle Interconnect represents another solder alternative. While originally developed for automated test, particle interconnect holds considerable promise in a variety of applications including LED assembly and printed electronics.

This presentation surveys the landscape of alternatives to solder in interconnect, packaging, and assembly. Next, the presentation treats practical implementation challenges such as yield management strategies and supply chain restructuring. Finally, the presentation concludes with a discussion of scenarios in which solder alternatives offer highly compelling business and technical benefits.

Key words: lead-free, conductive adhesives, nano-scale fillers, nanotech fillers, TLPS, particle interconnect, embedded packaging.

INTRODUCTION

Solder embodies the chief method for attaching components to a printed wiring board (PWB) during the manufacturing of electronic assemblies. Long the primary choice for assembling electronics, eutectic tin-lead (SnPb) solder exhibits attractive reflow properties, low melting point, and ductility. Lead, however, suffers from increasing regulatory scrutiny due to its relatively high toxicity to human health and the environment. In 2001, the European Union (EU) proposed the Waste Electronics and Electronic Equipment (WEEE) and the associated Restriction of Hazardous Substances (ROHS) directives that ban the use of lead in electronics devices sold in the EU beginning in July 2006.

The legislation and market trends leading toward the implementation of lead-free electronic assemblies raised several issues including the need to increase the thermal tolerances of electronic components. Lead-free solder alloys such as tin-silver-copper (SnAgCu) with a melting point of 217°C, require higher processing temperatures than traditional tin-lead (SnPb) alloys thereby reducing the process window and focusing on the need for rigorous control of the thermal process during soldering. Raising component thermal tolerances places a significant economic burden on electronics manufacturers since they face higher overall costs.

MATERIALS-BASED ALTERNATIVES

Conventional Conductive Adhesives

Electrically conductive adhesives (ECA) provide potential solder replacements in microelectronics assemblies. Two types of ECAs exist: isotropic conductive adhesive (ICA) and anisotropic conductive adhesive (ACA). Although ICAs and ACA employ different conduction mechanisms, both materials consist of a polymer matrix containing conductive fillers. ICAs conduct in all directions and typically contain conductive filler concentrations between 20 and 35% by volume. Hybrid applications and surface mount technology primarily utilize ICAs. In ACAs, electrical conduction occurs only in the direction of applied compression during curing. Typical ACA conductive filler volume loading ranges between 5 and 10%. ACA technology suits fine pitch technology especially flat panel display applications, flip chips and fine pitch surface mount devices [1].

Electrically conductive adhesives consist of a polymer binder that provides mechanical strength and conductive fillers, which offer electrical conduction. Polymers include both thermosets (such as epoxies, polyimides, silicones and acrylic adhesives) and thermoplastics. ECA conductive fillers consist of metallic materials such as gold, silver, copper, and nickel or nonmetallic materials such as carbon.

Compared to conventional solder interconnection technology, the advantages of conductive adhesives include:

- More environmental friendly than lead-based solder;

- Lower processing temperature requirements;
- Finer pitch capability (ACAs);
- Higher flexibility and greater fatigue resistance than solder;
- Simpler processing (no flux cleaning);
- Compatible with inexpensive and non-solderable substrates (e.g., glass).

Despite the advantages of ECA technology, lower electrical conductivity than solder, poor impact resistance, and long-term electrical and mechanical stability concerns limit widespread adoption of ECAs by the electronics industry.

Figure 1 illustrates a recent application of ACA in film form (ACF) for fine pitch chip on film (COF) assembly. In this scenario, the high probability of electrical shorts between adjacent bumps, due to the accumulation of conductive particles between the bump during the bonding process led to the development of a triple-layered ACF with functional layers on both sides of conventional ACF layer to improve interface adhesion and control bonding property for fine pitch application during thermo-compression bonding as shown in Figure 1 [2].

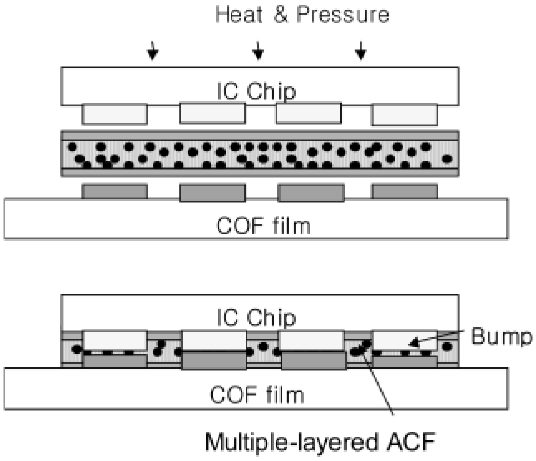

Figure 1. COF bonding process using triple-layered ACFs.

