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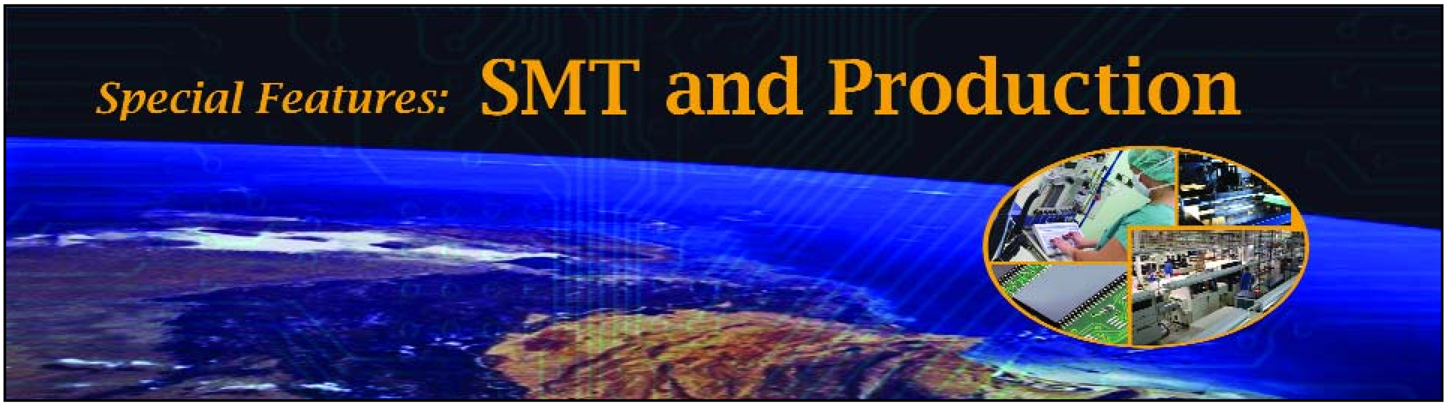

Reducing CTE Mismatch Defects in Flip Chip Reflow

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The miniaturization of electronic components has led to the use of copper pillars, smaller bump sizes and narrower pitches. This has resulted in lower flexibility of joints and more sensitivity to the influence of coefficient of thermal expansion (CTE) mismatch. Component tilt, open solder joints and cracks with the use of extreme low-K (ELK) dielectric materials are defects that increase with this trend.

BTU's solution, TrueFlat technology, which uses negative pressure reflow is designed to alleviate yield losses due to CTE mismatch during reflow soldering. Advanced thermal control (ATC) is introduced to control the rates of heat transfer for processes sensitive to abrupt expansion and contraction.

ATC is an enhancement of existing control for heating and cooling rates to achieve continuous, uniform heat transfer. This provides the ability to control the abrupt expansion and contraction stress produced by micro spikes.

Challenges of Miniaturization

Silicon flip chip and thin organic substrates have significantly different CTEs. CTE mismatch for flip chip on thin substrates has been a challenge for more than 10 years. Controlling defects in mass reflow caused by warpage- and CTE stress-related cracks has long been the focus of reflow process engineers. Other reflow techniques, such as thermal compression bonding, are available. However, these processes are expensive and have low throughput, which makes mass reflow a preferred process.

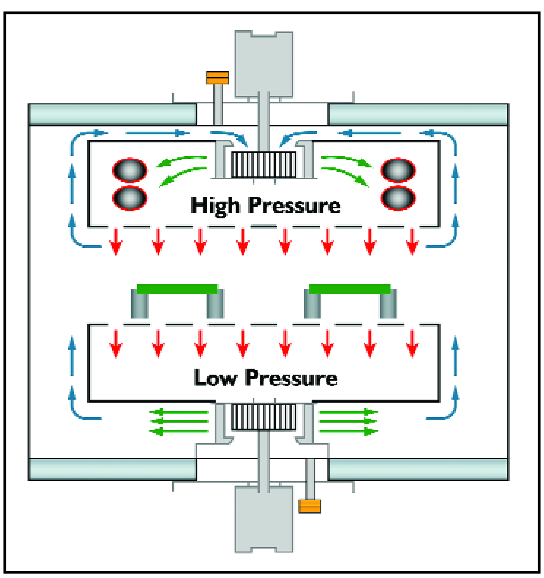

Figure 1: Negative pressure reflow design.

