ANISOTROPIC CONDUCTIVE FILM FOR FLIP-CHIP INTERCONNECTION OF A HIGH I/O SILICON BASED FINGER PRINT SENSOR

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***Abstract* — Anisotropic conductive film (ACF) has been used for flip chip interconnection of a silicon based MEMS finger print sensor to a signal processing ASIC. The assembled sensor device was subjected to a short term high temperature profile with peak temperature 260 °C simulating subsequent reflow soldering of the device, and to thermal shock cycling from -40 to +85 °C. The reliability of interconnects during ageing was investigated by monitoring changes in electrical resistance of single interconnects and interconnect daisy chains. The electrical resistance increased after exposure to the high temperature soldering profile, but no failures were observed even after 10 repetitions. Thermal shock cycling showed an increase in electrical resistance and no failures. A relatively large resistance increase was found for some interconnection points.**

***Keywords:* Anisotropic conductive adhesive, flip-chip, fine-pitch, reliability**

I - Introduction

Anisotropic conductive film (ACF) has during the last decade emerged as an alternative to soldering for interconnection of devices to various substrates such as glass, PCB and flex. ACF offers advantages like fine pitch capability and improved mechanical and thermal properties [1]-[3]. Solder interconnects struggles with pitches below 200 μm whereas ACF has been demonstrated down to 70 μm for display applications [4].

ACF consist of an adhesive film matrix filled with mono-disperse conductive particles. The particles can be solid metal spheres or metal coated polymer spheres (MPS). Electrical connections is achieved when the spheres are trapped between interconnect bumps on substrate and device, see Figure 1.

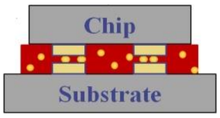

Figure 1. *ACF interconnection of chip to substrate.*

This paper reports the use of ACF for flip-chip interconnection of a silicon based MEMS finger print sensor to a signal processing silicon ASIC. The device has more than 250 I/O's, and fine pitch is required to minimize the size of the assembled device and reduce the device cost. The device is intended for handheld devices and must withstand rough environments including large temperature variations, mechanical shock and humidity exposure. The assembled device will be soldered to a PCB, see Figure 2, and thus it is important that the ACF interconnection is compatible with subsequent reflow soldering. In the present work assembled sensor devices have been subjected to short term high temperature exposure simulating subsequent reflow soldering. Devices have also been subjected to thermal shock cycling from -40 to +85 °C. The device reliability during ageing has been investigated by monitoring changes in electrical resistance and by cross-sectioning and microscopy analysis of the interconnections.

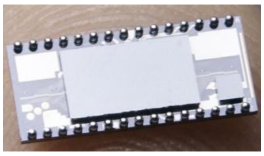

Figure 2. *The assembled finger print sensor from IDEX ASA, ASIC on top. The larger solder balls are for subsequent interconnection to PCB. Outer dimensions: ASIC (5.5 x 3.1 mm), sensor (10.1 x 4.4 mm)*

II - Experimental Details

Sample description

Silicon test dies with similar outer dimensions and pad distribution as the actual fingerprint sensor and ASIC were designed for interconnect testing. The dies were populated with 80 μm diameter electroless Ni/Au bumps with a 200 μm pitch. Two different types of test samples were produced. The two types were identical except in the number of interconnection bumps on the MEMS and ASIC chips. The *reduced* and the *identical* versions had 73 and 286 bumps respectively. The reduced version had two daisy chains along its long side borders (named D1 and D2) and the identical had two additional chains extending to the central parts under the ASIC (D3 and D4). Both versions had six structures for 4-point resistance measurements distributed at each corner and on the two short sides (referred to 41 to 46).

Assembly process

The ACF used in this study was a 20 μm thick single layer ACF. The conductive particles in the ACF are Ø5 μm Ni/Au coated polymer spheres fabricated by Conpart. The assembly process involves two main steps: pre-bonding and final bonding. Bond parameters including bond temperature, time and pressure were selected based on a previous study of Nguyen *et al.* [5].

A MAT-6400 flip-chip bonder at HiVe was used to assemble the reduced version of MEMS sensor to ASIC substrate. For the identical version, a relatively larger bond force is required due to significantly higher number of interconnects, compared to the reduced version. The force limit of the MAT-6400 flip-chip bonder is 4 kg, which is not sufficient for the assembly of the identical version. Therefore, the bonding process of the identical version was conducted using Toray FC1000 flip-chip bonder at Tampere University of Technology, which can provide a bond force corresponding to more than 20 kg. The assembly processes of the reduced version and the identical version of the sensor were slightly different due to the differences in the availability of the equipments. Table 1 summarizes the assembly processes of the MEMS sensor to ASIC device. A photo of an assembled sample is shown in Figure 3.