The joining of the driver ICs in tape-carrier packages (TCP) to LCD glass panels and other interconnection areas for flat panel display manufacturing comprise the most common use of ACFs. Figure 2 shows various packaging technologies using ACF for LCD modules; TCP, COG and COF bonding [3]

Nano Enhanced Conductive Adhesives

Developments in nanotechnology spawned a virtual renaissance in conductive adhesives and other solder-less joining materials. Nanotech enhances the performance of conductive adhesives via three distinct routes:

- Cost (reduced precious metal loading);
- Conductivity (improved filler packing and sintering);
- Reactivity (vast surface area).

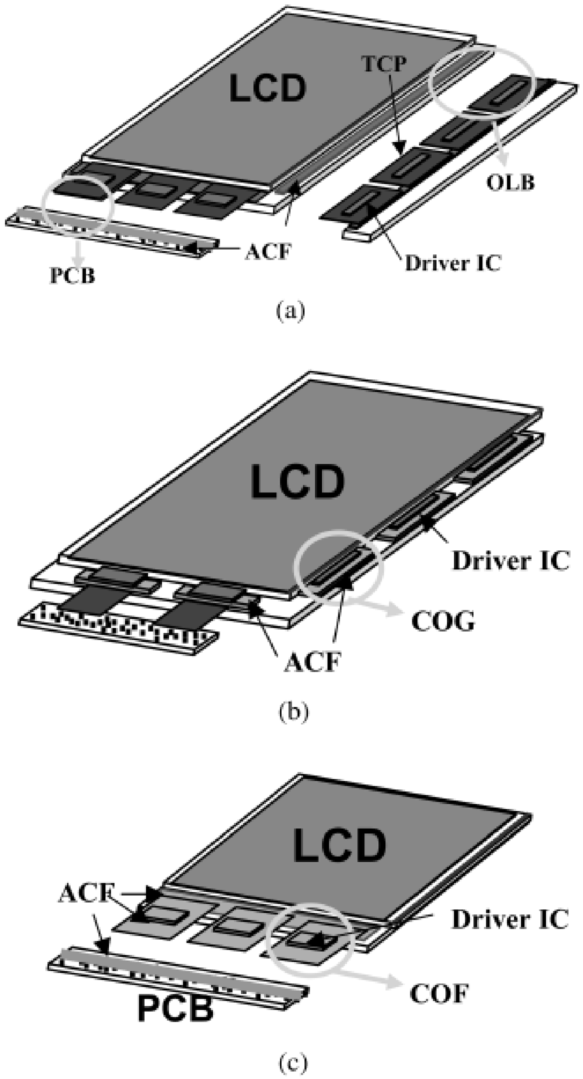

Figure 2. Various packaging technologies using ACF in LCD modules (a) TCP; Outer Lead Bonding (OLB) and PCB bonding, (b) COG bonding and (c) COF bonding.

Contact resistance between filler particles limits the conductivity of conventional conductive adhesives. The introduction of nano-scale fillers increases electrical conductivity by a combination of mechanisms, including more efficient filler packing and facile sintering of filler particles into high conductivity networks. The tendency for nanoparticles to agglomerate makes effective and uniform dispersion critical to practical nanoparticle conductive adhesives.

Researchers at Endicott Interconnect Technologies demonstrated the use of Cu, Ag, or low melting point alloy nanoparticle filled adhesives during lamination to enhance wiring density of organic laminate based electronic packages and circuit boards as shown in Figure 3.

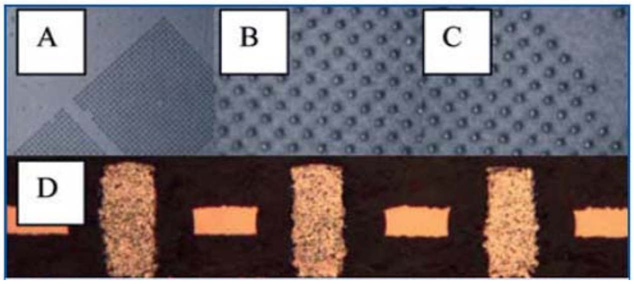

Figure 3. Optical photographs of adhesive filled joining core (A-C) top view, and (D) cross-section [4].

