Resistivity Measurement of Nano Ag Wafer Level ACF Interconnects

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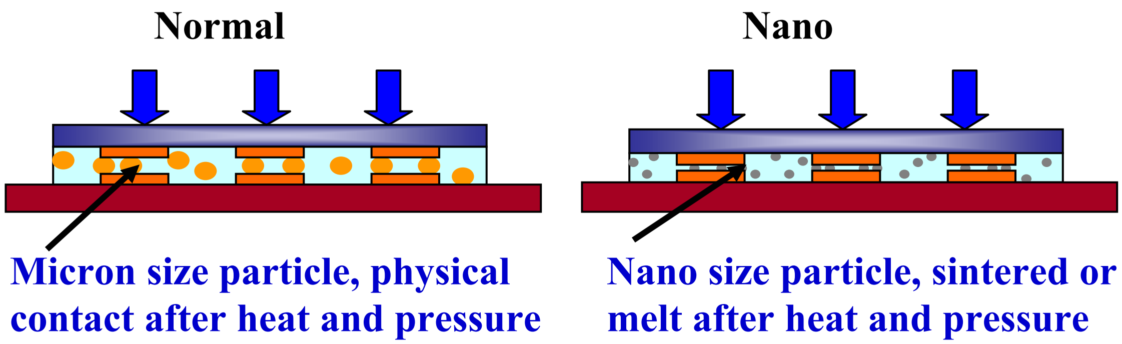
Until recently, tin/lead based alloy solder has been used as the primary interconnect material across the various packaging levels of most electronic systems. However, with growing concern regarding the toxicity of lead and its detrimental effects on both the environment and the human body, many governments and governmental organizations are calling for the replacement of lead-containing solder. Although several lead-free commercial solders have emerged on the market, their melting point is considerably higher than that of the more widely used SnPb eutectic solder; increasing the energy needed for assembly and consequently increasing assembly costs. The higher solder reflow temperature needed for such materials also limits their applicability to organic components and low-cost organic printed circuit boards.

Therefore, an alternative to both lead based solder and lead-free solder is needed. One possible alternative to the solder material available is an electrically conductive adhesive (ECA). These ECAs are essentially organic/polymeric binder matrices with metal fillers which act as conductors. In this way, ECAs accomplish both functions, of adhesion and conduction, while remaining environmentally benign. There are two main types of ECAs: isotropic conductive adhesives (ICAs) and anisotropic conductive adhesives (ACAs). ACAs are also available in a film form, anisotropic conductive film (ACF). ICAs contain more metal fillers (above the percolation threshold) and therefore provide conductivity in all directions. ACAs and ACFs, however, are only conductive when pressure is applied and direct contact is achieved between the pads and the metal fillers. Because of their composition, ECAs can be processed at much lower temperatures (thereby reducing cost). In addition, because of the small particle size (usually a few microns) of the conducting particles, ECAs are able to bond at very small pitch.

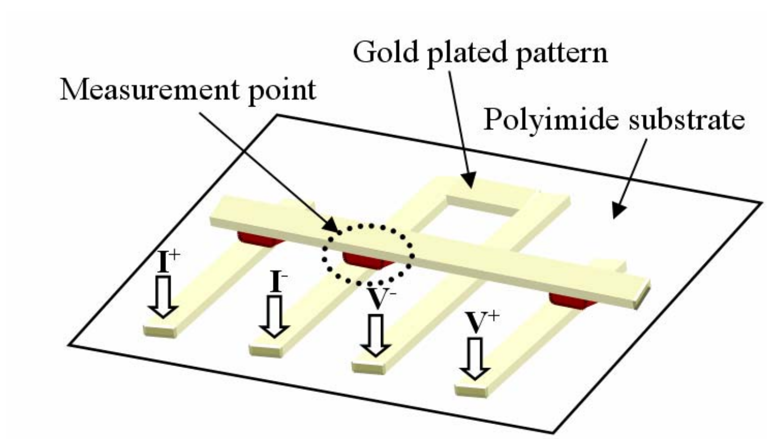
However, although ACFs have ultra-fine pitch capabilities and lower process temperatures, there remain many obstacles to overcome before ACFs can effectively replace lead/tin based solder in commercial use. Because electrical interconnect can only be achieved through direct contact rather than metallurgical joints, ACFs cannot be used in high power devices. Also, because of their unstable contact resistance, poor current carrying capacity, and poor reworkability, further exploration of ACFs is necessary. A possible solution to many of the challenges that ACFs present is to produce nano wafer-level ACFs which would (because of the smaller filler size) increase both the fine pitch capability of the joint as well as the conductivity of the interconnect.