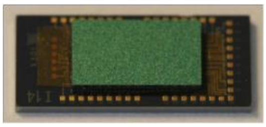

Figure 3. MEMS finger print sensor dummy assembled onto a dummy ASIC.

Reflow compatibility test

To simulate the compatibility of the MPS filled ACF technology with industrial reflow processes, a total of 19 samples were subjected to a typical reflow process. A Madell Technology AE-RF330-R reflow oven were used for the reflow tests. The profile used were 160 °C – 220 °C – 260 °C and the speed set to 500. The oven does not have heating from below the belt.

Reduced – Two sets of reduced samples were tested. Six samples were subject to a single reflow process. Three samples were exposed to two sequential runs through the reflow oven. Two of the three samples were placed on a carrier where holes were made to expose them to more direct cooling. This was done since some devices may be stacked onto a PCB with a hole in it to make room for the device, exposing them directly to the environment on the other side of the PCB. The last sample was kept as a reference.

Identical – Ten samples were subjected to ten sequential runs through the reflow oven to investigate the degradation properties when exposed to longer times at high temperatures, above T_g ($T_g \approx 140$ °C of the film epoxy). This corresponds to an exposure of more than 30 min at 100 °C or more and more than 13min above 200 °C.

Thermal shock cycling

Identical – Ten samples were prepared for thermal shock cycling (TSC). A Heraus HT 7012 S2 was used to expose the test samples to TSC. The test profile was calibrated to cycle between -40 °C and +85 °C with a dwell time of 5 min, see Figure 4. Since the test chamber consist of a two chamber solution with a lift system enabling a fast transition from hot to cold and back, it was possible to generate a tough ramp rate during testing. The fast temperature transition for the samples puts them under large local thermal gradients, or thermal shock. I.e. the thermo-mechanical stress is high within the components compared to when exposed to more regular thermal cycling (TC) with slower transitions. TSC is believed to age the test samples faster than with TC.

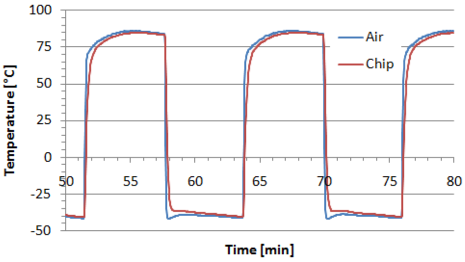

Figure 4. *Thermal shock cycling profile. A temperature change of 90% of the maximum* $\Delta T = |T_{max} - T_{min}|$ *was reached in less than one minute.*

Electrical resistance measurement

The electrical resistance of the single interconnects was measured with a Keithley 3706 system switch/multimeter using a custom-made Wentworth Laboratories 4-point probe card and LabVIEW 8.2. In a 4-point measurement separate pairs of current-carrying and voltage-sensing electrodes are used. This voltage and current separation minimizes the resistance contribution of the wiring and contact resistances, giving very accurate local measurements.

Table 1: Assembly process of reduced and identical versions of the MEMS finger print sensor to ASIC device

Bond steps	**Reduced version**	**Identical version**
Pre-bonding	▪ ACF is laminated on MEMS chip. ▪ Bond pressure: 1.5 MPa (Estimated force per area of ACF) ▪ Bond temperature: 80 °C ▪ Bond time: 5 s	▪ ACF is laminated on ASIC substrate. ▪ Bond pressure: 1.5 MPa (Estimated force per area of ACF) ▪ Bond temperature: 80 °C ▪ Bond time: 11 s
Final bonding	▪ Bond pressure: 90-110 MPa (force per area of bump) ▪ Bond temperature: 180 °C (Heat comes only from bottom stage where ASIC substrate is placed.) ▪ Bond time: 30 s	▪ Bond pressure: 100 MPa (force per area of bump) ▪ Bond temperature: 180 °C (Heat comes from both pick-up tool on top via MEMS chip and bottom stage via ASIC substrate) ▪ Bond time: 30 s ▪ Cooling time after 30 s of bond time: 10 s with external cooling air while keeping bond force

Visual inspection

To inspect the quality of bond and interconnect, cross-sections were performed on both the reduced and the identical samples. Each cross-section was prepared with polishing. The finest polishing step was with ¼-µm sized particles.

