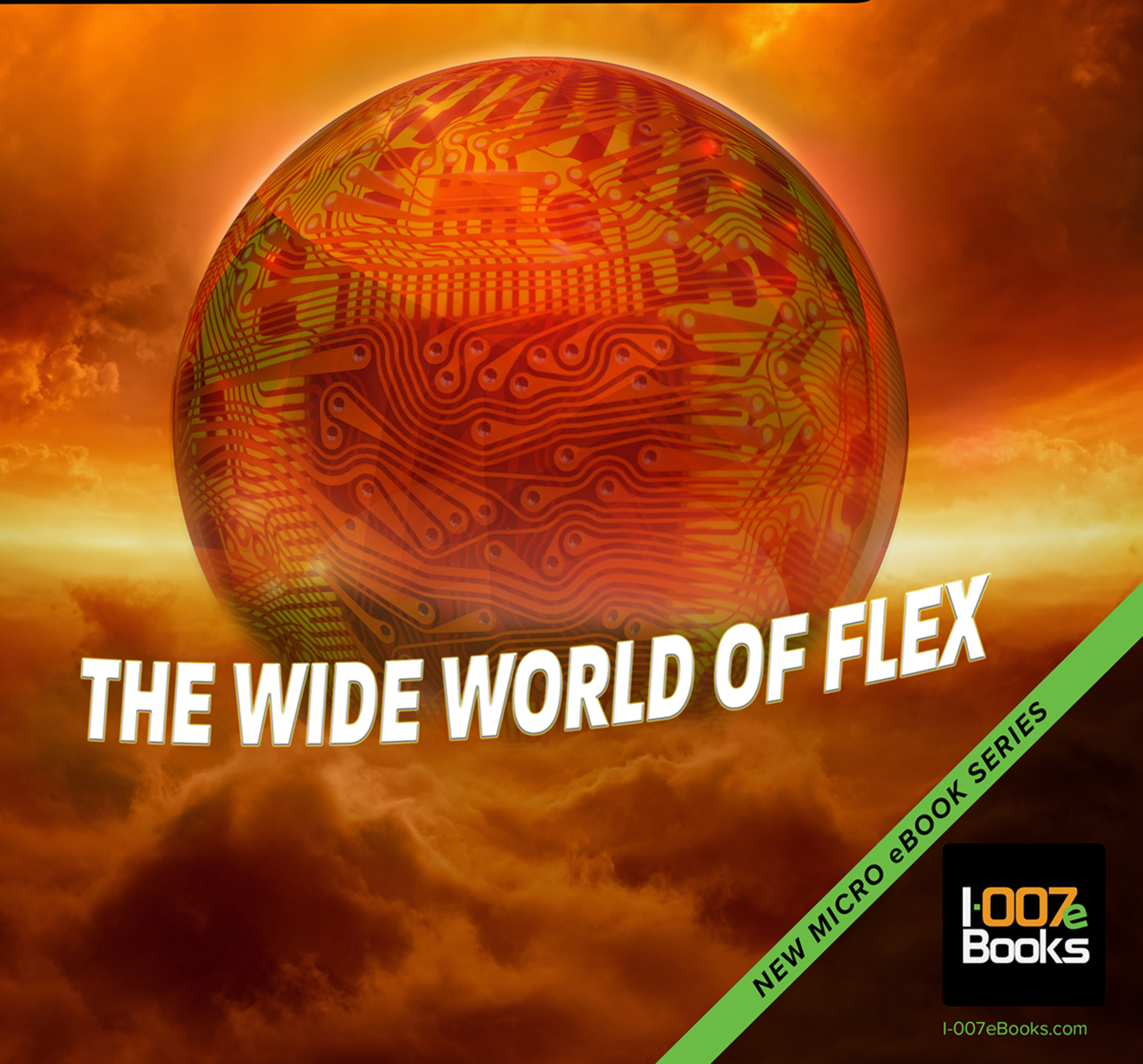
I-Connect007 Presents

March 2017

the pcb magazine



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“This book is a terrific resource for those new to flex design and those more experienced looking to streamline the design to fabrication transition.”

-Tara Dunn

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I-Connect007 is excited to announce the release of the next title in its ***Printed Circuit Designer's Guide to...***™ series, *The Printed Designer's Guide to…Flex and Rigid-Flex Fundamentals*.

Written by Anaya Vardya and David Lackey, both of American Standard Circuits, this micro eBook provides circuit designers, both new and seasoned, with valuable, important information that will help to assure first-pass success in getting their products to market.

The Printed Designer's Guide to… Flex and Rigid-Flex Fundamentals is a must-read for anyone in the supply chain using flex/rigid-flex technology.

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We hope you enjoy *The Printed Designer's Guide to… Flex and Rigid-Flex Fundamentals!*

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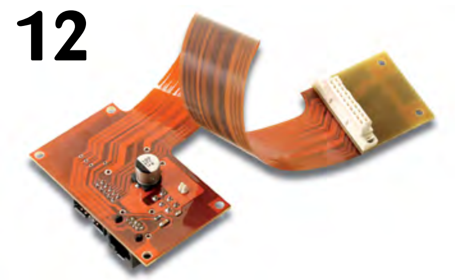
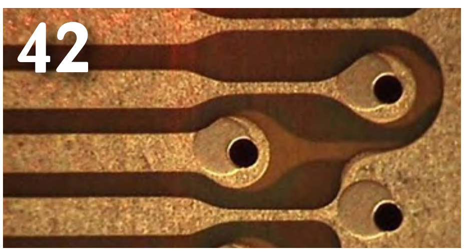
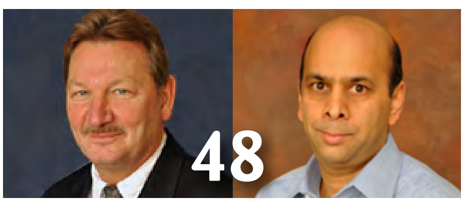
Featured Content

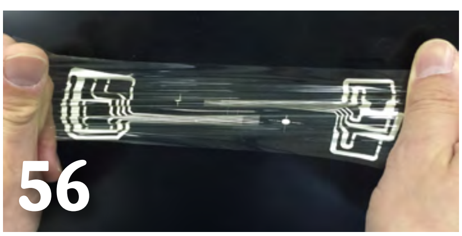
The Wide World of Flex

This month, we're talking flexible circuits, including all the variations of same, which is why we're calling this issue "The Wide World of Flex." The world of flex is broad—and it's rapidly getting wider!









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DEPARTMENTS

185HR

High-Tg, Low-CTE Materials with High Thermal Reliability

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  - Thickness: 0.002″ (0.05 mm) to 0.060″/0.062″ (1.5 mm)
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  - Roll or panel form
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Stay Flexible!

by Patty Goldman
I-CONNECT007

Now, isn't that the mantra we all hear today? For me, it's Tai Chi to maintain physical flexibility. But of course, that is not what we're here for. We're talking flexible *circuits,* including all the variations of same, which is why we called this issue "The Wide World of Flex." Because the world of flex is broad—and it's rapidly getting wider.

We just came from a dynamic IPC APEX EXPO in San Diego. Spirits and optimism were high all around. We had fun with some new video equipment in our booth; IPC celebrated its 60th anniversary; the show floor was busy and so were the conference rooms; there was a really good PCB Executive Forum; I met a bunch of new people and a few that I have been wanting to talk with over the past year.

So, as mentioned, our topic this month is flex circuitry and it is more than apropos as the flex market is going nowhere but up. As more designers learn about the versatility of flexible circuits, not just the well-known bending and flexing, but building into unusual shapes and sizes. So we have a varied lineup of articles and columns covering many different flex types.

I asked All Flex's Dave Becker to write a lead article about the different types of flexible circuits and he did just that. We gave it the title of our topic: The Wide World of Flex. Who knew there was more to this topic than just flex and rigid-flex?

Anyone who has worked with flex circuits knows that one of the most difficult problems is handling them during fabrication and assembly. Tara Dunn of Omni PCB supplies us with many tips to help improve in this area.

Next, John Talbot of Tramonto Circuits gives us a fine article on flexible heaters, an interesting market for flex manufacturers. He explains common uses of these heaters and then gets into detail on design criteria.

ESI's Patrick Reichel continues the ESI series on laser processing with a discussion on process development. Discussing tradeoff choices,

he advocates taking the time to test, document and adjust laser processes for specific materials and constructions to build a process library that reflects your company's business goals.

It is unusual to have two articles by the same author or company in one issue, but this next column was just too perfect to pass up. So, we have a second piece by Becker, this one on dimensional stability in flex circuits, certainly one of the most challenging aspects of flex manufacture, especially as feature sizes and tolerances continue to shrink.

Did I mention that PCB designers are learning more about designing flex? What could be more perfect than a new e-book on just that subject, which brings me to our next article. In a short interview with the authors we learn about *The Printed Circuit Designer's Guide to… Flex and Rigid-Flex Fundamentals,* which published March 1. The interview includes a link for downloading your own free copy.

As one would expect, nothing in electronics ever holds still. New processes, new equipment, and new materials are constantly being developed to address new products with new performance requirements. One of those new technologies is stretchable electronics. Andy Behr of Panasonic Electronic Materials gives us a great overview of the technology and also introduces a novel stretchable thermoset material that is being developed by his company.

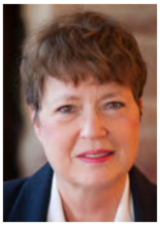
Switching gears, we have both a column and article on final surface finishes. First, Mike Carano, of RBP Chemical Technology, discusses corrosion resistance of two final finishes, ENIG and immersion silver, and a new development that shows promise in preserving solderability and minimizing corrosion.

Following this is a MACFEST article by Tom Jones of Heriot Watt University (UK), whose research project was carried out at Merlin Circuit Technology. The project involved using ionic liquid technology in place of other, more dangerous chemistries in the ENIPIG plating process. Several tests were performed on the final finish including solder reflow and wetting.

Bringing up the rear this month is IPC's John Mitchell with an inspiring column on advocacy. After explaining IPC's Global Policy Framework in some detail, he tells us what we all need to do to get involved. You've heard it here before, but I'll mention it again: One of the most important events is IPC's IMPACT Washington, DC, this year to be held at the beginning of May (see our Events page at the back of this magazine). There has never been a better time to get your congressperson's ear and make our collective voice heard (numbers do count in Washington, especially those of small business owners). And, as we keep hearing, "If you're not at the table, you're on the menu." I'm sure you know what that means!

So, that's it for March. Spring is showing a few weeks early here in Pennsylvania—Punxsutawney Phil got it wrong this year. (Of course, much can happen weather-wise in the next two months.) Next month our topic is high-speed materials, certainly a critical part of the PCB puzzle as the race for more speed continues.

A special callout to Gary Ferrari, FTG Circuits, my very good friend and colleague, who received the Dieter W. Bergman IPC Fellowship Medal at this year's IPC APEX EXPO conference in San Diego. Congratulations Gary! **PCB**



Patricia Goldman is a 30+ year veteran of the PCB industry, with experience in a variety of areas, including R&D of imaging technologies, wet process engineering, and sales and marketing of PWB chemistry. Active with IPC since 1981, Goldman has chaired numerous committees and served as TAEC chairman, and is also the co-author of numerous technical papers. To contact Goldman, click here.

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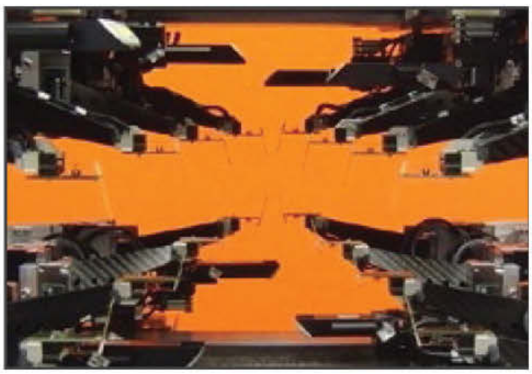

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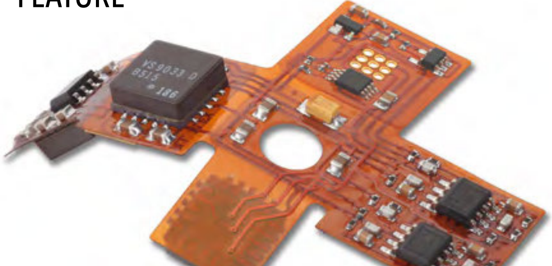
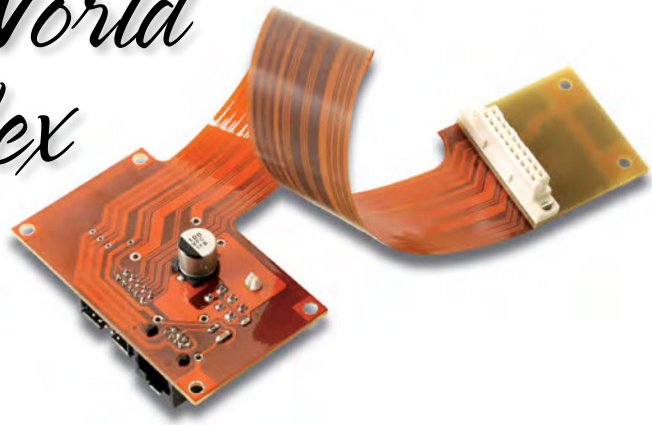


The Wide World of Flex



by Dave Becker
ALL FLEX FLEXIBLE CIRCUITS

Earlier this week, I saw my name in the company newsletter announcing my 10-year anniversary with All Flex. This wouldn't be so bad if the anniversary wasn't preceded by almost 30 years at my previous employer, who also happened to be a manufacturer of flexible circuitry. In other words, I have become an industry "greybeard." If I were honest with myself, I'd admit the nickname was probably appropriate several years ago, but it does allow me membership in a dwindling club who have witnessed the dramatic industry changes over the past four decades. But first, what are flex circuits?

The industry segments flexible circuits into three classes (per IPC-6013, an industry standard document).

1. Class 1 circuits are used in applications with the fewest reliability requirements and minimum inspection. In reality, almost no one calls out inspection at Class 1.

2. Class 2 circuits have moderate inspection, testing, and performance requirements and are typically found in consumer applications such as cellphones or cameras.

3. Class 3 circuits are found in the highest-reliability applications, require the highest inspection and test standards, and are often specified by in military and crucial medical electronics.

Flexible circuits are also categorized in IPC-6013 by "Types." There are five Types defined but only four (Type 1, 2, 3 and 4) are common. Although the insulating material and copper trace access also defines the circuit type, in general, Type 1 flex circuits are defined as those with a single conductive layer. These are known as *single-sided circuits*. Type 2 flex circuitry has two conductive layers and are referred to as *double-sided circuits*. These parts have plated through-holes connecting copper layers. Type 3 circuits are *multilayers* and have 3+ conductive layers with plated through-holes. Type 4 are *rigid-flex*, a combination of rigid and flexible circuit boards characterized by plated interconnect holes through both flex and rigid materials. Frequently confused with rigid-flex are flexible circuits with selective rigid stiffeners. These are more appropriately termed "rigidized flex" and might be any of the first three circuit types.

In one sense the flexible circuit industry has remained amazingly stable. Things I learned on my first day at work are still relevant. Polyimide remains the workhorse dielectric film; imaging is done by exposing a pattern on a photosensitive film; copper is subtractively removed from

a patterned substrate; and acrylic adhesive is commonly used to laminate polyimide coverlay as an insulation. But there have also been some rather dramatic changes…

So Big!

Flexible circuitry was launched in the United States as a commercial product about 50 (!) years ago. Minnesota remains a focal point for the technology, along with New England and California. The Minnesota nexus occurred as G.T. Schjeldal (the entrepreneur who founded Sheldahl Inc.) built equipment to handle thin flexible films in continuous reels. Automated equipment could cut and heat-seal polyester and was used to fabricate plastic bags. This technology foundation evolved and was adopted to produce electrical laminates. Value was then added through roll-to-roll electroplating, imaging, and etching continuous reels as part of the process of fabricating printed circuits. It was a very high-volume process targeting the automotive and communications markets. This technical heritage expanded regionally as engineers spawned new, related businesses.

In this time frame, the 1980s, the flexible circuit market size was estimated at less than $200 million as Asia had yet to emerge as an industrial player (that seems like a long time ago). Today the North American flex circuit market is estimated at about $350 million but is dwarfed by manufacturers in Japan, Korea, China and Taiwan. Worldwide market size estimates vary considerably and are complicated since few customers buy a simple "flex circuit." Added value is a common offering as circuits are frequently sold with components as an interconnect solution. A worldwide market size of $7–11 billion seems to be a common range. Almost any electronic application is a candidate for a flex circuit with cellphones, cameras, displays, and consumer electronics frequent adopters in Asia. The North American markets are characterized by medical, military, industrial and instrumentation applications.

Make Mine Smaller!

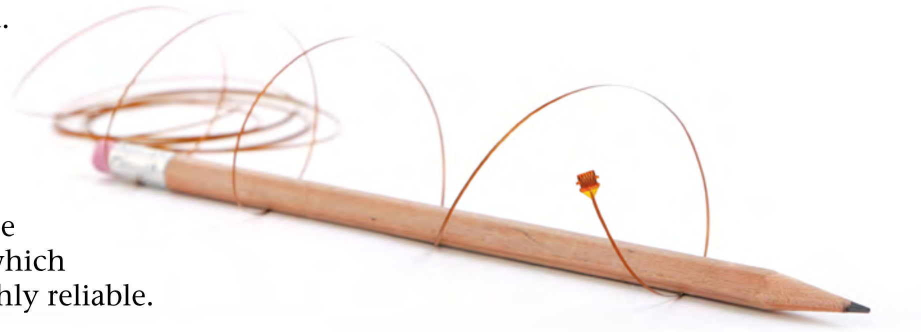
One technology trend has been a vector and can be summed up by the word "smaller." Plated through-holes used to be considered small at .015" (15 mils). Today they are created with lasers at sizes of .001–.002" and are often plated shut. Conductor traces and spaces struggled to get below .010" then; now, designs with .002" conductors are common. Complementing this trend has been improved soldermask placement accuracy with a locational tolerance of +.002", base film thickness common at .0005", and 01005 SMT components (with dimensions of .0157" X .0079") that are machine-placed at rates of multiple parts per second.

Two technical capabilities driving a significant portion of the improvements are optics and lasers. Using cameras for optical registration has significantly reduced or eliminated the use of punched or drilled tooling holes. Cameras find fiducials and product alignment is factored to create a best fit registration between sequential processes. Lasers are used extensively by laser direct imaging (LDI) equipment with software created by CAD files defining the artwork image during photolithographic exposing. No more 10:1 hand-laid artwork tapes (I won't mention how long ago that was being practiced)! Lasers are also used extensively to excise circuits from panels and cut film coverlay. Capability is enhanced as laser cutting can be accomplished without traditional restrictions imposed by drill and routing tools.

Get the lead out!

On July 1, 2006, the Restriction of Hazardous Substances (RoHS) mandate was implemented by the European Union, requiring manufacturers of electronic and electrical equipment to reduce/eliminate six hazardous materials. Lead was included in this restriction which meant new methods for circuit board surface treatment and tin/lead soldering had to be invented. Certain dopants used to make printed circuits

flame retardant were also prohibited. The industry did a remarkable job of responding with electroless nickel/immersion gold (ENIG) and organic solderability preservatives (OSPs) becoming workhorse surface treatments. Engineers also solved the struggles with lead-free soldering which has become widely adopted and highly reliable.

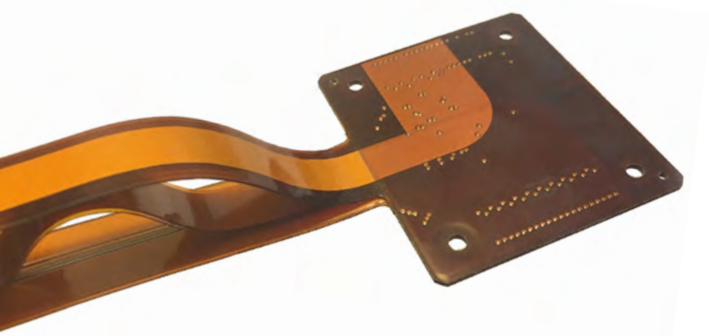


Get the glue out!

In the world of flexible circuits, adhesiveless laminates have become pervasive. Several technologies are used by multiple suppliers to create copper/polyimide composites sans adhesive. Vacuum deposition of copper onto polyimide, cast polyimide onto copper, and polyimide "adhesives" are used to fabricate these homogenous and high-performance structures. Several advantages result with improved chemical resistance and improved performance at elevated temperatures. This opportunity to minimize adhesive removes material generally considered to be the weak link in the construction of a multilayer flex circuit. Moisture absorption is reduced making delamination from abrupt or extended temperature exposure less likely.

Made in USA...NOT!

As consumer electronics transitioned to an Asian supply chain, the demand for printed circuit suppliers also shifted East. The growth of notebook computers, digital cameras, and cellphones drove incredible volumes and spawned many high-volume circuit board suppliers. Circuit fabrication technology was often transferred with the cooperation of US manufacturers anxious to get a foothold in a burgeoning market. While that practice has gone away, technical linkage with Asia remains with companies offering brokerage services. Applications engineers in North America serve as technical liaisons between Asian factories and contract manufacturers and/or OEMs. These suppliers buy circuits in Asia and sell in North America.



Product Life Cycle!

The relentless drive of product technology improvements has created new problems and opportunities for flex circuit board suppliers. First to market is often more important than having a better product. With electronic product life estimated at an average of 4–5 years, 20%+ of part numbers are obsoleted annually. Enjoying the ride is not possible (at least not smart) as part number obsolescence is always a threat. A process to constantly and aggressively gather new business is imperative to prevent a circuit company from becoming one of the "rusted-out factories scattered like tombstones across the landscape."