The sintering of the nano particles (around a few microns in size) creates metallurgical contact which leads to low resistivity and higher conductivity (fig 1). In this study, nano Ag was used for metal filler.

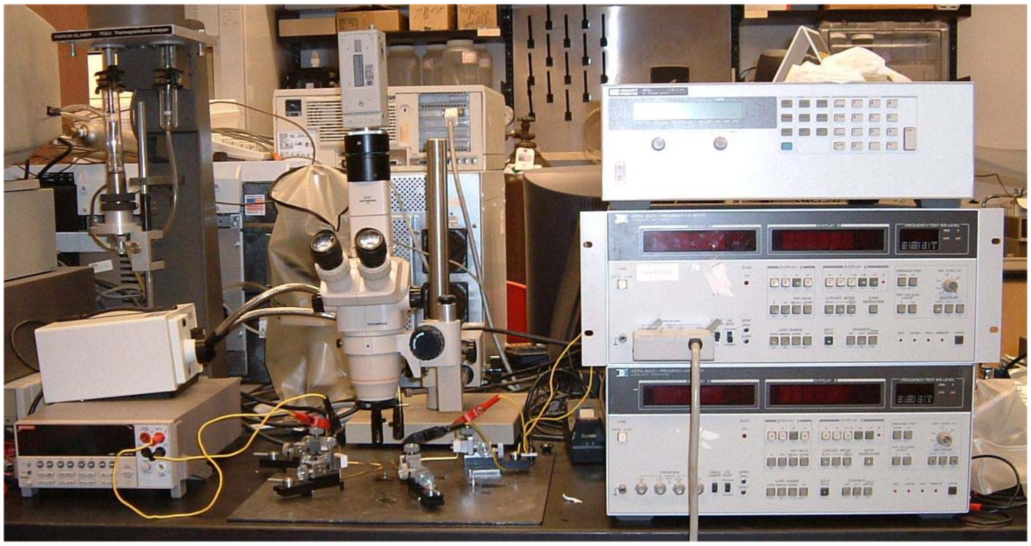


(fig 1) Difference between normal ACF and nano ACF

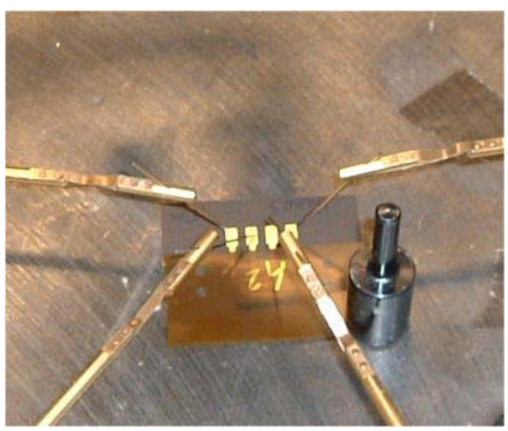
A study was first conducted using three samples of nano Ag dispersed in ethylene glycol at 3, 5, and 7 vol%. The samples were then deposited onto four-point probe test coupons (fig 2) and cured at 150˚C (for 1 hr) and 200˚C (for 30 min) under pressure.



