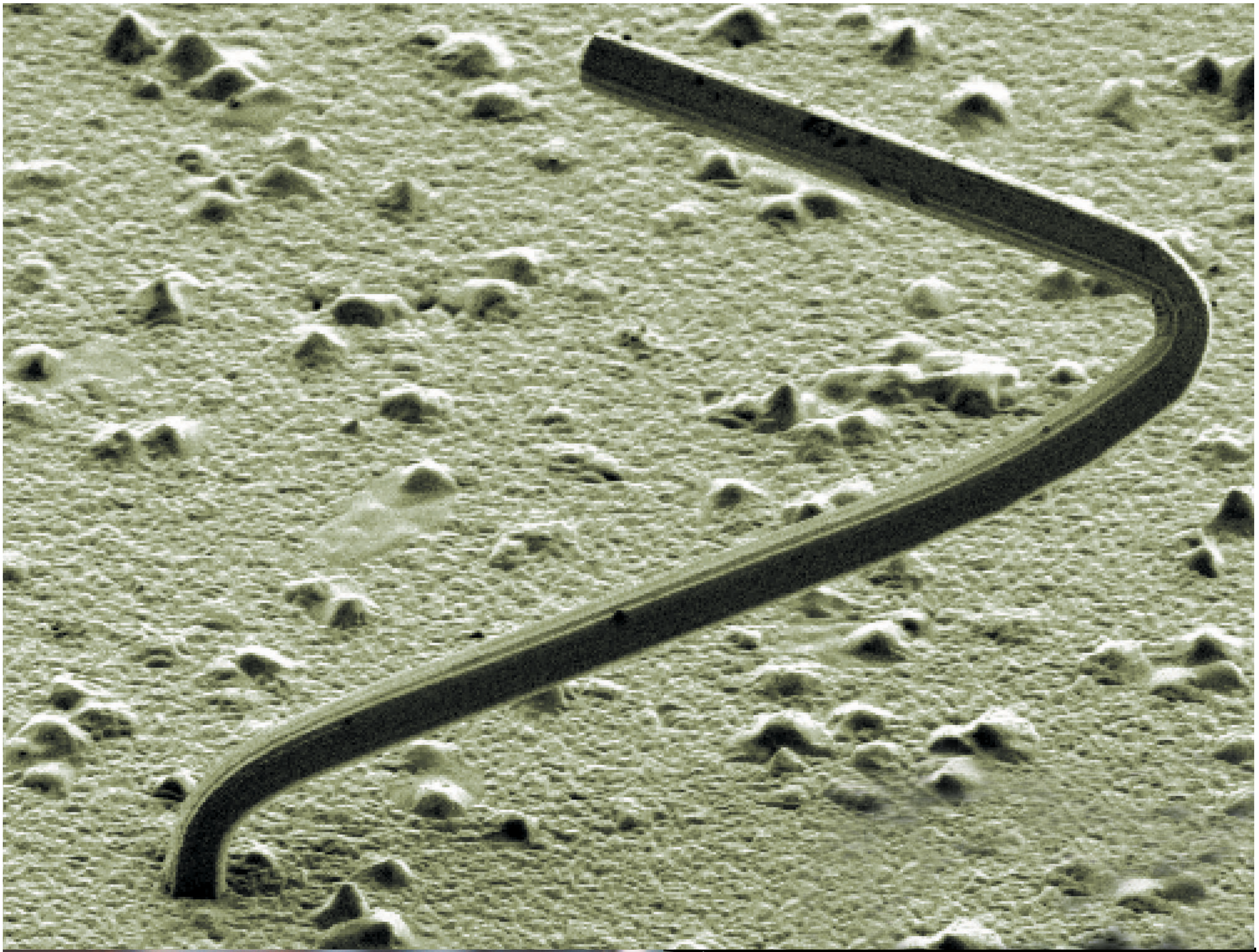

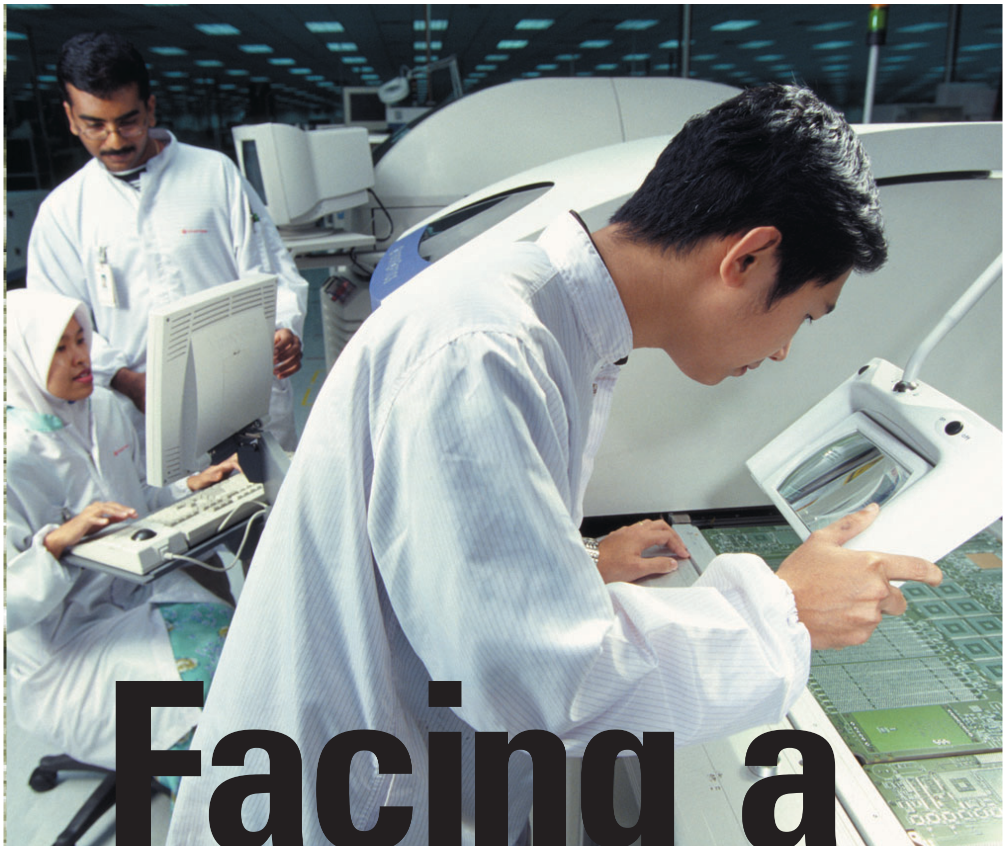

Environmental Concerns And Governmental Mandates are Forcing Component Makers to Get The Lead Out of Their Products. Is the Industry Ready to Adopt the Higher-Temperature Technologies That Will Result?

Facing a LEAD-FREE FUTURE

By Bernard Levine

Engineers may still argue over the environmental merits of the move to lead-free electronics, but political, legislative and market realities continue to push lead-free forward. Many firms in Japan, the U.S. and other nations already offer lead-free consumer products, and a 2006 legislative deadline looms in Europe.

Most global OEMs, contract manufacturers, component and board suppliers, packaging, assembly and test foundries and other industry players, anxious to have a single worldwide high-volume manufacturing stance, are moving past the broader debate over whether to go lead-free to the more nitty-gritty questions of how to make the transition.

The biggest stumbling block may be adapting to higher lead-free heat requirements without generating significantly higher costs for processing, components and assembly. It won't be easy, with companies feeling pressure to keep their own costs down while they put new demands on others up and down the supply chain.

The key technical challenges include developing suitable semiconductors, passive components and materials that can take the heat, adjusting production and assembly equipment, processing techniques and testing procedures, agreeing on lead-free solders and component terminations, preventing board failures

TIN WHISKERS IMAGES COURTESYOF NIST
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caused by tin whiskers as more tin replaces lead, gathering long-term reliability data, meeting more stringent reliability requirements of high-end computing, telecom, military, aerospace, medical and other applications, or allowing lead exemptions if necessary, and solving other reliability and standardization issues.

"The biggest issue is the temperature increase," said Jasbir Bath, process engineer at Milpitas, Calif.-based contract manufacturer Solectron Corp., who also heads a lead-free task group at the National Electronics Manufacturing Initiative (NEMI). "Tin-silver-copper (Sn-Ag-Cu) solder melts at 217 degrees C. Tin-lead (Sn-Pb) solder melts at 183 degrees C. That's a 34-degree difference. The process temperature goes up."

The North-American-based NEMI consortium and other groups and companies in Japan and Europe have been focusing on tin-silver-copper as a replacement for tin-lead solder, with slight variations in their formulas. Formulations with other elements have also been suggested.

"Some alloys add bismuth, which lowers the temperature, but creates other issues," Bath said. "At the solder joint, it could create low melting temperature phases as low as 96 degrees C which can create cracking in the solder joint or other reliability issues."

