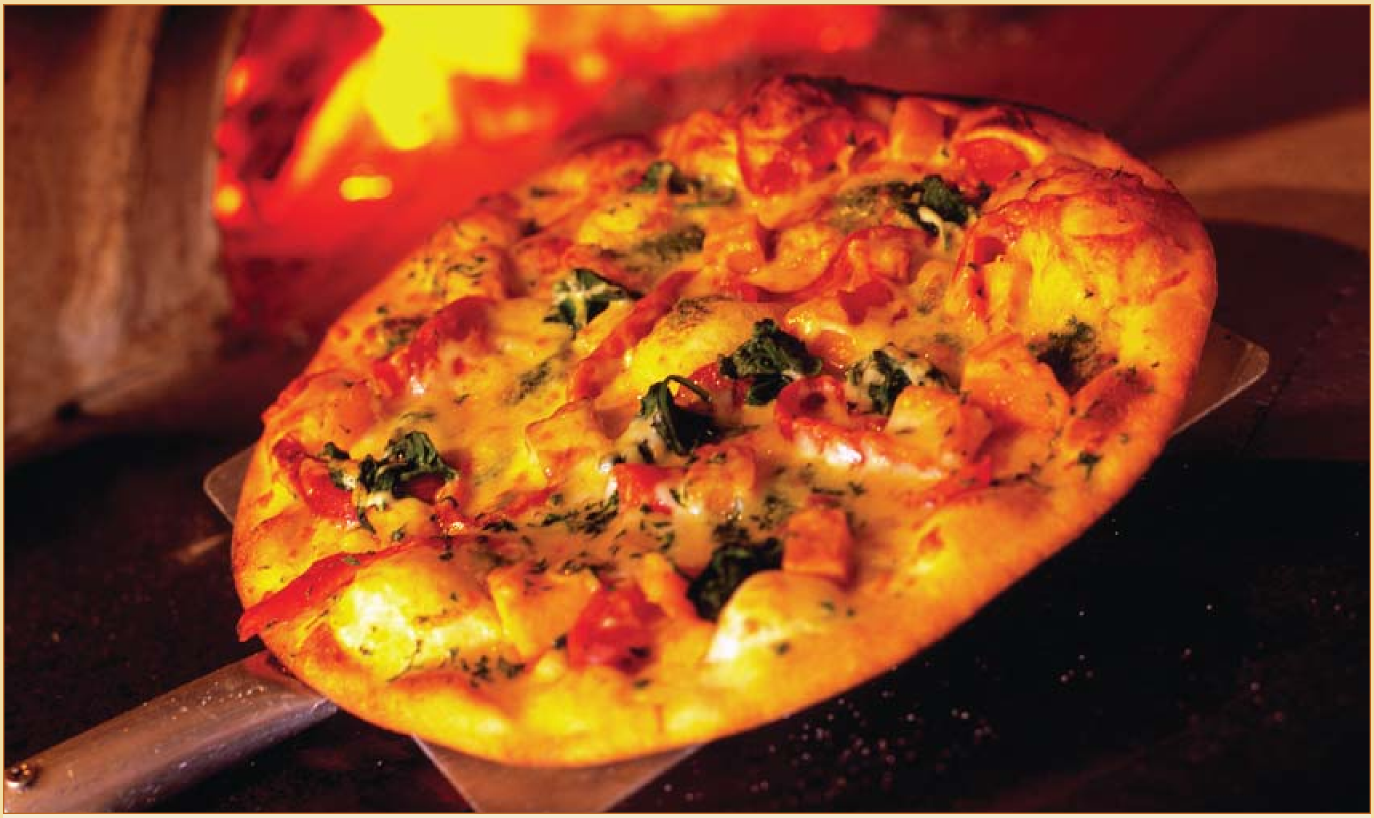
Chip Scale REVIEW

Reflow Options for Wafer-Level Packaging



Reflowing cheese onto a 400mm pizza is slightly less critical than the reflow process in electronics, but a failure to adhere to good practices brings the same result: An undesireable product.

One of the oldest process steps in the production of PWBs, the reflow oven has come into its own as a critical adjunct to wafer-level and multi-chip packaging. With the variety of types available, and the choices of hardware and software, users must exercise skill in selecting the "right" oven for their applications.

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Once upon a reflow, the primary oven use was for PWBs. Increasingly, however, it's for wafer-level and multichip packaging.

Reflow ovens are invaluable for WLP bump formation as well as for heating WLP photoresists, plated bumps, solder balls and screened solders. Reflow is easily scaled somewhere between loose PWB specifications and more demanding wafers to accommodate SiPs and other multichip packages.

Pb-Free Impact

How does the Pb-free era impact the selection of reflow ovens? Some necessary tweaking has already occurred, and there will doubtless be more.

Solder reflow has been a staple of the semiconductor packaging process from the beginning. The push toward 300mm wafers, and the development of more complex circuits, has made the reflow process even more critical. Despite the global rush to Pb-free, tin-lead is still widely used, so an oven that processes both is a worthwhile investment.

Precise temperature management is essential, and is often controlled by a combination of software and hardware. It's hardly surprising that wafer or package thermal uniformity during reflow has become a key buying point.