(fig 2) Four-Point Probe Test Coupons *The sample is placed on three of the four joints, leaving the third joint from the left free of sample.*

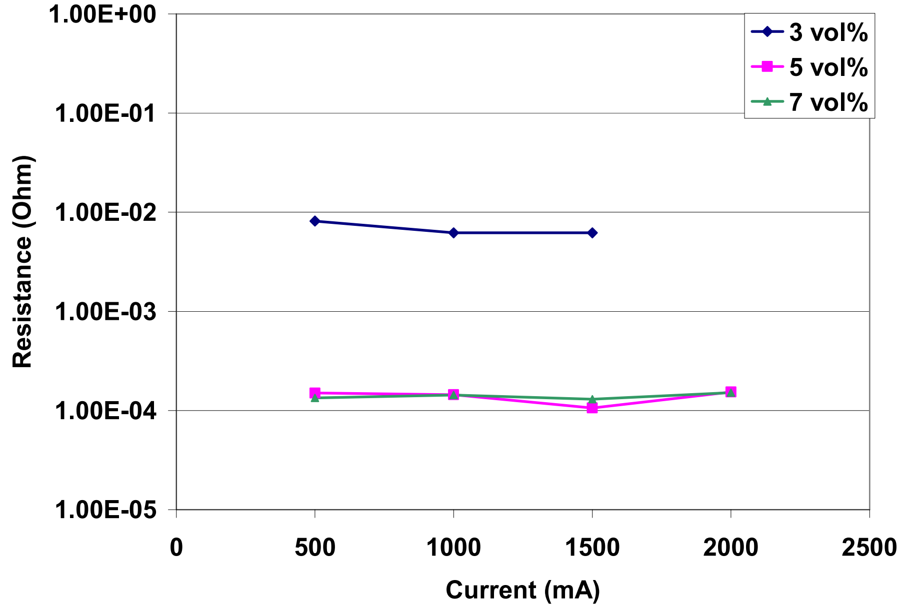


(fig 3) LCR meter

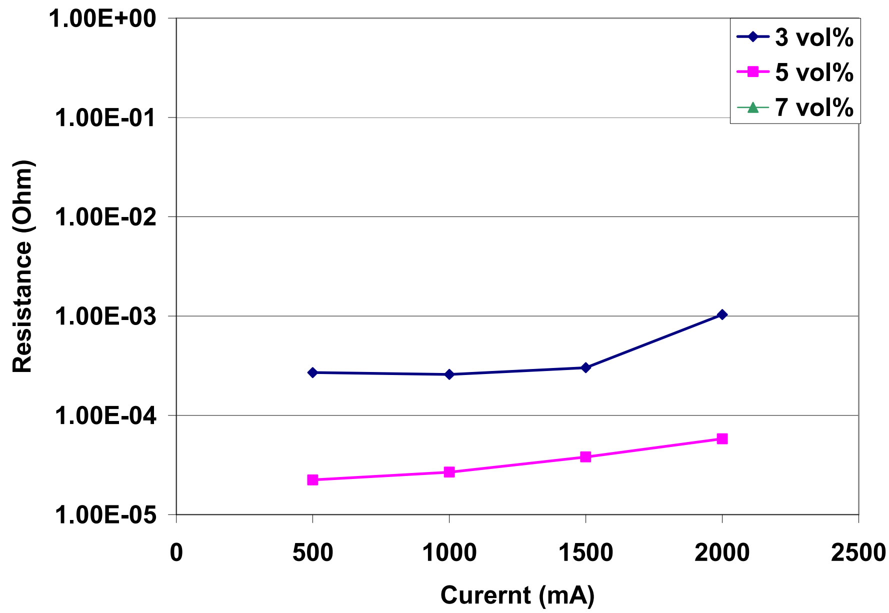


(fig 4) Closer look at Four-Point Probe test

After curing, the samples were ready to be tested using the LCR meter with four gold probes (fig 3&4). Once attached to the meter, current ran through the coupon and the voltage of the sample joint was tested. Each sample was measured at currents ranging from 500 to 2000 mA for 1 min. The results obtained indicated that a higher processing temperature was linked to a decrease in resistivity of the joint (fig 5&6).

