Testing Epoxy Fluxes for Hearing Aid Miniaturization

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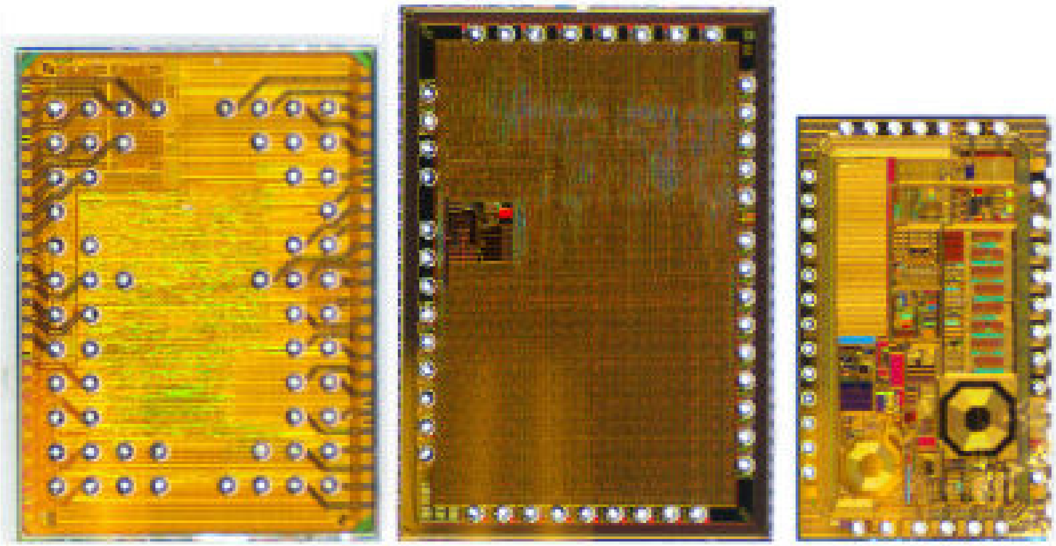
Breakthroughs in circuitry design have made adding new features easier than miniaturizing the hearing aid as a whole. This article follows the progress - as yet not entirely fulfilled - of one major hearing aid manufacturer in shrinking the product while simultaneously adding capabilities.

Starkey Hearing Technologies (Eden Prairie MN) decided to move beyond the die protection and die stability limitations of conventional surface mount technology, and chose underfilled BGA/flip chip designs to reduce the overall x-y area needed for each die. Underfill would protect the die when the flexible board is bent up to 180° during assembly.

The underfill process, though, can be tricky. To accommodate dispensing equipment, a “keep out” area off-limits to other components must surround the die. In this application, the die must also not be near the board edge or the lines along which the board will be folded.

For assistance, Starkey turned to the Center for Nanoscale Science and Engineering (CNSE) at North Dakota State University. CNSE specializes in miniaturizing electronic systems and has advanced equipment, including a Sonoscan [1] C-SAM acoustic microscope that nondestructively images internal material interfaces, including underfill defects.



The three die to be underfilled (Figure 1) were flip chips having BGA layouts:

- Digital Signal Processing die, 142.9 x 105 x 10 mils, with 48 balls, diameter 4.3 mils. SAC351 solder.

- Memory die, 152.0 x 107.7 x 8 mils, with 44 balls, diameter 4 mils. SAC351 solder.
- Radio die, 121.5 x 73.1 x 11.5 mils, with 35 balls, diameter 3.2 mils. SAC405 solder.

Two recently improved epoxy flux materials (Material A and Material B) were tested. Epoxy fluxes perform the functions of flux and underfill, and thus eliminate one processing step. They also eliminate one heat cycle, pre-underfill cleaning and the “keep out” zone.