Existing mass reflow methods to alleviate the effects of CTE mismatch consist of a solid carrier acting as a heat spreader, a cover plate to attempt to hold down the substrate during reflow and the use of a slow cooling process to control the rate of contraction. This method is being challenged as miniaturization continues.

The use of a reduced or negative pressure (pressure below atmosphere) below the carrier throughout the entire reflow process enhances the contact of the substrate on the carrier and helps to keep the substrate flat.

This enhances localized contact below the chip, where a cover plate is not effective. More effective heat spreading produces greater temperature homogeneity and reduces the impact of abrupt expansion and contraction due to CTE mismatch. Ensuring contact with the carrier helps to keep the substrate flat and reduces deformation.

Negative Pressure Reflow

To demonstrate experimentally, this requires two stages. The first stage is to ensure effective contact of the substrate to carrier. The second is to control the heating rates for the reflow process. The objective of negative pressure reflow is to generate a continuous suction from the start of heating to the end of the cooling process within the heated chamber. A slow cooling rate profile is adopted to minimize the impact of heat spikes.

Figure 1 demonstrates the gas flow to generate effective suction with edge rail conveyors. Redirection of gas flow on the bottom of the process produces a suction box effect, and a pressure below atmosphere, directly below the conveyor and product — hence the name "negative pressure reflow."

The carrier design is important for uniform suction and heating. A large suction hole size creates localized heat spikes. The recommended layout is 0.04 in. (1 mm) diameter hole grid

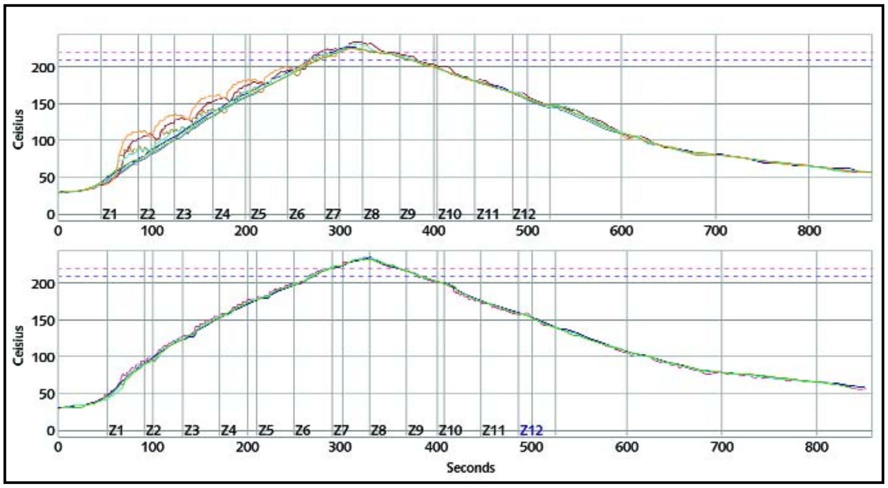

Figure 2: Window cover without suction (top) and with suction (bottom).

below the substrate. There are window and mesh top covers used in standard reflow ovens without suction. Mesh has the advantage of holding down the edges of each chip but has less flexibility and costs much more to produce. Window covers hold down the edges of the substrate and allow different layouts of chips on the substrate. The center of the substrate is subjected to deformation, as there is nothing ensuring proper contact of the substrate to the carrier.

Pressure should be measured below the carrier with a room temperature fixture overlaid onto a ramp to spike (RTS) slow-cool temperature profile — measured in the same oven. If the suction remains effective throughout the process, it ensures intimate contact of the substrate with the carrier above the Tg of the substrate where the deformation is at its worst.

As temperature increases, suction force will be reduced. This is a normal phenomenon as air density increases with higher temperature, reducing the efficiency of suction. With a normal tin-silver-copper (SAC) reflow profile, the suction reduction will be about 30 percent. However, this is still sufficient to keep the hotter substrate held down on the carrier. This can be demonstrated with a thermocouple (TC) mounted on the carrier, just below the TC on the top side of the substrate.

The top of Figure 2 shows the heating of the substrate as humps, due to the absence of the heat spreading effect as the substrate lifts off from the carrier as it deforms. With suction, effective heat spreading occurs, which evens out the temperature.

Advanced Thermal Control (ATC)

Below are the heat transfer formulas related to mass reflow ovens.