Since our industry is always building someone else's parts, we must exist on what I call "derived demand." I use this term when my boss wants to know what can be done to increase sales next month since, in the short term, we are at the mercy of our customer's success stories. With this drive to reduce cycle time, a good way to stay relevant is to compete by being fast. A rapid response is protected from changes in technology. Because, much like in the '60s, "The Times They are a-Changing." **PCB**

Dave Becker is the V.P. of sales and marketing at All Flex Flexible Circuits and Heaters. To contact Becker, or read past columns, click here.

Flex Material Handling: An Inside Peek

by Tara Dunn
OMNI PCB

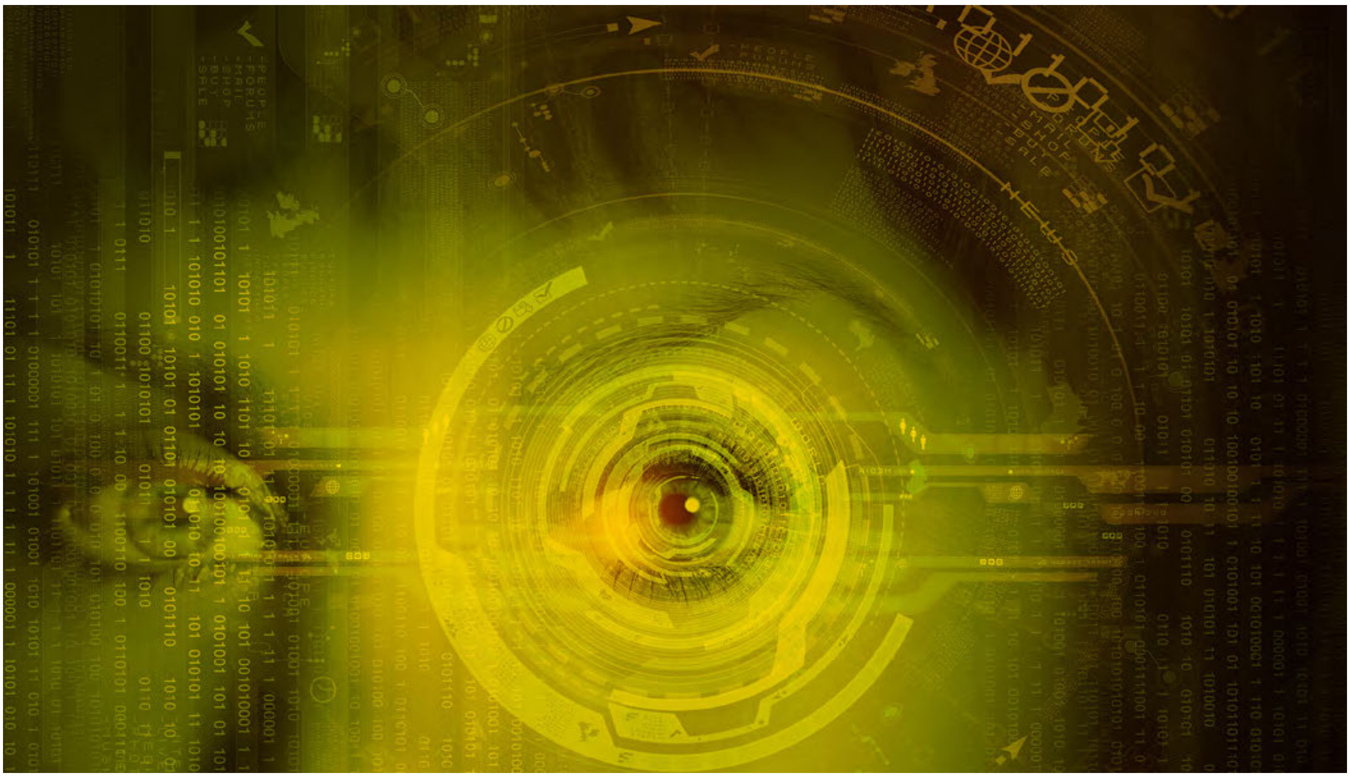
As increasingly more designs move to flexible materials to take advantage of space, weight or packaging benefits, it has been clear that flexible circuits require a different set of rules than their rigid counterparts. We spend substantial time working through the design to ensure that the flex is as robust as possible. We also spend quite a bit of time on material selection, again to ensure that the flexible circuit withstands the flexing that will be required and performs properly in the end environment.

One thing we do not often talk about is what happens behind the scenes during the fabrication and assembly of the flexible circuit. What types of special handling considerations are in place throughout the manufacturing process to accommodate these thin materials? When you are auditing a potential new supplier, what should you be asking about and looking for in their procedures?

Undoubtedly, the largest source of defects in flexible circuit manufacturing can be traced back to material handling. Drawing from my own knowledge and soliciting the expertise of several industry veterans involved in flex circuit manufacturing—David Moody with Lenthor Engineering, Anaya Vardya with American Standard Circuits, Jim Barry with Eltek, and Mike Vinson with Averatek—I have put together an insider's view of the nuances involved in manufacturing flexible circuits.

Fabrication

Everyone agreed that it is the handling of the thin flexible materials that is the key to the successful manufacturing of flex and rigid-flex designs. A wrinkle, ding or dent in the copper material can easily, and will most likely, cause a defect. In fact, wrinkles are typically the leading cause of defects for trace and spaces errors in



process imaging. So, what do fabricators do to mitigate this damage?

Skilled technicians are at the very top of the list. Thin, flexible materials require a unique set of processing parameters and significant time and effort is put into training operators on material handling. The movement of product between process steps is as critical as the precautions that need to be taken during each process.

When moving flexible materials between process steps, transport frames, slip sheets, and trays are required to provide the extra support needed to keep these panels completely flat—remember a ding or fold in the material will create a defect. When picking the material up for processing, consideration needs to be given to grasping the opposing corners to keep the panel flat.

"When picking the material up for processing, consideration needs to be given to grasping the opposing corners to keep the panel flat."

Special consideration and handling is also needed when processing. Most equipment is not specifically set up to handle thin core, flexible materials. For example, moving product through the etching process or other conveyorized equipment requires "leader boards" or some type of frame to be taped to both ends of the sheet of flex material to provide stability and prevent the sheet from being caught in the equipment rollers. If not done carefully, the process of applying the frame or leader and the subsequent process of removing the support structure is also an operation prone to damaging the thin materials.

Prior to wet processing, the panels are in full copper sheets. Once the excess copper has been removed to form the space and trace pattern, the panels are even more susceptible to handling damage. Care is given when creating the panel artwork to leave as much excess copper as possible on the panel. This could be the outer edges of the panel, the outer edges of each array, and between individual parts. It is not uncommon that the need for extra copper to add stability takes priority over the desire to maximize panel utilization.

Dimensionally, flex is far less stable than glass-reinforced rigid boards. The added copper in the panels also helps mitigate the material movement. This material movement creates unique challenges for registration in terms of coverlay application and in layer-to-layer registration for both multilayer flex and rigid-flex. Each manufacturer has a preferred method for registration and how they set up their tooling pin systems to best fit their processes.

Lamination is another area with unique requirements and special equipment for flex processing, including both lamination plates and specific lamination driver materials. Specialized materials are needed to fill air gaps and provide support through lamination. In the case of very thin core (.0005" polyimide) a base support layer may be needed.

More and more fine-line flex circuits, particularly medical and sensor applications, are using extremely thin polyimide substrates with densities requiring additive processing rather than subtractive etch processing. These products are primarily double-sided with one side much more densely plated than the other, using both gold and copper to form traces on 0.0005" polyimide or thinner. Because of this, any plating stress will cause the parts to curl. For routing operations, UV-sensitive tape can be added to the panel to improve stability and support and improve handling. This technology is similar to what is used in wafer processing. The parts will remain flat until the UV tape is removed. When removing the UV tape, the simple effort of being aware of in which direction the material stress will cause curling, and then removing the tape by pulling against that direction, will help minimize the effect.

Assembly

Whether the flexible circuit has just a couple of components and is hand assembled, or the circuits are going to be run through a surface mount process, the number one thing that

needs to be taken into consideration is the need to bake the material before subjecting the flex circuits to high temperatures. Hand assembly is especially prone to defects with flexible materials. This process requires special consideration as to temperature and time and is yet another area that operator training is critical.

Flex circuits (and thin core boards in general) require some support mechanism to run through either wave solder or a reflow process. There are several options to accomplish this. A design with many FR stiffeners may move forward by using an FR-4 carrier panel designed to provide stability to the array until assembly is complete and then have the excess FR-4 removed, leaving the intended stiffeners. While that is one approach, it is more common to build the flex circuit as a single, individual piece and have a carrier fixture made to transport the circuit through the assembly line. This allows the fabricator to maximize the panel real estate and provide a lower cost unit price for the flex circuit. Carrier tooling is relatively inexpensive and is generally more than off-set by the lower cost flex circuit.

Flexible circuits are certainly a growing segment of the market and require not only special design and material consideration, but special handling throughout the manufacturing process. With material handling cited as the largest cause of yield loss during manufacturing, this is an area with (and for) continuous improvement. We all agree that employee training and on-going education is the key to success. Many facilities specialize in just flex and rigid-flex processing and others have teams dedicated to this product subset, but the common theme is knowledge and specialization. Flexible circuits often have a slightly longer manufacturing lead-time than their rigid counterparts and this is often related to the special handling and processing required for flex. Whether that is extra time in tooling and process planning, extra time during wet process, extra care needed to properly register the layers prone to material movement, or extra care needed during assembly, all special handling is done to maximize yield and provide a robust product to the end user. **PCB**

Tara Dunn is the president of Omni PCB. To read past columns or to contact her, click here.

Living Sensors at Your Fingertips

Engineers and biologists at MIT have teamed up to design a new "living material"—a tough, stretchy, biocompatible sheet of hydrogel injected with live cells that are genetically programmed to light up in the presence of certain chemicals.

In a paper published this week in the *Proceedings of the National Academy of Sciences,* the researchers demonstrate the new material's potential for sensing chemicals, both in the environment and in the human body.

The team fabricated various wearable sensors from the cell-infused hydrogel, including a rubber glove with fingertips that glow after touching a chemically contaminated surface, and bandages that light up when pressed against chemicals on a person's skin.

Xuanhe Zhao, the Robert N. Noyce Career Development associate professor of mechanical engineering at MIT, says the group's living material design may be adapted to sense other chemicals and contaminants, for uses ranging from crime scene investigation and forensic science, to pollution monitoring and medical diagnostics.

"With this design, people can put different types of bacteria in these devices to indicate toxins in the environment, or disease on the skin," says Timothy Lu, associate professor of biological engineering and of electrical engineering and computer science. "We're demonstrating the potential for living materials and devices."

The paper's co-authors are graduate students Xinyue Liu, Tzu-Chieh Tang, Eleonore Tham, Hyunwoo Yuk, and Shaoting Lin.

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Crucial Considerations for Building Flexible Heaters

by John Talbot
TRAMONTO CIRCUITS

Figure 1: ATM.

Introduction

An electronic heater is created by driving electric current through a resistive element. As the current is drawn through the element, some of the energy is expelled as heat. That heat can then be transferred to other surfaces with positive effects. It is a convenient way to keep components above damaging temperatures or to heat surfaces to a specified temperature and keep them there. Some of the first heaters were simple nickel-chromium wires attached to a power source and wrapped around a mass to transfer heat. This is effective, but not practical in all applications. Heaters that are designed on flexible material can be attached to flat surfaces, equipped with temperature sensing devices, and monitored constantly so that adjustments are possible as the ambient surroundings change. Two types of flexible heater material are common: silicon rubber and polyimide. This article will focus on flexible polyimide heaters.

Common Uses

Flexible heaters are used to keep components, typically microprocessors, at a consistent temperature in devices that are exposed to conditions that have varying temperatures. They are used to heat surfaces as well. For instance, the seat or steering wheel in your car. Biological samples are sometimes better analyzed at the typical body temperature for a human or animal. Batteries and electronics in aircraft that must operate normally at 30,000 feet above the earth are kept warm with flexible heaters. Handheld electronics as well as ATMs that must operate accurately in cold climates will use flexible heaters to keep critical components in the specified temperature range. The uses are not trivial and one may say critical in many applications. No matter the product or what function it provides, flexible heaters are an important element in the electronics industry.

Design Criteria

For a flexible heater to be designed accurately, we must first understand several things:

1. The material to be heated
2. The temperature range of the product's surroundings
3. How fast the heat must be transferred to the material

4. What temperature the material should be during the process
5. The power source available
6. Whether the heater will be monitored and how it will be monitored

Armed with this information, an engineer can confidently design a heater that will fit the application and heat it to the prescribed temperature in the specified time range consistently.

Conductor Options

Conductor choice is important to a flexible heater design. The most cost-effective choice is standard copper, which is available on pre-laminated material and used extensively worldwide in flexible circuits. However, a heater designed with copper requires a lot of surface area because of its low resistivity of 669.29 x 10^{-9}/in^2, thus it is typically used for very low resistive designs. Heaters that are designed for small areas with high heat requirements are typically designed with some type of nickel/copper alloy such as Inconel or Constantan. They have resistivity levels of 40.55 x 10^{-6}/in^2 and 19.29 x 10^{-6}/in^2, respectively and allow for higher resistive circuits in much smaller areas. Nickel/copper alloys are not widely available pre-laminated on polyimide and therefore are less cost effective because the processes and material costs are higher. However, heaters designed with these conductors are just as robust as standard copper and perform very well in all applications.

A key specification is the target temperature of the material being heated. Once the required temperature is known, it can be converted to watts/in^2 and Ohm's Law may be used to calculate the proper resistance required for the heater. Obtaining the required resistance on the circuit in a pattern that emits consistent heat across the surface is easily accomplished with an interlocking serpentine pattern of the correct trace width and length. It is important to note that this pattern is best suited for the heated area and must be adjusted in 'non-heated' areas of the circuit, such as a tail that carries the signals outside of the heated product. More on that later.

Figure 2: Interlocking serpentine pattern on a flexible heater.

Temperature Sensing

Most heaters will include some type of sensing device that can be monitored continually, allowing the mass to be kept at a steady temperature. A resistance temperature detector (RTD) placed strategically in the heated area will alert the monitoring device when the temperature climbs above or below the specified range. The monitoring device can then adjust the power to the heater and bring the temperature of the mass back to its required temperature. RTDs come in many different shapes and sizes. Some are tubular, like a thermocouple. Others are flat, like a ribbon. Still others look like standard surface mount resistors. Whatever method is

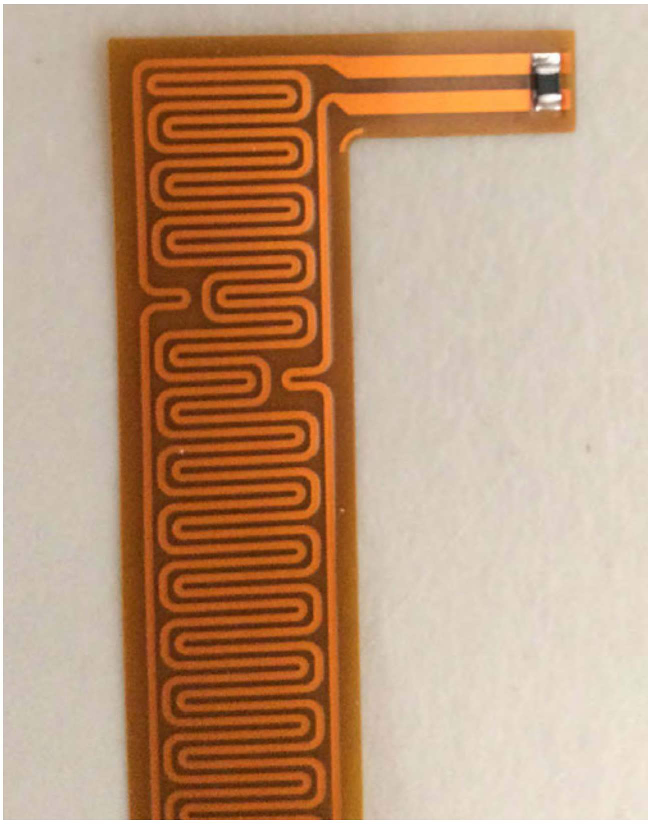


Figure 3: Thermistor temp sensing device on a flexible heater.

used, the concept remains the same. Monitor the temperature and adjust the power source to keep it in the desired range.

Fusing

We've mentioned earlier that some applications are very critical. In those cases, redundant safety features may be prudent. In applications where the heater is being continually monitored, it is intuitive to believe that the monitoring device will detect any issues with the heater running too hot or too cold. However, the device, which is controlled by a software program, might not detect these issues. Software programs often cannot prepare 100% for scenarios in practice. As well, a defective component that fails at an inopportune moment can cause the monitoring device to think all is well, when in fact it is not.

In these cases, a redundant safety measure is designed into the heater. A common method is to attach a thermal cut-off device (TCO). A thermal cut-off is an electrical safety device that interrupts electric current when heated to a specific temperature. These devices may be for one-time use, or they can be reset manually or automatically. In the case of a heater that is being misunderstood by the monitoring device, as needing more power, the TCO will heat up and eventually open like a switch, thus cutting off all power and preventing an unacceptable event such as a heater catching fire in an operating room.

Connection to Power Source and Monitoring Device

Once the heater is designed for power, monitoring and safety, it must have a method of attachment. Several methods are commonly used: Bare wires that may be soldered, a cable with connector that may be plugged, or a zero-insertion force (ZIF) connector that also may be plugged. These methods have all been used

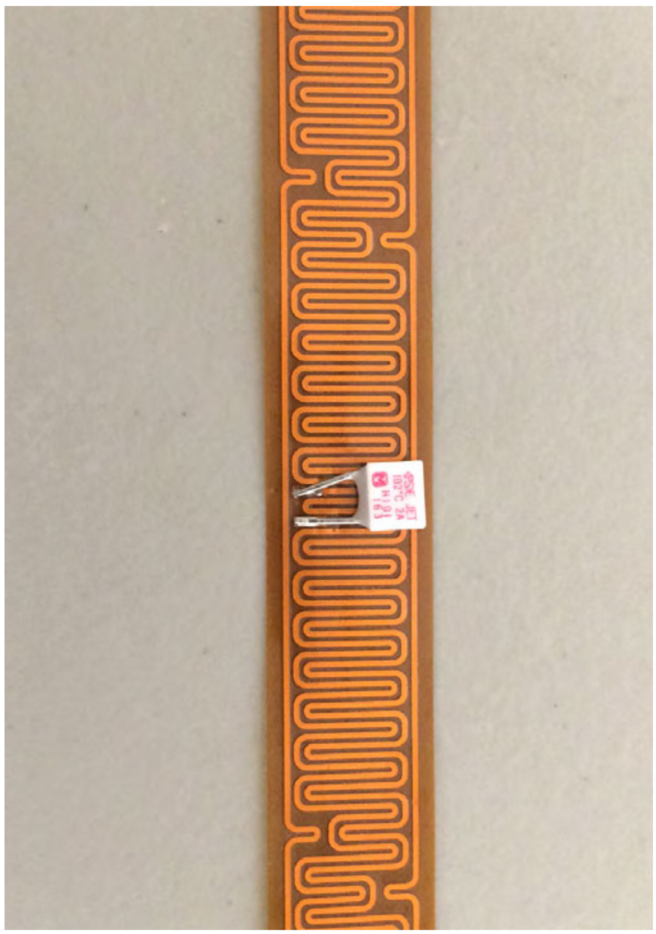


Figure 4: Thermal cut-off device on a flexible heater.

extensively and work equally well. When a cable is used, with or without a connector, it is typically soldered to the heater and then routed to the power source for attachment. A ZIF connector however is an inherent part of the flexible heater and requires less cost and inventory. There are no wires or connectors to stock or assemble. It only requires a mating connector on the power/monitor device circuits. This area of the heater is usually a "non-heated" area. The signals must be adjusted so that the power travels through them without heating as they do in the designated heated area.

Attachment Methods

If the flexible heater is to transfer its heat to a mass or surface, it must be firmly attached to that surface. Some methods that are typical are adhesion, clamping or blanketing. A standard adhesion scenario would include a pressure sensitive adhesive (PSA) attached to either the flexible heater or the surface to be heated. The clamping method is, as its name implies, a heater clamped between two surfaces. And the blanketing method is also intuitive. The flexible heater will be wrapped or blanketed around the mass that requires heating. In all cases, it's important that the heat is transferred evenly across the entire surface. Any void in the transfer will create hot spots and deter the heater from performing as intended.

Figure 5: ZIF tail on a flexible heater.

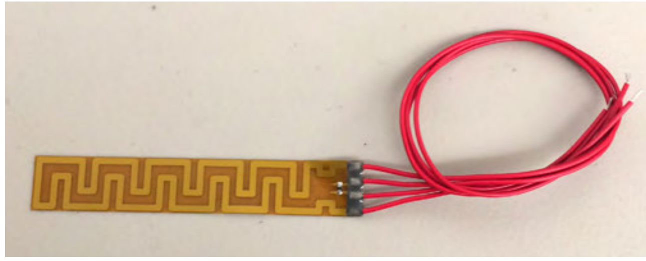


Figure 6: Wire cable attachment on a flexible heater.

Heat Spreaders

One way to help ensure that there are no hot spots is to include a heat spreader on the back side of the flexible heater. This would be a good practice if the blanket method is used to transfer the heat. Since the blanket method doesn't provide a solid method of transfer, spreading the heat on the heater itself is necessary. A spreader of a good thermally conductive material such as aluminum can be adhered or laminated to the flexible heater and ensure that the heat is spread evenly. It isn't necessary in all applications, but is very useful in some and is easily done.

Conclusion

Flexible heaters are used throughout the electronics industry because of their lightweight and inherent flexible capabilities. Their use as critical components in aircraft and medical devices require a thoughtful approach to their design. As well, their use in products such as heated automobile seats or clothing allows them to provide comfort to their user. They keep electronics warm to provide endless amounts of uninterrupted use in the roughest of conditions. Flexible heaters are useful for many applications and will continue to be valuable far into the future. **PCB**

John Talbot is president of Tramonto Circuits.