And there are more places besides solder where lead must be eliminated. "In terminations on the leads of components, which usually have tin-lead on them, the lead must be removed," Bath added. Parts will have to be re-qualified for higher temperatures. Many may have to be redesigned or built with more robust materials if, for example, they contain plastics or epoxies or anything else that will melt during lead-free solder reflow.

"There will be technical problems. If lead-free had been really easy, it would have been adopted a long time ago."

– William Chen, ASE (U.S.) Inc.

Why Go Lead-Free?

Lead is "one of the most technologically developed chemicals in the world," but it is also "a cumulative general poison with carcinogenic potential that can cause damage to the central and nervous systems, the blood system and the kidneys," according to the position paper "Growing Green Leaves in the Electronic Garden, the Quest for Lead-free Electronics by 2006," put out by electronic manufacturing services (EMS) provider Celestica Inc.

"In addition, because lead accumulates it poses toxic effects to the environment. When lead within items such as discarded electrical and electronic equipment is discarded into landfills, it has the potential to leach into the soil, and by extension, contaminate drinking water supplies." The paper cites studies showing that in the United Kingdom, approximately six million electronic products are dumped in landfills each year, and Americans will discard about 130 million cell phones a year over the next three years.

Getting the lead-free designation is a good marketing tool for OEMs, the paper adds. "While research and manufacturing retooling may increase costs initially, the long-term advantage for customers – apart from the obvious environmental benefits – in being able to apply a green leaf to their products can be substantial. For Panasonic, the green leaf has been attributed to an 11 percent increase in market share for its lead-free minidisk player. If consumers are given a choice, many will choose the more environmentally-friendly option."

Not everyone agrees on the environmental friendliness of lead-free electronics, however. Many argue that silver and other elements embraced as lead replacements might be just as bad for the environment, or worse. "Silver is more toxic than lead, and more soluble. In landfills, it kills micro-organisms," said Harvey Miller, data base creator and principal of Fabfile Online. "There's no stopping lead-free electronics, but it will hurt reliability," he added.

The extra energy consumed because of the higher heat requirements of lead-free is also a negative for the environment, many contend. Many also point out that the amount of lead use in electronics is infinitesimal compared to other applications, such as batteries, although little of the lead in electronics is recycled.

