Spin-Coating Waferbumping Fluxes for Semiconductor Assembly: Ensuring Pristine Microbumps in Dimensional Devices

Introduction

Moore’s Law, the driving force and *sine qua non* of the semiconductor industry for the last sixty years, is beginning to slow due to both physical and economic limitations. While advanced transistor technologies such as FinFET are facilitating the downward gate length trend, the ITRS has recognized the importance of so-called “dimensional devices”—i.e., stacked-die and die-on-interposer (2.5D and 3D architectures)—as key enablers of “More than Moore”.

As a concomitant, flip-chip on interposer technology (2.5D assembly) alleviates the majority of thermal cycling stresses on the increasingly delicate ultralow k (ULK) dielectric. 2.5D is also an essential element in high-speed heterogeneous “system-in-package” (SiP), i.e., integration of disparate die sizes and die types in a single unit. As semiconductor nodes and die shrink, the number of I/Os will either increase or remain relatively constant, leading to a need for finer pitches. With device-device interconnect pitches shrinking below the 100micron level, plated copper pillars with plated solder microbumps have supplanted the standard flip-chip waferbump (Figure 1).

The reasons for the move from standard solder bumps to copper pillars are primarily to:

- Allow high I/O ultrafine pitches (<100microns) without solder bridging
- Maintain high stand-off (chip-substrate clearance) to reduce shear stress on the chip surface during thermal cycling
- Eliminate or significantly reduce electromigration issues caused by current-crowding in solder near the UBM

Figure 1. Evolution of solderbump metallization and structure.
Flip-chip joining processes are also undergoing change—migrating away from standard reflow processes to new TCB (thermocompression bonding) processes (Figure 2).

Figure 2. Building a 2.5D assembly using TCB.

Whether the solder joint is formed by reflow or TCB, its reliability is strongly dependent on the assembly process. Main solder joint-related control factors for device reliability from TCB include:

- Uniformity of solderability of both the solder microbump and the solderable metallization
- Absence of solder joint voids (due to poor solderability or particulate entrapment)

After the solder microbump is deposited on top of the copper pillar, the photoresist and seed layer are then removed. The highly-reactive stripping fluids used in these processes react with tin in the solder, in the presence of oxygen, to form tin oxides and hydroxides on the surface of the solder.

The basic process flow for copper pillar/microbump formation is show in Figure 3.

Figure 3. Copper-pillar solder from plating to finished microbump.

The process successfully applied for the cleaning and planarization of post-strip solderbumps (the so-called “bump fusion” process) is spin-coating of semiconductor-grade bump fusion fluxes (also known as waferbumping or simply “wafer” fluxes) followed by reflow and cleaning.

Spin-coating is used to apply a uniform, thin layer of a material onto a substrate, which then spins to spread the solution out by centrifugal force. The typical steps of a spin-coating process include the following:

- **Deposition**: An excess of material is applied to the substrate, usually by simple dispense
- **Acceleration**: Takes the substrate up to its final rotation speed
- **Spinning**: Rotating the substrate at a constant rate, with mass of the material being lost during:
  - **“Spin-off”**: Excess fluid lost from the edge of the substrate due to centrifugal forces
  - **Evaporation**: Solvent vapor losses during this stage
- **Deceleration**: Slow down

Figure 4 shows a plated microbump-capped copper pillar after waferbumping flux reflow and cleaning.

Figure 4. 40micron diameter SnAg microbump on copper pillar.

Waferbumping flux is therefore a means of turning rough, ugly plated solder bumps into the low-oxide, coplanar bumps needed to form a reliable flip-chip joint in subsequent attach processes. In order to eliminate voids in the final reflowed flip-chip joint, it is critical to have a reflowed solder microbump surface that is perfectly hemispherical, smooth, organic and inorganic residue-free, and coated with a thin semi-passivating layer of tin monoxide (SnO).

The other instance in which the solder bump or microbump must be reflowed is when the bumps are subject to probe-testing in a way that coins (damages) the solderbump; damage to the upper part of the solder bump is especially worrisome. In these cases, the bump usually needs to be re-reflowed to return it from its coined condition to a pristine hemisphere. Coin-related voids, usually located in the center of the subsequent flip-chip joint, can be eliminated by this means.
Failure Modes Due to Flux Non-Uniformity

If grossly insufficient flux is deposited on the wafer, then the results are very poor. Figure 5 shows the spider-like result, caused by insufficient wetting, by putting only 5 grams of flux onto a 200mm wafer.

Figure 5. Insufficient flux gives a poor quality film.

In order for these fluxes to remove oxide, it is obviously critical to have sufficient flux in the correct location. It is obvious that the tip of the microbump on a copper pillar must be below the surface of the flux, at least initially during the reflow process. The experience of several customers has shown that if sufficient flux is not available, a “tide mark” may appear on the microbump surface (Figure 6).

Figure 6. Effect of waferbumping flux height.

Therefore, it is critical to be able to define a spin-on process that can provide a controlled, reproducible thickness of flux on the wafer before reflow.

Flux Thickness Measurement

The measurement of waferbumping flux thickness is not a simple task because it requires both specialized equipment, and knowledge of optical parameters for the flux that are not easily obtained. In order to speed customer time to market, data was gathered and a mathematical model was developed to guide customers on how to rapidly set up their waferbumping flux dispense process, depending on the final post-spinning/pre-reflow flux thickness requirement. Indium Corporation worked in close association with Solid State Equipment Corporation (SSEC) of Horsham, PA to validate the model.

In the case of waferbumping fluxes applied by spin-coating, the flux thickness is a function of several different factors, the most critical being:

- Initial amount of flux on the wafer
- Spin speed/time
- Flux viscosity
- Temperature

Mathematical models already exist for the application of photoresist, which is a Newtonian or near-Newtonian fluid. It is similar in rheological behavior to waferbumping fluxes; therefore, these were used as a starting point.

The final film thickness was measured at SSEC using a Filmetrics F60 thinfilm reflectometer. One example of the experimental data obtained and the close fit to the mathematical model is shown in Figure 7.

Figure 7. Modeling and experimental film thickness for 20ml of flux on a 200mm wafer.
Figure 8 is an example of an output wafer map, showing the small variations in flux thickness across the wafer.

**Figure 8. Flux thickness map on a 200mm wafer.**

### DI Water Cleaning

After reflow is complete, Indium Corporation waferbumping fluxes, such as WS-3401 and WS-3543, are designed to be cleaned with deionized water only. Customer process data confirms that no specialty solvents, cleaners, or other additives are required to completely dissolve post-reflow flux residues. For many customers, this has significantly reduced both solvent and disposal/waste treatment costs, as well as time to market.

### Conclusion

A uniform thickness of flux can be achieved with the correct process setup and by adjusting specific parameters. In general:

- The shorter rotational time produces a more uniform film thickness across the wafer than the longer rotational time.
- For the majority of the rotational speeds, the lower viscosity material also produced a more uniform film thickness. With the correct parameters adjusted for a specific application, the desired film thickness and uniformity can be obtained.

Generally, spin-coating for photoresist materials is well-understood, due to the predominance of this application method and material. A bump fusion flux differs from a photoresist material when spin-coating, even though they have similar viscosities. For the bump fusion flux, lower rotational times and speeds are needed to achieve a consistent coating, due to the lower viscosity and solvent evaporation rate.

### References

1. International Technology Roadmap for Semiconductors (ITRS) http://www.itrs.net/

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