Supply Lines Highlights

EuroTech: Raw Materials Supply Chain—Critical Challenges Facing the PCB Industry

In response to growing concern from members about cost increases and potential availability restrictions affecting copper-clad laminate and prepreg supplies, the EIPC 2017 Winter Conference in Salzburg included a special panel discussion on critical issues facing the raw materials supply chain for the PCB industry worldwide.

Meyer Burger Receives Order for Multiple Solder Resist Printing Tools

Meyer Burger (Netherlands) has received an order for multiple JETx SMP inkjet production printers for the application of solder mask from a major European PCB manufacturer.

Ventec International Expands USA Manufacturing Capacity with Investment in New Equipment

Ventec International Group has increased the manufacturing capacity at its Chicago facility with major investment into new state-of-the-art equipment for laminate/prepregs as well as its newest ranges of PCB base-materials including complementary products such as flex and rigid-flex circuit board materials, back-up, entry and routing materials, foils and coatings.

Saturn Electronics Installs New Micronic Drill Machine

Saturn Electronics Corporation, a manufacturer of advanced bare printed circuit boards, received and installed a new 4-spindle Micronic 86 Drilling Machine, which is being sold and serviced in North America by Calteks LLC.

Real Time with...IPC: MacDermid Enthone Positions to Meet the Needs of the Electronics Supply Chain

Warren Kenzie, Technical Director at MacDermid Enthone, discusses with I-Connect007 Guest Editor Mike Carano the critical need to develop equipment sets that are properly designed to ensure optimal functioning of the production processes. He also noted the need to understand the relationship between materials, chemistry, equipment, and people.

Study of Immersion Gold Processes Used for Both ENIG & ENEPIG

The use of electroless nickel/electroless palladium/immersion gold (ENEPIG) has been steadily increasing the past several years and benefits of the finish have now become well-known throughout the industry. The finish provides both reliable solder joints and wire bonds.

American Standard Purchases Two LENZ RLG 550-2 Routing Machines

American Standard Circuits CEO Anaya Vardya announced recently that his company has purchased two LENZ RLG 550-2 routing machines.

Eurocircuits Purchases Ledia Direct Imager from Ucamco

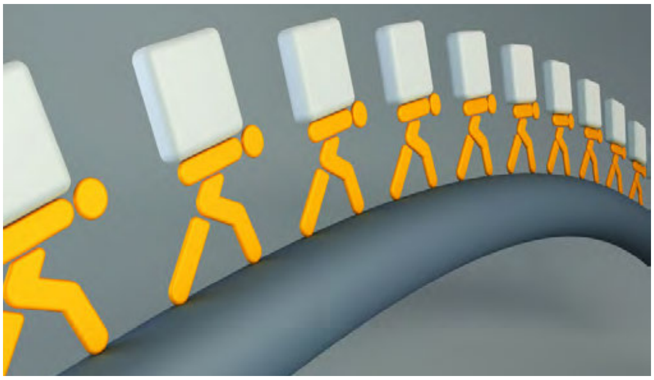
Eurocircuits has purchased a second Ledia direct imager, to be deployed in its manufacturing facility in Aachen, Germany.

Arlon EMD Expands Distribution with AMS Products

On December 21, 2016 Arlon EMD announced an agreement with Doosan-Electro Materials to distribute Doosan's DS600 flexible copper-clad laminates in North America, as well as Doosan's high Tg FR-4 and halogen-free laminate and prepreg product lines.

Insulectro Purchases 38,000 Square Foot Distribution Center in San Jose

Insulectro is moving its Silicon Valley branch operation from Mountain View to San Jose, California, a move that puts its warehouse closer to its customers for better service.



Stepping Up to Laser Processing for Flex, Part 5: Process Development

by Patrick Riechel
ESI

In Part 5 of this six-part series on effectively supplementing your flex production capabilities with laser processing, we'll discuss how to develop a process library and learn several best practices, tips and tricks for typical flexible circuit laser processes.

Introduction

Supplementing your production capabilities with flexible circuit laser processing can pay big dividends. It not only allows you to broaden the set of services to customers, but it also extends your reach into additional markets you might not otherwise be well-equipped to serve. Employing laser technology is one of the best ways to stay current in PCB processing, since it enables you to process more accurate and smaller features than what is possible using mechanical processing.

In Part 4 of this series, we discussed installation best practices, system verification testing, training and the safe operation of your system. With the system ready to process, it's time to move on to developing laser processes for the products moving through your production line.

1. Choices, Choices, Choices

What defines a good process?

An important point to consider is that the definition of a good process may vary between companies, the product being processed, the phase of a project and/or production backlog, and even from individual to individual. In theory, there are always trade-offs to be made among variables such as process development duration, cycle time, quality and yield.

Looking at this question from an organization's perspective, the process should support the organization's goals and strategy, each of which have an impact on company priorities. One company may prioritize speed to market over yield and process throughput cost. For this company, a good process might be defined as the first process to meet the minimum product requirements, allowing the company to quickly deliver on their commitments. Another company may prioritize quality and yield over other factors. For this company, a good process might be defined as one which exceeds certain stringent quality and yield requirements, despite

higher process cycle times. Yet another company may prioritize process cycle times or other factors. Which model does your company fit?

The product being processed can also have an impact on how a good process might be defined. For complex multilayer build-ups where yield loss in the final product can skyrocket, a "good" laser process may require a focus on higher quality than an equivalent double-sided FPC laminate process. Alternatively, the product material might be more expensive on one product than another, in which case yield might be prioritized higher.

The phase of a given project or the level of production backlog may similarly impact the priority of quality and yield, productivity, or time to develop such a process.

At a human level, one can even think about how different employee roles and responsibilities impact this question. Depending on organizational incentives, management structures, etc., different individuals may have different personal priorities that can influence their perception of a good process. A process engineer being pushed or incentivized to get the finished product out the door and qualified as quickly as possible may prioritize process development speed over yield or process cycle time. The factory manager, on the other hand, may be watching over total production costs and total production output and, therefore, prioritize these factors differently. Ideally, in a well-run organization, all employees will be aligned to the organization's goals and strategies and be cognizant of the product, project phase, and product backlog. Often that is not the case and needs to be continuously monitored and worked on.

Why are there tradeoffs in process development?

As discussed above, different circumstances will impact the relative priority of process development duration, process cycle time, process quality, and process yield in defining a good process. The reasons why it's not possible to deliver equally on these factors may not be clear to everyone.

Process Development Duration

It takes time to develop processes. In an ideal world, one would have access to a library of canned processes for every possible combina-

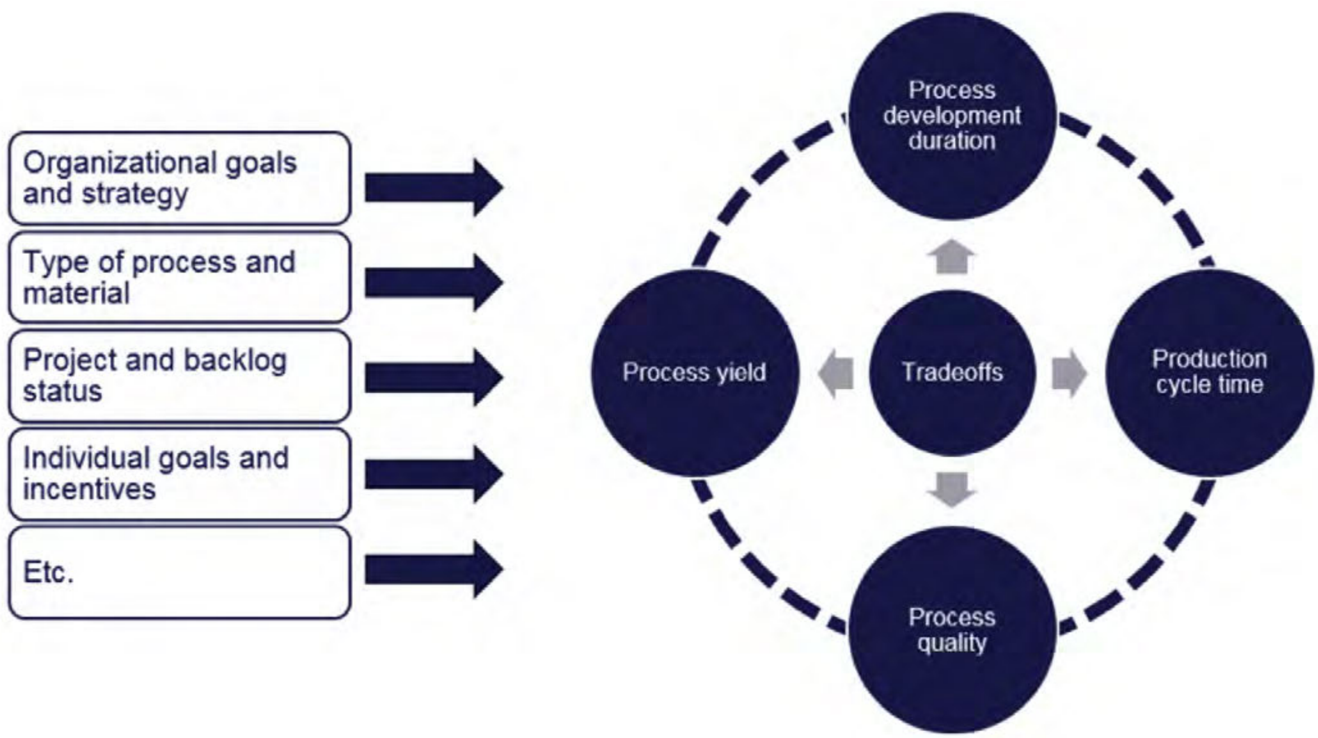


Figure 1: Many factors impact process tradeoff choices.

tion of via size, material, depth, quality, and target drill time. The massive diversity in process requirements and continuous evolution of the market prevents a single such library from being developed. Furthermore, developing processes for more demanding applications—whether due to sensitive materials, unusual feature characteristics, or stringent process quality, yield, or cycle time requirements—often requires significant trial and error to meet all the success criteria. As a result, each manufacturer will need to develop processes that best suit their needs—developing their own process libraries based on their unique set of products, customer requirements, cost profiles, market conditions, goals, and strategies. In building up such libraries and making use of known-good processes, process development duration can be reduced over time.

Process Cycle Time

Laser processing cycle time can be broken down into a few categories: time spent drilling features (drill time), time spent moving the laser between features (move time), time spent aligning to features (alignment time), time spent placing and removing the material on the system work table (handling time), and any time that the system spends performing additional tasks. Process development will generally affect drill time, sometimes also move time, but generally none of the other factors, which are mainly characteristics of the system and handling methods.

Process Quality and Yield

Process quality specifications differ between flex manufacturers. This can be traced back to both the diversity in company priorities as well as the diversity in downstream processing. Different downstream processing, such as types and effectiveness of patterning, desmear, etch, plating, and other processes, will all impact the laser drilling quality characteristics necessary to achieve a given end-product yield.

Similarly, yield requirements—the required percentage of product output meeting quality specifications—can differ between flex manufacturers. While all manufacturers prefer high laser processing and end-product yields, sometimes the cost profiles of yield loss versus process cycle time will favor a faster process over a few percentage points in yield.

Example Tradeoffs

In an extreme example of the tradeoff between cycle time, process development duration, and process quality/yield, a process engineer might choose to use a single laser pulse for a large-diameter through-via process. It would be an extremely fast process (cycle time) and have been very quick to develop (process development duration), but be very unlikely to meet any of the process quality or yield requirements for this application.

In an alternative extreme example, favoring process yield and extremely stringent process quality requirements, a process engineer might spend years getting closer and closer to meeting the necessary quality requirements, running thousands of panels through the entire manufacturing process flow to understand and improve on the end-product yield.

In practice, process development activities fall somewhere in between these extreme examples, balancing the relative priorities of each of these key criteria.

2. Flex Laser Processing Basics

Developing a Process

Although you may already have some idea of a process starting point, each new material and application generally has unique, unforeseen challenges. As a result, it is generally a good idea to generate several test grids on unpatterned materials to perform a broad sweep of the process space around that process starting point, as seen in Figure 2. For very new applications where the starting point is less clear, that process sweep can be an extensive design-of-experiments (DoE) around laser power, laser focus, laser pulse repetition frequency (PRF), process velocity, number of process steps, and tooling motions. For more well-understood applications, this process sweep might be limited to varying laser power and focus.

This process sweep would typically be followed by an iterative process of verifying quality, adjusting parameters, running process win-

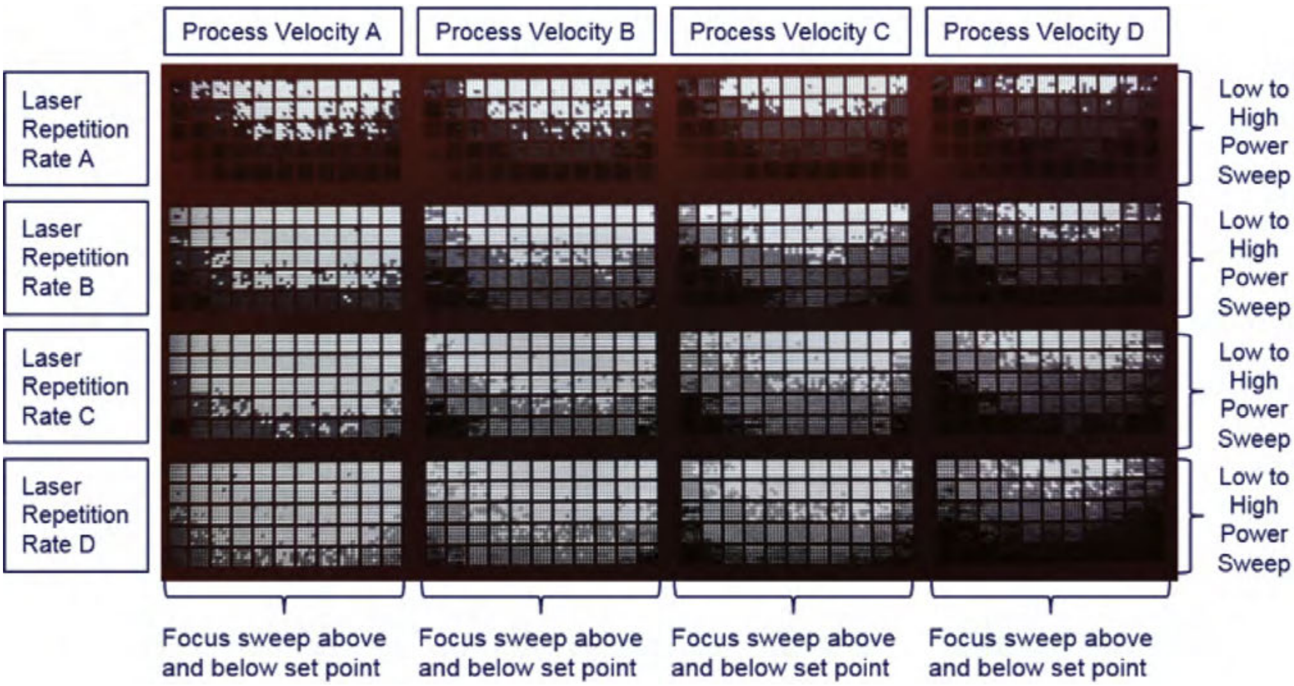


Figure 2: Example of a broad process sweep to find a robust through-via process.

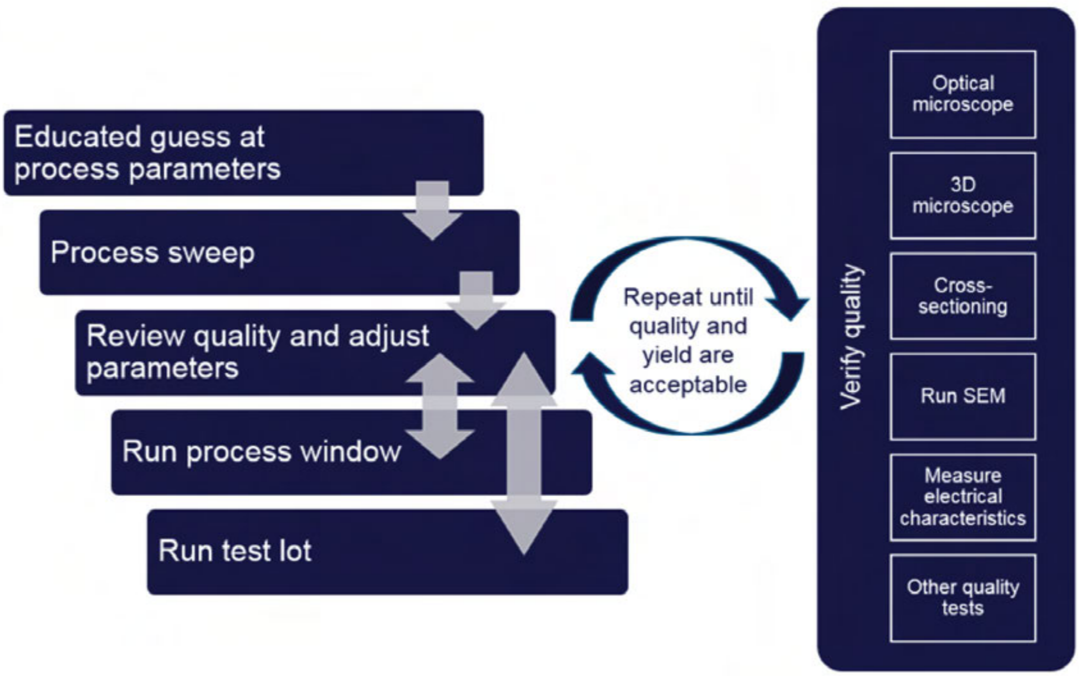


Figure 3: Example flowchart for process development.

dow tests, test lots, and eventually going into production, as seen in Figure 3.

For processes to eventually be used with patterned material and small internal-layer capture pads, the process developed on equivalent unpatterned material would then be revalidated on this patterned material in order to validate accuracy and any process shifts due to the dif-

ferent thermal response of the smaller pads. If that patterned material is scarce, evaluate smaller process shifts using selective processing of individual circuits on the panel.

Process Robustness Verification

At this point, we can introduce key process development concepts surrounding process robustness. Process robustness can be defined as the process' ability to meet the process quality specifications across the design tolerances in system characteristics as well as slight changes to system and material characteristics due to environment changes, handling, and contamination over time. Different manufacturers and even different product models each might have different tolerances on collimated beam size, laser spot size, focus accuracy, power control, and work table flatness as a few key examples. Similarly, the system, the material, and the process will be impacted by extrinsic factors such as facility temperature and humidity, facility vacuum, and compressed air pressure and flow rate, etc. that can impact process quality if not managed properly.

In short, process robustness is a key factor in ensuring high yield processes with consistently high quality. The alternative to spending time developing robust processes is accepting lower yields, system downtime and the expense associated with constant system adjustment and cleaning, and the higher expense associated with more stringent environmental control.

Process Windows

Process windows are a key method of quantifying the process robustness. Process window tests typically measure how much laser fluence (laser energy per unit area) change the process can tolerate before the process no longer meets quality specifications. Fluence is used as an evaluation metric due to its vital role in material ablation (removal). Furthermore, each of the system tolerances listed above (e.g., spot size, focus accuracy, power control, etc.) have an impact on either the laser energy or area over which that energy is delivered. Some manufacturers measure process window by varying laser focus above and below the process setpoint for the specified application. Some manufacturers measure process window by varying laser energy above and below the process setpoint for the specified application. Others do so by varying both laser focus and laser energy. No matter the precise method, it is critical to validate that the chosen process can withstand real world manufacturing conditions.

Laser Focus

For most laser processes, it is critical to find laser focus accurately. The reason for this is again related to the importance of laser fluence for material ablation (Figure 4). Not only will an out-of-focus laser spot be larger and therefore lower fluence, most lasers also suffer from lower beam circularity and higher beam distortion the further the laser spot is out of focus. This can result in poorer-quality and less predictable processes.

Note that it is equally critical to find and verify laser focus accurately both during process development and during production. If the process was developed in focus, but processed out of focus—or vice versa—the process quality will suffer significantly in production.

There are times that it is acceptable and even desirable to process out of focus, such as in clearing dielectric material from a blind via using the top copper opening as a conformal

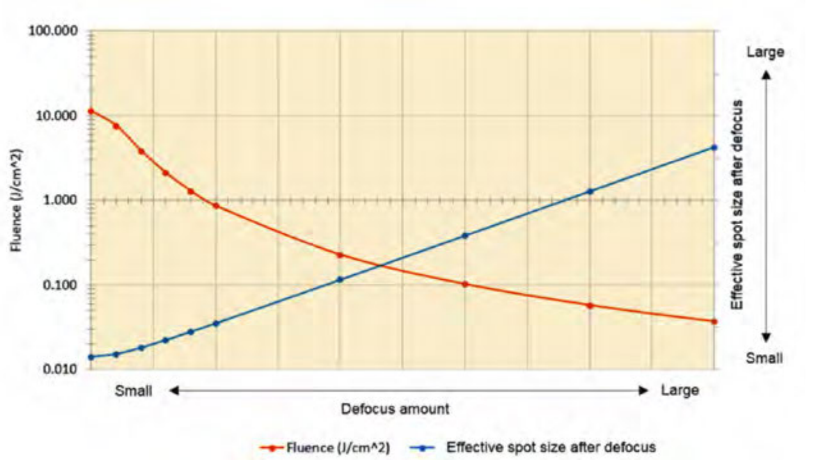
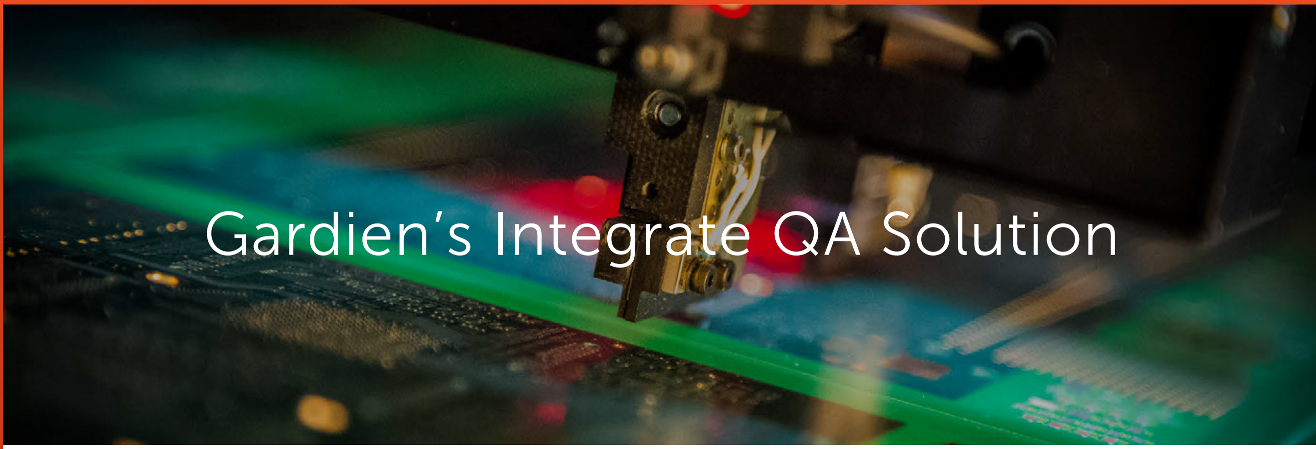


Figure 4: Laser focus has a significant impact on both effective spot size and laser fluence.