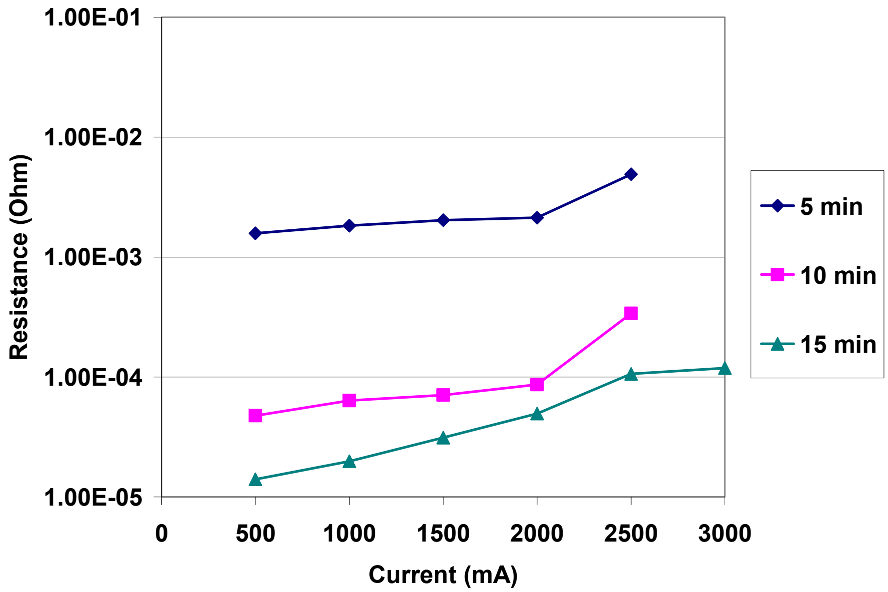


(fig 5) Samples Cured at 150˚C for 1hr

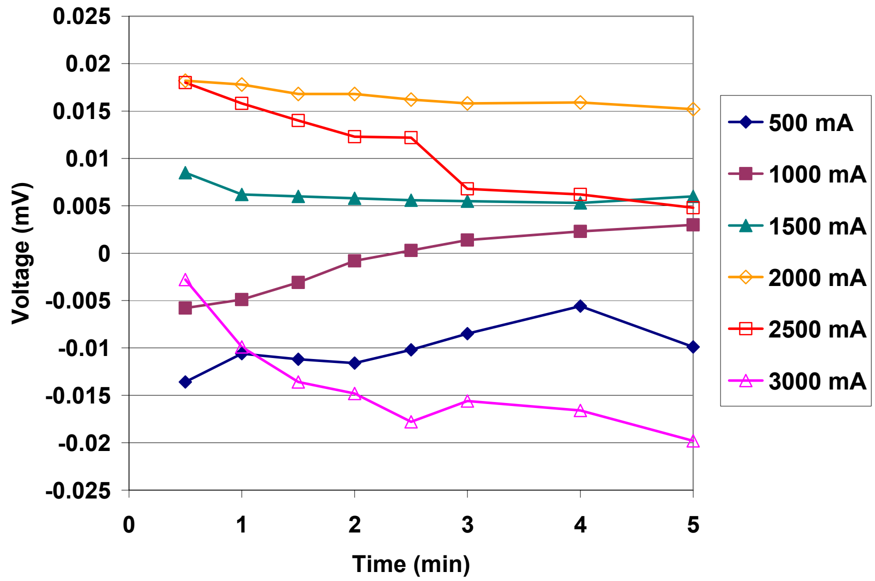


(fig 6) Samples Cured at 200˚C for 30 min (7 vol% is not visible because results were too low)

After establishing an approximate optimum curing temperature (200˚C), a study was conducted using 5 vol% nano Ag suspended in an epoxy/anhydride mix (without catalyst). Samples were cured at 200˚C for 5, 10, 15 and 30 min. The samples were then tested using the same procedure as above on the LCR meter. The samples cured for 5, 10 and 15 minutes were subjected to 500-3000 mAs of current for 1 min each and the results were compared (fig 7), and the sample cured for 30 minutes was tested for resistance stability over time (at current levels of 500-3000 mA for 5 min each – fig 8). The results showed stability both over time and with increasing current. The results of the comparison between samples cured at 200˚C for 5, 10 and 15 minutes (fig 7) showed an approximate relation between the length of curing time and resistivity (more time, less resistant). It can be seen from fig 8 that the voltage on the joint fluctuated across 0V. The resistance of the joint was too low to be measured in the current method.