General remarks

A total number of 144 plus 318 (reduced and identical samples resp.) individual interconnect resistance measurements distributed on six different locations around the periphery of 29 samples were performed. Corresponding daisy chain measurements were performed in addition.

III - Results and Discussion

Assembly process

Reduced – The assembled samples showed a non-uniform interconnect resistance at different locations around the periphery of the chips. The typical average interconnect resistance ranged from 40 to 225 mΩ, depending on location, c.f. Figure 5. This was found to be a result of a co-planarity issue between the ASIC and the MEMS sensor during assembly. The minimum individual interconnect resistance measured was 16.5 mΩ. Figure 6 show a cross-section of a reduced sample showing MPS deformed into their desired shape. MPS compressed to stand off height of about ⅔ to ½ of its uncompressed diameter is expected to be a feasible compromise between contact resistance and flexibility.

Identical – The identical samples showed similar co-planarity issues as the reduced samples did. The measured resistance typically ranged from 7.5 to 82.5 mΩ, with an individual minimum measurement of 3.6 mΩ. The cross-section, cf. Figure 7, show that the MPS were highly deformed beyond their optimum shape. Some MPS were observed to have collapsed and fractured, exposing the internal polymer core. This could explain the difference in measured interconnection resistance between the reduced and the identical samples. I.e. a more compressed interconnect produce more deformed MPS, hence creating a larger contact area between MPS and bump surfaces. It also shortens the distance between the bumps, both reducing the resistance. The main drawback is fractured MPS which increase the resistance. Nguyen *et al.* [5] showed that highly deformed MPS also may give random and unpredictable results. A highly deformed MPS is also believed to be less reliable than an optimally deformed one, since its flexible properties are inhibited.

Reflow compatibility

Reduced – The six samples run through the single reflow process showed a decreased interconnect resistance after the exposure, see Figure 8. This is believed to be a result of additional curing of the epoxy in the ACF when exposed to the high temperature. That would lead to additional shrinkage of the ACF, hence increasing the contact pressure i.e. reducing the contact resistance between the MPS and the interconnection pads.

The three samples exposed to two reflow processes also showed similar improvement in the resistance measurements, cf. Figure 9. No apparent difference in the interconnect or daisy chain resistance was found for the two samples mounted above holes in the carrier when compared to the one that was not exposed to the additional cooling. The variation was found to be noticeable typically stretching up to around 30% deviation from the average measurement. The divergence decreased some after exposure to the reflow process. This is again believed to be due to curing of the epoxy.

Identical – The interconnect resistance significantly increased after ten reflow processes, cf. Figure 10. Figure 11 show that also the daisy chains showed a resistance increase after the test. Note that the resistance increase, or interconnect degradation, is much clearer for the interconnect measurements than for the daisy chain ones. Thus, indicating the importance of actually measure the degradation properties at interconnect itself instead of using daisy chains. It shall be noted that the divergence is higher for the identical samples than for the reduced. This is believed to be due to the highly compressed MPS, as described in the *Assembly* section.

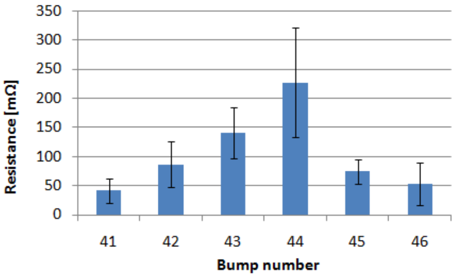

Figure 5. The average interconnect resistances for each interconnect location (all nine reduced samples).

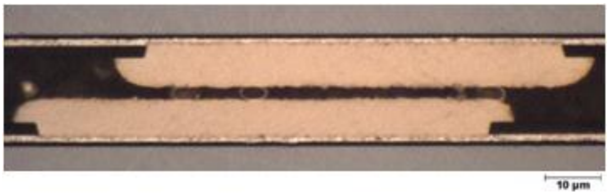

Figure 6. Cross-section of a reduced sample showing the shape of compressed MPS in-between two pads.

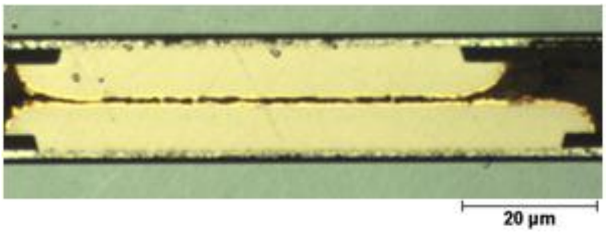

Figure 7. Cross-section of an identical sample showing highly deformed MPS in-between two pads.