It is also easy to demonize lead. "There is a universal perception that lead is dangerous," said Wayne Johnson, Ginn professor of Electrical and Computer Engineering at Auburn University, Auburn, Ala. "It is easy to convince people lead is bad. On the other hand, silver has a positive image from such things as silverware and jewelry." Nevertheless, he indicated the transition is underway. "Lead-free is happening. We are seeing it in some consumer products."

Critics of lead-free electronics note that while leaded gasoline is dangerous when lead emissions enter the air, and lead in paint is dangerous because the paint can chip and children might eat the paint chips, there are no lead emissions from electronic products, and it is unlikely anyone is going to eat a cell phone.

"Lead in electronics is different from lead in paint and gasoline," said Joe Fjelstad of Silicon Pipe. "No evidence has ever been presented of harm to humans from lead in electronics. People say lead in landfills can leach into the soil, but no one has ever presented definitive data."

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"Plastic components are rated to the tin-lead soldering temperature and tested to 225 degrees C," he noted, yet they will now have to withstand reflow temperatures of at least 250 degrees C, and many in the industry have been pushing for 260 degrees C.

All this creates plenty of hot issues – literally and figuratively. "We need to find materials that operate at a higher temperature and the manufacturing process needs to be set up for the higher temperature required by lead-free solder," noted Vivek Gupta, programs manager, lead-free initiative, at Intel Corp.'s Chandler, Ariz. facility.

All this must be done at the lowest possible cost. "Processors and OEMs want components that meet higher temperature requirements, without extra processing and costs for them. Component people want to deliver the components, but at no additional costs that might be incurred if they had to change to more expensive molding compounds or other materials," said Carol Handwerker, chief of the Metallurgy division at the U.S. Commerce department's National Institute of Standards and Technology (NIST), who also headed a NEMI lead-free sub-group.

None of this will come easy. "There will be technical problems," said William Chen, senior technical advisor at packaging and test foundry ASE (U.S.) Inc. "If lead-free had been really easy, it would have been adopted a long time ago."

Chen is confident the problems will be resolved. "Many in the industry,

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"Whether it makes sense or not, the reality is lead-free is going to happen, but it is questionable it will happen in the expected timeframe. The timeframe is a moving target."

– George Westby, Universal Instruments

Why Go Lead-Free? (continued from page 33)

And lead has many positives in electronics. "For over 50 years," according to the Celestica paper, "lead solder has been used as the electrical and mechanical connection path between a component and respective circuit card in the manufacture of electrical and electronic equipment. It has a proven track record for reliability, and its properties are well known."

While some still think the lead-free movement can be reversed, the consensus today seems to be that the matter is decided. "The momentum has gone too far to turn it around at this point," said Thilo Sack, advisory engineer, Celestica corporate technology, Toronto. "You might say you hope it goes away, but I don't think that will happen. The legislation has gone past the point it can be retracted."

And "it is a waste issue, not a direct public health issue," points out Carol Handwerker, chief, Metallurgy division, at the Commerce department's National Institute of Standards and Technology (NIST).

Still, some doubts linger. "I'm personally against the conversion in interconnect," said Ken Fleck, founder of Fleck Research. "Less than one percent of lead being mined is used for electronic solder. Over 80 percent is used in batteries. For there to be political and legislative movement to lead-free electronics is puzzling to many within the industry. Many people say there is no good scientific reason to ban lead. There is a groundswell of resentment in the U.S. toward lead-free electronics." Nevertheless, Fleck noted that market and legislative forces are driving lead-free, so the U.S. will likely follow suit. "Lead-free is almost here. It does appear Japan and Europe have moved towards lead-free. Now the challenge for connectors and the electronics industry is getting the lead out. Does there come a point, however, if people have to pay more, will they go back to the old product? It's fine to pass lead-free legislation, but when it comes to implementing it, will customers be willing to pay a higher price? That is the unknown today."

But calculating costs can be tricky. "Investing additional resources and funding during a struggling economy to produce lead-free electronics is a long-term initiative that many OEMs may wish to put aside right now, choosing instead to focus on the short-term goals of reducing costs and increasing profitability," the Celestica paper notes. "However, to sell into the European and Japanese markets, U.S.-based OEMs have to be able to supply reliable, lead-free parts and assemblies. Not being able to do so will actually hinder longer-term profitability and market share. OEMs need to be proactive in establishing procedures to reliably assemble and solder components with lead-free finishes, as the changes will undoubtedly have a major impact on production and quality control procedures. If OEMs wait too long to develop lead-free solutions, they will certainly spend more money and resources in the long run in an attempt to catch up, and will also lack the necessary historical data on quality and reliability."

And, the paper notes, "being at the fore of the lead-free movement provides a significant advantage to suppliers as OEMs and EMS manufacturers choose to buy from those who are capable of providing lead-free components."

