Green IC Packaging: Options, Challenges and Direction

by Allan Toriaga, Director of Operations, Assembly Engineering, and Jean Ramos, Manager, Package Development
Advanced Interconnect Technologies

The push from the semiconductor industry for complete Green IC packaging is stronger than ever. The lead-free (Pb-free) initiative is being driven on a global basis in Asia and Europe. For example, in Japan a standards body, the Japanese Electronic Industry Association (JEIDA), has been formed to monitor its Green progress, and in Europe the European Waste in Electrical and Electronic Equipment (WEEE) taskforce is directed to minimize the environmental impact of electronic waste. As the world turns to Green manufacturing, the next generation of assembly and test service providers must have this option in their portfolio in order to comply with industry legislation and demand.

Japanese OEMs are marketing environmentally-friendly household products, and as Europe prepares to meet the EC directives that will be enforced by July 1, 2006, the level of conversion to Green semiconductor packaging is sure to increase. In order to be compliant with the directives by the 2006 deadline, electronic OEMs around the world, especially those US companies who target customers in Europe and Japan are working with suppliers who are capable of offering a complete Green package solution. Although the US has no pending legislation to ban lead, there has been legislation introduced to Congress to encourage recycling of electronic products (See references).

Several pieces of the package material set have to be considered when developing Green IC packaging. This article discusses several options for Green replacement materials and the challenges that arise with the introduction of alternate materials; they must be evaluated, since IC manufacturers still require that assemblers come up with Green packages that meet the reliability standards.

With this in mind, let’s look at the primary components the industry is considering for green replacement solutions.

Creating The 100% Green Package: What To Consider And Why

There are several components of the IC Package material set that must be considered when creating a complete Green package. For Ball Grid Array (BGA) style packages, the substrate core and the soldermask material have to be considered in order to eliminate halogens while using Pb-free solders. For lead-frame based packages, an alternative solution must be found in the plating process to remove lead. For both package types qualified halogen-free mold compounds must be used.

What Are The Alternatives For Green Materials?

For each of these components that must be replaced with Green alternatives, there are several options for the package assembly provider to choose from. Each of these must be evaluated to determine the best material solutions such that both meet the Green Package standards as well as the reliability and quality standards of the assembler and the IC manufacturer.

1. For substrates, the primary objective is to eliminate Bromine, a halogen associated with ozone depletion. There are several replacements for Bromine, an organic material. Some of the available alternatives for bromine are inorganic, including metal hydrate, metal oxides and red Phosphorous. Because inorganic additives are mainly solid particles, they tend to have dispersing issues in the epoxy which cause potential reliability issues. Accumulated inorganic materials reduce the peel strength of the laminate. Moisture absorption tends to be higher also, especially for red Phosphorous which will affect package reliability, and may induce corrosion or delamination when exposed to high temperature. For organic replacements there are 2 types: reactive and non-reactive organics. Reactive organics are preferred because they react with the polymer thereby, eliminating leaching on the plate baths and other wet processes. Like inorganic replacements, high moisture absorption is also a common concern. Because of these, substrate suppliers have put in place added controls during fabrication: controlled staging, high temperature cure, leaching controls, etc
2. The soldermask does not have a substantial amount of Bromine. Present day soldermask materials are not flame retardant, and rely on the laminate for flame retardancy. A standard soldermask material contains ~2500 ppm of halogens, of which only 200 is Bromine, and 2300 is Chlorine. An issue addressed during the conversion to Halogen-free substrate is the green dye (phthalocyanine green), which has Halogen, and used in most standard soldermasks. Halogen-free dyes are available but they are blue in color (phthalocyanine blue). A leading soldermask manufacturer was able to formulate a green-colored, Halogen-free dye by combining phtalocyanine blue with anthraquinoid. Advantages offered by enhanced Halogen-free soldermasks are improved curing shrinkage of resin, better resolution on ball pads, reduced water absorption, better thermal stability and improved insulation
3. In molding compounds: metal hydroxide and multi-aromatic resin (MAR is a common alternative for the traditional Brominated flame retardant and its synergist Antimony). The flame retardant-mechanism of each varies from Bromine. While Bromine works in gas phase by preventing oxygen from getting to the fire, metal hydroxide at high temperature releases water and absorbs heat due to the endothermic nature of the dehydration process. MAR, on the other hand, is a self-extinguishing resin which is able to retard burning by forming a foamed layer to prevent oxygen passage. Metal hydroxide-based molding compounds are mainly used on discrete packages (SOIC, DIP) due to its cost; trade-offs are reduced spiral flow and strength. MAR is used for applications requiring flexibility in filler loading and high resistance to cracking, but the trade-off is that it is relatively more expensive. Phosphorus-containing compounds have