Both materials were applied to the flexible polyimide-based board by printing and by dipping. Printing was performed by an automated flux printer, using stencils of 3 mil and 4 mil thickness, and with two aperture sizes for each thickness. Material A had tacky flux characteristics and higher viscosity than Material B. Material B tended to pull in the direction of the squeegee blade, and to slump and spread after printing. Material A held its printed shape better, but the squeegee caused bubbles to form in both materials. After printing, the bubbles in Material A persisted, but those in Material B vanished.

To prevent peel-off during bending of the board, the die need a surrounding fillet. Dipping yielded more good fillets than printing; the large-aperture 4 mil gave the best results.

Before dipping, experiments determined an optimum dip height of 100 microns for the DSP and memory die, and 75 microns for the radio die. Dipping and placement were carried out by a high-accuracy, low force die bonder.

In dipping, the motion of the leveling blade caused large numbers of bubbles to form in both materials in the reservoir. When a die was dipped, the bubbles were picked up and caused incomplete coverage of the balls.

Dipping into Material A also caused die to drop into the reservoir. At the depth needed for full ball coverage, the DSP and memory die tended to become stuck; varying suction nozzle and strength and other parameters did not solve the problem. This problem did not occur with Material B. All three die types were successfully dipped with Material B, but only the radio die with Material A.

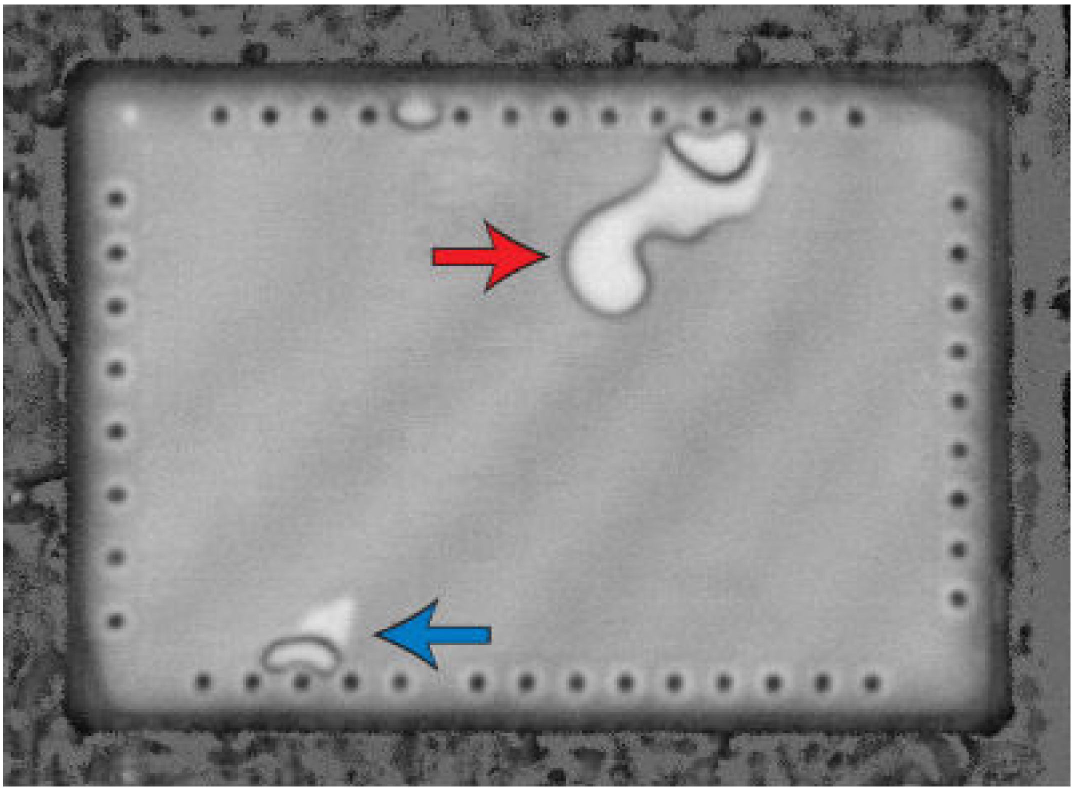
After they were placed on the board, die using both materials were reflowed in a convection reflow oven in N2 atmosphere with a maximum temperature of 260°C with about 50 seconds above 217°C.

