GREEN SEMICONDUCTOR PACKAGING

Addressing 21st-Century Environmental Concerns

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While integrated circuit (IC) designers and systems manufacturers have typically focused on issues such as process technology, performance yield, signal integrity, and the growing complexities of packaging, a new issue is quickly playing an increasingly pivotal role in IC and system design. For many electronics manufacturers today, no development can proceed without closely examining the environmental impact of using a product and its compliance with global environmental regulations.

Driving this concern is a growing recognition of the dangers of heavy metals, particularly lead (Pb), in the environment. For decades, environmentalists have warned of the impact of lead (Pb) on human health. As an example, many local building regulations, written in the late 1970s and early 1980s, began to prohibit the use of lead (Pb)-based paints and now require its removal before renovation. These regulations are founded on a significant amount of scientific evidence that lead (Pb), absorbed into the body through water or food, becomes a cumulative poison, which can lead to a variety of health problems.

Historically, lead (Pb) has been widely used in the electronics industry in semiconductor packages and electronic circuit boards for its excellent electrical and mechanical characteristics, and its ability to solder at lower temperatures. Lead (Pb) or lead (Pb)-based composites are employed in the solder, which attaches the components and ICs to the printed circuit board (PCB). Acting as the electrical interconnect between the IC and the board, lead (Pb) solder is commonly found on the leads of lead-frame packages, within the balls of a ball-grid array (BGA) package and on the board itself.

Today's environmental concerns include the disposal of lead (Pb)-based electronics systems. When electronics equipment is disposed in landfills, it is usually exposed to acid rain. As rain filters through lead (Pb)-based waste, it can carry lead (Pb) particles to groundwater and rivers, eventually contaminating the water supply where it is ultimately absorbed into the human body.

Evolving environmental standards

Over the last few years, momentum has rapidly accelerated behind the adoption of stringent "green" manufacturing requirements designed to protect the environment from further lead (Pb) contamination. In the United States, laws have been enacted to prohibit or restrict the use of lead (Pb) in various types of products. Three years ago, the U.S. Environmental Protection Agency reduced the reporting threshold for products containing lead (Pb). And support is continuing to build to eliminate lead (Pb) entirely from use in manufacturing.

The Japanese government has pursued similar policies, enacting multiple waste and recycling laws that require manufacturers to eliminate or sharply diminish lead (Pb) content in waste products. Recently, for example, the Japanese government introduced a new law that greatly increases the fees companies must pay to recycle items containing lead (Pb).

Europe	• Waste from Electrical and Electronic Equipment (WEEE) Directive manufacturers responsible for collection and recycling of used electronics, effective 2005 • Restrictions on the Use of Hazardous Substances (RoHS) Directive bans Pb, Hg, Cd, Cr^{+6} and two flame retardants, effective 2006
Japan	• New water pollution, air pollution, labor safety health laws Higher penalties for non-compliance
U.S.	• EPA—reduced threshold for products using lead (Pb) Electronic Waste Recycling Act of 2003
China	• Industry management methods for pollution prevention and control of electronic information products manage similarities to RoHS

Figure 1 Emerging environmental regulations

The most thoroughly protective environmental regulations are being enacted in Europe. The Restriction of the Use of Hazardous Substances (RoHS) Directive announced in 2003 and effective in July 2006, bans lead (Pb), mercury (Hg), cadmium (Cd) and hexavalent chromium (Cr^{+6}), as well as two brominated flame-retardants from electronics sold in the European market.

The impact of the RoHS Directive on semiconductor and electronics manufacturers has been profound. Because supply chains today often traverse the globe and combine materials and components from many different locales, few companies can afford to set up separate manufacturing lines to build lead (Pb)-free products for the European market and non-lead (Pb)-free products for non-regulated markets. Accordingly, most electronics manufacturers plan to comply with the RoHS requirements.

What's more, the Waste Electrical and Electronic Equipment (WEEE) Directive, which became effective in the European Union (EU) in 2005, holds manufacturers financially responsible for the collection and recycling of all used electronics in the EU. Applying to virtually all electronics products, this new EU regulation covers all future and "historic" waste. Importantly, it also allows individual countries in the EU to enact more stringent requirements.