Convection heat delivered: $Q = HA\left(T_{conv} - T_{Target}\right).t$

Target heat absorbed: $Q = MC_p\left(T_{final} - T_{initial}\right)$

This produces S-curve heat transfer characteristics and the heating rate will reduce when the target temperature approaches the convection temperature. Common parameters for mass reflow ovens based on the parameters for the above transfer are: M = mass of the product and carrier; C_p = specific heat capacity of carrier; A = exposure area; t = exposure time; H = coefficient of convection; and T = temperature.

Control of the heating rate can be achieved by adjusting the reflow parameters. The mass (M) of the product is an important factor. It is necessary to reduce excess area and weight of the carrier to minimize effects of forward heat sinking and backward conduction, which impact the thermal uniformity along the direction of flow.

It is typical to see the rear of the product with a higher temperature than the leading edge. The rear will act as a heat sink for the leading edge, while the leading edge will conduct heat to the rear as it gets hotter. This effect can be reduced with smaller temperature setting differences between the zones and avoiding high ramp rates, but may require longer zones or a longer oven.

With the oven size, conveyor speed and the product and carrier mass held as constant, the next parameter to investigate is the coefficient of convection (H). The variables for convection heat transfer will be the area of coverage and impingement pressure. Plenum orifice size and distance from target will determine the impingement force on the product. By optimizing the orifice size, distribution and distance from product, the thermal transfer rate can be optimized to a preferred condition. This creates a con-

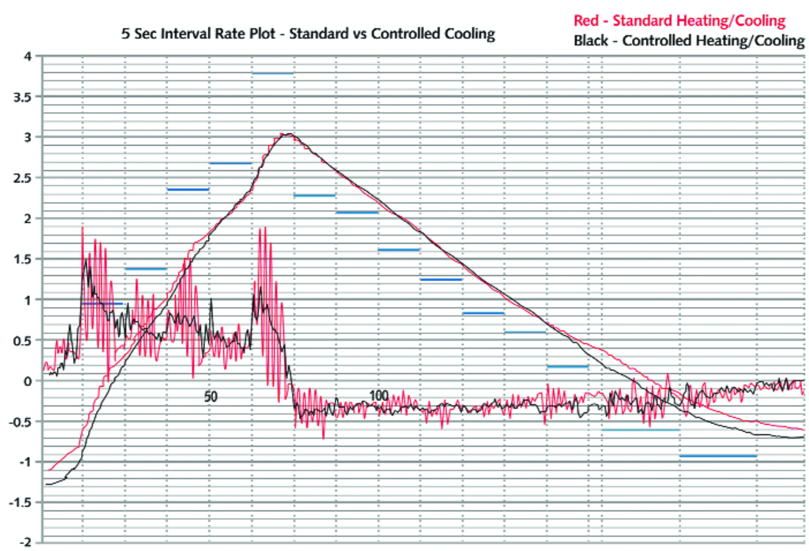

Figure 3: Profile comparison — standard vs. ATC.

trolled heating and cooling rate for the reflow process.

Figure 3 (page 67) displays the profiles with similar settings and some fine-tuning to accommodate the critical areas to control reflow and CTE differences. Unformed joints are not sensitive to CTE mismatch during heating. The area of critical control starts from the reflow ramp at zone 5 to the end of the oven cooling zones. The calculations for heating and cooling rates are made over five second intervals.

The control of the time above liquidus (TAL) is believed to influence the spread size of the solder joint. This determines the area of interface between the substrate and bump and will be more prone to cracks if the timing is too long. Typical TAL values are between 50 and 60 seconds.

It can be seen in Figure 3 that the cooling rates achieved with the controlled cooling from ATC are more consistent, even as those compared to the standard PYRAMAX TrueFlat oven. These spikes over short durations of five seconds are called micro spikes. How critical are these micro spikes to the reflow process?

If the pitch is wide, such as ≥120 micron copper pillars or simply by using soft solder bumps, the effect of these spikes may be less detrimental. With further miniaturization, brittle ELK dielectric with copper pillars and much finer pitch means less flexibility and more sensitivity to CTE-related cracks. Such products will require tighter control of the cooling rate.

TrueFlat negative pressure reflow technology ensures that thin substrates on carriers are kept flat to reduce die tilt and in direct contact for effective heat spreading during the reflow process. ATC complements TrueFlat technology in reducing micro spikes for optimal control of CTE mismatch-related defects.

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