After reflow, printed Material A left minor residue, while printed Material B retracted during reflow and left a larger deposit of residue around the die. Material B that had been dipped left a similar deposit after reflow, but with less overall shrinkage. Dipped Material A, however, deposited more residue, and left bubbles at the edge of the die.

Three destructive and two non-destructive test methods were used. Firstly, die were glued face down to a glass slide, and the flexible circuit then manually pulled from the die to permit examination of the fracture surface. For the second test, which evaluated the response of the materials to multiple reflow exposures, the assemblies passed through reflow four times. Red ink was then placed around the perimeter of each die and the assembly placed in a vacuum for 15 minutes to permit the ink to penetrate any edge voids. The die were peeled off to search for voids. The final test, shear testing, required the assemblies be glued to a rigid backing plate. The shear height was 30 microns and the shear speed 0.5mm/s.

The non-destructive test methods were x-ray and acoustic microscopy. Acoustic microscopes are often used to examine flip chips. A scanning transducer above the back of the die pulses ultrasound at high frequencies into the die. The ultrasound is reflected only from material interfaces. As the pulse travels through the bulk silicon, it produces no echoes. At the interface with the cured underfill material (or the base of a solder bump) the pulse is partly reflected as an echo. The material properties of the two materials at the interface determine the percent of the pulse that is reflected, but reflections between 20% and 60% are more or less the norm. The non-reflected portion crosses the interface and travels deeper, where it may be reflected and transmitted by additional interfaces.

Reflectivity is consistently >99.99% if the interface involves a solid and a gas - such as the air in a bubble - rather than two solids. The >99.99% echo from the solid-to-gas interface is imaged as a bright white pixel. Echoes from solid-to-solid interfaces are some shade of gray.



In flip chips, the underfill and solder bumps are the depth of interest. The excellent transmission of silicon permitted using a 230 MHz Sonoscan-designed transducer to image die after reflow. This frequency provides very high spatial resolution.

Figure 2 is the 230 MHz acoustic image of an underfilled custom memory die. The irregular white areas are voids in the underfill. In the largest void (red arrow), much of the air bubble does not reach the die face, but the more darkly outlined portion of the void toward the top of image does contact the die face. The smaller void (blue arrow) has a similar structure. Both of these voids are adjacent to solder bumps. In addition to blocking heat dissipation, voids are reliability risks because a solder bump may slump into an adjacent void until the electrical connection is broken.