– Bernard Levine

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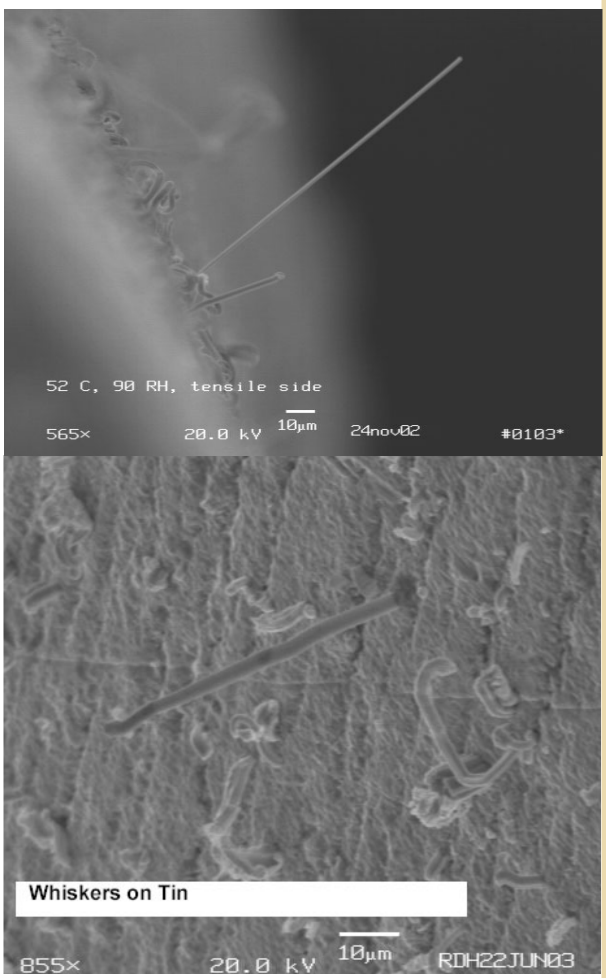
research and academia are working on them. At technical conferences, you learn that there is a significant amount of research going on. I don't see these as major roadblocks. These are technical areas that people have to work on."

But the work can't take too long, because the lead-free push is already well established in Japan, where it has been market-driven, with Panasonic, Sony and other leading firms seeking a competitive edge among consumers by going lead-free. In Europe, lead-free is mandated for July 1, 2006, and it is gaining attention in the U.S., where global players want the efficiencies of a single worldwide product offering. "You cannot make a product for a particular geography or application," said Intel's Gupta.

Many are aiming for the 2006 deadline. "We have about three years to go. There is still time for the industry to work on the details and meet the challenges," said Edwin Bradley, distinguished member of the technical staff at Motorola's Advanced Product Technology Center in Plantation, Fla., who was the leader of the recently-completed NEMI lead-free solder project. "Everyone is working on it. We should overcome whatever problems arise." ➡

IMAGES COURTESY OF TYCO ELECTRONICS



Tin whiskers, like those in these photos, extrude through weaknesses in solder. In time, they can cause short circuits.

TIN WHISKERS:
Casting a Shadow Over Lead-Free

Tin whiskers growing on component leadframes are a new worry for many designers and engineers of consumer and industrial electronic products as more tin enters the commercial manufacturing mix, but some applications have struggled with the phenomenon for decades. Tin whiskers may not be a threat to cell phones and products only expected to last a year or two, but people building cellular base stations, servers and other large systems may be worried. The unwanted whiskers are particularly vexing in more expensive and critical products that are in service a long time, because the stubble may take many years to grow before causing short circuits and board failures, although occasionally it happens more quickly.

What exactly are tin whiskers? "Tin whiskering occurs on the component leadframe," said Carol Handwerker, chief of the metallurgy division of the U.S. Commerce Department's National Institute of Standards and Technology (NIST). "The whole leadframe is plated. There is a layer of tin on the surface. You put the component on, with solder on the lead frame. The paste melts. The rest of the solder on the leadframe doesn't melt. Over time, there can be stresses on the unmelted solder. If there is a weakness somewhere, the tin will start extruding out. The whisker comes out like a thin, sharp needle, and can eventually cause a short circuit," she said.

Many, such as JEDEC and NEMI, are working on the problem, said Jasbir Bath, process engineer at Solectron Corp. "They are looking at whiskers, what's acceptable, what isn't. In high reliability [environments], such as military and servers, they don't want to take any risk, even a small one. We need standardization of testing for whiskers. What is the length you can accept if you do have whiskers? Are there mitigation strategies, such as heat treatment, bake it for 150 degrees for one hour? That is a possibility being looked at to reduce the risk of whiskers. Other possibilities are using different substrates, under the tin coating, such as nickel instead of copper. You would still have copper, but plate the nickel onto that and then the coating."

Baking may be crucial in the fight against tin whiskers. "We hope to have found a solution, to bake one hour at 150 degrees C directly after plating of the components. At the moment, this is the most hopeful solution," said Pascal Oberndorff, development engineer, Philips Centre for Industrial Technology, Eindhoven, the Netherlands.

If you want to see evidence of the impact tin whiskers can have, just look to the sky. The harsh environment of space, where vehicles costing hundreds of millions of dollars may be in orbit for 20 or 30 years and repairs are prohibitively expensive if possible at all, is a particular danger zone. NASA lists scores of satellite failures believed attributable to tin whiskers.

"There are two things you can do," said Reza Ghaffarian, electronic packaging strategic alliance manager, NASA's Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif. "Ideally, you solve the problem, but we have no solution for tin whiskers right now. The other is to understand the risk and to narrow it. NASA has been working on that for a long time."

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What are the challenges? In a paper at the recent Electronic Components and Technology Conference, Bradley wrote that "lead-free soldering of electronic assemblies is becoming a reality with the passage of the WEEE and ROHS directives in Europe and continuing pressure from Japanese manufacturers, even in the face of conflicting information on its environmental benefits. The bulk of data indicates that [lead]-free soldering is a process that, although not a direct drop-in replacement, can be applied with minimal reliability risk. Many components are compatible with lead-free assembly, and the biggest roadblock is to have all components compatible with the assembly process as well as the composition limits. As more companies gain experience in designing and building lead-free products, this will raise the maturity of lead-free technology into the mainstream." Added Bradley, "Some of the components that are susceptible to the Sn-Ag-Cu assembly temperatures are electrolytic capacitors, connectors, opto-electronics, and older style plastic components. Recently, a number of companies have issued press releases stating the availability of lead-free components that meet 260 degree C, and this shows that the development efforts are making progress. The pressure on components suppliers is developing components that work at the higher temperatures while adding minimal cost."

