



## Robust Process Solutions for MEMS Flip-Chip Applications With Medium Density Lead-Free Solder Interconnects

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With the proliferation of MEMS in sensor products in a variety of applications, packaging challenges continue to be at the forefront of successful production launches. Furthermore, package shrinkage, cost pressure and rapid time to market magnify these challenges because traditional approaches can no longer meet these constraints. The four major packaging challenges that consistently appear in product development are electrical interconnection, mitigating the effect of packaging strains on sense element performance, protecting the sensor from the environment, and proper management of temperature distribution and resulting material behavior. Given the complexity of these topics, this article will review the challenges in electrical interconnection for increasingly smaller MEMS flip-chip applications using lead-free solder for medium density I/O, size sensitive medical applications. With bump sizes of 90 $\mu$ m and bump pitch of 150 $\mu$ m, particular attention in component handling, material selection and process development were required to overcome challenges of poor reflow due to oxidation and shorting, while minimizing tooling and process cost. In particular, cleanliness, material handling, flux selection and application, metallization and reflow profile tuning are reviewed in detail for a robust design.

### Challenges of Lead-free Solder Interconnects

There are several factors that increase the difficulty of lead-free solder interconnects with medium density I/O for MEMS flip-chip applications. These factors include high reflow temperature, increased surface area of the bump relative to its volume, flux and cleaning limitations, necessity for underfill and tight I/O spacing. In the transition from Sn-Pb solder to those containing solely tin, tin, copper and silver, or other variants, the metal or alloy melting temperature increased requiring higher reflow temperatures to ensure proper wetting of the joint. This higher temperature causes oxidation to develop more quickly on metallization and solder making it more difficult to obtain a properly wetted bump. This problem becomes even more challenging as bump size decreases and the bump's external surface where oxide is present becomes a larger percent of the total solder volume. Therefore, the ratio of oxidized to non-oxidized solder increases and increased heat is needed to overcome this effect creating an undesirable cycle that cannot be sustained. Flux is used to prevent oxide growth and remove it from the bumps' external surface during reflow. However, aggressive fluxes cannot be used because of their corrosive nature, ionic contamination and inability to be cleaned post reflow. The fragile nature of MEMS devices for medical

applications and the narrow gap between chip and substrate make cleaning post reflow ineffective or not practical due to product damage. Underfill is also a requirement in this application to prevent shorts from tin whiskers between bumps and to minimize stress on the bumps from temperature fluctuations for medical products located outside of the body. The tight I/O spacing also results in a smaller process window to prevent solder shorting. Despite these challenges, there are a number of combined steps that can be taken to create robust lead-free interconnects.

### Process Considerations

Product cleanliness and material handling are crucial but often overlooked steps in creating a robust solder joint. Rigid and flexible printed circuit boards readily absorb moisture and this moisture is outgassed from the product during reflow thereby increasing oxide growth on the bump. To prevent this, circuit boards can be pre-baked at 125°C for 2-6 hours (depending on environmental exposure and moisture present) in an oven to drive off moisture prior to reflow. In addition, metallization on the substrates should be selected to minimize oxidation growth during this step. If the substrate is bumped rather than the MEMS flip-chip, another option is to ship the products in vacuum sealed, desiccant bags and store them in nitrogen back-filled

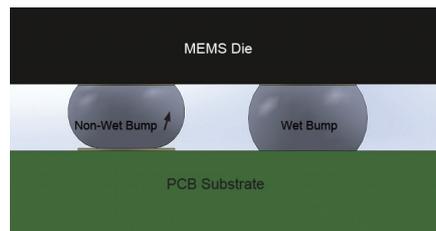
chambers when not being processed to limit exposure to humidity and oxygen. Product cleanliness is equally important because specific contaminations such as sodium chloride can accelerate oxidation growth and ionic contamination can create shorts in the presence of moisture. Clean process environments and aqueous-based cleaners followed by post bake are often effective.

The cleaning action of flux to remove oxide is another critical step to a proper solder reflow process. Without the post reflow cleaning option for many medical MEMS devices, rosin-based ROL0 fluxes without halides that completely evaporate during reflow are recommended for use. The use of halides in fluxes provide better cleaning action but are avoided because of their corrosive nature and they cause ionic contamination that can lead to shorts without cleaning. One flux option that provides more aggressive cleaning but contains no halides is ROM0. It is best to limit flux application to the lower half of the bump covering 30-50% of its surface. In some cases, more flux is required to clean the oxide present and maintain activity during higher temperature processing of lead-free solders. In either case, it is important to ensure no residue is left that may interfere with the underfill process creating voids or adhesion issues. Lastly, it is important to choose a flux with an 8+ hour working life and that has sufficient tackiness to prevent the part from skewing during reflow. MEMS devices are extremely light weight and can be easily moved from the desired position.