Gardien



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mask. However, even in these circumstances, in order to ensure a consistent process, it is important to have found the focus point accurately before purposely defocusing the beam by a known amount.

Tooling Motion Choice

While every laser tool manufacturer may have slightly different options and names for tooling motions, common choices include punches, circles, spirals, and routs, as seen in Figure 5. Each tooling motion has unique characteristics that result in different typical uses.

Punches may be used when the feature size is approximately equal to the laser spot size and are generally the fastest via formation method when it is possible to use them.

Circles can be used effectively when the via sizes are larger than the laser spot size. Since circle tooling motions only ablate the perimeter of the circle, it is often necessary to follow up with inset circle processes to remove more of the internal material to achieve a robust process. Such multi-circle processes are described in more detail later.

Spiral tooling motions can similarly be used when the via sizes are larger than the laser spot size. Spirals can be used in place of multiple inset circle processes for more process flexibility.

Finally, rout tooling motions are best used for cutting out or ablating any non-circular shapes. Pulse overlap and material removal rate are two important characteristics to consider for routs. Special process development attention should be given to areas with small turn radii, given the tendency for heat to accumulate in those areas.

Depth-Limited vs. Through Processes

There are distinct differences in process development best practices for depth-limited processes such as blind vias and soldermask removal versus processes that cut completely through a material, such as through-vias and excising parts. For depth-limited processes, one needs to be very careful about cutting too deep into the material and damaging the underlying substrate. On the other hand, for through processes, it is possible to develop much more aggressive processes since one does not have to worry about damaging the underlying material. These differences result in greater difficulty to develop optimal depth-limited processes—one needs to weigh cycle time vs. yield/quality tradeoffs between aggressive and more conservative processes.

In general, to ensure the most robust and high-yield process, it is important to completely clear the top copper using an in-focus spot before proceeding to the dielectric clearing step. Another best practice is to develop blind via and multilayer processes one step at a time. Test out and evaluate process parameters for each step of the via formation process.

For example, perhaps you have a three-step blind via process, cutting the top-copper perimeter with a circle tool first, then removing the

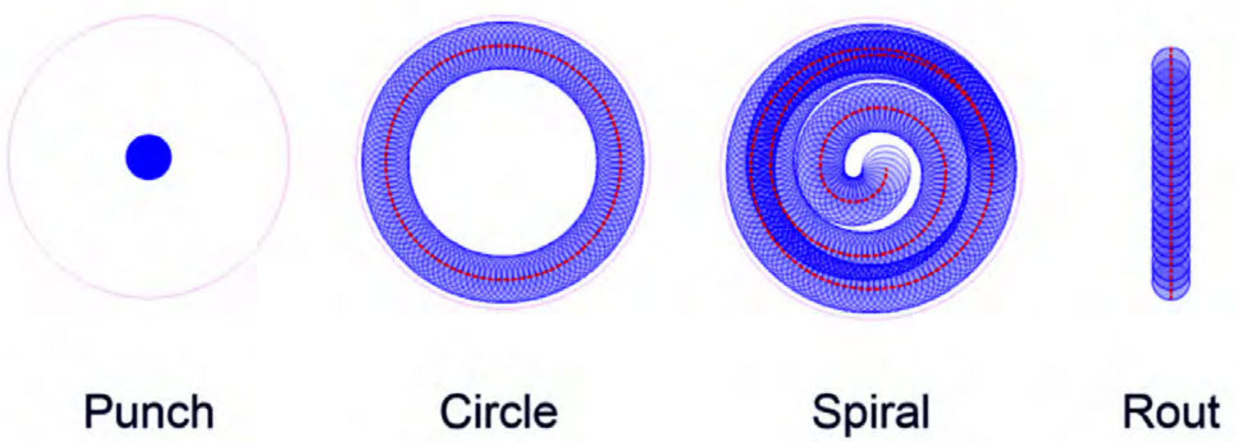


Figure 5: Common tooling motion choices.

Figure 6: Common types of alignment targets.

interior top-copper slug with a second circle tool, and finally cleaning up the polyimide dielectric with a spiral tool. In such a case, develop and evaluate all three steps individually. Verify that the first perimeter cut fully cuts through the top copper without penetrating the bottom copper. Then, after optimizing the first step process, verify that the central copper slug removal is complete. Finally, after optimizing the second step process, verify that the dielectric removal does not leave any residue and does not cause bottom copper damage.

Alignment Points and Geometry Transforms

There are many factors beyond the scope of this article that affect the registration accuracy between via holes and the landing pad. However, a few common-sense best practices can be followed to improve your registration today.

First, use the same alignment points for all processes, such as laser drilling, patterning, and drilling the tooling holes for layup—this results in the least amount of inconsistency.

Second, use the most accurate tool/process to create the alignment points—in many cases, this will be your patterning process or laser drill. While laser drills will often take more time, and have a higher cost per hole than a punch or mechanical drill, the registration accuracy will be higher.

Third, use the same scaling methods and geometry transforms (e.g., parallelogram, trapezoid, etc.) for your drilling and your patterning processes—this again results in the least amount of inconsistency.

Finally, make sure your alignment points are high contrast, highly consistent, and have a well-defined center at the small scale commensurate with the accuracy that you are trying to achieve. Patterned butterfly-type targets best meet these criteria. However, when used appropriately, cross-hair, circle, and donut targets can be used effectively as well.

Summary

Optimizing PCB laser processing for production requires a holistic view of the laser processes and their place in the production line. Taking the time to understand how those factors interact allows you to make informed decisions about where to focus your efforts and helps you to create a production process that effectively supports your organization's unique set of operational goals. But since process development is iterative and always ongoing, you will need to devote the necessary time to test, document, adjust and improve your process library. Following basic process development principles and best practices with a focus on constant improvement will not only allow you to be more flexible in response to changes in requirements but the resulting production processes will be better aligned to your business goals. **PCB**

Patrick Riechel is product manager for ESI's flexible circuit micromachining tools. To read past columns by ESI, or to contact the authors, click here.

Understanding Dimensional Stability in Flexible Circuits

by Dave Becker
ALL FLEX FLEXIBLE CIRCUITS LLC

The dielectric material sets used for fabricating a flexible circuit are what distinguishes a flexible circuit from a rigid printed circuit. Although both these products are often referred to in the industry as "boards," a better metaphor for a flex circuit might be a noodle! Glass epoxy is the most common dielectric used to fabricate most rigid printed circuits. Polyimide film (also known as Kapton®, a DuPont trade name) is the material of choice for the clear majority of flexible circuits. Developments in material science have resulted in several versions of polyimide tailored to meet specialty requirements in unusual environments including solar arrays and space applications.

Glass epoxy is produced in some very thin constructions and it can be bent for some simple applications but continuous flexing, twisting, or multi-planar folding is best accomplished with a polymer film. Polyimide films can be bent numerous times without degrading its electrical and mechanical properties and has proven reliable in applications literally requiring millions of bend cycles. This inherent flexibility provides a wealth of design options for the electronic packager, but a material disadvantage is they are not as dimensionally stable as the glass epoxy materials used to produce rigid board circuits.

Per DuPont[1], the dimensional stability of polyimide film depends on two factors—the normal coefficient of thermal expansion and the residual stresses placed in the film during manufacture.

This stability measure is only representing the effect of the film itself. Stability becomes a more complex characteristic when the film is exposed to the elevated temperatures and pressures to attach copper either through an adhesive lamination cycle or through processing to create an adhesiveless laminate. But creating a laminate, and then fabricating a circuit, in-

volves two very different processing effects as flexible substrates will dimensionally change during the fabrication process.

Most often these changes are not easily predictable. Dimensional changes might vary slightly due to raw material variation from batch to batch. Changes may also occur as a function of constructions (thin materials are less stable) and processing conditions. Material thicknesses, ambient humidity, copper electroplating densities, and percentage of copper etched can all be contributing factors.

As the circuitry panel is processed, it is exposed to a variety of chemistries, temperatures, pressures, electroplating, etching, and will undergo small dimensional changes. Etching copper releases stress and is sometimes called "etch shrink." This term mistakenly becomes a catch phrase for all the dimensional changes occurring during processing of a flexible circuit. Compensating for these changes may be considered by the fabricator when setting up a new flexible circuit part number, but often empirical data from actually producing parts is needed to accurately predict feature movements. The consequences of misalignment are illustrated in Figures 1 and 2.

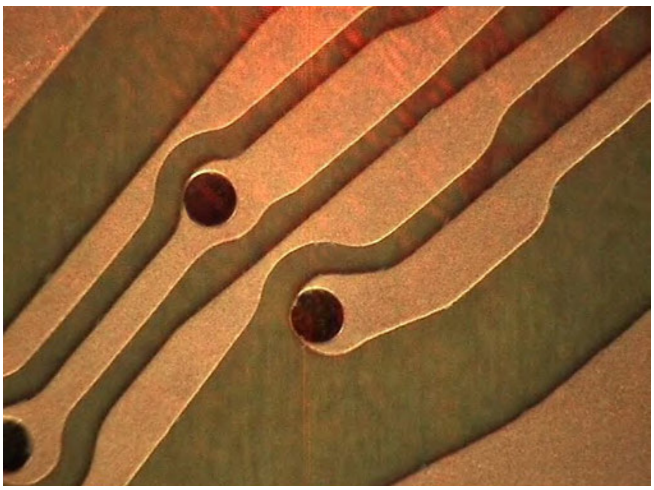


Figure 1: Material stability can create a violation of the minimal annular ring requirement or it can possibly cause full break-out of the hole-to-pad alignment (as shown). When the material change is predictable, then either the drill pattern or the conductor layout can be adjusted to re-center the plated-through-hole in the pad.

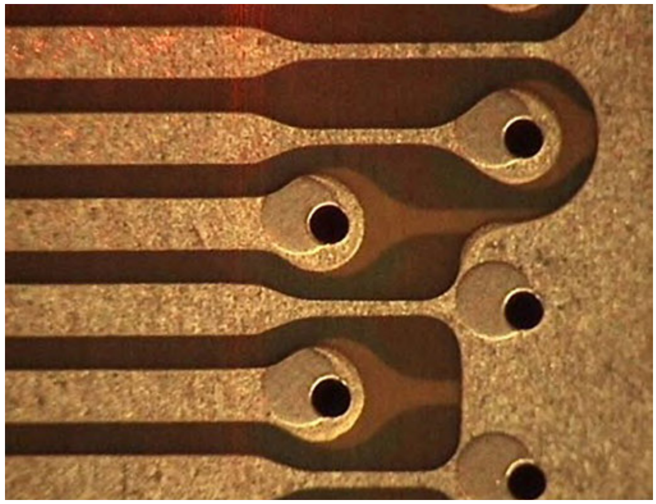


Figure 2: Example showing misalignment of coverlay.

One possible way to deal with dimensional changes is to minimize the panel size, which may be done when tolerances are extremely tight. The smaller the panel size, the less dimensional stability issues will affect registration and alignment. Handling damage is also minimized with smaller panels. The downside of smaller panel sizes is they are less efficient to process vs. larger panels, as many costs in a circuit "noodle" factory are panel-driven.

There are many ways to compensate for dimensional changes while balancing panel size for cost-effective production. The following are often adopted as methods to adjust for the dimensional changes that may occur during circuit fabrication:

• Scaling factors can be applied to secondary layers or tooling based on the predicted dimensional change of the material. Scaling factors can also be dynamically calculated based on in-process measurements for a given lot. One example could be a solder paste stencil that is created based on the measured scaling factor of a panel ready for component population. Dimensionally compensating a final drill program in a multilayer is another example.

• Software-controlled operations use alignment systems to detect dimensional shifts and compensate by using optical fiducials. Many fabrication machines can perform a dimension-

al analysis based on measuring these targets on the outside corners of the panel and then apply the proper X-Y and theta corrections for alignment.

• After the circuit image has been created, processing or dividing the panel into smaller "within panel" arrays is another strategy for handling dimensional changes. This approach looks at subsets of the panel, effectively gaining some of the advantages of smaller panel alignment, without compromising the cost advantage of processing a larger panel of parts. Using optical targets to place SMT components on a smaller subset panel is a common compensation for stencil registration. In another example, a hard tool die might cut four pieces at a time on an 80-piece panel. The panel could be cut into narrower strips and fed through the die.

A primary difference between flexible and rigid circuitry is dimensional change which may need compensation. While the flexible circuit material change is generally less than one tenth of one percent, as measured across a dimension of several inches, this can be significant. Compensating for the expected change can be a critical part of circuitry panelization and set up of a flexible circuit part number. This becomes a balancing act between maintaining dimension accuracy and tolerances, while maximizing processing efficiencies. The engineering team at the circuitry fabricator considers these options and tradeoffs when quoting a project and when specifying the process and panel layout. As always, early consultation with a supplier is encouraged to dodge avoidable problems. **PCB**

References

1. DuPont Kapton HN datasheet.

Dave Becker is vice president of sales and marketing at All Flex Flexible Circuits LLC. To contact Becker, or to read past columns, click here.

Engineers Build Robot Drone that Mimics Bat Flight

Bats have long captured the imaginations of scientists and engineers with their unrivaled agility, but their complex wing motions pose significant technological challenges for those seeking to recreate their flight in a robot.

The key flight mechanisms of bats now have been recreated with unprecedented fidelity in the Bat Bot—a self-contained robotic bat with soft, articulated wings, developed by researchers at Caltech and the University of Illinois at Urbana-Champaign (UIUC).

"This robot design will help us build safer and more efficient flying robots, and give us more insight into the way bats fly," says Soon-Jo Chung, associate professor of aerospace and Bren Scholar in the Division of Engineering and Applied Science at Caltech, and Jet Propulsion Laboratory research scientist. (Caltech manages JPL for NASA.)

Chung, who joined the Caltech faculty in August 2016, developed the robotic bat, along with postdoctoral associate Alireza Ramezani from UIUC, and Seth Hutchinson, a professor of electrical and computer engineering at the UIUC and Ramezani's co-advisor. Chung is the corresponding author of a paper describing the bat that was published on February 1 in Science Robotics, the newest member of the Science family of journals published by the American Association for the Advancement of Science.

The Bat Bot weighs only 93 grams and is shaped like a bat with a roughly one-foot wingspan. It is capable of altering its wing shape by flexing, extending, and twisting at its shoulders, elbows, wrists, and legs.

FEATURE INTERVIEW

American Standard Circuits Releasing e-Book on Designing Flex and Rigid-Flex

by Patty Goldman
I-CONNECT007

American Standard Circuits' VP of Business Development Dave Lackey and President/CEO Anaya Vardya have co-authored *The Printed Circuit Designer's Guide to…Flex and Rigid-Flex Fundamentals,* published by I-Connect007.

American Standard Circuits is an industry leader when it comes to high-technology printed circuit boards, especially flex and rigid-flex printed circuit boards. So, it was natural that they would write about flex and rigid-flex for I-Connect007's new "Guide to…" e-book series.

Goldman: ***Gentlemen, congratulations on the book. Tell me a little bit about what it covers and why you chose this subject.***

Lackey: We work so closely with designers all the time that we felt it would be a good idea to write this book for designers. We wanted to cover some of the more common fundamentals that we work on together. We focus on things like dos and don'ts of designing flex and rigid-flex boards, design guidelines, construction tips, and anything else we can help them with during the design process rather than while parts are being built.

Vardya: Our philosophy at American Standard is to help our customers in any way that we can. We want to be their experts and make it easy for them to get their boards built. Over the last few years, we have seen more designers venturing into the flex and rigid-flex arena. There are several differences between these boards and regular rigid PCBs. We wanted to share our knowledge with them and alert them to various items in the design process where they would want to consult with their PCB fabricator. We felt that this book was a perfect way to do this.

Goldman: ***I know you wrote it for PCB designers. How do you expect this book to help them?***

Lackey: It is critical for designers to work closely with their PCB fabricator when designing flex and rigid-flex PCBs. We wanted to educate them on several issues where they would want to collaborate with their fabricator while educating them about the various nuances of these circuit boards. If there is anything we can do to make building flex and rigid-flex boards more

Dave Lackey

productive and economical, we want to help them do that.

Goldman: ***Who else stands to benefit from the book?***

Vardya: Just about anyone who has anything to do with flex and rigid-flex PCBs should find this book useful, including engineers, program managers and even buyers, as well as PCB designers. It should also be helpful to those who are not yet buying or designing flex boards but are thinking about it. This will give them a good idea of what is involved.

Lackey: I'd like to add that we were especially interested in helping younger designers who are new to the industry and the technology. We are seeing many instances of PCB designers coming right of school with a lack of real understanding of the complexities of the products they are designing. Our goal is to help by educating them.

Goldman: ***So, what is your background and how long have you been in our business? Anaya, let's start with you.***

Vardya: I have been in boards for more than 30 years, working for a number of larger companies like IBM, Continental Circuits, Merix and Coretec. I have held several key management positions before I came here to American Standard Circuits 10 years ago as CEO.

Lackey: Well, I'm 37 years in the industry and counting. I've been in this business working with several shops here in the Chicago area. For 33 of those years I have been working with flex and rigid-flex circuits. I have worked in all areas of manufacturing and engineering before eventually moving into upper management.

Goldman: ***Now, tell me a little bit about American Standard.***

Vardya: We like to say that we are the best independent fabricator in the country. We provide just about all technologies of PCBs to our customers. We have development processes as well and hold many patents. Our goal is to grow through service by providing our customers with the best service, the best technology and perhaps even the best R&D in the business.

Anaya Vardya

Goldman: ***Can you give me some examples from the book as to what is different about flex and rigid-flex boards compared to rigid PCBs, especially designing them? What should designers watch out for?***

Lackey: I think one of the most valuable parts of the book is the one on material selection. This is an area that many designers do not have a good understanding of so they are asking for our help. I think they are going to find that part of the book especially valuable. We also discuss functionality and costs and how that differs from rigid PCBs.

Goldman: ***I am hearing and reading a lot more about flex technology these days and it is considered the fastest growing PCB technology. Why is that?***

Vardya: Because it is so useful as a technology. Flex and rigid-flex boards are so adaptable to space constraints. They can go around corners, they can bend, they are much more reliable than connecting two or more rigid PCBs with a connector. It is an idea whose time has come.

Lackey: They are also lighter and more functional, and they work well in all markets, from medical to aerospace, and from military to computer. There is a flex board in every laptop computer, for example.

Goldman: ***What are your thoughts about the future? Do you feel that that the demand for flex and rigid-flex technology is going to continue to grow?***

Lackey: Yes, absolutely! If you look at all the

market statistics from IPC, this is indeed the fastest growing market segment. So it is a great technology to invest in and a great product to design in. We have invested in both equipment and people to be able to provide our customers with all the flex and rigid-flex boards they need today and are going to need in the future.

Vardya: As Dave stated, they are now being used in essentially every market and in just about every electrical product being designed today.

Goldman: When is this book coming out and how can people get it?

Vardya: The book is being released March 6th, and it will be available for free download on a special website that we are designing for it.

Goldman: Once again, congratulations on this effort and on behalf of the industry, thank you and American Standard Circuits for giving this guide to us.

Vardya: Thank you. **PCB**

For more information about The Printed Circuit Designers' Guide to…Flex and Rigid-Flex Fundamentals, click here.

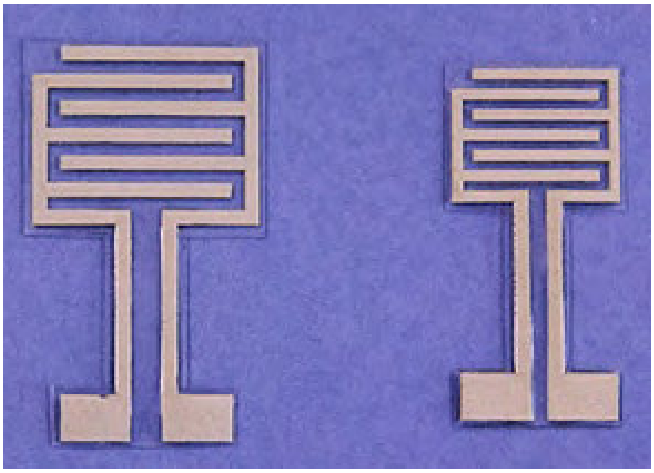
Wearable, Low-Cost Sensor to Measure Skin Hydration

Researchers from North Carolina State University have developed a wearable, wireless sensor that can monitor a person's skin hydration for use in applications that need to detect dehydration before it poses a health problem. The device is lightweight, flexible, and stretchable and has already been incorporated into prototype devices that can be worn on the wrist or as a chest patch.