Frequently, silver flakes provide the conductive network in ICA adhesives. The overall resistance of the network consists of resistance of flakes and resistance of contacts between flakes. The addition of nano-scale particles enables the formation of additional bridges between flakes, which may increases the density of the conductive network connections and decreases overall resistance [5]. Figure 4 illustrates this concept.

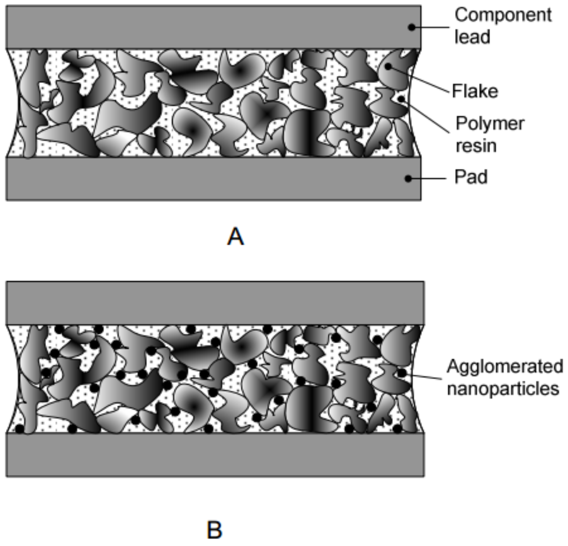

Figure 4. Adhesive joint without nanoparticles (A), and with added nanoparticles (B).

Transient-Phase Compounds

Transient liquid phase sintering conductive adhesives, with an interpenetrating polymer/metal network, mitigate some of the deficiencies of standard particle-filled conductive adhesives. A process known as transient liquid phase sintering (TLPS) forms a metal network in situ reinforced with the polymer matrix. Bulk and interface metallurgical electrical connections provide stable electrical and thermal conduction. The TLPS conductive adhesives utilize conventional surface mount technology dispensing and processing equipment. Electrical conductivity results also indicate values closer to those of traditional solder alloys. Reliability testing including humidity followed by air-to-air thermal shock (-55°C to +125°C) demonstrate that this type of adhesive performs substantially better than standard, passive filler loaded conductive adhesives.

Figure 5 schematically illustrates a transient phase compound developed by Ormet Circuits which begins as copper and alloy particles in a liquid organic formulation and sinters into an interpenetrating metal/polymer network. Figure 6 depicts an application of the material from Ormet Circuits as a die attach. [6]

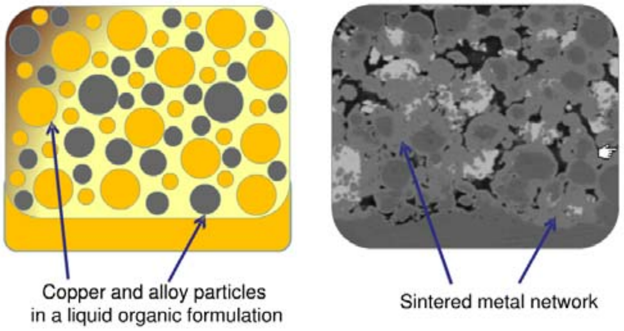

Figure 5. Ormet's transient liquid phase sintering material.

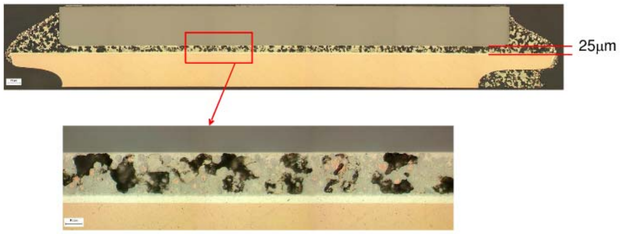

Figure 6. Application of Ormet material to die attach.

STRUCTURE-BASED ATERNATIVES

As a complement to the solder-less materials developments, embedded assemblies use conventional materials in novel ways to improve performance by cutting interconnect parasitics and increase reliability gains by eliminating wire-bonds and solder-bumps.

Freescale, Imbera, GE, Verdant, and many others develop and employ diverse approaches to embedding active devices.

Freescale – Redistributed Chip Package (RCP)

Freescale's RCP package employs thin-film build-up directly on devices embedded in molding compound, eliminating the need for wire-bonds and flip-chip bumping. Figure 7 depicts the RCP package.