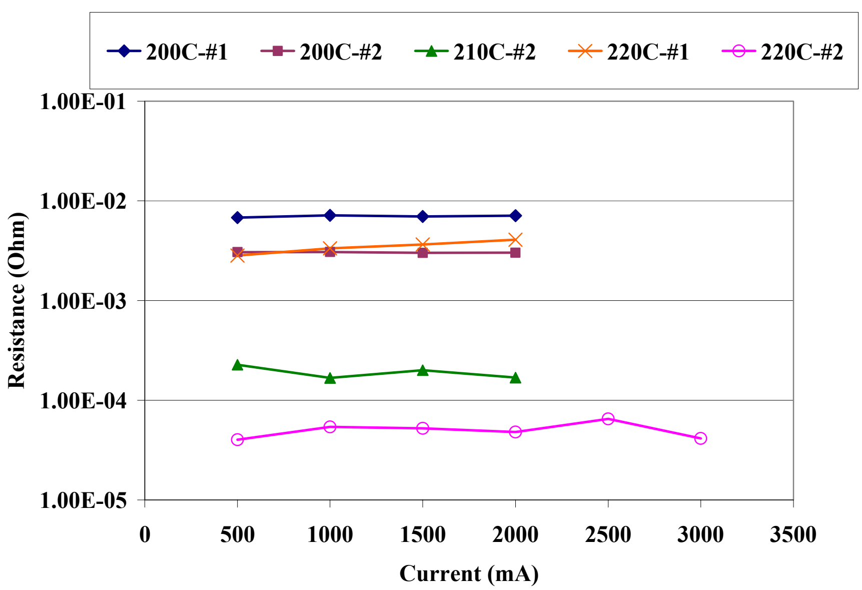


(fig 7) Resistivity of Samples cured at 200˚C for 5, 10 and 15 min (without catalyst)



(fig 8) Sample Cured at 200˚C for 30 min Tested for Resistance Stability (without catalyst)

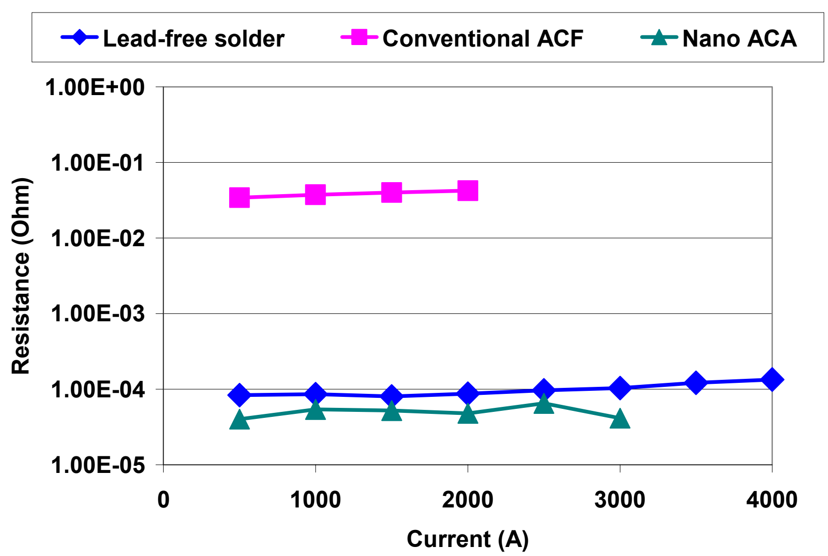
A similar study was then conducted on nano Ag/ epoxy/anhydride mix with catalyst. Samples were cured at 200, 210 and 220˚C then tested at currents between 500 and 3000 mA for one minute each. The results were inconclusive as one sample cured at 220˚C had a very low resistance whereas the other had much higher results. It would seem, however, that samples cured at 220˚C have a generally lower resistance (fig 9).