"It's difficult to measure a person's hydration quantitatively, which is relevant for everyone from military personnel to athletes to firefighters, who are at risk of health problems related to heat stress when training or in the field," says John Muth, a professor of electrical and computer engineering at NC State and co-corresponding author of a paper describing the work.

The sensor consists of two electrodes made of an elastic polymer composite that contains conductive silver nanowires. These electrodes monitor the electrical properties of the skin. Because the skin's electric properties change in a predictable way based on an individual's hydration, the readings from the electrodes can tell how hydrated the skin is.

In lab testing using custom-made artificial skins with a broad range of hydration levels, the researchers found that the performance of the



wearable sensor was not affected by ambient humidity. And the wearable sensors were just as accurate as a large, expensive, commercially available hydration monitor that operates on similar principles, but utilizes rigid wand-like probes.

The researchers also incorporated the sensors into two different wearable systems: a wristwatch and an adhesive patch that can be worn on the chest. Both the watch and the patch wirelessly transmit sensor data to a program that can run on a laptop, tablet or smartphone. This means the data can be monitored by the user or by a designated third party.

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Electronics Industry News
Market Highlights

Internet of Things Market in Central and Eastern Europe to Boom Through 2020

Spending on the Internet of Things (IoT) in Central and Eastern Europe (CEE) has reached an astonishing $11 billion in 2016 as organizations accelerated their investments in the hardware, software, services, and connectivity that enable the IoT.

Worldwide Sales of Smartphones Grew 7% in Q4 2016

Global sales of smartphones to end users totaled 432 million units in the fourth quarter of 2016, a 7% increase over the fourth quarter of 2015, according to Gartner Inc. The fourth quarter of 2016 saw Apple leapfrog past Samsung to secure the No. 1 global smartphone vendor position.

Top 3 Chinese Smartphone Vendors Grab Nearly Half of China's Market in 2016

According to the latest IDC Quarterly Mobile Phone Tracker, the smartphone market in China saw a 19% YoY growth and 17% QoQ growth in 2016Q4. For the full year of 2016, the market grew by 9% with top Chinese smartphone vendors taking up a larger share of the market.

Apple Tops Samsung in Q4 to Close Out a Roller Coaster Year for the Smartphone Market

Preliminary data from the International Data Corporation (IDC) Worldwide Quarterly Mobile Phone Tracker shows that smartphone vendors shipped a total of 428.5 million units during the fourth quarter of 2016 (4Q16), resulting in 6.9% growth when compared to the 400.7 million units shipped in the final quarter of 2015.

OPPO and Huawei Make Strides as Samsung Remains Malaysia's Top Smartphone Player in 2016

According to the latest International Data Corporation (IDC) Quarterly Mobile Phone Tracker, total smartphone shipments in Malaysia recorded approximately 2.7 million units in 2016Q4, bringing 2016 to a close with approximately 8.8 million units shipped, a reported 5.9% decline year-over-year (YoY).

Internet of Things: A Promising Future for Sensors

The MEMS and sensor offering has never been so diverse. Inertial, pressure, temperature, (bio-) chemical and gas sensors as well as microphones, fingerprint and iris recognition. All devices are part of the IoT revolution.

Advances in Artificial Intelligence to Help Machines Understand Human Thoughts using Brain Computer Interface

The concerted efforts toward making artificial intelligence (AI) technology capable of human-like cognitive behavior such as learning, reasoning, problem solving, planning and self-correction have received a huge boost with advances in deep learning and neural networks.

Top China Vendors Consolidate Share in Emerging Southeast Asia Smartphone Market in 2016

Per the latest International Data Corporation (IDC) Quarterly Mobile Phone Tracker, total smartphone shipments in the emerging Southeast Asia (SEA) region in 2016 recorded approximately 101 million units, or a 4.3% year-over-year (YoY) growth versus last year.

Researchers Devise Efficient Power Converter for Internet of Things

The Internet of Things is the idea that vehicles, appliances, civil structures, manufacturing equipment, and even livestock will soon have sensors that report information directly to networked servers, aiding with maintenance and the coordination of tasks.

IDC Asia/Pacific Predicts 3D Printing to Hit Mainstream Market in Asia Pacific in 2018

IDC has just unveiled its latest predictions for the 3D printing market titled IDC FutureScape: Worldwide 3D Printing Predictions – APeJ Implications and reveals that 3D printing will hit mainstream in Asia Pacific excluding Japan (APeJ) in 2018.

Stretching Beyond Flex

by Andy Behr
PANASONIC ELECTRONIC MATERIALS

Emerging end-use electronic applications are driving dramatic innovations in circuit board and interconnection technology. New form factors, functionality and durability requirements are challenging the status quo for the PCB industry and pushing design, material and process development to the limit. Incipient devices like wearables, epidermal monitors, embedded sensors, smart labels, human machine interfaces (HMIs), conformable antennas, flexible displays and in-mold electronics (IME) require a combination of circuit stretchability and toughness that isn't achievable with conventional circuit manufacturing technologies.

Device manufacturers are seeking alternative methods for creating wiring patterns and interconnecting components that are more conformable, elastic and durable than currently available. To set the stage for a discussion on stretchable circuit technology, this article describes two classes of polymers commonly used for manufacturing circuit boards and outlines the developmental arc of two fundamental PCB materials, conductive circuits and organic substrates. The article concludes by reviewing state-of-the art, commercially available stretchable substrate and conductor technologies, as well as new materials and processes that are being researched.

Thermoplastic and Thermosetting Polymers

Broadly speaking, the polymers used for manufacturing electronics may be divided into two classes: thermoplastic and thermoset. The division is based on the degree of chemical cross-linking between the constituent molecules and the temperature-related mechanical properties this cross-linking (or lack thereof) imparts. Depending on the resin system, both classes of polymers can exhibit a wide variety of properties. For example, both thermoplastic and thermoset resins can run the gamut of hardness physiognomies from rigid and brittle to flexible and bendable to elastomeric and stretchable.

Thermoplastic polymers typically have a low degree of intermolecular cross-linking. The long chain polymer molecules are tightly "tangled" at temperatures below the glass transition (Tg), resulting in a solid or "glassy" material. These same molecules loosen up and untangle at el-

evated temperatures, resulting in the material becoming increasingly rubbery as the temperature climbs, and ultimately becoming plastic above the melt temperature (Tm)—and thus the term thermoplastic. The fundamental polymer structure of these materials does not change with temperature, only the degree of molecular entanglement. Nor is the basic polymer composition altered by repeated melting and cooling cycles. Some common thermoplastic resins used in electronic manufacturing include polyethylene terephthalate (PET), polyethylene naphthalate (PEN), polycarbonate, polyamide, polyetheretherketone (PEEK) and polyvinyl chloride (PVC).

Additionally, thermoplastic materials can be categorized into two subclasses based on their sub-Tg molecular arrangement: amorphous and semi-crystalline. In amorphous thermoplastic polymer systems, the molecule chains are completely randomly arranged and tangled with each other. The molecules of semi-crystalline thermoplastic polymers form a crystalline structure in some regions of the polymer matrix. (A crystalline structure is any structure of ions, molecules, or atoms that are held together in an ordered, three-dimensional arrangement.) In addition to other performance differences, the pockets of ordered polymers in semi-crystalline thermoplastics impart a degree of toughness in the transition region between the Tg and the Tm as compared to amorphous thermoplastic materials.

"In amorphous thermoplastic polymer systems, the molecule chains are completely randomly arranged and tangled with each other."

Thermosetting polymers undergo a non-reversible chemical reaction during curing. Lower molecular weight compounds like monomers and oligomers are chemically cross-linked and form high density, three-dimensional polymer networks. Material formulations based on thermosetting polymers often require energy input such as heat or high intensity light to initiate, accelerate and complete the polymerization process. Some of the more common thermosetting polymers used in electronic assembly applications include epoxies, silicones and urethanes. Generally, thermosetting materials exhibit lower coefficient of thermal expansion (CTE), better temperature tolerance and chemical resistance than thermoplastics. Thermosets have dominated the circuit board materials and electronic assembly markets. Epoxies have been the primary chemistry for circuit board laminates, solder masks, adhesives and potting compounds. Polyimide films are a mainstay for the copper-clad flexible substrate market, urethanes are used for many types of conformal coatings, and silicones are a binder common in thermal interface material (TIM) formulations.

Rigid PCBs—The Industry Workhorse

Circuit boards have been around for decades. In their oldest, and still most common, embodiment, a PCB consists of copper circuits formed on rigid thermoset polymeric substrates. The circuits are fashioned subtractively by employing photolithographic resists to create a pattern on the surface of the copper-clad laminate. When the imaged copper is etched and the resist is removed, the basic printed circuit construction is formed. Copper circuitry works well for a variety of reasons including the fact that it's very conductive (1.72E-08 ohm-m), solderable and a comparatively abundant element. Rigid circuit board laminates are commonly composed of woven glass fibers impregnated with a thermoset resin (typically epoxy). This combination of cured thermoset resin and glass cloth creates a stiff and stable substrate which is relatively easy to handle in fabrication and assembly processes. This type of construction is also conducive as a rigid substrate for mounting components and can withstand the temperatures required for forming soldered connections.

Circuit board technology has progressed far beyond this very basic conductive copper circuit on an epoxy glass substrate model and includes variations such as ceramic, multilayer laminations, blind and buried vias, functional coatings, plating chemistries, hybrid circuits, buried passives, surface mount component assembly processes and a plethora of other technologies. Rigid circuit boards are generally suitable for applications where a static and planar wiring substrate meets the design requirements, but the inflexible form factor faces challenges in applications requiring out-of-plane circuit routing.

Flex PCBs—The Second Wave of PCB Technology

Although developed later than rigid circuit boards, flex circuits have also been in existence for many years. The advent of flex circuit technology was a major breakthrough in electronic device design. This new form factor enabled the development of many of the electronic devices we are familiar with today. As with rigid circuit boards, there are countless variations of flexible PCB technology. This section will briefly review copper-clad polyimide because this material set has emerged as the dominant technology for solid metal conductor flexible circuits.

Over the years, many types of thermosetting polymer films have been used for making flex circuits including fluoropolymers and flexibilzed epoxies. However, because of its combination of mechanical, chemical, electrical and thermal properties, polyimide film has emerged as the prevalent thermoset substrate material for flex copper-clad film PCB constructions. While there are many types of polyimide available from a number of suppliers, generally they all exhibit flexibility over a wide temperature range, with good electrical properties, excellent chemical resistance, superior tear resistance and high tensile strength.

In a typical scenario, the polyimide film is clad on one or both sides with a copper foil. Rolled and annealed copper (known as RA copper) is the most common type of copper foil for PCB manufacturing. As with rigid PCB technology, the circuits are formed using photolithography and subtractive chemical processes. The copper foil is imaged and etched to form copper traces. Luckily, it turned out that copper also works well for flexible circuit constructions. As demonstrated by applied mechanics, bending strains decrease linearly with thickness. The result is that any material, in sufficiently thin form, is flexible. Combining this mechanical principle with copper's ductile properties means that thin copper foils with the correct grain structure can bend repeatedly without cracking, within certain parameters.

In addition to being bendable, flexible polyimide based PCBs are generally thinner and lighter than their rigid counterparts, with the result that end products incorporating these flex circuits can also be smaller and lighter.

In addition to being bendable, flexible polyimide based PCBs are generally thinner and lighter than their rigid counterparts, with the result that end products incorporating these flex circuits can also be smaller and lighter. And, as their name implies, flexible PCBs are designed to bend and twist, freeing product designers from the constraints of a two axis PCB layout. Flexible PCBs readily route circuitry, surface mounted components and interconnections out of the X-Y plane and into the Z plane. Depending on the assembly process and end-use functionality of the device, flexible PCBs may be subjected to either static bending (bend and hold) or dynamic bending (repeated flexing) stresses. Engineers have a wide variety of material sets and design rules at their disposal to find the necessary combination of construction, substrate and conductor materials to achieve the desired bending performance.

Polymer Thick Film—The Low-Cost Circuit

Additive manufacturing is a hot topic today. Many people aren't aware that high-volume production circuits have been made using additive manufacturing technology for decades.

Low-cost printed circuits can be formed by printing and drying conductive paste on flexible films via roll-to-roll processing. Screen printing is the predominant paste application process. These silver filled pastes are commonly referred to as polymer thick film (PTF) pastes because they have a significant polymeric component (commonly polyester) and are generally thicker than copper foils or vacuum deposited thin films. Like-wise, the most popular substrate is heat-treated polyester film. (Polyester is a common name for the semi-crystalline thermoplastic polymer PET.) This method of additive manufacturing enabled the development of literally thousands of low cost electronic circuits from membrane switches used in computer keyboards to disposable electro-chromic battery testers.

"While these types of flexible circuits are cost-effective and easy to produce, they also have performance limitations relative to those made with copper-clad thermoset substrates."

While these types of flexible circuits are cost-effective and easy to produce, they also have performance limitations relative to those made with copper-clad thermoset substrates. One issue is increased conductor resistance. Typical silver-based PTFs are approximately two orders of magnitude less conductive than solid copper (1.0E-06 ohm-m versus 1.8E-08 ohm-m). Therefore, circuit traces of similar dimensions have much higher resistance. Additionally, the thermoplastic resins typically used for this type of flex circuit construction have a much lower temperature tolerance which can limit their compatibility with conventional surface mount assembly processes and their applicability for harsher end-use environments. PEN and PEEK films are sometimes used as substrates for PET in flexible circuits that require incremental additional heat tolerance is required.

New Electronics—New Performance Requirements

New generations of electronic devices are pushing the limits of current circuit manufacturing technologies. Evolving product designs need PCBs which are beyond flexible; they require circuits that are pliable, conformable, and resilient. In short, they need stretchable circuitry. Stretchiness can be defined as the ability of a material to resume its normal shape after being deformed. The terms stretchable and elastic are often used synonymously.

In addition to withstanding occasional stretching, bending, compression, twisting and other deformation forces, product designs require stretchable circuits that are durable. Depending on the end-use, they may need to withstand hundreds of wash/dry cycles, UV exposure, water immersion, chemical contact, thermal excursions, shock, vibration and mechanical abrasion.

While flexible, nether of the conventional flex circuit material sets (copper-clad polyimide or silver PTF on PET) meet the requirements for truly stretchable circuitry. The basic materials like copper, polyimide and PET just aren't capable of being elongated to a significant degree without imparting permanent deformation. Product design engineers are seeking alternative approaches to provide circuitry that is both stretchable and durable.

First Generation Stretchable Circuit Materials—Thermoplastic Films and Silver Pastes

Screen printed circuits formed on thermoplastic elastomers have emerged as the go-to material set for the first generation of stretchable electronics. Elastomeric resins are the principle polymer system for creating both the stretchable substrates and conductive pastes on the market today. These materials have found their way into high volume production in several markets including the wearable device and health monitoring sectors.

While polydimethelsiloxane (PDMS) and several other types of elastic thermoplastic films

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have been evaluated as viable high volume substrates for stretchable circuitry, thermoplastic polyurethane (TPU) based films have emerged as the current market leaders. Although urethanes are generally associated with the thermosetting class of resins, a thermoplastic version is the substrate of choice for many stretchable circuit applications. TPUs are cost-effective, widely available and have good elastic properties.

"TPUs are cost-effective, widely available and have good elastic properties."

However, they exhibit some degree of hysteresis (permanent deformation) after stretching: approximately 3–15% after one cycle of 100% elongation. The hysteresis performance can be improved by modifying the resin, but generally, there exists a trade-off between the elastic properties and heat resistance for TPU films. If the formulation is modified to increase elasticity (i.e., reduce hysteresis), the temperature resistance is lowered.

Conductive PTF pastes are applied in the desired pattern on the TPU film. These paste formulations generally combine surface treated metal particles (usually silver flake), thermoplastic resin, solvent and rheological modifiers. The amount of metal relative to the amount of polymer is a critical factor in determining electrical and other properties of the paste. Ideally, the amount of conductive particles should be sufficient to achieve the percolation threshold—the minimum filler content in the polymer matrix after which there is no significant change in the electrical properties of the dried composite. Screen printing and rotary gravure are the most established paste application methods. However, inkjet, aerosol jet and other additive PTF circuit patterning processes are also in development. After application, the pastes are dried at relatively low temperatures to evaporate solvents and other VOCs without melting or damaging the paste or the substrate. (Occasionally, this process is mistakenly referred to as the curing step, but as noted earlier, thermoplastic polymers don't crosslink, so drying is the more appropriate term.)

Typically, TPUs have lower temperature resistance than the PET materials used for creating non-stretchable PTF circuitry via the same process. Because of temperature limitations, subsequent assembly of stretchable thermoplastic circuits can be challenging. Neither the conductive traces formed with thermoplastic PTF silver pastes nor the TPU films can withstand the elevated temperature regimes required for typical reflow soldering processes or bonding with epoxy based thermosetting adhesives. Interconnection and component attachment are usually accomplished using thermoplastic adhesives or crimp type mechanical connectors.

Many electronic material suppliers, EMS companies and OEMs are actively developing alternatives to thermoplastic film and PTF constructions. They are seeking approaches to manufacture stretchable circuitry that overcomes the inherent limitations of the thermoplastic based materials.

Stretchable Thermoset Films

Numerous companies are actively developing thermosetting elastomeric films as an alternative to TPU films as a stretchable circuit substrate. These new materials hold the promise of stretchability combined with superior temperature tolerance, better chemical resistance, higher surface energy and increased durability.

Thin versions of addition-cured silicone rubber films have been introduced to overcome some of the challenges associated with TPUs for electronic applications. These films feature attractive properties like stretchability, high dielectric strength, chemical inertness, low glass transition temperatures and good heat resistance. Silicone films tend to have very low surface energy which creates adhesion challenges. Surface treatments like plasma cleaning and primers are used to enhance the interfacial adhesion between the silicone film and conductive paste.

Panasonic Electronic Materials has developed a proprietary non-silicone thermosetting

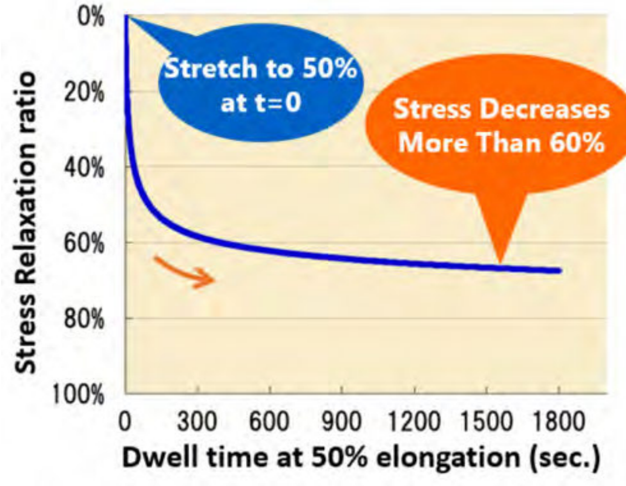


Figure 1: Graph illustrating the stress relaxation properties of Panasonic's developmental stretchable thermosetting film.

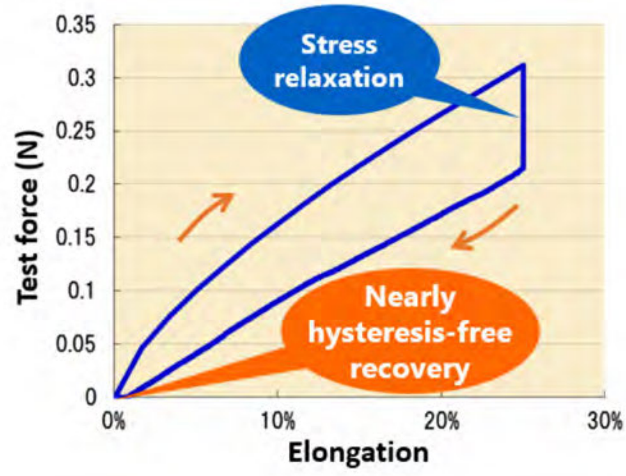


Figure 2: Graph illustrating the ultra-low hysteresis characteristic of Panasonic's developmental stretchable thermosetting film.

stretchable polymer technology that may address many of the challenges with other stretchable materials. This resin is currently being used in a number of developmental electronic material embodiments including a stretchable film which exhibits some unique and attractive properties. The material has good elongation properties (stretching up to 170%) and the current version of the film has a stress relaxation value in excess of 60% at 50% elongation, which is attractive for epidermal devices where skin comfort is a design priority (Figure 1). The stress relaxation properties may be tailored to meet specific application requirements. Additionally, the film also exhibits very low hysteresis—well under 1%, which means that it incurs practically no permanent deformation after elongation (Figure 2).

This same film has a high surface energy which allows it to bond well with many other materials without priming or surface treatment. Both thermoplastic and thermosetting resin systems have been successfully tested for bonding and encapsulation. Because the film is supplied on a polyester liner, it can be laminated with pressure sensitive adhesives and die cut using conventional roll-to-roll converting processes. Encapsulated constructions have been made by laminating B-staged film over circuits, components and other features. The material can be selectively ablated using conventional lasers. It also has a high temperature resistance. The film does not melt or degrade even after floating in solder at 260°C. Polymer decomposition occurs around 325°C. This combination of elastic properties, temperature resistance and material compatibility opens up entirely new avenues for circuit metallization, assembly and end use applications.

Stretchable Conductors—a Substantial Challenge

Even as promising stretchable thermoset substrate materials arrive on the scene, the creation of stretchable circuitry that combines desired attributes such high conductivity, high elasticity, high solderability and high durability remain an industry challenge. In the short term, it appears that design engineers will be forced to accept trade-offs as they evaluate the market-ready approaches for creating the next generation of stretchable circuits.