RCP targets System-in-Package (SiP) for mobile electronics applications. [7] Electrical performance and the potential for miniaturization increase thanks to the lack of wire-bonds and flip-chip bumps. RCP and similar embedded chip package technologies disrupt the standard packaging food chain by moving bare die into interconnect fabrication. Freescale shipped limited products that utilize RCP starting in 2008.

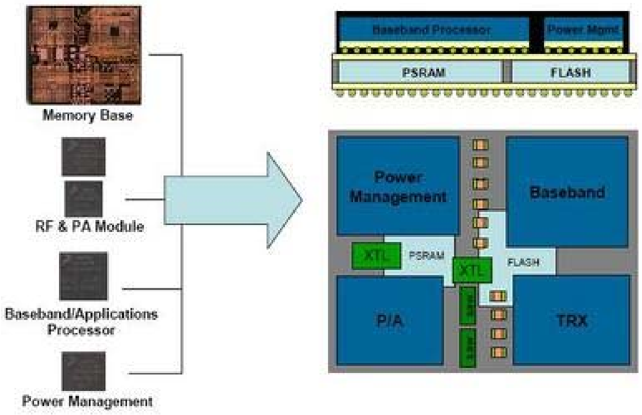

Figure 7. Freescale RCP.

Imbera – Integrated Module Board (IMB)

Imbera's Integrated Module Board (IMB) integrates active and passive devices in organic boards by laminating the bare die within conventional printed circuit board layups. After pressing, micro-vias and through-holes are drilled and plated. Chip connections include Cu/Cu or Cu/Au with no intermetallic compounds. Figure 8 shows the Imbera package.

Targeted applications include SiPs and System-in-Board for advanced consumer electronics. Based in conventional printed circuit board fabrication technology, IMB demonstrate moderate to low electrical performance and size reduction, but expects to offer strong cost advantages and good infrastructure compatibility.

GE – Embedded Chip Build-Up (ECBU)

The GE Embedded Chip Build-Up (ECBU) technology utilizes bare and pre-metallized flexible dielectrics to form thin-film build-up directly on devices without wire-bonds and flip-chip bumping. Figure 9 depicts the ECBU package [8].

GE promoted the ECBU technology in applications including microprocessors, video processors and ASICs with demanding interconnect and thermal requirements. The lack of wire-bonds and flip-chip bumps permits excellent electrical performance and very dense wiring capability. ECBU's placement of bare die in the interconnect structure requires some rearrangement of the existing packaging infrastructure and supply chain. Technical evaluations of ECBU currently underway at leading microprocessor and graphics processor suppliers indicate significant performance benefits.

Verdant Electronics – Occam Process

The Verdant Occam process, illustrated in Figure 10, positions pre-tested, burned-in components on an adhesive layer of a temporary or permanent. After encapsulating the components, the adhesive layer is then removed over the component leads mechanically or by laser ablation. Finally, plating the holes and forming traces with a conductive, copper connection provides an interconnection structure.