Emerging economies, particularly those in Asia where many electronics manufacturers are building new manufacturing facilities, are also beginning to address these rising environmental concerns. In China, the Ministry of Information Industry Management Methods for Pollution Prevention and Control in Electronic Information Products, influenced by the European RoHS Directive, is considering the adoption of similar regulations in the near future. Under a proposed two-step directive, the Administrative Measure on the Control of Pollution Caused by Electronic Information Products, electronic information products manufactured in China must comply with many of the same restrictions found in the RoHS Directive by March 1, 2007.

Semiconductor manufacturers facing this growing wave of hazardous material restrictions are addressing global environmental issues by adopting a wide array of green product development strategies. The key new environmental requirement they must satisfy is the elimination of lead (Pb) in semiconductor packaging—a requirement that has a wide-ranging impact on manufacturing processes.

Since lead (Pb)-free solders have higher melting points than lead-based solders, the components using these solders must be able to withstand significantly higher reflow temperatures. While traditional components were processed at 240 degrees Celsius or below, the new lead (Pb)-free packages must be able to withstand board mount reflow profiles with a 260 degrees Celsius maximum peak temperature, and still maintain adherence to current Joint Electronic Device Engineering Council (JEDEC) Moisture Resistance Levels and reliability standards. These requirements are defined in JEDEC J-STD-020 rev. C.

At the same time, semiconductor manufacturers meeting these new package requirements must implement lead (Pb)-free plating processes and use lead (Pb)-free solder balls. To meet certification, package terminals must have plating that meets lead (Pb) limits of less than 1,000 parts per million (ppm). Similarly, manufacturers must migrate to BGAs with solder balls comprised of tin/silver/copper (Sn/Ag/Cu) and meet the same less-than-1,000-ppm lead (Pb) limit. These strict package requirements also mandate limits on traditional bromine (Br)- and antimony (Sb)-based flame-retardants, which not only threaten the environment, but also are corrosive and shorten the life of products.

Levels of compliance

To help semiconductor manufacturers comply with these rapidly evolving lead (Pb)-free requirements, IDT has adopted multiple levels of compliance. The first step is compliance with the new reflow process. Parts that have met the requirements laid out in the JEDEC J-STD-020 rev. C specification can withstand the higher 260 degrees Celsius reflow temperatures required for lead (Pb)-free solder pastes.

Step two is the identification of products as lead (Pb)-free. This designation is granted to products that use a lead finish that does not contain more than 1,000 ppm of lead (Pb). The elimination of lead (Pb) is one of the requirements of RoHS compliance. To achieve RoHS qualification, semiconductor packages, including the mold compound, lead finish, lead frame, and die attach, must not exceed a maximum of 1,000 ppm of lead (Pb), 1,000 ppm of mercury (Hg), 100 ppm of cadmium (Cd), 1,000 ppm of hexavalent chromium (Cr^{+6}), 1,000 ppm of polybrominated biphenyl (PBB), and 1,000 ppm of polybrominated diphenyl ether (PBDE). The standard packaging for IDT products meets the requirements of RoHS compliance, with the exception of the elimination of lead. This level of compliance is also known as RoHS 5, and these products are suitable in applications exempted from lead (Pb)-free directives. In addition, a small number of IDT products are currently offered as “RoHS” compliant. The products that fall under this category are flip-chip packaged products. These products meet the limits of the RoHS directive for packaging material and solder balls, but may currently employ lead (Pb) in the internal package interconnect, as allowed by the RoHS directive, to achieve a viable connection between the semiconductor die and carrier.

Fulfilling step three, IDT Green packaged products, which includes over 98% of the current product offering, comply with all industry-wide expectations for green, meeting the requirements for full RoHS compliance, and exhibiting no more than 900 ppm of bromine (Br) and chlorine (Cl), 900 ppm of antimony tri-oxide (Sb_2O_3) or 750 ppm antimony. Finally, IDT has also eliminated red phosphorus (P_4), making the company’s Green packaged devices halogen-free—a step above the industry accepted definition for green packaged products.