One obvious choice for creating stretchable circuit traces is to use thermosetting elastomers to formulate conductive pastes analogous to the flexible and stretchable thermoplastic pastes reviewed previously. This is an attractive approach for many end use applications because the fairly stretchable circuitry can be manufactured with conventional processes. While using thermosetting resins increases temperature resistance and durability issues, other challenges remain. These PTFs must be compatible with the substrate they are applied to. The PTF needs to adhere well to film and the film needs to be capable of withstanding the curing regime of the thermosetting resin (Figure 3). Circuits made with polymers (regardless of thermoplastic or thermoset) are orders of magnitude less conductive than those made of solid metals like copper. Additionally, the volume fraction of the resin required for a conductive paste to achieve cohesive and adhesive integrity generally prevents soldering, which means that these circuits remain limited to interconnection via mechanical connectors or conductive adhesives.

One option for creating higher conductivity circuits using additive processes like screen printing or inkjet printing is the use of sinterable metal technology. Sintering is the process of using heat to fuse discrete metal particles (like powders and flakes) into solid mass without melting it to the point of liquefaction. Depending on the formulation, silver, copper and other metal powders may be sintered with heat or high energy light sources. In terms of bulk conductivity, the sintered metal pastes tend to fall between their bulk metal counterparts and PTFs made with particles of the same metal. Nanoparticle technology is being incorporated into some sintered paste formulas. Nanoparticles behave very differently than larger particles of the same materials. For example, nano-scale metal particles can significantly reduce the amount of heat required for sintering to occur. In addition to improved conductivity, circuits formed by sintering can often withstand elevated assembly and end use temperatures, and in some cases, they may be soldered. The thermosetting stretchable film from Panasonic noted above has been successfully metalized with sintered conductive pastes. While these conductors formed in this manner are not stretchable, they can be used to selectively create islands of rigidity and solderable areas for attaching components via conventional reflow solder paste processing. Creating these types of features on stretchable films may open the door for high volume assembly with existing PCBA equipment and materials.

Some clever work has been done creating stretchable conductor structures with bulk metals. One approach involves creating metal structures on the surface of pre-stretched elastomers. When the substrate is relaxed, the metal buckles into wave structures as the substrate contracts. This type of structure can then be repeatedly stretched and relaxed in the pre-stretch direc-

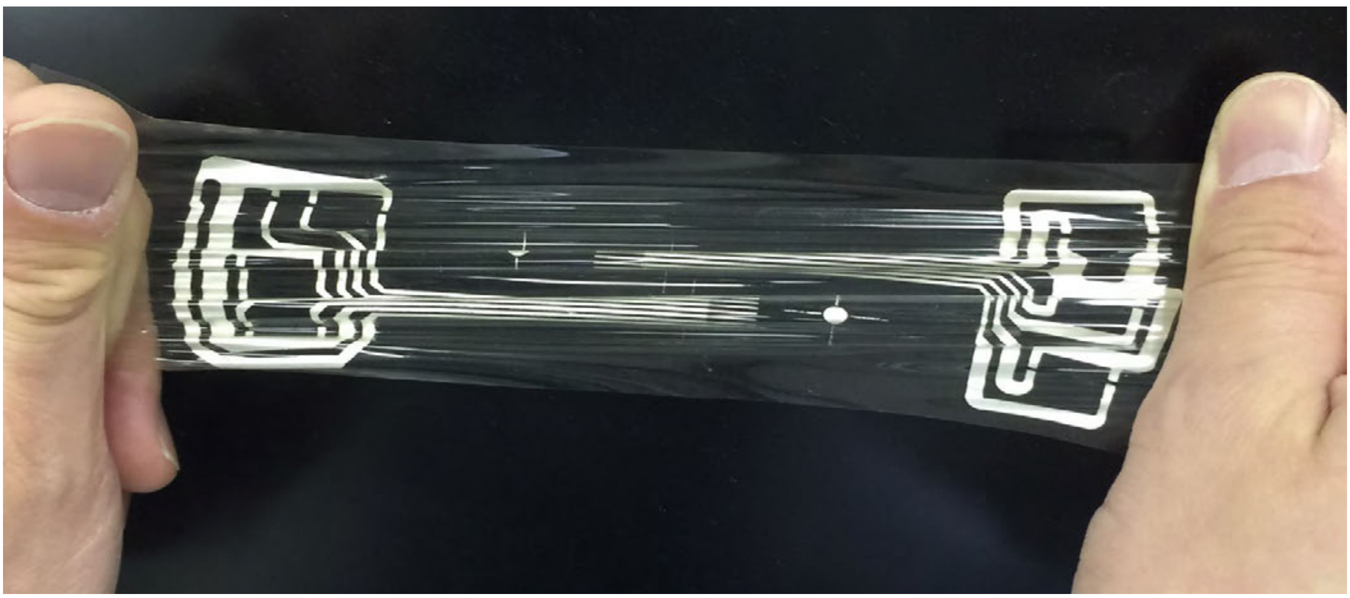


Figure 3: Panasonic developmental thermosetting materials: stretchable PTF circuits created on stretchable film.

tion. Another approach uses in-plane pattern designs to create metal traces capable of elongation. One pattern variant (variously termed sinusoidal, serpentine or meandering) uses interconnected "S" shaped circuit structures to accommodate deformation forces. This pattern scheme essentially creates a two-dimensional spring structure that reduces localized strain concentration on specific points along the traces. Other types of bulk metal stretchable patterns include mesh, spiral and fractal designs.

Looking Ahead

Many companies and universities are conducting novel research on new materials that may be used to create better stretchable circuits in the future. Super atoms are clusters of atoms that behave like single elemental units. Methods for linking super atoms so that they may be used to imitate the properties of naturally occurring molecules have recently been discovered. This breakthrough may provide scientists the ability to tune properties like elasticity in metals or conductivity in polymers.

> "This breakthrough may provide scientists the ability to tune properties like elasticity in metals or conductivity in polymers."

Conductive polymers have long been a subject of electronic materials research and they may provide another avenue of research for developing stretchable conductors. Poly (3,4-ethylenediox-ythiophene) or PEDOT based compounds have been used in flexible display applications and are showing promise in other areas of electronics.

Along with continued investigation of established metallic conductor morphology for creating stretchable conductors, there is research focusing on conductive nanomaterials to address the challenge of creating elastic circuits from inflexible conductors. Silver, copper and gold nanowires have been used to create stretchable circuitry by forming a flexible network of conductive filaments. Researchers are also investigating carbon-based materials like carbon nanotubes and graphene stretchable circuitry applications.

Work is being conducted on liquid metals such as gallium indium alloy (75.5% Ga and 24.5% In) and ionic fluids for use as stretchable circuit conductors. It's easy to envision how liquid conductors would fill a channel formed in a stretchable substrate matrix and maintain conductivity after repeated deformations without risk of conductor cracking. However, stress induced fractures in the surrounding matrix may allow the conductive material to leak.

Stretchable film substrates have historically consisted of homogenous polymeric compositions. Researchers are investigating alternative constructions such as nano-layered co-extrusion and the inclusion of polymeric and non-polymeric particles to improve mechanical and electrical performance and provide other functional advantages.

Conclusion

In the late 19th century, the famous American architect, Louis Sullivan, coined the oft-used and frequently misquoted phrase "form follows function." This sentiment seems particularly apt for the future development of stretchable circuit materials. The PCB industry has entered the next phase of circuit board technology development. Driven by novel designs and new end uses in many markets, the era of stretchable electronics is fully upon us. Like flex circuit boards and the rigid boards before them, there isn't likely to be a single "silver bullet" universal substrate/conductor combination that will meet the needs of every end user. There is still much development work to be done that will probably include a significant degree of technological cross-breeding. Ultimately, however, the required combination of materials and processes will be developed for each end use. **PCB**

Andy Behr is technology manager with Panasonic Electronic Materials Business Division.

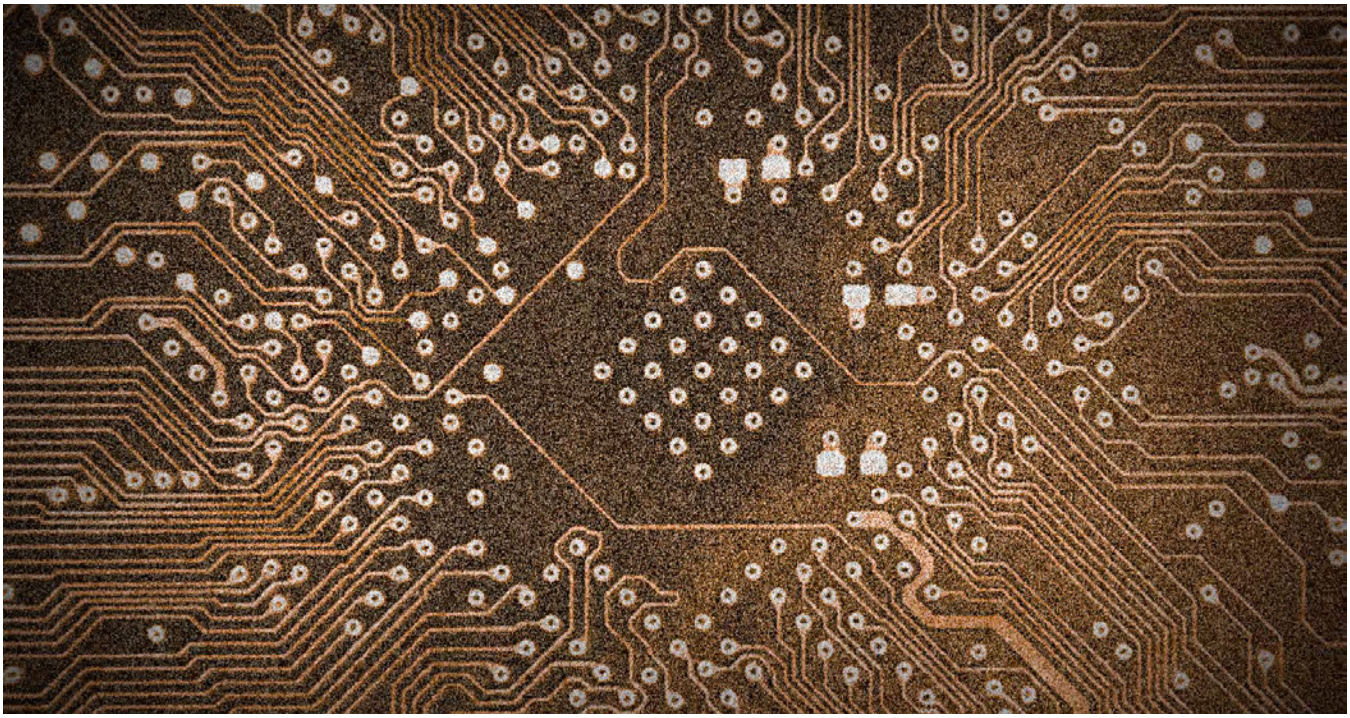
Improving Solderability and Corrosion Resistance for Final Finishes, Part 1

by Michael Carano
RBP CHEMICAL TECHNOLOGY

Introduction

The process of forming a reliable solder joint between the component and the printed circuit board is paramount with respect to the manufacturing of robust circuit board assemblies. For example, an electronic connection between circuits using a through-hole is typically carried out by coating the through-hole walls and other conductive surfaces of a printed wiring board with hot, molten solder to make electrical connections by wetting and filling the spaces between the conductive through-hole surfaces and the leads of electrical components which have been inserted through the through-holes.

Soldering inconsistencies (e.g., inconsistent or weak adherence to the conductive surfaces) are often the result of difficulties in keeping the conductive surfaces of the printed circuit board clean and free of tarnishing and corrosion prior to and during the soldering process. There are several techniques to protect the solderability of the printed circuit board and prevent soldering inconsistencies which have been developed. The most common involves the deposition of a coating of metal or a combination of metals on the conductive surfaces of the printed circuit board. The deposited metal coatings are often referred to as "final finishes." Common final finishes include, for example, electroless nickel (EN), electroless palladium (EP), electroless nickel/immersion gold (ENIG), electroless nickel/electroless palladium/immersion gold (ENEPIG), immersion silver, and electroless nickel/electroless palladium (ENEP). However, there has been new research with respect to protecting solderable finishes from corrosion and in the preservation of solderability. Several published research reports detail the issue of creep



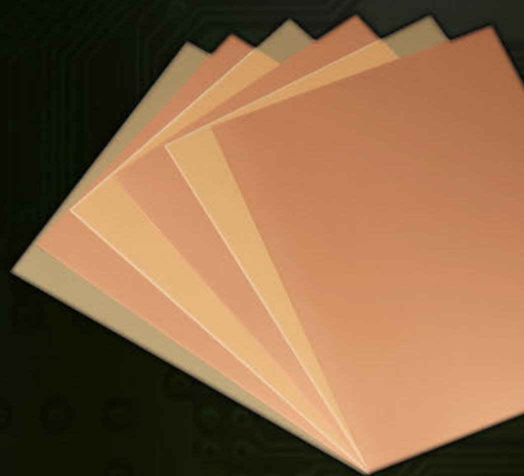
Panasonic

Ultra-low Transmission Loss Multi-layer Circuit Board Materials for ICT Infrastructure Equipment

MEGTRON7

Laminate **R-5785(N)**
Prepreg **R-5680(N)**

H-VLP2 Cu and Low Dk Glass-Cloth Specifications



Features

- H-VLP2 copper foil and Low Dk glass-cloth allows for 30% loss improvement than MEGTRON 6
- Glass transition temperature (Tg): 200°C (DSC)
- Reduce process cost (Improve drill processability and ENIG (Electro-Nickel Immersion Gold))

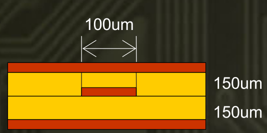
	Dk	Df
R-5785(N) + H-VLP2 Cu	3.4	0.002 @ 12GHz
R-5775	3.6	0.004 @ 12GHz

Applications

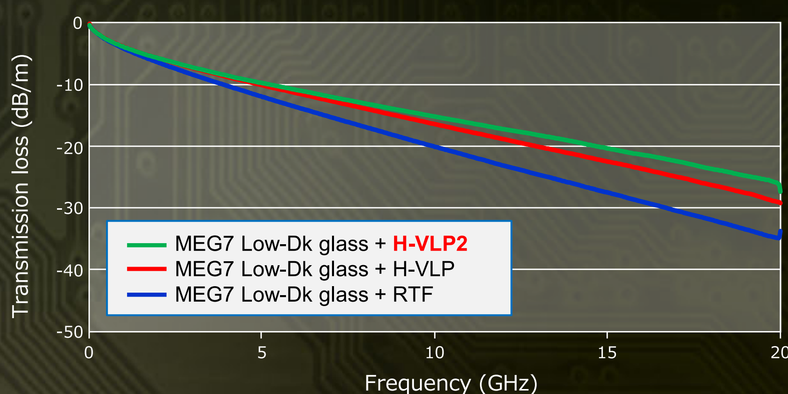
- High-end servers, High-end routers, Supercomputers, and other ICT infrastructure equipment, Antenna (Base station, Automotive millimeter-wave radar), etc.

Trasmission Loss

- Evaluation Sample



Line Length	1000 mm
Impedance	50 Ω
Copper Thickness	18 µm
Inner Cu Treatment	No-surface Treatment
Core Type	#1078 (RC67%) x 2ply
Prepreg Type	#1078 x 2ply



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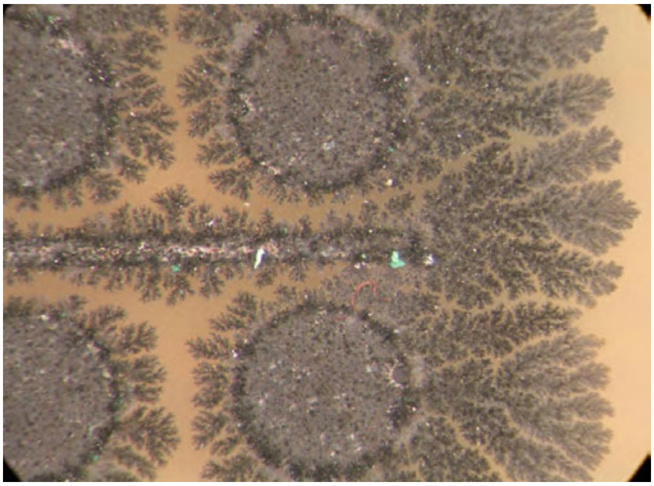


Figure 1: ENIG coated copper surface showing extensive creep corrosion. (Source: R.K. Veale, Rockwell Automation[2].)

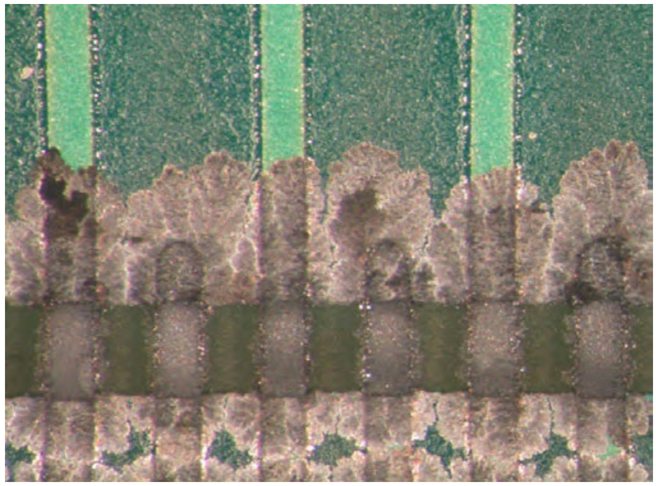


Figure 2: Immersion silver deposit over copper exhibiting creep corrosion. (Source: IPC Process Effects Handbook 9121.)

corrosion. One new development that may show promise both in preserving solderability and minimizing creep corrosion is the use of self-assembled monolayers.

Self-Assembled Monolayers

Self-assembled monolayers (SAMs) of alkanethiols adsorbed onto clean metal surfaces have been the focus of research chemists and engineers for several years. These molecules have shown promise as a way to control oxidation of active metals such as copper and silver. In addition, there is speculation that these SAMs may also be effective in bonding with copper under certain conditions and essentially acting as an organic solderability preservative (OSP).

The molecules typically possess a functional group that has an affinity for the substrate, also known as a head group, and a tail group. In forming a self-assembled monolayer, the head groups of molecules chemisorb to the substrate, arraying the tail groups to form a dense assembly that extends from the surface of the substrate. Known head groups include thiols, silanes, and phosphonates. In many applications, the tail group of the molecule is functionalized to provide the resulting monolayer with desired properties relating to, for example, wetting adhesion, chemical resistance, biocompatibility, and the like. Due to the strong affinity of the thiol head group to metal substrates, alkanethiols have often been used in the formation of self-assembled monolayers. Alkanethiol self-assembled monolayers have found applications in electronics, for example, for modifying the surface properties of metal electrodes[1].

Why is this important?

Many circuit components and printed boards used in electronic equipment are exposed to harsh environments. This description includes PCB assemblies under the hood of an automobile or in instrumentation and controls subjected to corrosive environments. The latter would apply to electrical units deployed in paper mills, clay modeling studios and other areas where sulphur in the atmosphere may come in contact with any susceptible exposed metals. A good example of corrosion is shown in Figure 1.

Electroless nickel/immersion gold coatings are not the only finishes susceptible to creep corrosion. In Figure 2, immersion silver (with soldermask) exhibits corrosion.

Specifically, the corrosion product seen here is copper sulphide. Creep corrosion is the migration of copper sulphide across the circuit. For creep corrosion to occur, there must be exposed copper (on the PCB) and sulphur in the atmosphere. Silver sulphide will also form when exposed to sulphur in the environment. There

H_2S: 100 ppb +/- 10 ppb	Test Pressure: atmospheric
NO_2: 200 ppb +/- 25 ppb	Test Temperature: 30°C
SO_2: none	Test Relative Humidity: 75% +/- 2%
Cl_2: 20 ppb +/- 5 ppb	Test Duration: 20 days

Table 1.

is ample documentation highlighting the vulnerability of certain solderable finishes to creep corrosion.

Robert Veale of Rockwell Automation determined that immersion silver and ENIG exhibited corrosion when subjected to Battelle Class III harsh environment and ASTM B845[1]. The IPC B-25 comb pattern was the test vehicle used in the study. The center comb pattern was biased with 5V DC and all the other areas were unbiased. There were two sets of test boards with one set having no soldermask applied and a second set with a soldermask overlaying the comb pattern conductors as described below. (The results with the soldermask applied will be presented in a future column.) The test conditions are shown in Table 1.

At the end of the 20-day test period, the test vehicles were examined for the extent of corrosion. In a future column, more information on creep corrosion prevention will be presented as well as the performance of other solderable finishes under corrosive environmental conditions[2]. What has not been determined in this study is the effect, if any, on corrosion resistance with the use of self-assembled monolayer chemistry. That will be the subject of a future column.

Summary

Corrosive environments have an adverse effect on some solderable finishes. In this edition of "Trouble in Your Tank," the corrosion resistance of ENIG and immersion silver was discussed. Creep corrosion is a definite issue for these finishes when subjected to a corrosion environment under conditions described in ASTM B845 and Battelle Class III. Future studies will be undertaken to determine the effect if any of self-assembled molecules on solderability improvements. **PCB**

References

1. C. Zhou, M. R. Deshpande, and M. A. Reed L. Jones II and J. M. Tour, "Nanoscale metal/self-assembled monolayer/metal heterostructures." Downloadable here (possible subscription required).

2. R.K. Veale, "Reliability of PCB Alternate Surface Finishes in a Harsh Industrial Environments," SMTA, 2005.

Michael Carano is VP of technology and business development for RBP Chemical Technology. To reach Carano, or read past columns, click here.

Coming Soon in *The PCB Magazine:*

Material Choices for High-Speed Flexible Circuits

by G. Sidney Cox, COX CONSULTING

Abstract

High-speed rigid boards have existed for many years, with fluoropolymers being the most common dielectric initially used. More recently, flexible circuit materials have been developed, and these new products use a variety of polymer (including fluoropolymers) and composite film approaches to allow high-speed flex circuits. This paper will provide guidelines on how to compare the different options. The electrical benefits of the different polymers and constructions, as well as physical and flexible properties of different constructions will be reviewed.