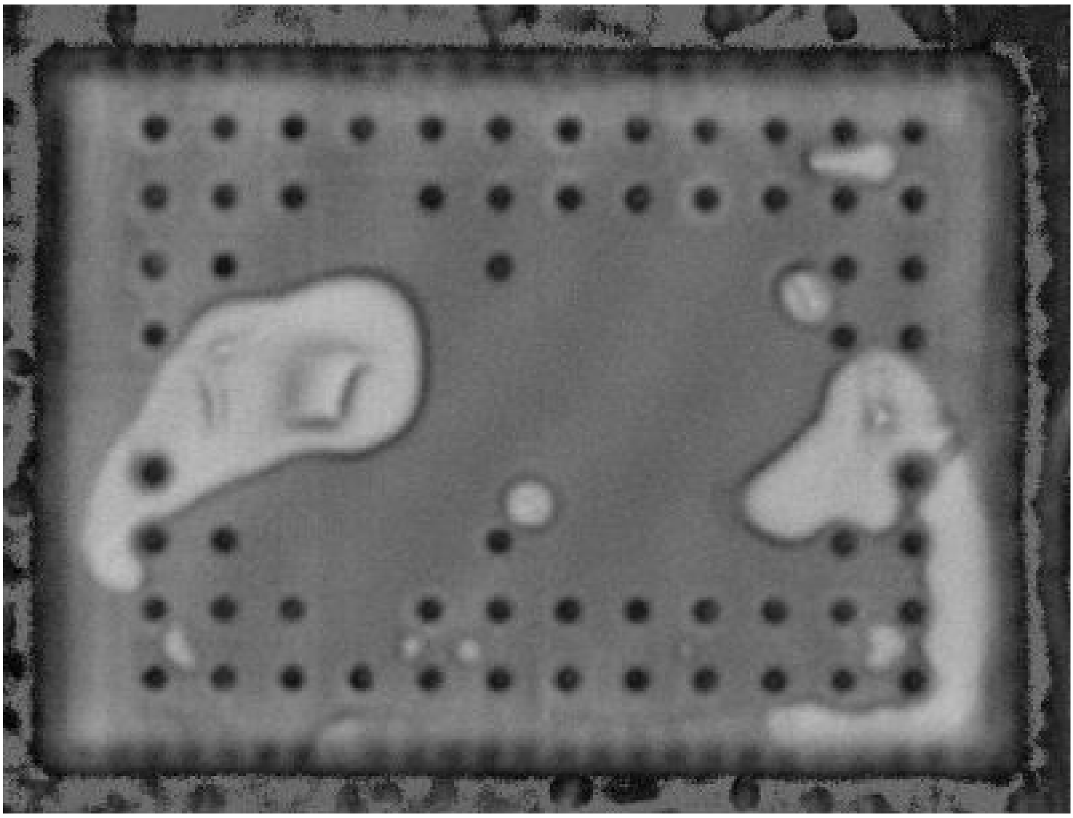


Figure 3 is the 230 MHz acoustic image of the DSP die. Here the underfill has numerous voids of various sizes. The large void at left completely surrounds one solder bump, and both it and the large void at right are adjacent to several solder bumps. The void at right also appears to reach the edge of the die.

X-ray was used to examine the assemblies after reflow for solder shorting, opens and extrusion. None of these anomalies were found with either Material A or Material B. The fluxing behavior of the epoxy fluxes appears to have worked successfully. Die peel testing gave results similar to x-ray and acoustic imaging. Overall, the following observations were made:

- Both dipped and printed assemblies had voids and edge cavities.
- Material A printed assemblies had many voids of various sizes under all three die types, regardless of stencil thickness or aperture size.
- Material B printed assemblies had fewer voids, and those present generally smaller.
- Material A and B dipped assemblies had voids of various sizes. All radio die had large edge cavities.
- Void size was larger in dipped assemblies than in printed assemblies.
- Die peeling showed that in Material B, although voids were smaller, there

was incomplete coverage of some solder balls in, for example, edge bumps on the DSP die. Dipping resulted in more complete ball coverage of Material B on the DSP die.
- Both Material A and Material B remained somewhat tacky post-reflow.
- The denser ball layout of the DSP die appears to trap air bubbles and prevent them from coalescing to form larger (but fewer) voids.
- During the multiple reflow tests both materials continued to shrink, although Material A shrank more than Material B. Both materials shrank more when printed. Curing continued through the multiple reflows, and tackiness disappeared.
- After the multiple reflow tests, some shorted solder balls were seen, and adhesion strength was markedly reduced.
- Shear testing yielded an average value of 5.2 kg, with standard deviations of 1.1. In nearly all stencil thicknesses and aperture sizes, Material B showed greater strength, but all values were considerably below those expected from normal flux and underfill.

Neither of the two materials tested met Starkey’s requirements for reducing the size of the die footprint and thus of the product package, but the testing gave insights for ongoing testing. Starkey continues the evaluation of epoxy fluxes as new ones become available. They have also undertaken other measures, such as the use of smaller ceramic chip capacitors and reduction of solder bump size, that will help reduce overall dimensions.

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