Design of Filled One Step Chip Attach Materials (OSCA) for Conventional Mass Reflow Processing: Curing Kinetics and Solder Reflow Aspects

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Abstract

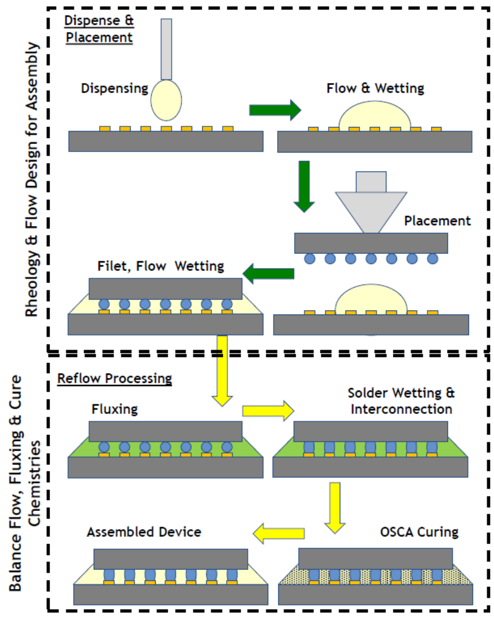
One step chip attach materials (OSCA) are dispensable polymeric materials for flip chip assembly, which are designed to flux metallic interconnections and subsequently turn into an underfill upon curing. OSCA materials enable a drastic simplification of the assembly process by combining the reflow (fluxing / soldering), flux residue cleaning and capillary underfilling steps used in traditional processing into a single step. OSCA materials designed for conventional mass reflow processing (gang reflow) are designated as OSCA-R. A key challenge when designing OSCA-R materials is timing the cure kinetics with fluxing activity and solder reflow during reflow processing. OSCA-R materials must also have a process-friendly rheological design that integrates seamlessly with standard dispensing equipment when formulated to contain high filler loading levels. The consideration of the interactions between the filler particles and the organic portion of OSCA materials is critical for achieving fluxing and interconnection during reflow and curing to develop target thermo mechanical properties for reliability such as Tg, TC, CTE modulus and adhesion after reflow. This paper presents research focused on understanding the impact of filler loading, size, type and surface chemistry on curing, fluxing and interconnection kinetics during reflow processing measured by thermal and rheology methods. Preliminary results indicate the presence of chemical interactions between the filler and organic formulations as well as non-obvious physical interactions that need to be accommodated to design OSCA-R materials for device assembly using conventional mass reflow processing.

Introduction

There is a need in microelectronics assembly to increase throughput of manufacturing processes. Focusing on the portion of the assembly operations involving the assembly/attachment of flip devices it is clear that materials which simplify and remove steps from the assembly process are of great utility. The traditional assembly process for flip chip devices proceeds by a multistep process [1,2]. First, application of a flux to solder bumps on a die (dipping), then placement onto a substrate (pick and place machine) followed by reflow processing (oven) to melt the solder and form interconnections for a total of three steps. Sometimes a cleaning step is used to remove flux residues from the gap between the die and substrate before the gap is filled using a capillary underfill process adding two more process steps. Finally the underfill is solidified in a curing step to bring the total to 6 process steps for flip chip assembly. To increase throughput of the device assembly process it would be advantageous to combine the flux and underfill materials into one single material enabling three steps; fluxing, underfilling and cure to occur during the reflow processing step thus eliminating the defluxing and capillary underfill steps [3]. Materials that accomplish this are referred to here as One Step Chip Attach or OSCA materials. Fig. 1 illustrates the OSCA process where the materials are dispensed onto the substrate prior to die placement and processed by conventional mass reflow techniques. The key technical challenge for OSCA material design is combining the flow properties, fluxing/soldering performance, curing kinetics and the final reinforcing performance properties into a single material [5], [6]. Performance properties such as low CTE, enhanced modulus, increased thermal conductivity, improved reliability are achieved in OSCA materials by the addition of particles (fillers) following the same approach used for traditional capillary underfill materials. This paper is focused on the balance of the flow properties required for dispense and die placement with the fluxing/curing kinetics. In particular, the influence of particles (fillers) and consideration of their impact during design of OSCA materials is discussed.