Read MORE in the April issue.

MilAero007 Highlights

NASA Selects Proposals for First-Ever Space Technology Research Institutes

NASA has selected proposals for the creation of two multi-disciplinary, university-led research institutes that will focus on the development of technologies critical to extending human presence deeper into our solar system.

Trackwise Improved Harness Technology Achieves Major Milestone

Trackwise, a UK-based specialist manufacturer of products using printed circuit technology, is pleased to announce the successful completion of a major milestone in the development of Improved Harness Technology™—the manufacture of a 30-foot, 6-layer flexible multilayer PCB.

EuroTech: ENIPIG—Next Generation of PCB Surface Finish

MACFEST is a multi-partner project co-funded by Innovate UK to develop an electroless nickel/immersion palladium/immersion gold (ENIPIG) "universal surface finish" for printed circuit boards. Project partners are University of Leicester, MTG Research, C-Tech Innovation, A-Gas Electronic Materials, Merlin Circuit Technology and the Institute of Circuit Technology.

TTM Celebrates Grand Opening of Denver West, Colorado

TTM Technologies celebrated the grand opening of its Denver West Building in Littleton, Colorado with government officials, customers, TTM leaders, and employees. The Denver West Building allows TTM to expand its capacity and capabilities to better support customers.

Global Commercial Avionics Systems Market Posts Revenue of $25.34B in 2016

Transparency Market Research (TMR) has prognosticated the global commercial avionics systems market to take advantage of the rising investments and adoption of leading-edge technologies to register a CAGR of 3.5% between 2016 and 2024. By the end of the forecast period, the global market is envisaged to reach $31.07 billion. In 2016, the market had generated a revenue of $25.34 billion.

Accurate Engineering Purchases New Hot-Air Solder Leveler from New Technology Overman

Accurate Engineering has purchased a new NTO-1824LF HASL machine to upgrade that process and give their customers an unsurpassed surface finish.

Space Radio Could Change How Flights are Tracked Worldwide

NASA's powerful radio communications network allows us to receive data such as pictures of cryovolcanoes on Pluto—or tweets from astronauts aboard the International Space Station. But to send larger quantities of data back and forth faster, NASA engineers wanted higher-frequency radios that can be reprogrammed from a distance using software updates.

Engineers Build Robot Drone that Mimics Bat Flight

Bats have long captured the imaginations of scientists and engineers with their unrivaled agility, but their complex wing motions pose significant technological challenges for those seeking to recreate their flight in a robot.

EIPC 2017 Winter Conference Review of Day 2

Almost everyone made it back to the conference room for the start of the second day of the EIPC Winter Conference in Salzburg, even those who had enjoyed the late networking session into the early hours!

All Flex Adds IPC Expert Steven Bowles as Senior Engineer

All Flex expanded its product engineering talent pool by hiring Steven Bowles to join the company and relocate to Minnesota after spending two years at L-3 Fuzing and Ordnance Systems in Cincinnati, Ohio.

ARTICLE

MACFEST: Benchmarking a New Solderable PCB Finish

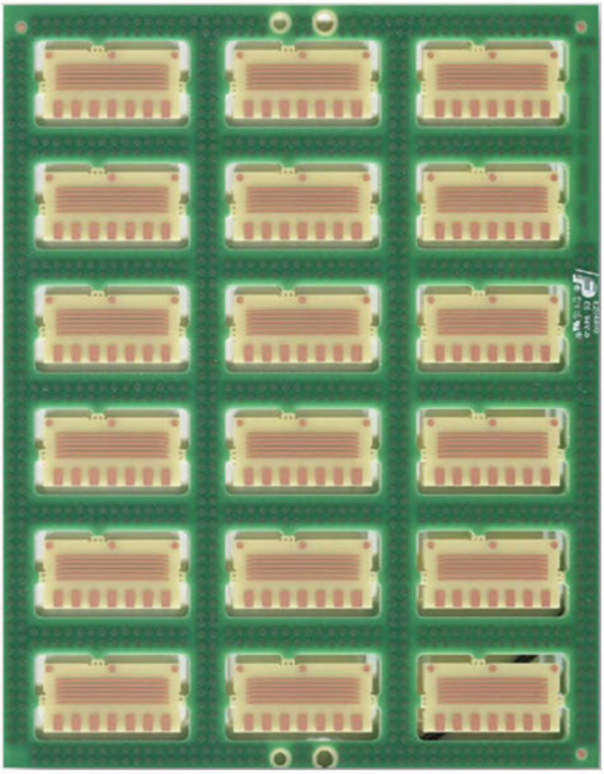
by Thomas Jones
HERIOT WATT UNIVERSITY

New, innovative manufacturing procedures have been developed by the recently completed project, Manufacturing Advanced Coating for Future Electronics SysTems (MACFEST), which has been funded by several partners and the government's Innovate UK. The objective of the project was to harness the potential of ionic liquid technology, to be used as a substitute for dangerous and costly processing chemistries applied in printed circuit board manufacture.

The specific process under consideration for ionic liquids was the electroless nickel/immersion palladium/immersion gold (ENIPIG) plating finish. ENIPIG is recognised as a universal finish[1], as it allows a circuit designer to cater for the competing needs of wire bonding and surface mount soldering, which are often both required for high-density circuit designs. The chemistries currently applied within the ENIPIG process employ the use of complex multistage processes with high material costs and with dangerous chemical formulations. These costly processing factors can be overcome by the substitution of novel ionic liquids, developed by the University of Leicester (UoL), within the ENIPIG process[2,3].

Merlin Circuit Technology has worked closely with UoL and Bob Willis, a recognised global expert in microelectronics testing and training, to benchmark the performance of the ionic liquid-ENIPIG coatings developed in the project. Tests were performed on the finish, where an evaluation of the solderability was made. Solderability provides a measure of the ease with which a solder joint can be made between materials and includes a review of the wetting of the solder to the board surface. Solderability is a vital parameter defining the success of component assembly onto a PCB, where poor quality could result in a manufacturing or an in-service failure.

A PCB test board was provided by Bob Willis to evaluate the quality of the new ionic liquid-ENIPIG finish for the 2016 Swedish Electronics Exhibition (SEE) in Stockholm. As



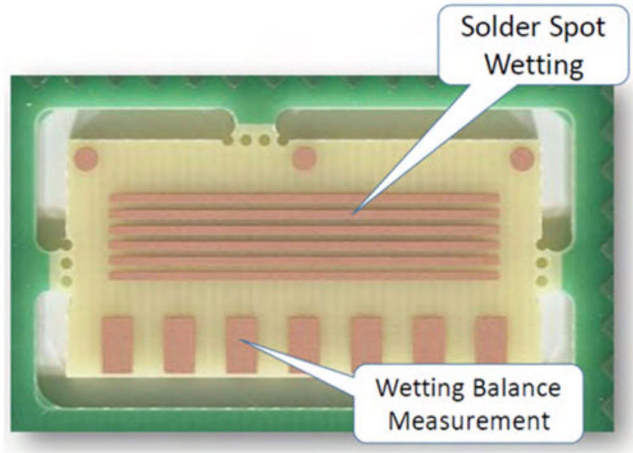


Figure 1: Test board for solderability evaluation. 18 test coupons for solder spot and wetting balance measurements. Six rows of tracks for spot patterning of 22 paste dots and seven pads for wetting balance measurement.

part of the testing, Bob offered to benchmark the performance of the ionic liquid-ENIPIG finish against existing finishes applied in industry.

The test boards are highlighted in Figure 1, showing a 15.3 cm x 10.2 cm panel with a copper finish which includes smaller pop-out coupons. A single board contained 18 test coupons for solder spot wetting and wetting balance measurements.

The test boards were plated at the UoL with an ionic liquid-ENIPIG finish. The thickness of the finish was measured using an X-ray fluorescence (XRF) device at Merlin Circuit Technology, Deeside. The plating outcome is displayed in Figure 2, showing a plot of the metal thickness measured tangential to the surface of the board for the different metals applied in the ionic liquid–ENIPIG and on different pad sizes. Two pads were measured. One was a 10.5 mm2 rectangular pad and the other was a 1.8 mm2 circular pad. The plating behaviour typically varied for the immersion palladium and gold plating processes, depending on the area and shape of the pad plated. The general trend showed that pads of a larger surface area produced thinner deposits. The ionic liquid-ENIPIG was no different, showing a variation in plated thickness dependent on the pad feature size.

When processing the panels, the amount of metal plated was deposited down to within the standard set by the IPC, and as outlined for ENEPIG plating, which stipulates Ni, 3–6 µm, Pd, 50–150 nm and Au, 25 nm or larger[4]. The measured thicknesses were within the guidelines, showing that the ionic liquid chemistry could be made to perform comparably to the existing processes. The Pd thickness failed to measure on the large pad due to the detection limit of the XRF device, although independent measurements, not shown, confirmed that Pd had deposited to within minimum specification.

After plating, the first quality test was a solder wetting balance measurement. The solder wetting balance test evaluated the ability of solder to adhere to the test panel, as it was vertically submerged with flux on its surface into a bath of molten solder. Once submerged, the solder climbed up the panel and the quality of the soldering was evaluated from the total increase in weight of solder adhered onto the board and its wetting speed[5].

Solder wetting was performed on the test coupon, as highlighted in Figure 1, where the sample was lowered into a bath and the rectangular pads took up solder. The process is outlined in Figure 3, showing a plot of the weight of solder, measured as force against time, which is officially known as a wetting curve.

The tests were benchmarked against a variety of other widely used surface finishes including organic solderability preservative (OSP), electroless nickel/immersion gold (ENIG), immersion tin and hot-air solder levelled (HASL). The different finishes are applied in PCB manufacture due to the differing costs of materials and the conditions they will be expected to perform under, for example, use in the defence, aerospace, or space industries, etc.

Two test boards were pre-treated before soldering. This was to mimic the conditions which the boards would undergo if they were processed in component assembly. A board may require several solder cycles dependent on the complexity of the component assembly, such as when components are added to both sides of the PCB. This will occur in two separate process heating operations. One such process could involve: the pre-treatment of the surface by a flux solution, the application of solder paste to the conductive pads, the application of the components to the paste covered pads and, finally, heating of the board to a temperature beyond the melting point of the solder, to enable the solder paste to reflow onto the pads, whilst aligning the components into the correct positions on the pads. If the board requires further component assembly then the pads on the unprocessed side of the board will have degraded in surface quality, due to thermal expansions caused by the first heating operation. Therefore, it was useful to test the condition of the test boards after a heating operation to evaluate changes in quality.

Different commonly applied heating methods are convection reflow, which in these trials applied 200 mg, Sn-Ag-Cu (SAC) lead free solder alloy at peak temperatures of 260°C and vapour phase reflow, which applied Galden®

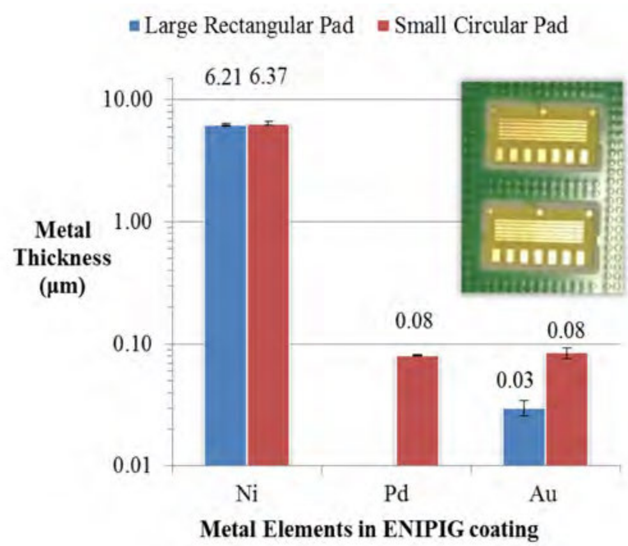


Figure 2: X-ray fluorescence measurements obtained at Merlin Circuit Technology, of the ionic liquid–ENIPIG finish plated at the University of Leicester. Results show average thickness for different metals on rectangular and circular pads of sizes 10.5 mm2 and 1.8 mm2, respectively.

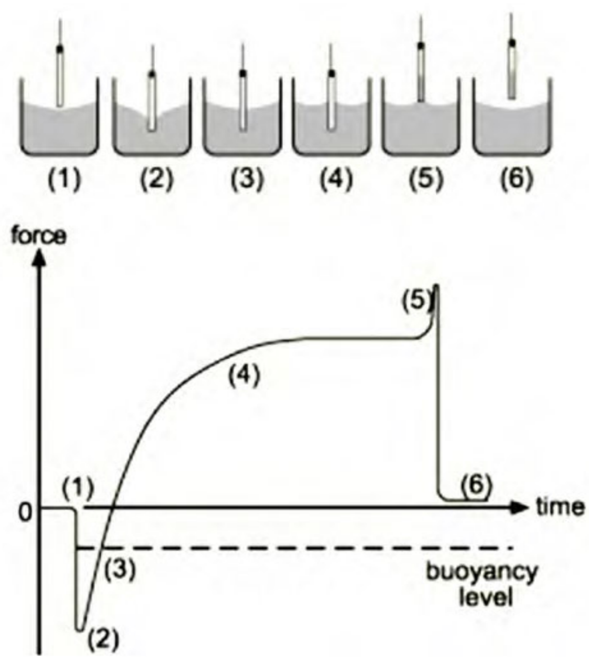


Figure 3: Solder wetting balance test with plot of adhered solder weight force against time on a wetting curve.

(an inert high boiling inert heat transfer fluid) at peak temperatures of 240°C. Vapour phase soldering typically induces a more uniform distribution of heat to the board by the process of latent heat of condensation, enabling a more uniform solder quality of the different components. It also provides reduced operational costs and risk from fires, due to the more safe heating method, and so for these reasons is often used in manufacturing[6].

Highlighted in Figure 4 is a plot of the average force of the wetted solder weight after two seconds immersion for the different finishes and pre-treatments. The ionic liquid–ENIPIG results showed that the amount of solder wetted varied little between the different processing conditions and that the temperature ageing of the board induced only small performance changes. The finish performed on par with existing industry finishes such as ENIG.

Figure 5 shows a plot of the average solder wetting time taken to reach 2/3 of the final wetting force. This shows how fast the solder wetted to the surface, where a short time is desired. The ionic liquid–ENIPIG showed a range of behaviours, which differed depending on the pre-treatment conditions. Its performance dropped—shown by the increase in time to wet—for the application of convection reflow. Convection reflow is processed at higher peak temperatures than vapour reflow and so the impact of thermal expansion on topography, and thus solder-ability, would have been greater. Regardless, the performance drop was not significant and the time to wet was less than the majority of the other surface finishes. This showed that the surface topography of the deposit was of a sufficient quality to enable wetting to the board and displayed a high surface energy like the other surface finishes, despite heating damaging its surface.

The final evaluation of the solderability was the wetting dot test. This evaluated the ability for solder paste to flow across test pads plated with a surface finish[7]. The test was performed using the test coupon highlighted in Figure 1 again. Twenty-two solder paste dots were stencil printed onto the six tracks above the rectangular tracks, with an example shown in Figure 6. The board was then subjected to reflow heating

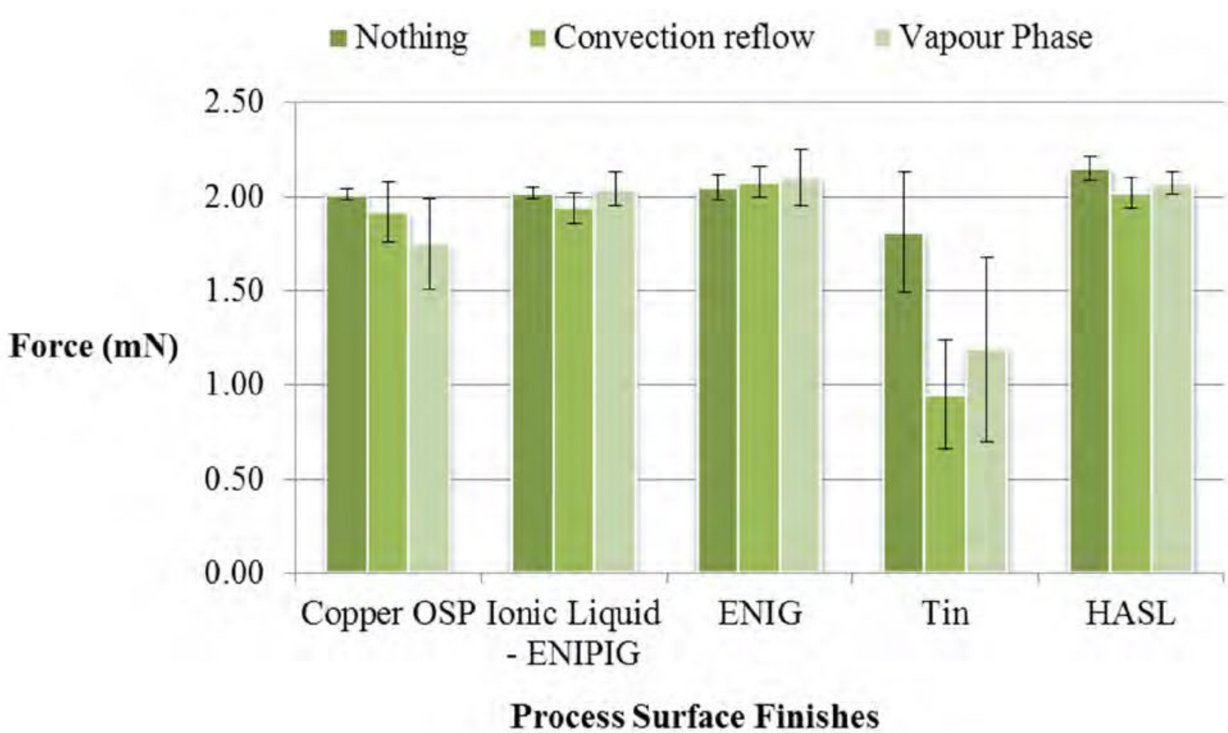


Figure 4: Average solder wetted weight after two seconds immersion. Test performed on five different finishes with each pre-processed under three different conditions.

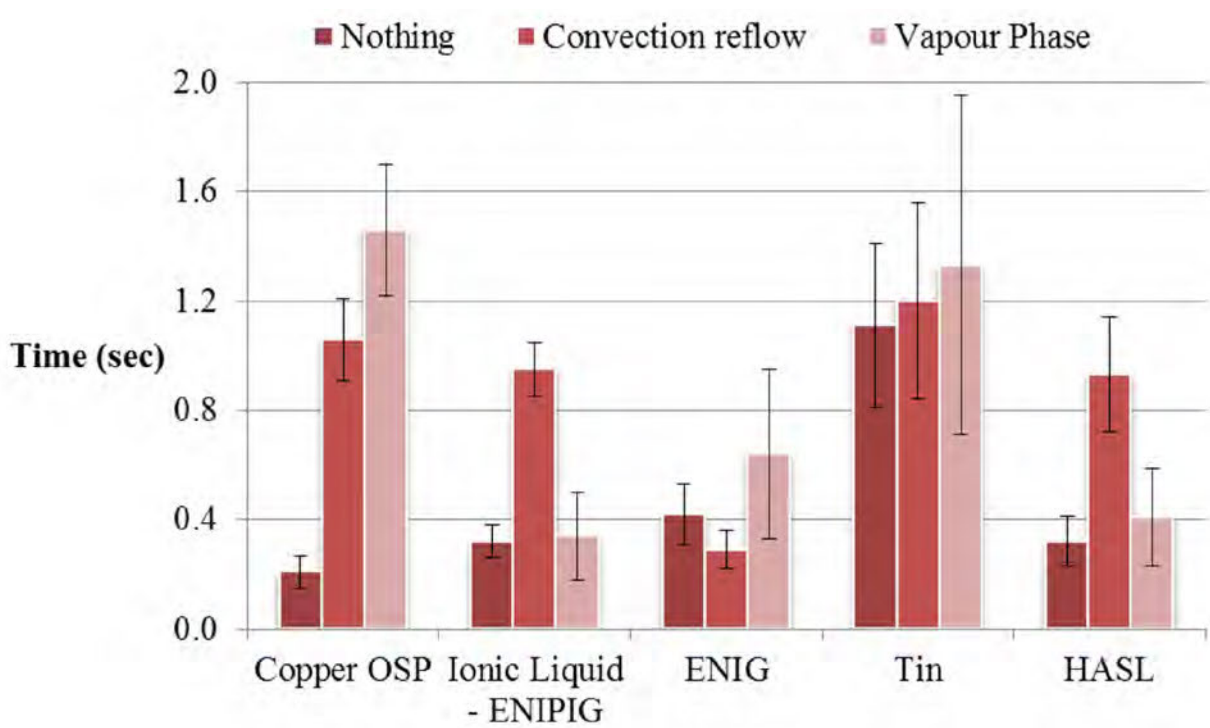


Figure 5: Average solder wetting time taken to reach 2/3 of the final wetting force. Test performed on five different finishes with each pre-processed under three different conditions.

which melted the solder paste. Upon melting, the paste spread across the surface of the pad and coalesced when it came into contact with surrounding spots. After a heating cycle the number of spots remaining on the board surface was counted, two or more coalesced spots were counted as one.

A surface finish with high wettability allows for increased coalescence and a smaller number of counted solder spots on the surface after reflow heating. The results for the spot test are displayed in Figure 7, showing the number of spots counted for HASL, ENIG, ionic liquid–ENIPIG, immersion tin and OSP. The test was performed with different pre-treatment conditions, which were convection, vapour phase, no pre-processing, and the application of nitrogen, which is used to aid soldering and to prevent surface modification[8].