also been considered as alternatives due to their low level of hazard; however, high moisture absorption, among others, has led to their unpopularity. Latest generations of Halogen-free molding compounds are substantially free of Phosphorus, Bromine and Antimony

4. The industry-standard solder balls, which typically come in a 63% tin/37% lead structure are now being replaced by Sn/Ag/Cu alloy. The typical combination is 3% - 4% Ag, 0.5% - 1% Cu with the remainder Sn. The 96.5Sn/3.0Ag/0.5Cu alloy is the most popular with Japanese customers. The main drivers are cost, melting temperature, and good board level performance (solder wettability or solderability to the PCB). Using an alloy with a melting temperature above 230°C is generally discouraged (where feasible) due to the stress induced on the components during the high temperature solder ball reflow process. A higher melting point requires higher IR reflow temperatures during PCB assembly which, in turn, could degrade other components on the board if they are not specifically designed to survive the hotter process.

For lead finish, the Tin/Lead (Sn/Pb) common replacements are 100% Tin plating or pre-plated leadframes (PPF). PPF leadframes come in different composition and stack-up, ranging from 2 to 4. A typical 3-layer PPF has Nickel on the first layer, Palladium on the second layer and Gold on the top layer. The advantage of a 100% Tin plating is that is does not require a major change in the plating bath and the two process changes will be on the plating chemistry and the anodes. Plating line control is also much easier with a single plating composition.

What Are The Challenges Of Each Of These Material Changes?

When introducing new material set components for Green packaging, package assembly providers face many challenges and must evaluate the tradeoffs to determine what makes the most sense for their customers.

- Substrates
    1. Cost. Until the volumes are at par or greater than non-green packaging, customers pay a premium for Green alternatives
    2. Supply. Most of the suppliers remain cautious in making huge investments to increase capacity for Green. With the current demand for standard substrates, most major substrate supplier's capacity is already near 100% utilization
    3. Standardization. Substrate supplier A quite often has different preferred material than substrate supplier B. This becomes a challenge for assemblers as IC manufacturers are always aiming for less variation of the package material set. There is no standard substrate material yet defined but this will be driven by the reliability of the product produced from the various material sets

- Mold Compound
    1. Mold compound. These materials must survive delimitation at Pb-free reflow temperatures, so manufacturers have increased the adhesion of the mold compound. In most cases, they have been successful in attaining good reliability performance, but unfortunately, the mold compound also sticks well to the mold chase, increasing assembly equipment downtime due to frequent cleaning
    2. Green mold compounds also have to be optimized for less wire sway, a problem that can occur with wirebonded packages during the mold process. This optimization is either done at the mold process or by optimizing mold material properties such as spiral flow and filler distribution
- Lead Finish
    1. A popular industry concern associated with 100% Sn is tin whisker formation. It is believed that the uneven inter-metallic layer between the Copper and Tin (Cu6Sn5) creates stress that results in whiskers. The major problems caused by tin whiskers are electrical shorts in electronic assemblies. The lack of understanding about tin whisker growth factors and a lack of testing methodology to proactively identify whisker-prone products have made pure tin treatments risky in high reliability applications, such as satellites.

