PCB007 PRESENTS

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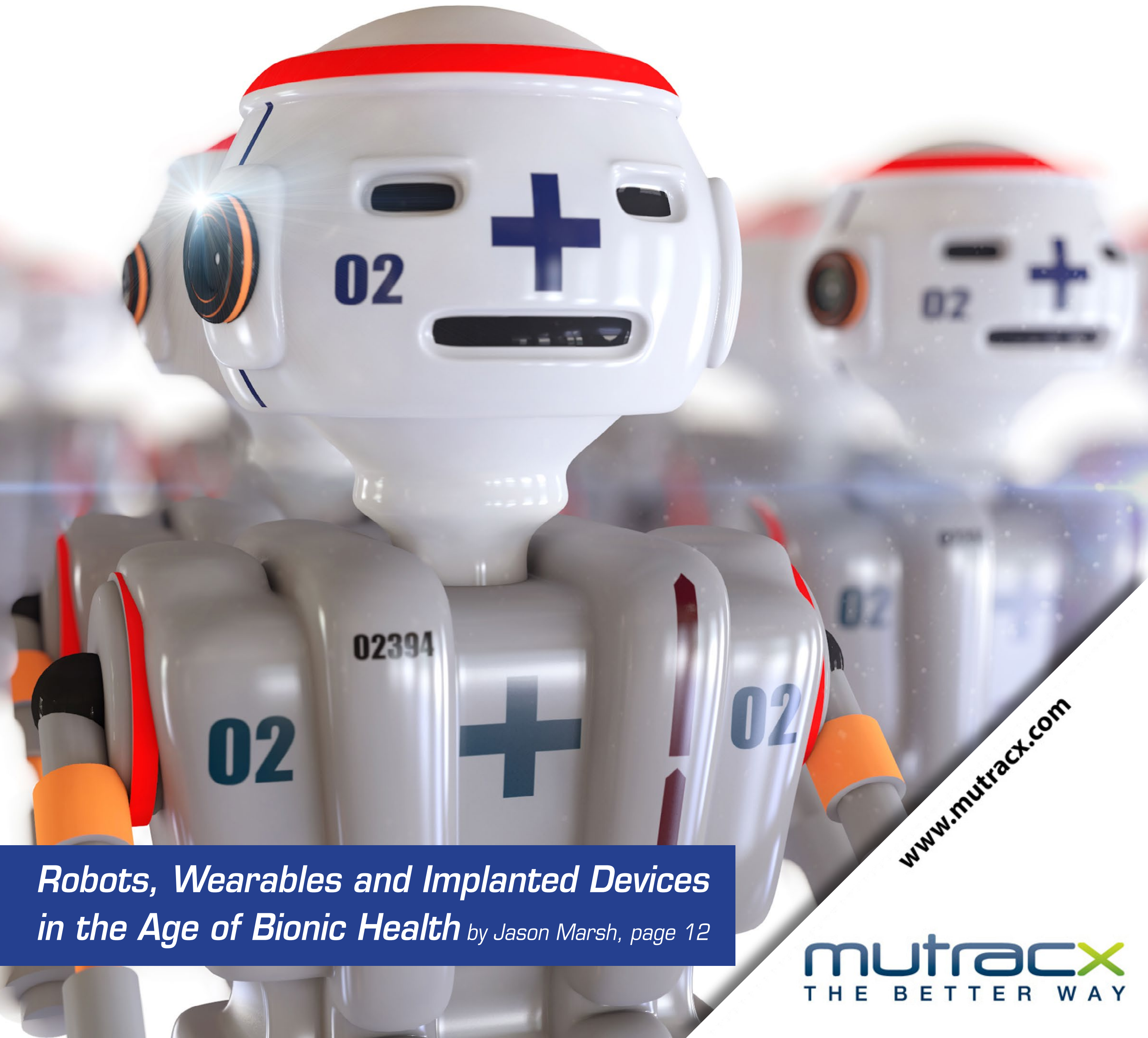
40 Flex: Just What the Doctor Ordered for Medical Devices

January 2016

the pcb magazine

an I-Connect007 publication

MEDICAL ELECTRONICS



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PCB007 PRESENTS

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This Month's Feature Articles

Medical Electronics: Getting the Vitals

We're providing a thorough work-up for our readers this month, with features that diagnose the current state of the medical electronics segment. From robots and wearables to novel developments in gold metallization processes for neural probes, we've got head-to-toe coverage.