Discussion

Figure 1 illustrates an assembly process using OSCA materials where the assemblies are processed using auger or jet dispense systems and interconnected using conventional mass reflow oven technology. Taking a closer look at the OSCA performance requirements in the two block process steps, shown in Figure 1 "dispense and placement" and "reflow processing" respectively. During the dispense step OSCA-R materials must have rheology and flow conducive to dispense by positive displacement and jet dispense systems. After dispense the "flow and wetting" of OSCA-R must be controlled to keep the material on the target location and from flowing into no-go zones. During die "placement" step OSCA-R needs to flow sufficiently to allow contact between bumps and pads without effecting alignment. After die placement OSCA-R must remain close to the device perimeter forming a filet with target dimensions and not bleed out. The rheological design of particle filled OSCA-R materials to accomplish the first portion of assembly requires specific attention to the design/selection of the filler particles. The details of OSCA-R rheology design for die placement are discussed in greater detail elsewhere [7].



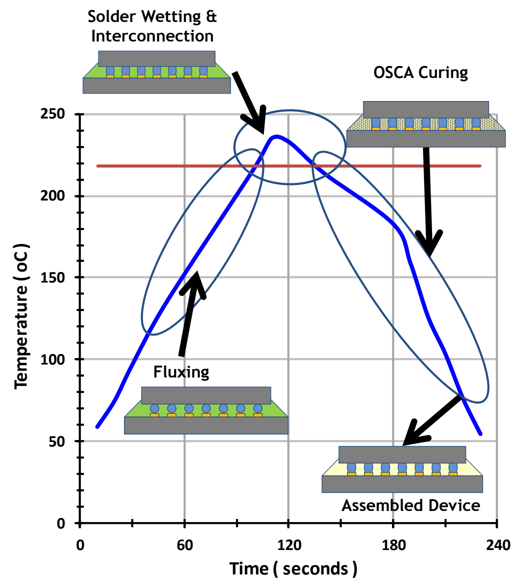


Figure 1: Assembly process using OSCA-R materials. **Figure 2:** OSCA role during reflow processing.

During the "reflow processing" step, the effect of the filler particles on fluxing, solder flow and polymerization needs to be considered to design and integrate OSCA-R materials into assembly processes. Figure 2 shows the process steps in the "reflow processing" overlaid on a temperature profile used for processing OSCA-R materials. During the "fluxing" step the polymerization must be negligible enabling the chemical fluxing action to occur. The filler particles in the formulation must not interfere with the fluxing of the solder joints via chemical or physical interactions. When the assemblies pass the solder melting point OSCA-R materials need to allow for solder wetting and joint collapse to form interconnections. This implies that the degree of polymerization must be sufficiently low and far below the gel point when the solder melts. The filler particles should not interfere with solder wetting and joint formation or remain trapped within the joint. Once the solder joints are interconnected the OSCA-R material polymerizes as the device drops below the melting point and enters the final heating/cooling zones of the reflow oven. OSCA-R materials are designed to achieve 60% to 90% cure after reflow processing. The degree of cure achieved depends on the length of time spent above the solder melting point and the time spent in the final heating/cooling zones.

Curing kinetics of OSCA-R materials during reflow processing can be studied via analysis of DSC heat flow curves following the method described by Borchardt and Daniels [10], referred to here as the BD analysis. The BD analysis produces a set of empirical modeling parameters that can be used to track and understand the influence of reflow oven profiles on the cure of OSCA-R materials and conversely design OSCA-R materials for specified reflow profiles. In addition the BD model provides a method to track the response of the curing kinetics to the filler level, type, surface properties, size and dispersion state. Figures 3 and 4 illustrate the curing behavior of OSCA-R materials during reflow with 0% and 40% filler content respectively. The filled system achieves a higher final degree of cure than the unfilled system but both systems achieve gel point conversions sufficiently far into the solder liquid allowing for interconnection. Table 1 presents the parameters determined by the BD model for the systems shown in Figures 3 and 4.