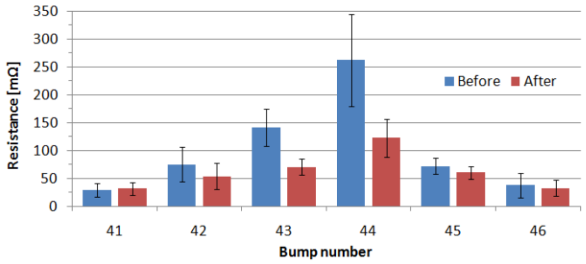

Figure 8. *Average interconnect resistance before and after exposure to a single reflow process for six reduced samples.*

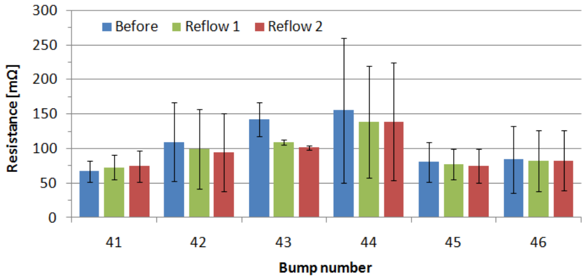

Figure 9. *Average interconnect resistance before and after exposure to two reflow processes for three reduced samples.*

Thermal shock cycling (TSC)

Identical – The results from the TSC tests shows, a trend with increasing electrical resistance as the samples were exposed more cycles, see Figure 12. It also shows an increase in the divergence. Interconnect 42 was excluded from the results due to a malfunctioning probe card, i.e. non reliable measurements. Two data points were excluded from the statistics for point 46 due to an unexpectedly large increase in resistance for the 1000 cycle measurements. These are believed originate from the randomly behavior described in the *Assembly process* results section.

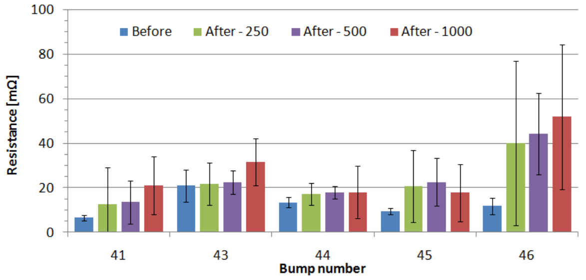

Figure 12. *Average interconnect resistance before and after exposure to 250, 500 and 1000 TSC for ten identical samples.*

IV - Conclusion

The electrical resistance measurements show resistances ranging from a few to hundreds of mΩ, depending on the quality of the assembly process. An industrial and optimized process is expected to give resistances in range of tens of mΩ. This is well within the feasible range (up to 250mΩ) of the intended use in the fingerprint sensor described in the introduction.

Considering the number of measurements, it's remarkable how consistent and reliable the MPS filled ACF are when exposed to thermal stress, even when the MPS was a bit too deformed for the identical samples.

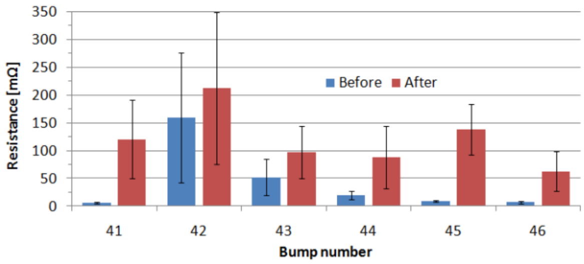

Figure 10. *Average interconnect resistance before and after exposure to ten reflow processes for ten identical samples.*

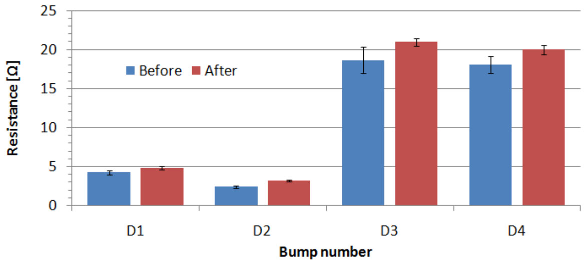

Figure 11. *Average daisy chain resistance before and after exposure to ten reflow processes for ten identical samples.*

Future and ongoing work to be published includes thermal ageing and humidity/thermal ageing and MPS shape response tests.

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