Isotropic Conductive Adhesives: Future Trends, Possibilities and Risks

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Abstract

This brief summary of the questions facing isotropic conductive adhesives is intended to provoke discussion in the research community, and suggest future research priorities. The primary impediment to widespread industrial adoption of the technology is a lack of confidence in its reliability, specifically in its drop-test performance. The key to solving any such technical problem is to fully understand the technology, but at this point there are still far too many fundamental questions on multiple aspects of it to inspire confidence. Some basic research questions are identified, the answers to which should lead to improved product performance.

Introduction

The initial driver for electrically conductive adhesive (ECA) development was environmental concern about the Pb content of solder. In the US, however, industry was slow to recognize the significance of external environmental legislative threats to its global market, and reluctant to embark upon research into no-Pb and electrically conductive adhesive alternatives alike. Its own early isotropic conductive adhesive (ICA) technology review [1] focused on the twin failures of resistance drift and impact (drop test) survival, and did not produce a view of ICAs as likely reliable solder replacements. At the same time, of course, (and until relatively recently,) many were also insisting that no-Pb solder technology could not work either. However, once the no-Pb imperative was recognized, the industry's vast developmental resources focused on the supposedly impossible no-Pb solder technology, with eventual consensus on the viability of Sn-Ag-Cu alloys. One can only wonder if a similar level of research effort into ICA reliability issues might have led to earlier solutions than no-Pb solder's.

Regardless, the future trend is that no-Pb solder will continue as the industry mainstay, with ICA as a niche alternative where higher temperature processing is prohibitive, usually because of excessive thermo-mechanical stress. It is still remotely possible that mainstream attention could swing back to ICA (or other ECAs) if the solder solution develops reliability problems, but unlikely. It is also worth noting that industry, e.g. Bosch, (which has employed ICAs under harsh environmental conditions for many years,) has never published the comprehensive industrial reliability data which must exist to compare ICA and solder.

Readers are also referred to the recent outline review [2], as a bibliographic resource.

Past Research Outcomes

Much has been learned from (mainly academic) research programs, building on prior (mainly industrial) experience. Focusing on resistance drift, it has been established that the primary (destructive) mechanism is galvanic corrosion at the ICA filler to contact interface [3]. With understanding, solutions have come in terms of contact materials choices and polymer choices and additives. Similarly, much has been learned about drop test failure. The primary result is that survival correlates with the loss modulus of the material, i.e. its ability to absorb mechanical energy [4]. However, there are still puzzles, e.g. the modulus is a bulk property, but failure is almost always adhesive rather than cohesive.

Work will continue on pursuing economic cures for both problems, e.g. electrochemically compatible metals selection for contacts, leads, and filler, and moisture-resistant polymers. Impact failure needs further fundamental research. Is the loss modulus inherently different at the interface? Or, since a pre-heat stage during cure improves impact resistance [5], failure may be initiated at bubbles, polymer-flake interface voids, or other defects, and these may be inherently more prevalent at the contact interface. But the hypothesis needs study. This leads to the need for a nano-scale study of the internal mechanical structure, especially of the polymer-filler interface.

Another failure mechanism which is understood, although with a lower recognition profile, is by accumulated plastic strain under thermo-mechanical cycling. Coffin-Manson plots of mechanical strain cycling to failure show ICA reliabilities an order of magnitude above solders' [6], in direct correlation with higher creep coefficients. In typical thermo-mechanical cycling, however, the temperature range goes above the glass transition temperature, exacerbating viscoelastic effects which lead to strain accumulation [7].

Systematic Property Measurements

ICA research data has emphasized failure, rather than reliability. And the failure mechanisms are different to solder's failure mechanisms, so the tests most commonly emphasized are also different. Coffin-Manson data is an example; the results cited above [6] have yet to be validated by replication and publication by another group. ICA credibility requires the widespread distribution of data demonstrating equivalent or superior performance in comparison with solder. In particular, it needs the publication of the high volume reliability data that can only be obtained by an on-going commercial operation, and which is often mentioned anecdotally.

Similarly, users need the sort of mechanical data that is routinely available for solders, e.g. thermal coefficient of expansion, (complex) mechanical modulus, visco-elastic coefficients, Coffin-Manson coefficients, creep data, etc. Ideally, these need to be measured by multiple independent laboratories for validity. But unfortunately, the range of commercial materials is simply much more diverse than standardized solder compositions, and, compounded by the greater complexity of the ICA system, the only likely source of such data will be the manufacturers. It is noted that standardizations of no-Pb formulations was recognized by suppliers and users alike, and became an early priority for industrial consortia, (e.g. NEMI.) A similar approach, or at least second-sourcing agreements, would increase ICA adoptions.

The Obvious Research Needs

It is reasonably safe to predict some near-term profitable areas of research:

- Carbon nano-tubes (CNTs) will be used as supplementary filler, between the Ag flakes. Ag nano-particles do not reduce resistivity for a given total Ag content. Nor do carbon fibers much, but they improve impact resistance [8]. CNTs will win on both fronts.
- Almost all ICA research has been based on Ag/epoxy systems. However, there are commercial silicone-based products which need similar attention.
- Thermal conductivities must be specified along with electrical resistivity, since interconnects also contribute significantly to chip cooling.
- Electrical noise measurements can provide diagnostic data, but interpretation is elusive [9].
- Empirical high current failure has been interpreted in terms of internal Joule heating [10], but the detailed examination of inter-particle contacts at high current must also seek evidence of electromigration [11].
- Electromigration current densities may be much higher than solder's [11], but contact areas may be very small [12], a point also requiring verification.
- The mechanisms of flake orientation need to be understood, both at surfaces and in the bulk, e.g. including the effects of pressure prior to cure [13] by ICA flow modeling.

Internal/Bulk Materials Properties

This list makes another point, i.e. that more attention needs to be paid to the ICA bulk, rather than the interface, which has been the target of most the research to date. In particular, there has been no work on the adhesion of the polymer to the Ag flake surface. This is the most likely source of "cracks" to initiate fracture. And clearly the pre-cure "soak" improvement in performance [5,7] is from the elimination of such or similar defects. Metals are known to diffuse in atomic form from such interfaces into the polymer, and to cluster into islands there [14]. What effect will this have on electrical or mechanical properties? The nature of the inter-particle conduction is unknown, and a first step towards understanding this must be the direct observation of such contacts, with physical characterization of dimensions and metal surface.

Conclusions

There is a general problem with the way ICA research has been conducted in the past: There have been insufficient personnel and funding, which has led to piecemeal approaches, piecemeal data, and piecemeal understanding.

The first future trend is that ICA technology will continue in a niche role where the higher process temperatures required for no-Pb solder alloys are not possible or lead to reliability problems. The second is that R&D efforts need to diverge to (a) a research focus on fundamental materials issues, and (b) a development goal to establish a standardized multi-vendor database of materials specifications and reliability, modeled after the widely accepted solder testing protocols. Of course, ICA applications will continue in die attach and vias, where there are lower perceptions of reliability issues.

Some suggestions for specific research projects are included in the text, and the possibility exists that the greater basic understanding of the materials which will come with success will lead to radical performance and reliability improvements. The risk is that ICA research will stall with the perception that no-Pb solder technology is the complete environmental solution.

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