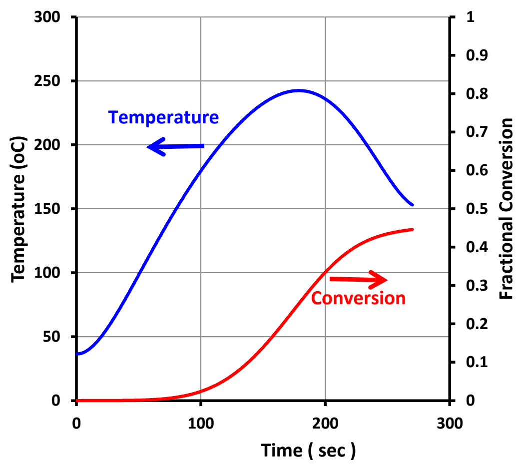


Figure 3: Curing of unfilled OSCA-R material during reflow.

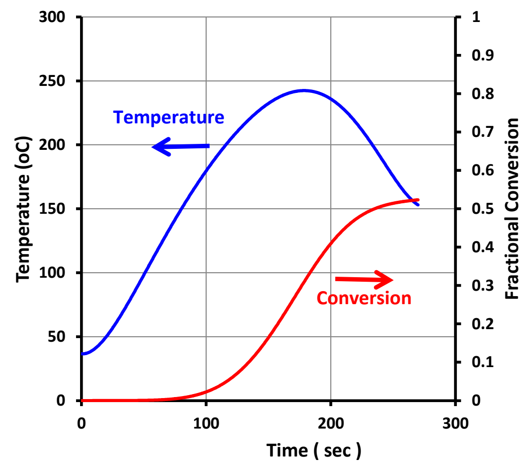


Figure 4: Curing of filled OSCA-R during reflow.

Table 1: BD model parameters for silica filled and unfilled OSCA-R materials.

BD Model Parameter	Definition	Units	Unfilled, 0%	Filled, 40%
N	Reaction order	--	0.4	0.6
Ea	Activation Energy	kJ/mol	44	52
Log (Z)	Pre Factor	1/min	3.9	4.9
ΔH	Reaction Enthalpy	J/g	360	235

The addition of the filler particles decreases the reaction enthalpy (ΔH) as the fillers dilute the reactive polymer and reduce the total enthalpy of reaction. Table 1 also shows an increase in the reaction order (N) as well as the activation energy (Ea). Increasing the reaction order (N) tends to speed up the reaction rate while increasing Ea tends to slow down the reaction rate. The pre factor (Z) loosely represents a reaction frequency factor, probability for events to occur. Adding filler in this case increases (Z) and thus increases the overall rate of reaction. The results suggest that the reaction rate for OSCA-R materials containing filler particles is a balance of pure chemical (enthalpy) and physical reaction contributions such as frequency, diffusion of heat or mass. The suggestion that curing kinetics can depend on the diffusion of mass suggests a possible relationship with particle size, shape and aspect ratio. The dependence on heat transport suggests that the thermal transport properties of the particles may require consideration when tuning chemistries for reflow processing. Silica fillers are amongst the most commonly used in underfill materials and help to achieve higher toughness and thermo-mechanical properties that improve device reliability. However, there are some short comings of silica fillers including low thermal conductivity even at higher loading levels. In the pursuit of developing high thermal conductivity OSCA-R materials for applications where heat dissipation is required for even greater device reliability a series of filler particles varying in chemical type and heat transport properties are being investigated. Table 2 outlines the filler materials currently being studied in OSCA-R formulations.

Table 2: Thermal conductivity of fillers explored in OSCA-R materials.

	Description	Shape	TC (W/m-K)
SiO2	Silica	Spherical	~1
Al2O3	Aluminum Oxide	Spheroid	20~29
ALN	Aluminum Nitride	Platelet	~200
BN	Boron Nitride	Platelet	250~300
CNF	Carbon Nano Fibers	Rods	~2000

Summary

The studies demonstrate OSCA-R materials with thermal conductivity levels > 1.5 W/m-K require a balance between the rheology stemming from the particle shape and loading with the filler impact on curing kinetics. The BD kinetics model in conjunction with detailed rheology investigations [7] can be used to understand the contributions from the different particle types and design OSCA-R chemistries appropriately to achieve device assembly using the OSCA process.

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