When populating both sides of a PCB with components and applying two heating operations, an unintentional pause may be introduced in the manufacturing process between heating cycles, due to the work load of the assemblers. During this pause in processing oxidation occurs on the metal surface, negatively influencing the performance of the board for soldering[9]. For this reason, an additional test was performed whereby convection and vapour phase reflow operation were performed individually on test boards, and a hold period introduced—to simulate degradation which may occur when leaving the boards during component assembly—before spot wetting testing.

The results showed that the most effective finish for coalescence of spots was the HASL, and the least effective was the OSP, which were unsurprising results. The performance of the finishes dropped with the introduction of a hold cycle and for processing at higher temperatures—such as processing under convection reflow—which was also as expected. The ionic liquid–ENIPIG performed well relative to the other finishes, where coalescence was high on its surface regardless of the pre-treatment conditions. The finish specifically performed better than the ENIG, which had a similar material composition and topography.

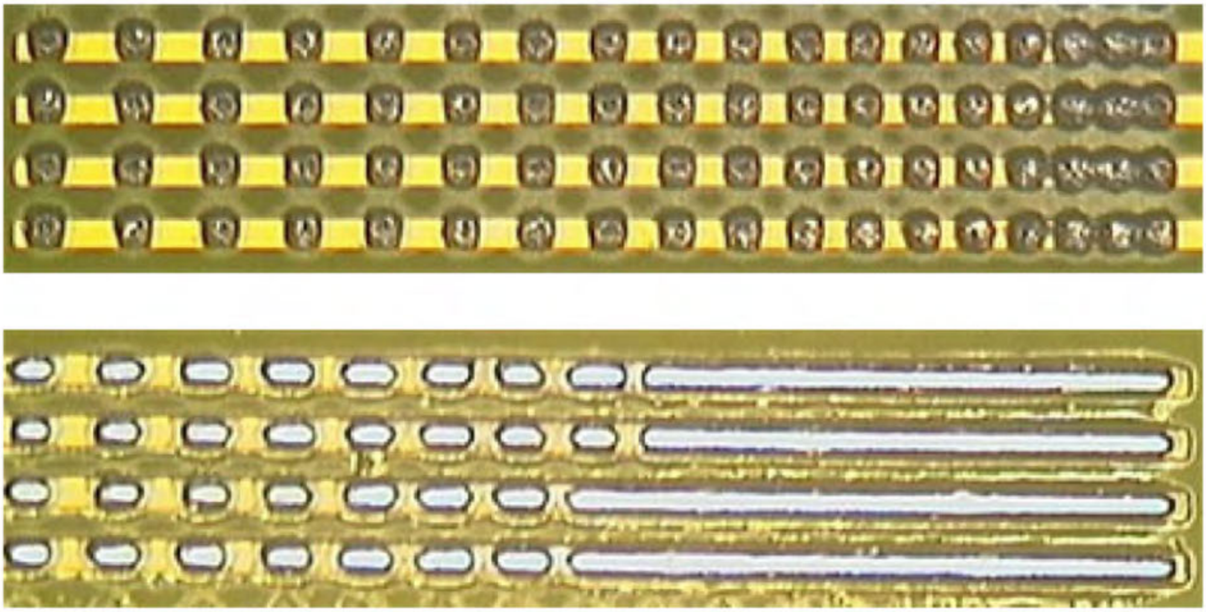


Figure 6: Example of solder spot test. Top shows solder spots added to tracks with reducing distance between features. Bottom shows coalesced spots after reflow heating of board.

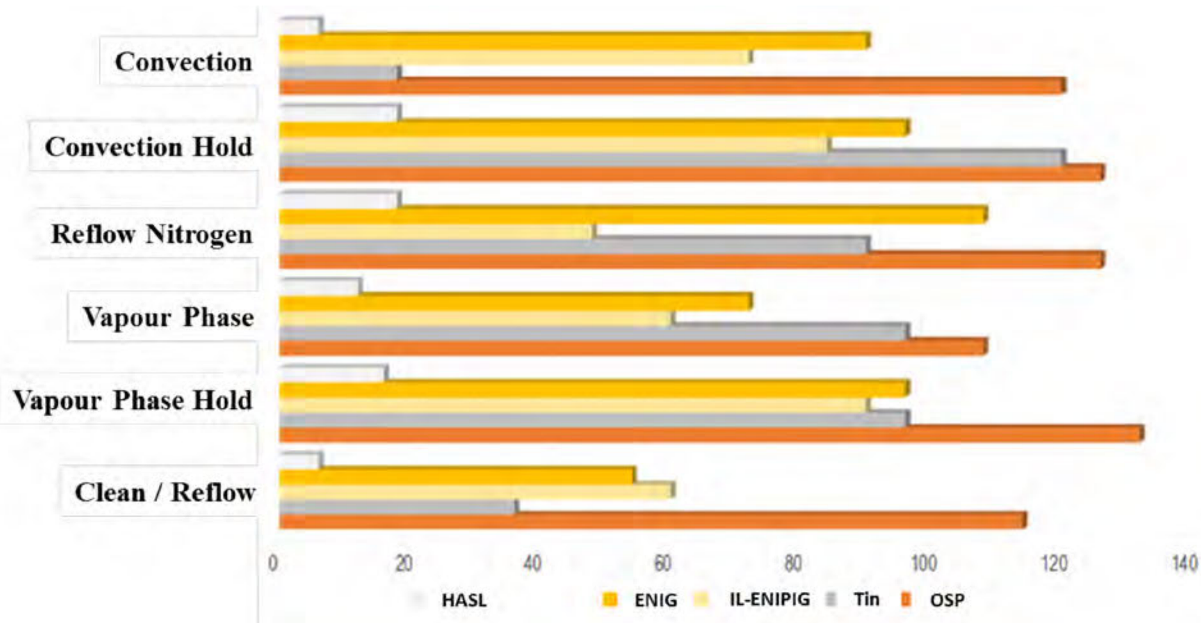


Figure 7: Solder spot wetting test results for different plated finishes and processing conditions.

Conclusions and Future Studies

The performance of the new ionic liquid-ENIPIG finish was benchmarked against widely applied surface finishes for the PCB industry, where its performance was exemplary in terms of the solder-ability.

One of the uses of the ENIPIG finish is for high-density circuit builds with small feature sizes. To connect the PCB to the small pad features on the integrated circuit component, wire bonding is required. Trials are being developed for the remainder of the project, looking to test the ability to wire bond to the surface finish, defining its bond strength and performance on differing pad sizes.

To date, ionic liquids have performed well in their bespoke applications within PCB manufacture. The success to date of the MACFEST project and the potential for cost savings from the novel chemical formulation shows that their continued development and introduction into manufacturing is well worth pursuing. **PCB**

References

1. Tm, Ultrasource, 2016. '09: ENEPIG—The "Universal Finish." Available here.

2. A.P. Abbot & K.J. Mckenzie, 2006. "Application of ionic liquids to the electrodeposition of metals." Royal Society of Chemistry, Phys. Chem. Chem. Phys, 8, pp. 4265–4279.

3. A.D. Ballantyne, G.C.H. Forrest, G. Frisch, J.M. Hartley & K.S. Ryder, 2015. "Electrochemistry and speciation of Au+ in a deep eutectic solvent: growth and morphology of galvanic immersion coatings." Phys.Chem.Chem.Phys.,, 17, pp. 30540 –30550.

4. IPC, 2013. "Specification for Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG) Plating for Printed Circuit Boards." IPC-4556.

5. Systems, Gen 3 "MUST SYSTEM 3 Solderability Testing System." Solderability Testing System.

6. Wood, E.R., 1983. "Printed Circuit Board Reflow by Vapour Phase Heating." Emerald Insight, Circuit World, 10, pp. 26–27.

7. IPC, 1995. "IPC-TM-650 Test Methods Manual." Available here.

8. R.J.K. Wassink, M.C. Seegers & M.M.F. Verguld, 1993. "Use of Nitrogen in Reflow Soldering." Emerald Insight, Soldering & Surface Mount Technology, 5, pp. 21–27.

9. L. Zhang, G. Sun, L. Li & J.K. Shang, 2007. "Effect of Copper Oxide Layer on Solder Wetting Temperature under a Reduced Atmosphere." 8th Internation Conference on Electronic Packaging Technology. Shanghai, China: IEEE.

Thomas Jones is based at Heriot Watt University and is carrying out research at Merlin Circuit Technology as part of his Engineering Doctorate (EngD).

Agility Robotics Evolves from OSU Research, Aims to Revolutionize Robot Mobility

The rapidly expanding robotics program in the College of Engineering at Oregon State University has spun off one of its first businesses, a company focused on legged locomotion that may revolutionize robot mobility and enable robots to go anywhere people can.

The firm, Agility Robotics, based in Albany, Oregon, and Pittsburgh, Pennsylvania, already has several of its first customers and will license some technologies first developed at OSU.

A leading application for this type of mobility is package delivery, company officials say. In the long term, advanced mobility will enable shipping so automated and inexpensive that its cost becomes inconsequential, opening vast new possibilities in retail trade while lowering costs for manufacturing and production.

"This technology will simply explode at some point, when we create vehicles so automated and robots so efficient that deliveries and shipments are almost free," said Jonathan Hurst, an associate professor of robotics in the OSU College of Engineering, and CTO at Agility Robotics.

"Quite simply, robots with legs can go a lot of places that wheels cannot. This will be the key to deliveries that can be made 24 hours a day, 365 days a year, by a fleet of autonomous vans that pull up to your curb, and an onboard robot that delivers to your doorstep."

IPC's Global Policy Framework for 2017–Smart Advocacy for the Industry

by John Mitchell
IPC—ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES

If you are like most readers of I-Connect007 publications, you may already know that IPC places a high priority on government relations work because so many government decisions have major impacts on our industry.

But how much do you really know about IPC's advocacy program?

As President Trump was being sworn in several weeks ago, and as the new Congress was getting down to work, IPC released its Global Policy Framework for 2017[1]. As we work to represent more than 3,800 member facilities across the electronics industry's global supply chain, IPC will adhere to this framework to guide our policy work in the coming months. All of our advocacy efforts are aimed at fostering an environment in which electronics manufacturers and their suppliers can thrive and grow.

The IPC Global Policy Framework breaks out into three broad areas:

- Promoting a 21st century economy and workforce
- Driving technological innovation and advanced manufacturing
- Advocating for smart regulation and environmental policy

Let's delve into each one.

Promoting a 21st Century Economy and Workforce

At the highest level, IPC advocates for government policies that lower obstacles to trade and facilitate broad-based economic growth and competitiveness.

Among its priorities, IPC advocates for lower corporate tax rates and incentives that stimulate business investment; and for international trade agreements that advance open and fair trade among countries.

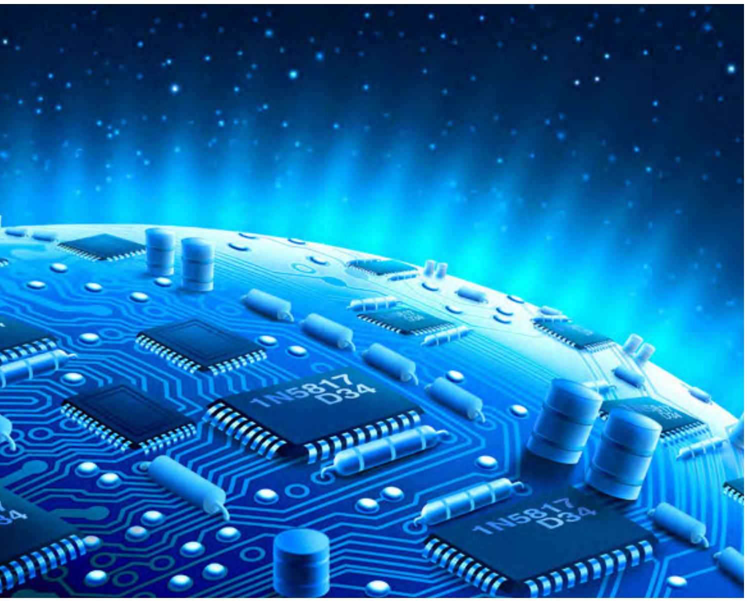
Further, IPC endorses ambitious workforce development initiatives, especially in science, technology, engineering, and math (STEM). As part of this, we support immigration policies that allow for international mobility among highly skilled workers to ensure that companies have access to the talent they need to be globally competitive.

Simply put, industry lives or dies on its people. Thus, workforce development and high-skilled immigration are two critical policy priorities that will help ensure our member companies can both recruit and maintain the next generation of workers.

Driving Technological Innovation and Advanced Manufacturing

For more than 60 years, IPC member companies have supplied high-reliability electronics for a wide array of applications in defense, transportation, aerospace, industrial, medical, and other industries.

Staying competitive in the global economy requires continuous investment in basic and applied research and development (R&D), as well as programs to spur advanced manufacturing innovation. For example, IPC is a strong supporter of public-private partnerships such as the innovation institutes established through Manufacturing USA in the United States and the Fraunhofer Institute in Germany.



Furthermore, IPC continues to promote strong intellectual property protection and strives to prevent counterfeit products in the supply chain through our standards initiatives and advocacy efforts.

Advocating for Smart Regulation and Environmental Policy

Manufacturers in many parts of the world face a complex and overwhelming regulatory compliance burden that negatively impacts their abilities to develop innovative technology, create jobs, and compete in a global marketplace. Oftentimes, regulations, such as those on conflict minerals, are overly burdensome and do not achieve the intended result.

IPC strongly supports efforts among governments to reform their regulatory processes to ensure greater public scrutiny and a balance among risks, costs and benefits based on the best available scientific research.

IPC also supports voluntary environmental initiatives and thorough, life-cycle evaluations of substances and their alternatives prior to any restrictions.

Your Turn

There's an old expression in politics: "If you're not at the table, you're on the menu!"

In other words, leaders of our industry must work hard to ensure we have a seat at the table. If we forfeit our right to educate our elected officials and propose solutions, then our interests could be at risk. Opportunities to strengthen the industry could be lost.

That's why IPC places such a high priority on our government relations program, and our lobbying team is on the job for this industry, year-round.

But here's where you come in. We need you to help us help you!

Because quite often, IPC member company leaders are the industry's best spokespersons. You have front-line experience—you vote—and in many cases, you have influence in your communities.

Visit our Getting Involved page to discover the ways you can pitch in and help, including:

• Stay informed on the issues that affect us all by subscribing to IPC's Global Advocacy Report.

• Be in contact with your elected representatives. Send emails, make phone calls, or meet with them at the local coffee shop or district office. IPC's government relations team can help arrange meetings and provide you with talking points and handouts. Also, be sure to participate in IPC action alerts.

• Host an elected official at one of your facilities. You can offer a tour, a briefing or a demo, and a chance for them to speak to your employees. Again, IPC's government relations team is here to help.

• Attend one of IPC's annual advocacy events, called "IMPACT," in Washington[2], DC, or Brussels. IMPACT events give C-level executives of IPC member companies a chance to meet face-to-face with top government officials to discuss the issues we care about.

• Every year, have your company sign a prior authorization form for the IPC Political Action Committee (IPC PAC). The IPC PAC supports pro-manufacturing Congressional candidates, from both parties. Visit IPC.org/PAC to sign the prior authorization form and to learn more about the IPC PAC.

At the end of the day, government should craft smart policies that allow businesses like ours to innovate, deliver great products and services, and create well-paying jobs. We may be based in different countries and face a variety of regulatory regimes, but we are all part of one world, one industry, and one team in advancing the electronics industry. **PCB**

References

1. IPC Global Policy Framework
2. IMPACT Washington D.C. 2017

John Mitchell is president and CEO of IPC—Association Connecting Electronics Industries. To read past columns, or to contact Mitchell, click here.

Advances in AI will Help Machines Understand Human Thoughts

The technological complexities inherent in developing perceptions for machines, as well as the verification and validation of these tools, have been eased to a large extent by the advancements of artificial intelligence (AI) technology. These developments will open a plethora of opportunities for AI in smart applications that can make critical decisions autonomously and accurately, without human intervention.

"With brain-computer interface (BCI), AI can power future machines to understand human thoughts and emotions, even without physical or vocal communication," noted Frost & Sullivan TechVision Senior Research Analyst Debarun Guha Thakurta. "Instead of simply mimicking the human brain structurally, AI will be able to impart human-like intelligence to machines."

Artificial Intelligence (AI) - R&D and Applications Roadmap is part of the TechVision (Information & Communication) Growth Partnership Service program. Leveraging convergent ideas with technologies, AI can open new horizons in groundbreaking applications. Moving beyond syntactical understanding of human words, future applications will understand the semantics hidden in human language, and observe, understand, and detect objects accurately in their surroundings, making them more responsive. Additionally, the study explores the roadblocks to technology implementation.

AI has complex hardware and software infrastructural requirements, as the intelligent algorithms require exceptional processing capabilities to process large data sets in real time. Innovators, with incremental technology evolution, are successfully meeting these needs.

Recent Highlights from PCB007

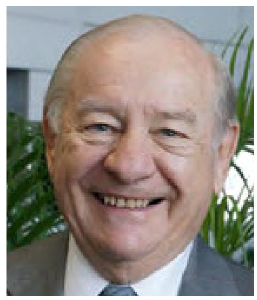
1 Help Wanted! Our 2017 Industry Hiring Survey

This month we conducted an industry survey on plans for hiring during the year. We started by simply asking, "Do you plan to hire additional people this year?" More than half of the respondents answered yes, while about a third said no—which we take as an optimistic sign that our industry plans to expand in 2017.

2 Flex Talk: Final Surface Finish—How Do You Choose?

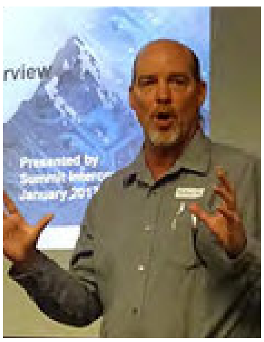
There are so many final surface finish options to choose from today. How do you decide which is best? HASL—both tin-lead and lead-free—immersion tin, immersion silver, ENIG, OSP, and ENIPIG are the primary finishes used in PCB fabrication.

3 Weiner's World—January 2017



This month's column is a bit shorter than usual as we prepare for next month's IPC APEX EXPO and its Executive Forum for PCB fabricators and their supply chain. This month also marks the 65th anniversary of Epec LLC in New Bedford, Massachusetts. The company, founded in 1952, is the oldest printed circuit fabricator in North America.

4 Cirtech Names John Stine as Vice President of Operations



John will oversee the day-to-day operations to support the growth and profitability of Cirtech. John will focus on strategic planning and goal setting, as well as provide leadership to enhance our overall performance and customer service experience.

5 All About Flex: Creating a Flexible Circuit Cutline

The perimeter dimensions of a flexible circuit are often referred to as the cutline. While rigid printed circuits are often rectangular and generally a less complex outline, the requirement for a flexible circuit to be an integrated part of the product packaging often involves unusual sizes, shapes and features in the circuit perimeter.

6 Electroplated Copper Filling of Through-holes: Influence on Hole Geometry

The process consists of a two-step acid copper plating cycle. The first step utilizes periodic pulse reverse (PPR) electroplating to form a conductive copper bridge across the middle of a through-hole and is followed by direct current electroplating to fill the resultant vias formed in the bridge cycle.

7 AT&S Provides PCB Technology and System Integration Expertise to World's Smallest Speaker

Graz-based start-up USound, in partnership with several Fraunhofer Institutes (IDMT, ISIT, IIS and IZM) and utilizing PCB technology together with system integration expertise from AT&S, has developed what is not only the world's smallest speaker, but also the first based on micro-electro-mechanical systems (MEMS).

8 Time-Lapse Video: The IPC APEX EXPO 2017 Show in Under Seven Minutes!

During IPC APEX EXPO 2017, I-Connect007 had time-lapse camera running from setup to closing. The camera was positioned high in our studio, where we conducted our RealTimewith...IPC APEX EXPO video interviews, aimed down the main aisle.

9 TTM Technologies Posts Sales of $706.5M in Q4 Fiscal 2016

Net sales for the fourth quarter of 2016 were $706.5 million, compared to $668.9 million in the fourth quarter of 2015 and $641.7 million in the third quarter of 2016.

10 EPTE Newsletter: 47th INTERNEPCON JAPAN

The 47th INTERNEPCON Japan electronics trade show was held on January 18 at Tokyo Big Sight. I attended the three-day NEPCON show in hopes of discovering the next electronics breakthrough, and examine the business trends within a shrinking electronics industry.

For the latest PCB news and information, visit: PCB007.com

Events

For IPC Calendar of Events, click here.

For the SMTA Calendar of Events, click here.

For the iNEMI Calendar of Events, click here.

For the complete PCB007 Calendar of Events, click here.

China International PCB & Assembly Show (CPCA)
March 7–9, 2017
Shanghai, China

14th Electronic Circuits World Convention
April 25–27, 2017
Goyang City, South Korea

IPC Reliability Forum: Manufacturing High Performance Products
April 26–27, 2017
Chicago, Illinois, USA

KPCA Show 2017
April 25–27, 2017
Goyang City, South Korea

IMPACT Washington D.C. 2017
May 2–3, 2017
Washington, D.C. USA

Thailand PCB Expo 2017
May 11–13, 2017
Bangkok, Thailand

JPCA Show 2017
June 7–9, 2017
Tokyo, Japan

IPC Reliability Forum: Emerging Technologies
June 27–28, 2017
Düsseldorf, Germany

SMTA International 2017 Conference and Exhibition
September 17–21, 2017
Rosemont, Illinois, USA

electronicAsia
October 13–16, 2017
Hong Kong

IPC Flexible Circuits: HDI Forum
October 17–19, 2017
Minneapolis, Minnesota, USA

TPCA Show
October 25–27, 2017
Taipei, Taiwan

productronica 2017
November 14–17, 2017
Munich, Germany

HKPCA/IPC International Printed Circuit & South China Fair
December 6–8, 2017
Shenzhen, China

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Taking a look at the latest in materials for high-speed PCBs

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Finding, hiring, and retaining skilled and/or experienced workers