Technologies Abound

The primary oven types used today for reflowing solder on wafers or in packages are **conduction**, **forced convection**, **infrared** and **muffle**. Some reflow furnaces combine more than one of these technologies.*

Conduction technology (typically using atmosphere, or better yet, nitrogen to prevent oxidation) uses the transfer of heat from a hot plate to the bottom of the wafer. Conduction heating is robust for solder bump reflow, particularly for solder paste bumping.

By heating a wafer from below, the silicon conducts heat to the under-bump metallization, which heats and activates the flux to create a reliable solder joint. The drawback of some conduction systems is the "hot plate" concept that may result in non-uniform heating and mechanical stress on the wafer.

Forced convection technology is widely used in PWB component mounting and other reflow processes. Heated process gas (typically nitrogen) is forced at high velocity onto the wafer with solder to be reflowed. Heat is transferred by convection to the wafer and solder. Because the system heats from the top down, drying of the flux may result.

Infrared heating employs lamps that emit medium- and short-wavelength radiation. This radiation interacts with wafer and solder causing both to heat. With a high degree of short wavelength IR, profiling can be difficult, but not impossible, as a change in a material's emissivity will change the rate at which it absorbs heat.

Muffle technology employs a process chamber and belt surrounded by a heated metal shell (i.e., the *muffle*) for the entire belt length. Heat transfer occurs through a combination of medium wavelength IR radiation from the muffle and convection.

Ambient temperature process gases such as nitrogen and/or hydrogen are introduced, normally over the wafers. The insulation and muffle have significant thermal mass, limiting quick response to varying loads and profiles.

The inability to shut down this type of furnace if it is operated less than 24 hours per day, however, can result in a high cost of ownership.

Conductive, Convection or IR?

Kail Wathne, Sikama International Inc., Santa Barbara, Calif., notes, "Most reflow ovens, whether they are infrared, convection or a combination of both, use air or gas to transfer their latent heat to the product (PWB, wafer, package) to be heated.

"One can transfer heat energy through metal, typically aluminum, directly to the product via conduction."

A dramatic example that proves the point, notes Wathne, is a very simple experiment that anyone can perform:

"Take a saucepan full of water and place it on the electric burner of your range top, and set it at medium to high. This pan of water will reach boiling temperature in less than 10 minutes, because of the direct conduction of the heat. However, if you preheat a standard kitchen oven to 400-500°F, then insert an identical pan of water, it will take over an hour to reach the boiling point!"

Sikama Ultra Profile 2000 System for BGA strip sphere soldering with small 48" x 38" footprint.

Combination Systems

Wathne suggests simply combining the excellent heating characteristics of conduction heating with optional convection heating for highly controllable reflow heating.

Convection holes in the conduction plates allow for efficient heating even if full contact is not made with the wafer or substrate. This also allows the nitrogen atmosphere to enter through each zone at precisely the temperature set for each plate.

Combined with an inert gas hood, says Wathne, "this technology adds up to an incredibly efficient and versatile reflow oven. By bringing the temperature of the product down quickly, below the liquidus point of the solder, the solder is above the melting point for a minimum period of time."

This reduced "time above liquidus" allows for a tight grain structure in the solder to be achieved.

"This grain structure is directly affected by length of time above the melting point of solder," he adds, with the strength of the solder fillet diminished by longer liquidus times.

Thermal cycling of these solder bonds will show that MTBF will increase with the tighter grain structures formed by shortened times above liquidus, Wathne observes.

Reflow Refinements

Tilo Keller, ERSA GmbH in Wertheim, Germany, says, "Further developments in the reflow process and in reflow equipment will be determined by future component development as well as by innovations in soldering materials.

"In general, a reduction of the thermal load on the board/wafer/substrate and the components will remain critical."

Keller insists that wafer-level integration (3-D integration in particular) will certainly be an ongoing issue in the future.

Mechanical and electrical integration with the view of further miniaturization (heterogeneous system integration), as well as flexible assemblies will offer more functionality on an ever smaller area—more I/Os per square millimeter of board space is the key. Selective reflow may be a possible solution for very challenging microwave packaging.

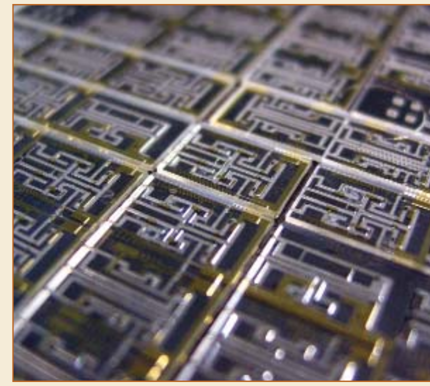
Needs Change

Heike Schlessmann, SEHO Systems GmbH, Kreuzwertheim, Germany, notes, "The changing requirements of customers, new products and new materials—especially refractory compound alloys—demand a shift in thinking for reflow soldering.

"Although four heating zones were absolutely enough to produce a good reflow temperature profile with a low *Delta T*, the Pb-free compound alloys represent a new challenge and more flexibility for otherwise identical lengths of heating zones and machines."