Solder reflow profile selection and substrate metallization are of equal importance to the previous steps in achieving proper bump wetting and collapse. In an ideal scenario, it is desired to achieve a 15-30% collapse of the solder bump and have the solder completely wet the substrate surface. Examples of properly wet and non-wet

bumps are provided in **Figure 1**.

A typical reflow profile for SAC 305 lead-free solder consists of pre-heating



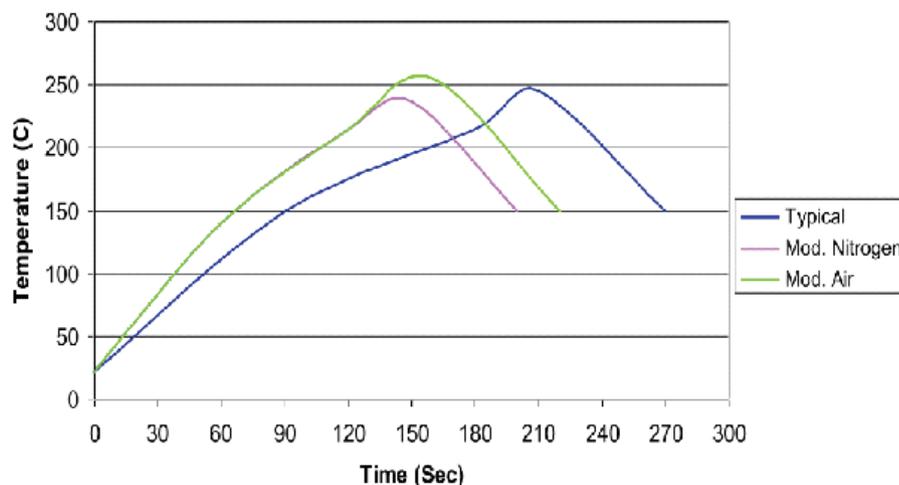
**Figure 1.** Non-wet and wet solder bumps.

including soak, reflow and cool down zones. To achieve the proper wetting defined above for MEMS applications, the typical reflow profile needs to be adjusted. More specifically, it is important to minimize the preheat zone to keep the flux active and prevent it from drying out. This could result in nearly a straight ramp to the reflow zone. In addition, the reflow zone needs to be adjusted to compensate for the level of oxide on the bumps and type of solder being used. It's best to keep reflow peak temperature as low as possible while still maintaining a reasonable process window. If the reflow is performed in a nitrogen atmosphere, which is highly recommended to limit oxide growth, the peak temperature will be lower and the reflow zone shorter. If reflow is performed in air, one can expect

higher reflow peak temperature for longer duration. Although a nitrogen atmosphere is recommended, it is not always easily implemented, especially when production equipment is already in place, or funds are extremely limited in a medical device startup. In other cases, the product may already be launched with an air reflow process with poor yield, and it could be weeks before an equipment upgrade to add nitrogen can occur. **Figure 2** shows a typical lead-free solder reflow profile with two modified versions, for air and nitrogen, as described above.

After reflow is complete, underfill application is an important step to minimize the stress induced in the solder joints from differing coefficients of thermal expansion (CTE) of the substrate and MEMS flip-chip. The underfill minimizes shear forces on the bump and causes the substrate and chip to slightly bend as one unit. Another critical function of the underfill is to prevent tin whiskers from creating shorts between the bumps. Lead-free solders have a high percentage of tin and are highly susceptible to this unpredictable failure mode. NASA has observed whisker formation after a few hours, and in some cases, they do not form for many years [1].

A robust metallization for the bond



**Figure 2.** Typical and modified lead-free solder reflow profiles for SAC 305.

pad on the mating substrate is also required to prevent oxide growth, ensure proper wetting and excellent adhesion. On printed circuit boards, this metallization is often electrolytic or electroless nickel with flash gold over a copper base layer. There are multiple options for the chip metallization, but one popular example is immersion gold over electroless nickel with a zincated aluminum base layer. Both Pac Tech and Uyemura have reported differing levels of success with palladium as a diffusion barrier between the nickel and solder. The tin and nickel intermetallic is brittle and can be a source of failure in high stress conditions such as drop test. There are examples of palladium use between the nickel and gold layers, or as the top layer without gold [2-3].

### Summary

The difficulties in creating robust lead-free solder joints for medical MEMS flip-chip applications of increasing smaller size with

confounding process parameters and materials is a real challenge. The solution to this problem lies within an intertwined mix of oxide growth minimization, proper material selection and application, and subtle process parameter adjustments. More specifically, cleanliness, proper storage and handling or pre-bake, flux and its application, the solder reflow profile, chip and substrate metallizations and underfill, are all critical elements in the process. Hence, when each of these parameters and materials are designed to work together, robust lead-free solder joints with high first-pass yields can be achieved. 

### References

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