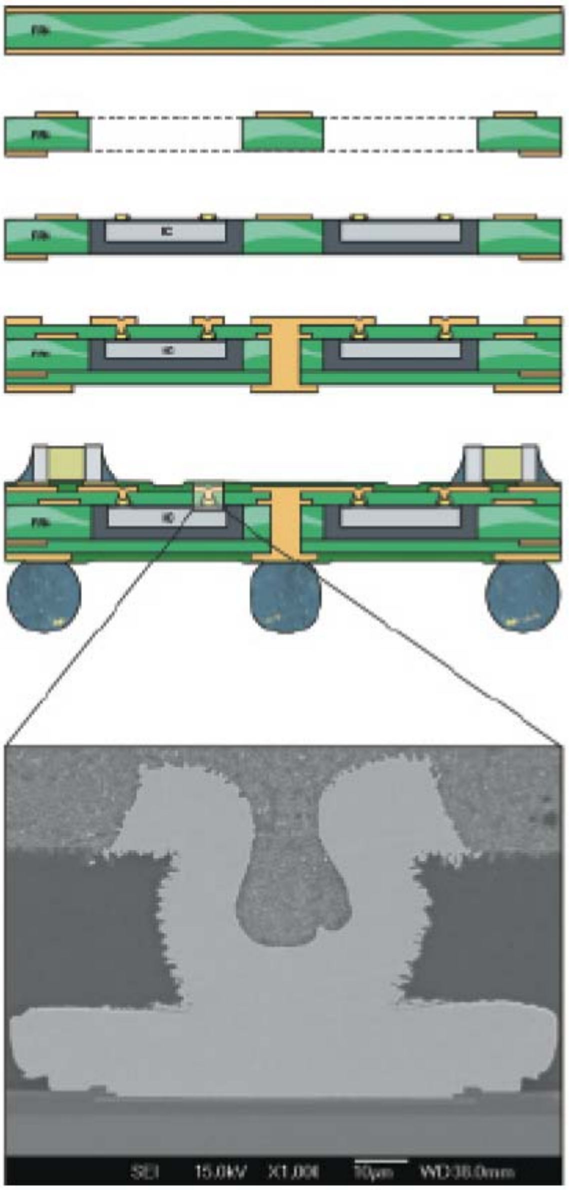

Figure 8. Imbera IMB.

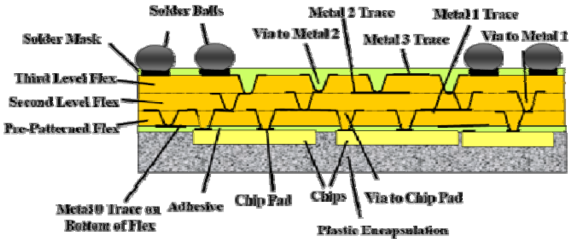

Figure 9. GE ECBU.

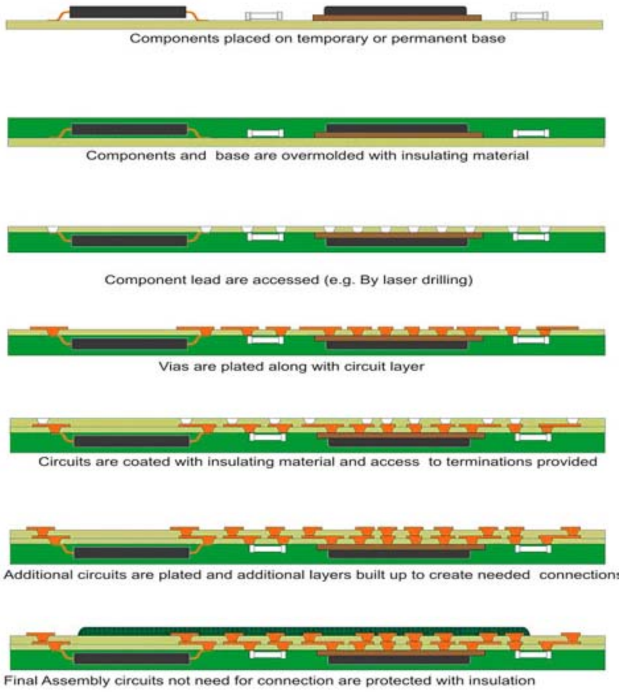

Figure 10. The Verdant Electronics Occam Process.

PROCESS-BASED ALTERNATIVES

Particle Interconnect

Particle interconnect represents another solder alternative. Originally developed for automated test, particle interconnect offers low contact resistance with low damage.

Particle Interconnect provides low contact resistance contact by means of hard and irregularly shaped particles on the bond pad. This particle enhanced surface easily pierces into the mating substrate even with the presence of a nonconductive oxides layer and adhesive on the mating substrate surface. Figure 11 shows a cross-section micrograph of such a piercing connection.

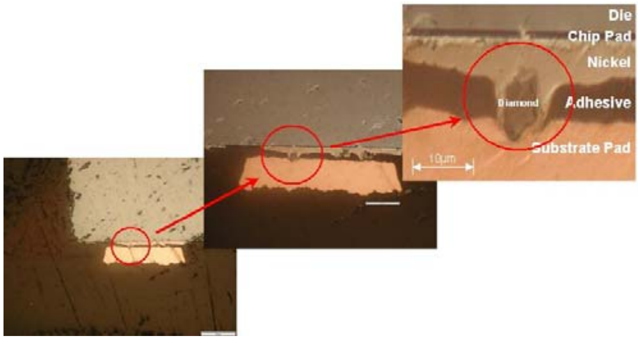

Figure 11. Particle enhanced contact between a Si chip bond pad and a pad on a PWB [9].

The schematic drawing shown in Figure 12 illustrates the principles of an electroless version of the Particle Interconnect process. Particle Interconnect begins surface preparation of Al bond pads on the wafer (cleaning and zincating), followed by a modified electroless nickel-particle co-deposition. A second electroless nickel-plating is followed by a finally an immersion gold treatment.