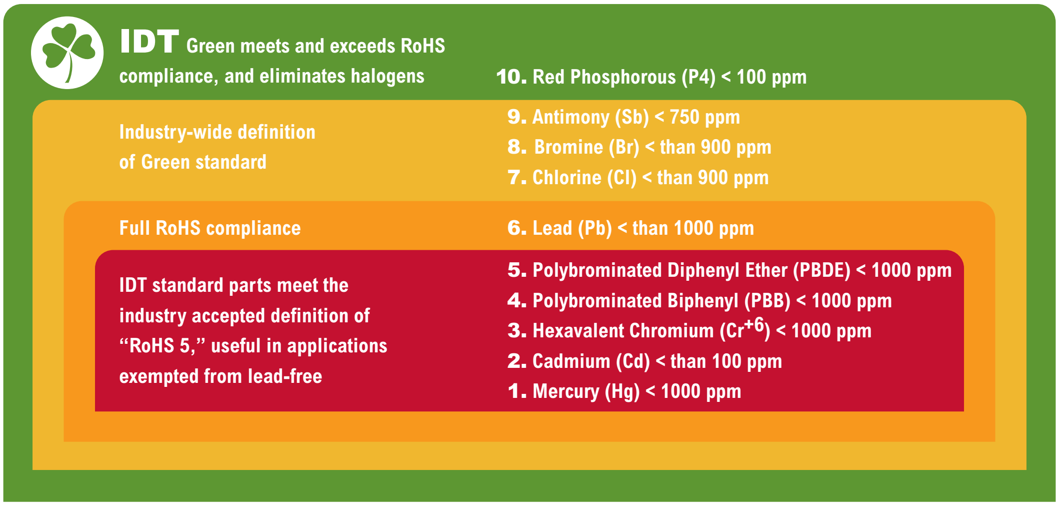


Figure 2: IDT exceeded RoHS requirements 2 years before the compliance deadline.

Leading the industry

The proactive IDT Green initiative is comprehensive, effective and greatly simplifies environmental compliance for customers. This program encompasses packaging, processing, and all aspects of the company's business operations. IDT launched its Green package program in 2000, and exceeded RoHS requirements two years before the compliance deadline. Now virtually all IDT products surpass RoHS compliance, are fully green, and comply with or surpass the most comprehensive worldwide safe-product rules. The only exceptions are the IDT flip-chip products. While not compliant with full IDT Green product specifications because they contain lead (Pb) in the solder used to complete the electrical connection between the die and package carrier, flip-chip products do meet all RoHS requirements. In an effort to meet emerging customer needs and regulatory requirements, as well as environmentally safe product practices, IDT Green products are also halogen-free – a step above RoHS compliance and industry green definitions.

IDT has taken a multi-faceted approach to its Green product program, moving its entire product line to the higher 260 degrees Celsius reflow temperature requirement, and qualifying all packages to the current JEDEC moisture-level classification at 260 degrees Celsius reflow. In the test process, lead (Pb)-free assemblies were tested at an average ramp-up rate of 3 degrees Celsius per second maximum and preheated for 60 to 180 seconds at temperatures between 150 and 200 degrees Celsius. Packages were then heated at temperatures above 217 degrees Celsius for 60 to 150 seconds. Peak temperature tests at 245 degrees Celsius (+0/-5 degrees Celsius) were conducted for 10 to 30 seconds for large body assemblies and at 260 degrees Celsius (+0/-5 degrees Celsius) for 20 to 40 seconds for small body assemblies. The temperature ramp-down rate was 6 degrees Celsius per second maximum. The test process defined large body assemblies as those with package thickness greater than or equal to 2.5 mm or package volume greater than or equal to 350 mm^3. Small body assemblies were defined as those packages whose thickness was less than 2.5 mm and package volume less than 350 mm^3.