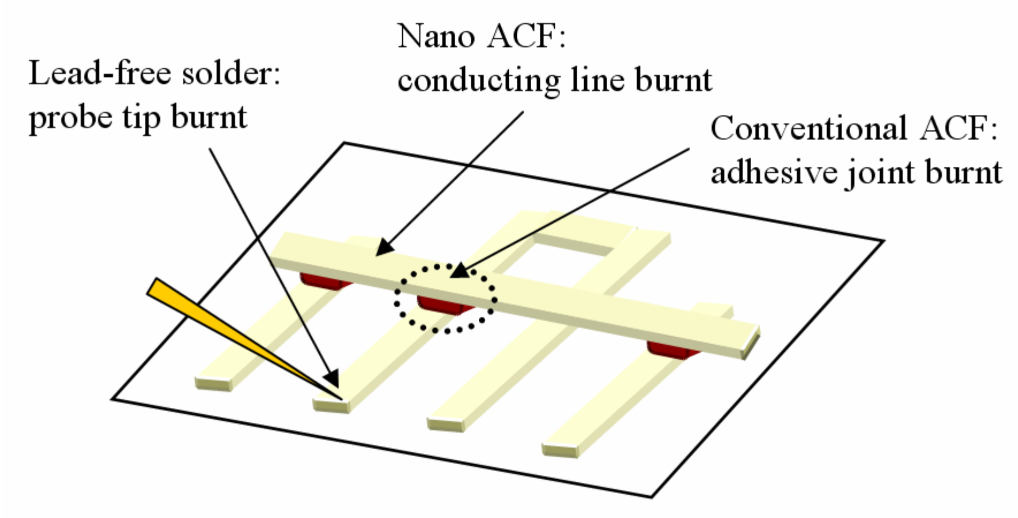
(fig 9) Resistivity of nano Ag/ epoxy/anhydride mix with catalyst cured at 200, 210 and 220 ˚C

A test was then conducted comparing lead-free solder, commercial ACF and nano ACF. Using the same four-point probe test as above, the samples were tested with currents between 500 and 4000 mA for one minute each until the sample burned (fig 10).

The test showed that nano ACF had the lowest resistance. The lead-free solder burned under a much higher current than the conventional ACF and nano ACF. This may have been caused by a faulty probe as coupon burned at point of contact with probe rather than at joint. The conventional ACF joint failed at a very low current (2000 mA) when the joint was burned due to the joule heating. The nano ACF joint failed at a higher current (3000 mA) due to the conducting line burned at this current. The conventional ACF joint failed at 4000 mA (fig 11).



(fig 10) Comparison between the resistivity of lead-free solder, conventional ACF and Nano ACF



(Fig 11) Showing where the tests on lead-free solder, conventional ACF and nano ACF failed

The comparison study showed that the nano ACF was not only the least resistant of the other samples, but also that its joint can withstand more current than the conventional ACF as well.

However, while mixing the nano Ag/ epoxy/anhydride mix with the catalyst, a red-brown gas was formed. A hypothesis was formed attributing the colored gas to a possible contamination of silver nitrate. The silver nitrate would then be broken down: $4AgNO_3$---->$2Ag_2O+4NO_2+O_2$, which would account for the red-brown gas observed. In order to test for the presence of silver nitrate, small samples of nano Ag were washed with distillated water in the ultrasound machine for 10 minutes before being centrifuged for five minutes. The resulting solution was poured off of the silver (leaving the sample inside the beaker) and tested with 5 drops of 1M NaCl. If a precipitate formed and the solution turned a cloudy white, the presence of silver nitrate was indicated. After successfully establishing that the nano Ag used in the above experiments was contaminated, the above method of cleaning was repeated until no precipitates formed in the solution. Then the silver was dried and could be used for future experiments. In general, 2-3 repetitions of the cleaning process were sufficient to obtain clean nano Ag.

In conclusion, through various studies, nano Ag ACF was found to both reduce joint resistivity and improve the current carrying capability. Although nano Ag is tainted by AgNO3, it can be easily eliminated through the proposed cleaning method. Although the above experiments are far from conclusive, the results indicate that nano ACFs provide a solution to the search for a low cost, fine pitch, environment-friendly interconnect to replace tin/lead and lead-free solder.

Thank you to everyone in Prof. Wong's lab that put up with me this summer, especially to Zhuqing for her guidance and patience!