"Tin-silver-copper (Sn-Ag-Cu) solder melts at 217 degrees C. Tin-lead (Sn-Pb) solder melts at 183 degrees C. That's a 34 degree difference. The process temperature goes up."

– Jasbir Bath, Solectron Corporation

Accompanying Bradley's paper was a photo of the Motorola i85 handset assembled with a lead-free Sn-Ag-Cu solder paste. "All indications are that [lead]-free did not introduce any major issues as compared to conventional Sn-Pb," the paper states. But the greater heat of lead-free is raising various concerns over components, many note. "Heat causes components to fail," said Joe Fjelstad of Silicon Pipe. "Capacitors can blow up because of moisture sensitivity."

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It's been decades. "The first tin whiskers I came in contact with were in 1962, when I worked for NASA," said Leon Hamiter, who now heads the Components Technology Institute, Huntsville, Ala., which organizes CARTS and other conferences. "It was on a transistor from a hearing aid that someone decided to use in some space hardware. It failed in ground testing."

Over the years, NASA and others greatly reduced the tin whisker risk by pushing to add lead to tin on the finishes of component leadframes. The industry also heavily moved from bright tin to matte tin, which is less prone to whiskers.

But now the lead is coming out of component leadframes, and many in the industry believe using just matte tin will be the best replacement alternative, even though it is still pure tin and poses a tin whisker risk.

The main cause for whisker formation on today's matte tin layers is the irregular growth of intermetallics. Effective countermeasures to avoid or minimize whisker growth are known and can be categorized in two classes. These are symptomatic effects, in which the origin of stress remains untouched but the stress distribution is influenced and the stress level is minimized, for example, by the deposition of thick tin layers (e.g. 7.5 microns at minimum). There are also causative effects, which are the formation of irregular intermetallics is suppressed by diffusion barriers (e.g. Ni, Ag or Cu_6Sn_5, artificially grown by heat treatment.) No accelerated test method is known today, but whisker safety can be judged in reduced time by appropriate extrapolation of the growth rate, according to a paper at the recent Electronic Components and Technology Conference co-authored by Oberndorff of Philips, Marc Dittes of Infineon Technologies and L. Petit of ST Microelectronics.

Packaging firms have been active in the tin whisker fight. "We have been providing a low organic matte-tin lead finish since early 1999," said Paul Smith, marketing director at Carsem Inc. "To date, 16 customers have fully qualified our process and we have shipped tens of millions of packages including our MLP package. We have not experienced any problems associated with tin whisker issues and attribute it to the fact we have a robust and well-controlled matte-tin plating process. In addition, we are doing ongoing extensive long-term tin whisker studies on a wide range of packages including storage at about 50 degrees C at about 60 percent relative humidity (RH). At the 54 months time frame we have seen no evidence of tin whiskers. We are also doing long term studies after surface mount onto PCBs using a variety of lead-free solder pastes and, after 42 months, we have seen no evidence of whiskers."

Testing and other issues remain, according to Ram Ramakrishna, member of the technical staff, Advanced Packaging Technology, ST Assembly Test Services, Inc. (STATS). "In addition to understanding whisker phenomenon, there also needs to be a standard for a whisker formation test method. Today packaging foundries and their customers have their own internal standards which do not overlap in many cases. As an example, maximum whisker criteria vary between 50 microns and 75 microns, and temperature cycle conditions can vary from –35 degrees C to 125 degrees C and –55 degrees C to 85 degrees C with a minimum requirement of 500 cycles. Another standard that needs to be developed is one that quantifies matte surface finishes."

– Bernard Levine

Component and Equipment Makers Brace For Costs of Lead-Free

The lead-free electronics movement is creating tough new demands on makers of components and materials, assembly and test equipment. Lead must be completely eliminated, and everything else in the manufacturing process, whether it directly involves lead or not, must survive the higher heat and other rigors of lead-free production. But no one wants costs to go up.

Perhaps the greatest challenge is on makers of components. Virtually every semiconductor and passive component will require some modification and re-qualification.

Most semiconductor terminations, for example, are currently made with lead, which will have to be replaced. Semiconductor dies will often have to be glued to the substrate with different epoxies, because the older epoxies melt at too low a temperature. Many connectors, meanwhile, include plastic parts that can't withstand the higher heat of lead-free wave soldering, so other, more expensive plastic materials will have to be used. And a part numbering system will have to be agreed on to distinguish all the new lead-free components from earlier lead-bearing models.

On the production and assembly floor, many pieces of machinery will have to be reset or reconfigured to handle the different solders, epoxies and other new materials added to the manufacturing process. What do component and equipment vendors think about lead free electronics?

"Switching to a lead free version of the same component product, the added cost can be an enormous problem," said Robert Hilty, director of materials research at component maker Tyco Electronics, Harrisburg, Pa. "As a consumer, you don't want to pay more for a lead-free laptop or cell phone. OEMs and contractors don't want to pay more. It drives through the supply chain. How can you make these changes without raising costs or keeping cost increases as minimal as possible? It is a real challenge for component makers."