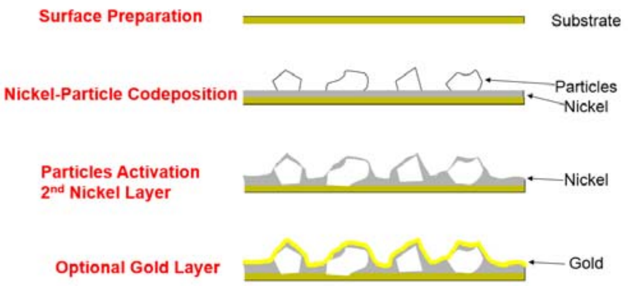

Figure 12. One of several plating-based processes for depositing particle interconnect

The first electroless nickel (EN) plating step utilizes a modified composite electroless nickel plating method to co-deposit nickel and particles onto Al bond pads by mixing hard particles with the EN solution. After the co-deposition, a particle surface activation step ensures adhesion of the metal to exposed particle surfaces during the second nickel plating. The second conventional electroless nickel plating step casts a layer of metal over deposited particles. Figure 13 shows a micrograph of a completed Particle Interconnect surface on Al bond pad.

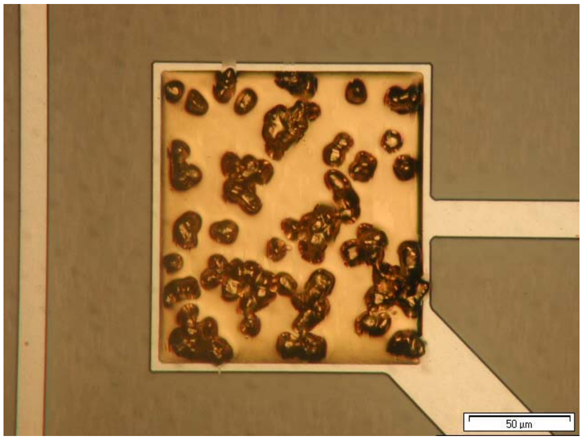

Figure 13. Particle Interconnect on an Al bond pad [9].

Particle Interconnect holds considerable promise as a solder replacement in a variety of applications including LED assembly and printed electronics.

Solder often attaches LED devices to package substrates. However, solder can short LED junctions by wicking up the sides of the device. Evaluations of Particle Interconnect together with a non-conductive adhesive indicate that the Ni-coated diamond particles provide enhanced electrical and thermal conductivity without danger of junction shorting. Figure 14 shows a LED with Particle Interconnect on the bottom face of the device.

Similarly, Particle Interconnect may prove beneficial in thermally sensitive applications such as printed, organic electronics.

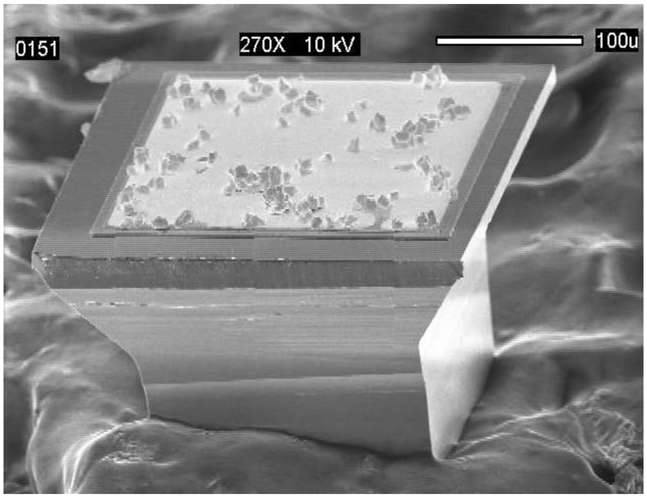

Figure 14. Particle Interconnect on the bottom of an LED die provides superior thermal and electrical conductivity without danger of shorting the p-n junction.

SUMMARY

The disruptive nature of the effort to replace lead-based solders reveals the central role played by solder in electronics assembly. Lead-free solders require higher temperatures and increase the thermal tolerance requirements of electronic components. As a result, the industry has become increasingly open to solder-less alternatives.

TechLead has identified three broad families of solder alternatives: materials-based, process-based, and structure-based. Each family enjoys renewed interest and new applications.

As with many disruptive technologies, the need for some supply chain restructuring limits adoption. However, TechLead forecasts that demand for performance and reliability will overcome adoption barriers.

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