       Counter-measures being used to relieve stress on the plated surface are:
       a. post-plate reflow, Tin over Nickel
       b. optimizing plating bath chemistry
       c. annealing

       Post plate baking will enhance the tin and the copper intermetallic, avoiding stress areas which will prevent whisker growth. Having nickel as a coating of the copper will avoid the intermetallic formation between the Tin and the Copper and help avoid whisker growth. Finally, it’s worth the effort to optimize the plating bath chemistry for these new processes since it will provide a more even distribution of Tin on the Copper surface which also minimizes whisker growth
    2. High-temperature delamination problems can be controlled by matching the PPF leadframes with the optimum assembly bill of materials (mold compound and die attach). Lower stress die attach materials that can withstand higher reflow temperatures are available to provide a matching CTE with the mold compound to avoid adhesion problems
- Die Attach

  There are several considerations when choosing the best die attach material to match the other Halogen-free components: high thermal stability, low stress on the die, minimal out-gassing, minimal bleed-out, compatibility with mold and leadframe/substrate interfaces, low moisture absorption. The most accurate way to determine which of these properties has the most significant contribution still has to be by actual experimentation and testing

Conclusions

With the push from semiconductor manufacturers for complete Green IC packaging growing and becoming a global initiative, assembly and test providers must find the right combination of Green IC package materials. Simply offering Pb-free versions of packages is not enough. For each package material component, the Green alternatives must be evaluated and the challenge of using these new materials must be overcome to meet the reliability demands of the IC manufacturer.

Best-Practice Suggestions:

- Die attach and mold compounds
  Drop-in alternatives are available from various die attach epoxy suppliers and mold compound suppliers. These are readily available for evaluation depending on the application
- Substrates
  Substrate for laminate products are also available. However, these need to be evaluated due to the challenge of higher IR re-flow conditions
- Lead Frames
  1. Pure Tin Plating:
     100% Sn is available from various chemistry suppliers with the corresponding 99.99% Sn anodes to ensure a low Pb-plating bath contamination. Controls are established to have a good surface solderability. Whisker Mitigation strategy must be in place to minimize the risk of whisker growth attributed by the 100% Sn surface finishing
  2. Pre-Plated:
     Pre-Plated leadframe is an available solution but in the past has been cost prohibitive. However, improvements in 3-layer plating have significantly reduce the cost

     Reliability concerns on PPF Leadframe have been addressed by additional gold strike on the palladium surface to enhance compound adhesion

     Assemblers must offer a total package solution that is Green, robust, reliable, standardized and not cost prohibitive

References

For more information on green packaging and legislation, please see the following links:

http://www.ipc.org/3.0_Industry/3.4_EHS/IPC_Maine_BFR_Testimony.pdf
http://www.leadfree.org/LF_1-0.htm
http://www.europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=32002L0096&model=guichett

AIT can be contacted at +1 (408) 734-3222.

About The Authors

Jean Ramos, Manager, Package Development

Based on Batam Island, Indonesia, Ramos manages, directs and leads an engineering team which includes establishing manufacturing capabilities for new packages, developing creative strategies to improve customer service and identifying optimal materials, and processes. While at AIT, she has established unique breakthrough programs in advanced product quality planning procedures.

Prior to joining AIT, Ramos held various roles at Amkor and American Microsystems, most recently as a team leader for BGA (ball grid array) packages. Her noted experience is in BGA, FxBGA, PBGA, HS-PBGA, FCBGA and Ceramic BGA packages with an emphasis on process improvement programs. Ramos has worked in process development and the manufacturing environment for over the past 10 years. She earned a bachelor’s degree in chemical engineering from the University of the Philippines in Quezon City.

Andy Hawkins, Vice President, Worldwide Customer Service and Asia Sales Region

Based in Singapore, Hawkins' responsibilities include leading the company’s global customer support initiatives and overseeing key strategic accounts in Japan and the Asia Pacific region.

Prior to joining AIT, Hawkins held a wide range of senior positions in Asia, Europe and North America. Recently, Hawkins held a role at Hana Semiconductor as vice president of business management where his responsibilities included overseeing customer service programs and managing production, logistics and material controls. In addition, Hawkins also served as an operations manager at Hana Microelectronic and technical program manager at Swire Technologies. His noted experience includes work in a wide range of operation and support roles, researching new factory locations throughout the world and handling Swire Technologies company logistics that lead to the acquisition to Hana Microelectronics. Hawkins earned his BSc in Physics from the University of Bristol, and a MBA from the Henley School of Management at Brunel University, both in the UK.