Lead-free electronics, he added, "is a done deal from a legislative perspective, the WEEE and ROHS European directives on waste from electronic equipment. Most technical problems can be overcome, but with cost penalties," said Hilty, who is the lead-free technical lead at Tyco, a maker of connectors, relays and many other parts.

In connector products, there are two key aspects to the lead-free conversion, he said. "The first is getting lead out of the plating. We have switched from tin-lead to pure tin, and done it without a price increase to our customers. The big thing is start-up costs. The second aspect, when our customer goes to solder our product on a board, the temperature is much higher. Some of the plastic we use now will melt at the higher temperatures. We have to switch plastics, and that is where cost comes in. You can easily double the cost of the plastic material needed by increasing the temperature. As a rule of thumb, whenever you raise the temperature, it means an increase in price."

Therefore, a connector firm must carefully monitor its customers to be ready for lead-free when they are, but not get too far ahead of them and suffer that cost penalty needlessly, he indicated. "We need to be careful in our business decisions. We can't afford to switch to plastics that are lead-free process-capable if the customer isn't using a lead-free process. We have to have the technology in place to make the switch and know when the customer is ready."

But things are moving quickly and a sizable amount of Tyco's production is already geared to lead-free. "A lot of big OEMs here in the States, who want to sell globally, understand they don't want to have separate processes. They want a limited number of processes. We've seen a lot of action from guys in Japan. Globally, there is a lot of action from every region. Lead-free will happen earlier than 2006. Any new product that will be on the market beyond 2006 should be designated as a lead-free product. It is smart to do that. Companies are designing for lead-free in products. OEMs will see significant ramp up in 2004 and the biggest in 2005 so they can build up inventories. For component suppliers, it should be a little earlier, but not too early, you have that cost penalty. You don't want to get ahead of your customers."

Equipment vendors face different technical challenges, although pick-and-place remains pretty must as before. "From the placement aspect, it really doesn't change anything," said Scott Wischoffer, applications engineering manager, Fuji America Corp., Vernon Hills, Ill. "We make component pick-and-place equipment and screen printers. The parts still look and behave the same to us. As far as the screen printer and pick-and-place, the lead-free solder behaves the same. It is invisible to us. The differences I have seen are in reflow and beyond, and that doesn't affect our equipment. It affects guys who make ovens and automatic optical inspection equipment."

Longer ovens are vital, but most built in recent years fill the bill.

"There are minimum changes relative to the ovens," said George Westby, director of the SMT Laboratory at Universal Instruments Corp., Binghamton, N.Y., and leader of its Area Array consortium. "You can run these profiles with many of the ovens today. People are looking to longer ovens, 10 zones rather than seven or eight. It provides greater flexibility and better ability to achieve good thermal gradient across the PCB."

Many pieces of equipment will have new materials to deal with as lead-free takes hold. "The change we see is our

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Component and Equipment Makers Brace (Continued from page 42)

customers are changing their materials on epoxy applications," said Peter Buehlmann, technical manager for die bond products at ESEC USA, based in Phoenix, Az. "There is no direct connection to lead free, but indirect, because customers may need new types of epoxies that can meet higher temperatures. There are no major changes for our equipment, but new requirements. The new epoxy may not flow as well as the old epoxy. We as equipment suppliers may have to change the settings of the equipment, and the new materials may be tougher to process. We must support the customer. The new epoxy may not be as forgiving. They may require different set up of the dispensing on the die bonder."

Other component changes will also bring about changes in the assembly process. And all components won't be ready for lead-free at the same time, so the transition period will present headaches.

"It will take time. It won't happen overnight, and there will be complications," said Universal's Westby. "You will end up with some parts qualified for lead-free, and some not on the same board. When you put assemblies together, there will be mixed alloys for a period of time, and that will create all sorts of technical issues."

But component makers have many issues to resolve before they all can be ready for lead-free. One of the key ones is choosing lead-free terminations for lead frame packages. Intel researchers presented a paper at the IPC-JEDEC conference in Taiwan last December "to make a case to the industry to accept matte tin as the lead-free material for lead frame packages."

The paper by G. Achut Kumar, Greg Clemons, Jack McCullen and Vivek Gupta of Intel in Chandler, Ariz., notes that "the integrated circuit industry has been working feverishly to develop lead-free alloys for component terminations to replace the alloys containing lead. The industry has made good progress in developing a lead-free termination (SnAgCu) for ball grid array (BGA) packages that is cost competitive, reliable and manufacturable." The SnAgCu alloy, although not a drop-in replacement for SnPb alloy, has been widely accepted by the industry as a lead-free termination of choice for BGA packages. However, for lead frame-type packages such as PLCC, PQFP and PDIPs, an agreement on a widely accepted lead-free solution has not been reached yet. Among the various solutions being investigated, matte-tin appears to be the leading choice.

The paper notes that historically, "bright tin" was the popular choice for the metal coating of component leads. The increasing reliability requirements on electronic components introduced burn-in to the industry in 1970s, which resulted in solderability failures due to oxidation of bright tin coatings during burn-in. The industry developed a low organic content matte finish tin as a solution for solderability issues. While the industry was in transition to matte finish tin coatings, military specifications drove the industry to SnPb solder dipping, which was a rework solution for solderability failures in bright tin coated parts. Introduction of finer pitch electronic components brought back the plating process since solder dipping was not viable anymore, and extended the use of SnPb to the plating process. With the need to transition to lead-free metal finish, matte-tin plating was proposed by several manufacturers. Almost simultaneously the concern of a tin whisker potential was raised in industry forums."