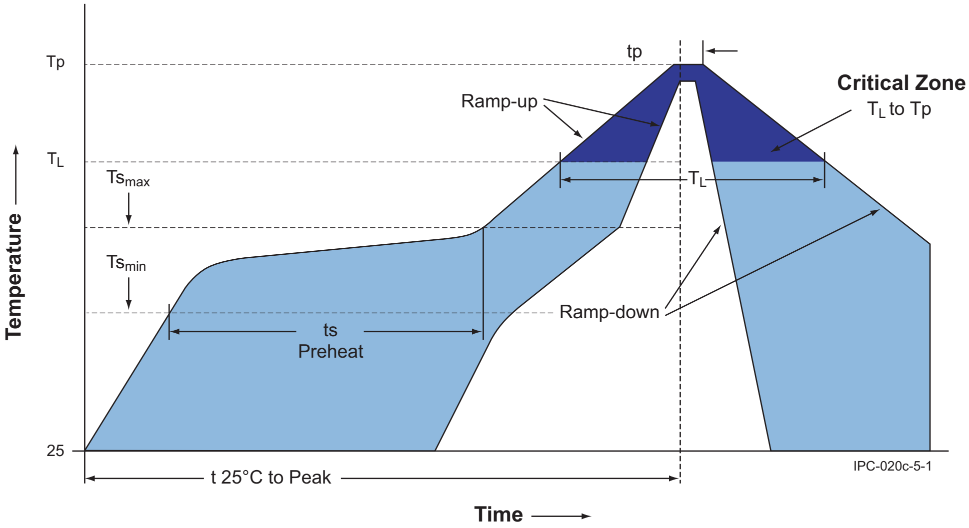


Figure 3: IDT reflow profile chart

IDT also qualified a pure tin (Sn) plating process and lead (Pb)-free solder balls, and developed a process that is consistently applied to both the company's assembly subcontractors and within its own internal processes.

To meet the industry standard lead (Pb)-free definition, all IDT Green lead-frame products now use terminals that are plated with pure tin. Green BGA products employ solder balls comprised of tin/silver/copper. In addition to meeting RoHS requirements, all IDT Green products meet the package material limitations for bromine + chlorine (<900 ppm) and antimony (<750 ppm). Lead (Pb) in all Green products has been verified at < 1,000 ppm.

IDT Green products have also passed a solderability test per J-STD-002B and reliability tests for preconditioning (260 degrees Celsius) + Autoclave (168 hr), preconditioning (260 degrees Celsius) + HAST (100 hr) and preconditioning (260 degrees Celsius) + temperature cycle (-65 to 150 degrees Celsius, 500 cycles for lead-frame packages; -55 to 125 degrees Celsius, 1,000 cycles for BGA packages). The products have also been tested for high-temperature storage at 150 degrees Celsius for 1,000 hours.

Mitigating whisker growth

One of the challenges of moving to lead (Pb)-free solder plate is the potential for whisker growth. All IDT Green tin-plated products are annealed at 150 degrees Celsius for 1 hour. This bake ensures a uniform growth of copper-tin intermetallic within the grain rather than in the grain boundary, which helps to minimize stress in the plating mitigating whisker growth.

