Cleaning up the flip-chip production act

Post-reflow cleaning processes significantly affect the uniformity of the underfill. Experiments carried out at Dexter Electronic Materials and, in part, at Kyzen Corp. with a single underfill material and multiple no-clean fluxes yielded results to support this.

In flip-chip production, successful underfilling of the gap between the die face and the substrate is a particular challenge because it not only involves the material properties and dynamics of the fluid underfill, but is also affected by earlier process stages. The presence or absence of flux residue can determine the reliability of the flip-chip package.

Delaminations (red areas) between the cured underfill and the die face, imaged acoustically after stress testing.

Experimental procedure

The test samples consisted of silicon nitride passivated die having 48 peripheral eutectic solder bumps with a 0.46mm pitch. Before reflow, the bumps were attached using three commercially available no-clean fluxes. After reflow, cleaning was carried out with a total of four cleaning solvents. Two similar cleaning units were used and two of the four solvents were used with each unit. The parts were then underfilled using a single commercial available epoxy-based underfill material and a single dispensing method.

For assembly, the die was placed on a 0.38mm thick bed of flux, then placed on the FR4 laminate substrate. Reflow took place in a five-zone reflow furnace where the highest temperature was 230°C. After reflow, two sets of assemblies were preserved as controls, while the others were subjected to cleaning. Cleaning took place in one of two sealed units where the samples were automatically rotated in the cleaning solution. One unit rinsed samples with a spray of de-ionized water, followed by the application of forced hot air. The second cleaning unit rinsed samples with a spray of dense phase CO_2, followed by forced hot gaseous CO_2 for drying. During rinsing and drying, centrifugal force was applied to the samples.

Both the cleaned samples and the control samples were then heated to 90°C and underfilled with a low-stress material suitable for semi-rigid and flexible substrates having gaps as small as 20µm. Curing was for 30 minutes at 165° C in a forced-air oven.

After cure, all samples were examined by acoustic micro imaging to reveal underfill defects, including delaminations, voids, and striations in the underfill. Striations consist of concentrations of filler particles, often in more or less longitudinal patterns coinciding with the flow direction of the fluid underfill. Delaminations and voids are imaged acoustically because they are gaps that reflect virtually all of the ultrasound. Striations are imaged because of the difference in acoustic impedance between areas of high and low concentration.

Initial acoustic inspection was followed by JEDEC level-3 preconditioning (192 hours at 30°C with 60 percent relative humidity) and then by three simulated reflow processes with a maximum temperature of 240°C, ±5°C. After this treatment, the samples were again inspected acoustically.

As a final step, the samples were exposed to accelerated stress testing at 121°C, 100 percent relative humidity, and 2.2 atmospheres of pressure for 48 hours. Acoustic inspection was then repeated.

The results

Throughout the procedure, evidence was sought of defects that would reduce the performance reliability of the flip-chip assemblies and in particular for evidence of defects resulting from flux residue and cleaning processes.

After the JEDEC level-3 preconditioning process, acoustic imaging of both control samples and cleaned samples showed few delaminations, cracks or voids. There were no distinct differences at this point between the control samples having flux residue and the cleaned samples, and no distinct differences in the cleaned samples among the four cleaning solvents.

But after the 48-hour pressure cooker exposure, the results changed dramatically. Samples using one of the three flux materials show;ed significant delaminations when no cleaning was employed. Of the total of four cleaning processes (two cleaning agents used in each of two cleaning systems), one prevented the formation of delaminations, while a second reduced but did not fully prevent delaminations. More surprising was the finding that two combinations of cleaning systems and cleaning solutions actually degraded the reliability of the flip-chips by promoting the formation of defects. In these cases, yield was actually worse than it would have been if the assemblies had not been cleaned at all.

Somewhat similar results were obtained with the second of the three fluxes. Striations in the underfill and delaminations were both observed in the control samples. Both of the cleaning processes reduced the occurrence of these defects, but neither process eliminated them.

Flux residues, the tests suggest, may adversely affect the underfill flow process and result in striations and voids in the cured underfill. After pressure-cooker exposure, the same flip-chips were likely to form stress-related delaminations, apparently because inadequate cleaning leaves a weak interface of flux residue between the die surface and the cured underfill. Of the three flux materials, the one resulting in the lowest level of residue contamination also resulted in no striations, voids or delaminations. But this material is also less active than the other two flux materials and might not be suitable in all situations for yielding optimum solder joints. The other two flux materials–both more active–also left higher levels of residue. But both cleaning solvents were successful in removing flux residue from these two flux materials to acceptable levels.

Qualifying flip-chip processes

This study points out that compatibility of materials in flip-chip production is extremely important. The cleaning solvent and the cleaning process in particular must be able to remove flux residue without creating additional defects. The study also suggests that a cleaning step may be advisable even when no-clean fluxes are used.

The study also demonstrates that acoustic micro imaging can be used to qualify both the flux material and the cleaning process used in a given flip-chip line. The striations, voids and delaminations resulting from flux residue are visible acoustically and give important data about the success or failure of the preparation of the flip-chip for underfilling.

The striations observed in this study are one form of the more general phenomenon of uneven filler particle distribution during the underfill process. Overall, two types of uneven distribution are possible: underfill particles settle downward toward the substrate, or underfill particles are irregularly distributed primarily in the x-y axes. Some degree of particle settling is normal and not harmful, although extensive fall-out of particles onto the substrate (caused, for example, by excessively low viscosity of the epoxy) may result post-cure in an underfill having two distinct layers with different thermal and mechanical properties.

Irregular distribution of filler particles in the x-y axes may be caused, by flux residue or by other phenomena such as large particle size or low viscosity. It has long been observed in work at Sonoscan that regions of high particle density are also regions where voids are likely to occur. Even if voids do not occur, variations in particle density may lead to fatigue failures in the solder bumps.

In summary, the study demonstrates that cleaning is likely to be beneficial even when using no-clean flux materials, that compatibility of materials and cleaning agents is very significant and that acoustic micro imaging is useful in characterizing the behavior of both flux and cleaning agents.

[Printed Circuit Fabrication]

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