The paper concludes that "with the EU legislation implementation date firmed up (July 1, 2006) the industry needs to quickly move towards consensus on an acceptable lead coating solution for components. Considering the whisker formation potential and the process control issues of other proposed solutions (SnBi, SnCu, etc.) matte finish" tin coating is the most viable option available to the industry. As the proposed whisker inspection and acceptance criteria are already under development, the attention needs to be paid towards process development and the associated controls that minimize the potential for whisker nucleation and

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Component and Equipment Makers Brace (Continued from page 46)

growth. Electronics industry has a history of resolving tough process issues and this case should be no different."

Once this and other issues are worked out, new parts will appear. Many active and passive component firms are readying new additions to their product rosters. Various units of component maker Vishay Intertechnology, for example, are getting ready for lead-free. Vishay Siliconix is targeting the end of 2004 for full availability. The company said it has begun converting all of its products (except those with solder bump termination packages and Hi-Rel parts) to have 100 percent matte-tin plated termination finishes and expects to phase out parts with tin/lead terminations in about 12 months, or as soon as industry conversion permits.

Vishay Semiconductors, which makes small signal diodes and transistors, has also begun a conversion to lead-free termination tinning for its products and will convert all packages to lead-free designs no later than 2005.

Meanwhile, at Vishay BCcomponents, Theo van de Steeg, product marketing, aluminum capacitors, said that for aluminum caps with leads, "SMD, axial and single ended/radial capacitors, which currently have a coating containing Pb, these leads need to be replaced by leads with a pure tin coating. Aluminum capacitors having snap-in or screw-terminal termination are already lead-free."

The cap maker "has been working towards a consistent way to manage the changeover to lead-free products, and has been very active in investigating the causes of whisker growth, looking specifically at the type of finish and conditions that influence it. Currently, Vishay BCcomponents can, on special request, deliver leaded aluminum capacitors with a lead-free finish having a low chance of whisker growth. Samples are already under approval at several customers. Ultimately, Vishay BCcomponents' intention is to replace the standard leads that currently have the tin/lead combination coating, with a pure tin coating. A key issue here, however, is the production capacity of the approved suppliers of the leads."

As for soldering, the firm "is currently working on surface mount device (SMD) components that can withstand the 260 degrees C temperature for up to 10 seconds, which should be sufficient for the soldering in a lead-free process. Vishay BCcomponents is aiming to have these ready by the end of 2004."

Also, "a practical point for the equipment manufacturers is backward compatibility, i.e. can they use components with a lead-free finish in a lead containing solder process. Vishay BCcomponents' target for aluminum capacitors is to provide lead-free coating ensuring this backward compatibility."

Another big issue is part numbering, according to many in the industry. Some firms want a new part number for every lead-free part, but others think that would be unwieldy. Yet people will have to distinguish which parts are lead-free and which are not, and which are forward and backward compatible.

– Bernard Levine

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In other words, watch out for popcorning. “If moisture is trapped in the packaging, and it is heated quickly, it can cause interfaces to debond or separate,” says NIST’s Handwerker. “It can cause an audible pop. That’s why it is called popcorning.” How can it be prevented? “There are different molding compounds that can be used. Extra baking may be required, but it will cost time and money,” she said.

Meanwhile, the EMS companies – who will often have the direct responsibility to make lead-free happen – have been closely monitoring the lead-free progress of their component suppliers. Solectron regularly surveys them on their lead-free efforts, Bath said. “Awareness is going up.” And “when Solectron says lead-free, we mean lead-free terminations and the component has been qualified to higher processing temperatures,” said Kim Hyland, director of process integration. “We are putting more effort into getting as many parts as possible that don’t have to be wave soldered,” he added. “Also, we are enhancing capability with selective soldering machinery.”

Others are also busy. “There are discussions between suppliers and producers across the supply chain,” said Dongkai Shangguan, director – advanced process technology at contract manufacturer Flextronics’ San Jose facility. Lead-free will definitely happen, he and most others believe. “I don’t see a chance to go back. Once you convert to lead-free, it would cost money to convert back. Initially, to make the transition, there will be some costs. When the volume increases, it could settle to some equilibrium.”

“Component people want to deliver the componenets, but at no additional costs that might be incurred if they had to change to more expensive molding compounds or other materials.”

– Carol Hadwerker, NIST

Meanwhile, many process standardization issues must be addressed. “There is still no accepted standard for both reflow profile and peak temperatures,” said Ram Ramakrishna, member of the technical staff, advanced packaging technology, at packaging and test foundry ST Assembly Test Services Inc. (STATS) in Tempe, Ariz. “For smaller body size/volume packages, although JEDEC J-STD-020B defines the peak reflow temperature for lead-free devices at 250 (+0/-5) degrees C, the majority of the users have not adopted it. Many integrated device manufacturers (IDMs) are insisting on a 260 degrees C peak temperature. This can create confusion to packaging foundries that have embarked on qualification of lead-free packages at 250 degrees C peak temperatures. Packages already qualified for lead-free assembly at 250 degrees C must be re-certified to meet the new 260 degrees C peak reflow temperature.”

For the finish of leads on leadframe-based packages, according to Ramakrishna, “the industry is settling towards pure tin with matte finish for lead-free packaging because of its cost effectiveness, known material and process, and reflow capability.” However, there are concerns that use of pure tin will cause tin whiskers that produce short circuits, but much research is underway to resolve such difficulties.

As for lead-free and flip-chip, many note there are special challenges. The European directives have exemptions covering flip chip as well as military/aerospace products and other segments, and automotive products are not covered at all.