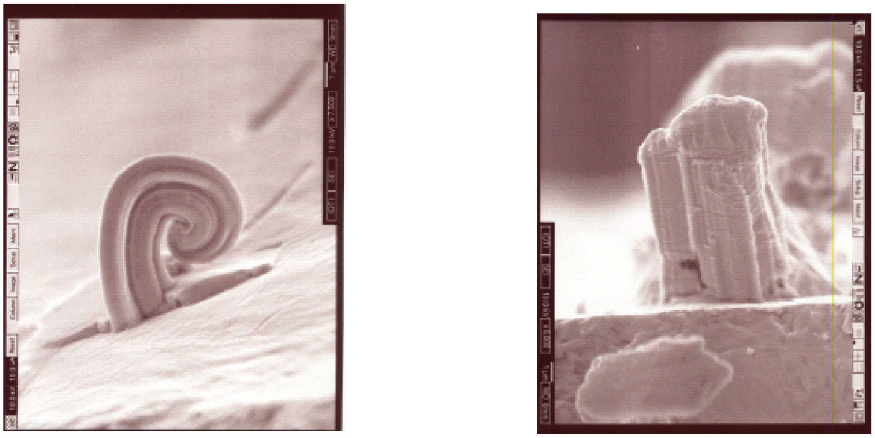


Figure 4: Tin whisker examples

To measure potential whisker growth, IDT conducted tests for pure tin for ambient storage (2,000 hours), temperature/humidity (60 degrees Celsius 90% Relative Humidity (RH) for 2000 hours) and for temperature cycle (T/C) (-55 to 85 degrees Celsius for 500 cycles). The tests were conducted on two pure tin plating chemistries (designated A and B) from two separate subcontractors (see Figure 5 evaluation matrix). Three lead-frame alloys were selected for each chemistry, and tests were conducted on packages with the narrowest pitch from each lead-frame alloy family. The test process also included a 215 degrees Celsius reflow preconditioning phase, which was used to simulate the tin-lead (SnPb) reflow process employed by some customers with their lead (Pb)-free parts.

Whisker Test Conditions Tin Whisker Tests	Conditions	Pre-condition	Bias	Inspection Points	SS
Aging	60ºC/90% RH	None	No	0, 1000, 2000hr	3 units, 3 leads per unit
		Reflow @ 215ºC	No	0, 1000, 2000hr	3 units, 3 leads per unit
		Assembly @ 215ºC	Yes	0, 1000, 2000hr	3 units, 3 leads per unit
Storage	25ºC/30%–80% RH	None	No	0, 1000, 2000hr	3 units, 3 leads per unit
		Reflow @ 215ºC	No	0, 1000, 2000hr	3 units, 3 leads per unit
		Assembly @ 215ºC	Yes	0, 1000, 2000hr	3 units, 3 leads per unit
T/C	-55ºC to +85ºC	None	No	0, 500 cycle	3 units, 3 leads per unit
		Reflow @ 215ºC	No	0, 500 cycle	3 units, 3 leads per unit
		Assembly @ 215ºC	No	0, 500 cycle	3 units, 3 leads per unit

Qual Vehicle Assembly Facility	Plating Chemistry	Leg	L/F Alloy	Package Type
Subcon X	Chemistry A	1	C7025	TVSOP 80L
		2	Olin 194	TVSOP 48L
		3	EFTEC 64T	TQFP 120L
Subcon Y	Chemistry B	4	EFTEC 64T	TQFP 100L
		5	Olin 194	LQFP 100L
		6	C7025	PQFP 208L

Figure 5: Whisker test matrix. The evaluation matrix also included a 5-volt bias test.

The tin whisker evaluation process provided a variety of useful data. Preconditioning at 215 degrees Celsius reflow had no discernable impact. Chemistry A performed better than chemistry B under the 60 degrees Celsius 90% RH aging test (see Figure 7). In fact, the 60 degrees Celsius 90% RH aging process turned out to be the most effective test for accelerated whisker generation. The highest number of whiskers were found in this condition including a 41 µm whisker in one control unit that was plated with tin-lead (SnPb) (see Figure 6). Temperature cycle accelerated whisker growth as well, but whiskers from both chemistries were found to be less then 30 µm after 500 T/C (see Figure 8).