The same thing applies to cleaning the process gas, notes Schlessmann. The noticeably increased process temperatures for Pb-free soldering processes inevitably lead to higher rises in evolutions of exhaust gas, i.e., from the solder paste components, solder resist and conductive materials, as well as from the reactive products of these substances.

These process temperatures inevitably lead to decisive changes in the plant



Bio-chem sensor wafer-level packaged in hard vacuum at <10 mTorr is very susceptible to excessive reflow heat. This device's hermetic seal has better than a >98% yield. (Massachusetts Institute of Technology) engineering and process engineering of modern reflow systems.

Pb-free Cautions

Debbie Liguori of Qualitek International Inc., Addision, Ill., warns, "The reflow soldering process using lead free is very similar to the conventional eutectic solder reflow process. However the differences are very important and must be taken into account when using Pb-free solder.

"Lead-free materials require higher reflow temperatures, and the process window is narrow in comparison to typical tin/lead soldering."

Both PWB materials as well as wafers and IC packages must be able to withstand higher reflow temperatures without warpage or other damage. Solder alloy and flux chemistries must be appropriate to handle the higher melting temperatures as well.

Liguori notes that the increase in peak reflow temperatures in combination with a narrow process window makes the development of an optimal reflow profile a critical factor for ensuring a successful lead-free assembly process.

Challenges

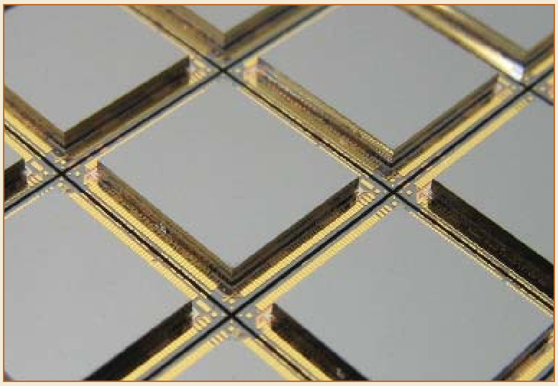
Monteith G. "Monte " Heaton of Innovative Micro Technology (IMT) in Santa Barbara, Calif., notes, "Customers seeking wafer-bonding services should look for a vendor with a broad range of proven experience in bonding in a variety of environments and with a variety of bonding methods.

Contract manufacturers for MEMS devices and other wafer-bonding services feel the greatest impact with reflow processes, especially for WLP and manufacturing of microfluidics devices. Bond methodologies include glass frit, anodic, fusion, polymer, and low-temperature eutectic bonding, but have even tighter temperature requirements."

"For efficiency and the best results for vacuum bonding and WLP, customers should seek a vendor that can not only bond but also deposit the getter required for maintaining vacuum over the life of their product—which is definitely affected by reflow temperatures and uniformity.

"The devices most at reflow risk are both IR and hazard detection devices under vacuum (1 mTorr) using glass frit bonding and proprietary getters. Also, MEMS devices for switch arrays use low-temperature eutectic which bonds at less than 200°C.

"Low-temperature eutectic bonding—or solder reflow—is particularly valuable for customers with very temperature-sensitive devices," Heaton adds. "Whether for IR devices, resonators, switches, or other products, hermeticity is in most cases the key to long-term device performance."



Wafer-level packaged switch arrays at 1 atm pressure for copper interconnect and reflow. They are hermetic with >98% yield. (Innovative Micro Technology)

Temperature, Time, Atmosphere

Sikama's Wathne says reflow technology has undergone some major changes recently. This is largely due to the requirements in the industry to improve process control. "Three major factors contribute to achieve this: temperature, time and atmosphere. Not only do you have to control each parameter, but you have to do it at the same time, as each interacts with the other."

It is no longer tolerable that one of the ingredients is held to spec and the other can just be so so according to Wathne. Today's furnaces must be compact, and it must be "green," i.e., use less electricity, nitrogen and/or forming gases. For the processing of plastic BGAs, a cycle rate of 10 seconds or less is essential, he says.

Effective Heat Transfer

Heat transfer efficiency is one of the most important criteria for modern reflow soldering systems. Generally, the lower the oven's set temperature is in the zones, the lower the thermal stress on components and the carrier's materials. Typically, the rate of oxidation is correspondingly lower, too.

The reflow soldering system's flexibility plays an important role because the Pb-free soldering process offers less scope for potentially defective influences due to shorter processing times.

Systems that have a sufficient number of zones—especially in the peak area—are definitely ahead in this case.

The design, thermal dynamics and function influence how the reflow oven is ultimately manufactured. The heat zones are the heart of any furnace with uniform heat distribution a must.

Conclusion

As comedian Steven Wright once said, "A conclusion is the place where you got tired of thinking," which leads us to the biggest problem with solder reflow: its higher melting point for Pb-free solder.

* T. Goodman and P. Elenius, E&G Technology Partners, Tempe, Ariz., and J. Marcin and C. Richert, Radiant Technology Corp., Fullerton, Calif., "Evaluating Wafer-Level Solder Reflow Options to Maximize Yield," *Chip Scale Review*, August 2003.