"Based on conversations with companies around the globe, we see the adoption of lead-free solders first in the solder paste for the boards, board finish, and leads or balls of the packages, followed by flip chip bumps last," said Jan Vardaman, president of TechSearch International, Austin, Texas. "The amount of solder used in the flip chip bumps is relatively small. There are reliability concerns, especially on organic substrates, and these will need to be addressed. Changes in bump metallurgy may also require changes in the UBM, and this can have important implications for reliability. While many of the merchant wafer bumping houses have seen requests for information on lead-free solders for flip chip applications, few have seen volume orders," she added.

Lead-free is "moving into wafer level packages and direct chip attach, but flip chip will be slower," said Scott Barrett, business unit manager at Kulicke & Soffa's Flip-Chip Division in Phoenix. "We are seeing large European and Asian cell phone manufacturers design-in lead-free for 2004 for wafer-level package and direct chip attach."

For BGA package families, according to Ramakrishna of STATS, "standardization to a single solder alloy does not exist today, even though the industry seems to be settling towards Sn-Ag-Cu alloys, with some variations in composition. As an example, Japan's JEITA has adopted Sn3Ag0.5Cu, where as in the United States and Europe several IDMs have adapted Sn4Ag0.7Cu, or alloys with very similar composition. From a packaging foundry perspective, lack of standardization to one alloy increases the cost of packages as a result of multiple package level qualifications, board level assembly evaluations and second level reliability tests. In addition, the maintenance of multiple alloy inventories reduces the leverage to negotiate price when different alloys have to be sourced from multiple vendors."

Inspection procedures for lead-free electronics will be different, noted Reza Ghaffarian, electronic packaging strategic alliance manager at NASA's Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif. "People doing the inspection procedure and [operating] the inspection machine must be trained to look for different things and accept things that previously were not accepted. Previously, if the solder looked grainy, it would be rejected. Now with lead-free, if it is grainy, it is still acceptable. That's the nature of the lead-free solder."

"You must look at everything on the manufacturing floor," said Flextronics' Shangguan. "Can we manage the supply chain, procurement, material handling, quality inspection, equipment for testing? Automatic optical inspection equipment and X-ray equipment will have to be recalibrated and re-programmed for lead-free. Ovens, it depends on what you have. If you have a very old and short oven for reflow, you may have to upgrade the reflow oven. Most newer ovens are okay."

Even though military and aerospace firms have lead-free exemptions, they should expect difficulties because they have been increasingly relying on less expensive commercial parts which often now will become lead-free. "I keep telling customers in the exempt bucket to give consideration to future component needs," said Thilo Sack, advisory engineer, corporate technology, at contract manufacturer Celestica, Inc. in Toronto, who also heads a lead-free initiative on reflow process optimization at the High Density Packaging User Group (HDPUG).

"At NASA, we have to understand how to live with lead-free and manage the risk," said Ghaffarian. "It appears there are some issues, but it's not something that can't be managed. The biggest issue is that reliability data is lacking." Component and system adjustments can be made where necessary, he indicated.

Others also note that exempt sectors will still be impacted. "Even with the exemptions, the reality is, they may be stuck," said George Westby, director of the SMT Laboratory at Universal Instruments Corp. in Binghamton, N.Y., and leader of its Area Array Consortium, which has been working on lead-free issues. "They will be stuck with what the component industry decides to offer."

The other alternative is buying custom parts specially packaged at great cost, noted Wayne Johnson, Ginn professor of Electrical and Computer Engineering at Auburn University, Auburn, Ala. The military in recent years has been shifting to more COTS (meaning "commercial off-the-shelf," not the semiconductor industry's "customer-owned tooling services") parts to save money. "This is one more issue making COTS more difficult," he said.

And everyone faces the possibility during the transition to lead-free that mixed technologies will be in use, Johnson said. "You may have lead-free solder, but still some components with lead. It's hard to say on this one date, the whole industry is switching."

There still isn't even full agreement on lead-free solders, he pointed out. "The industry seems to have chosen some flavor of tin-silver-copper, but I suspect there will continue to be some slight variations of tin-silver-copper formulations because of patent issues and metal cost. The less silver, the less expensive." While some are considering other elements such as bismuth, Fjelstad of Silicon Pipe noted "there are medicinal applications of bismuth, and a limited world supply."

According to NIST's Handwerker, "In the National Center for Manufacturing Science study, we eliminated a lot of classes of solders. Once it was determined there was no drop in replacement for lead tin eutectics in terms of economics, toxicity, processing and reliability, we began looking for solders that met NEMI's requirements. NEMI didn't want a solder with more than three elements in it. And NEMI wanted something more forgiving in the transition period when there was lead in the surface finishes in boards and components." The final NEMI solder recommendation is Sn-3.9Ag0.6Cu, plus or minus 0.2 for each element.

Some note the legislative dates have been changed previously, and the deadline could be changed again. "Whether it makes sense or not, the reality is lead-free is going to happen," said Universal's Westby, "but it is questionable it will happen in the expected timeframe. The timeframe is a moving target."

Reliability of lead-free will also be key to its implementation. "A bill of goods has been sold and we are headed down the road to lead-free electronics. There are reliability issues today, but there may not be a preponderance of failures to justify going back to lead-content solder," said Leon Hamiter, who heads the Components Technology Institute, Huntsville, Ala., which organizes the annual CARTS and other conferences.

Whether they like lead-free electronics or not, engineers are determined not to let those failures occur. "At technical conferences," said Flextronics' Shangguan, "lead-free sessions draw big crowds."

There is a lot to learn, and the electronics industry has only been dealing with lead-free for a short while. "Fifty years of database with products made with lead is gone," said Johnson. "It makes one nervous."

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