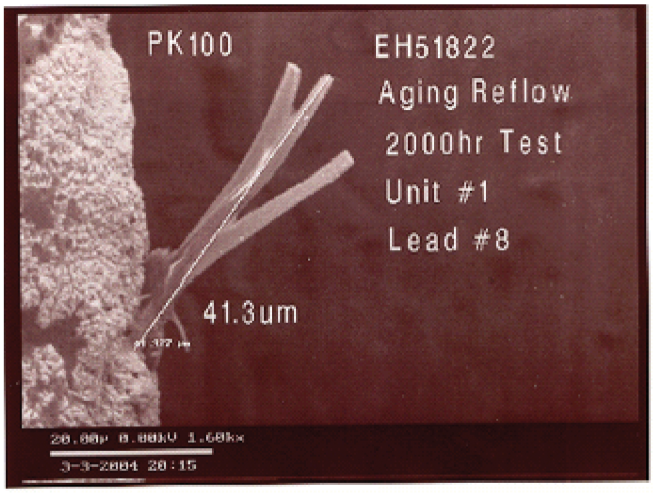
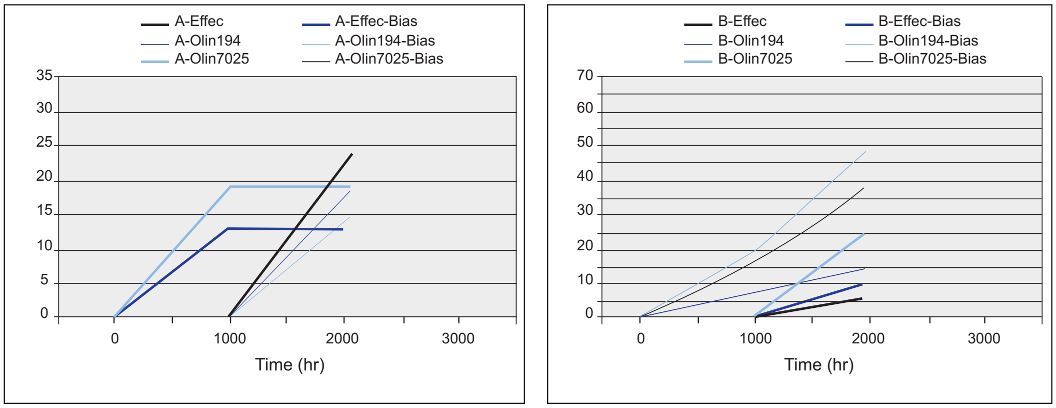


Figure 6: SnPb whisker after 2000hr 60 C 90% RH

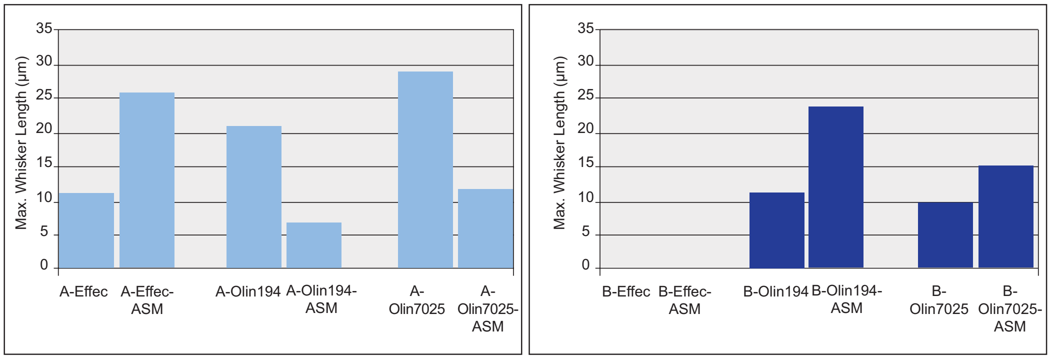


Chemistry A

Chemistry B

Figure 7: Chemistry A after 2000hr 60 C 90% aging, chemistry B after 2000hr 60 C 90% aging

The lowest propensity for whisker growth occurred at room temperature, no whisker was observed for both chemistry A and B after 2000hr test. The tests determined that lead frame alloys perform differently for different plating chemistries at aging condition. But little difference was observed for different lead-frame alloys across the two different chemistries after 500 T/C (see Figure 7). Finally, the 5-volt bias had little impact on whisker growth. IDT has selected chemistry A as its tin-plating process based on evaluation results.



Chemistry A

Chemistry B

Figure 8: Chemistry A after 500 T/C, Chemistry B after 500 T/C

Conclusion

Green product development is only at the early stages of the adoption curve. Many OEMs are just beginning to understand the implications of the transition and explore the changes they will have to make to modify their manufacturing processes. But it is becoming increasingly clear that as new environmental regulations are enacted and a universal recognition of the benefits of environmentally-safe product design and manufacturing practices percolates, adherence to manufacturing regulations will become a basic requirement for participation in world markets. The introduction of the first comprehensive IC product line conforming to and exceeding industry green requirements marks a major stepping stone to that eventual goal.

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