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PCB007 PRESENTS

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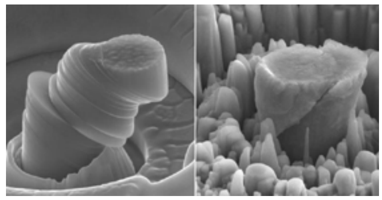

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COLUMN

PATTY'S PERSPECTIVE

The Fascinating Possibilities of Medical Electronics

by Patty Goldman
I-CONNECT007 TECHNICAL EDITOR

If you remember our September issue on automotive electronics, you probably recall that the applications for electronics in the automotive industry seemed to be exploding with limitless possibilities. Well, after reading up on this month's topic, I believe medical electronics is doing the same—and then some. I see the medical electronics industry today as overlapping several of the traditional market divisions—computer (from the doctor's office to you to the hospital to caregivers), communications (think of it as "telehealth"), consumer (it's for us, right?), industrial equipment and of course medical. And who knows when it will also encompass automotive and milaero? But let's not forget security, since equipment and wearables are definitely part of the Internet of Things. We don't even want to think about a surgical laser being hacked, or an implanted pacemaker suddenly being commandeered.

So many sub-segments to medical electronics exist, such as sensors, diagnostics, monitoring technology, medical devices and surgical equipment (think lasers and beyond), and components like batteries and computers. And let's not forget wearables, implantables and ingestibles, along with the IoT connectivity that brings it all together. We are living in a fantastic age.

I am fascinated by the possibilities of an ingestible capsule that can be directed to exactly the right spot in the body to target diseases and cancers. Laser-assisted surgery just seems to make so much sense as does the ability to visit multiple specialists and get multiple diagnoses without leaving your living room. Could the increased use of sophisticated sensors and monitors in (and outside of) hospitals help alleviate the chronic shortage of nurses?

As an aside, I came across an article in Smithsonian Magazine about Lilianna Zyszkoski who designed the PillMinder, a device to help doctors check that patients are properly taking their medications. This was encouraging to read, because she was in the sixth grade when she began building a working prototype of her invention, teaching herself about components, circuit design and even how to hand-solder in the process (note to New England SMTA chapter: track her down!). Now, at age 15, she has filed a patent with Gatekeeper Innovation for a pill bottle that houses her technology in the "smartcap."

So let's talk about this issue. Jason Marsh of Insulectro starts us out with a comprehensive overview of today's market for this ever-broadening category called medical electronics. He divides it into segments like medical equipment, wearables and sensors, monitoring devices, implantables…the applications do indeed seem to be endless.

Columnist Tara Dunn of Omni PCB, in her regular column Flex Talk, details some interesting applications for flex circuits in the burgeoning medical electronics field and then explains the need for gold-plated circuitry for biocompatibility.

Next, I-Connect007's Pete Starkey reviews Atotech Marketing and Sales Manager Robin Taylor's recent presentation at productronica. After discussing the coming decade in light of current trends and developments in electronics, Robin sat for a conversation afterward with Starkey, where he made five projections, including computers reaching the processing speed of a human brain, the coming rapid advances in healthcare innovations, the impending "dematerialisation, demonetisation and democratisation" of business systems, and significant advances in artificial intelligence that are on the horizon. It doesn't take a lot of imagination to envision the three major areas of mobile, medical/wearables and the Internet of Things merging into a single entity.

Dave Becker of All Flex Flexible Circuits details the many medical applications for flexible circuits and then goes on to explain the most important reasons why flex circuits are ideal for the medical industry. It seems flex circuitry is truly coming into its own with these burgeoning applications.

Following this, we get back to earth with IPC's VP of Government Relations John Hasselman, who gives us a comprehensive review of IPC's efforts across the world with government policies and issues. He presents his team's New Year's resolutions to help IPC's member companies and the global electronics industry "survive and thrive."

Bringing us further back into day-to-day reality is Gardien's "Testing Todd" Kolmodin, with a serious discussion on fab drawings as they pertain to electrical test. He stresses the importance of ET reviewing the entire documentation package to determine such things as performance class, proprietary specifications, and stamp requirements.

I'm pleased to announce that Happy Holden has returned. Happy is working on a new book, "Essential Skills for Engineers." His contribution this month serves as an introduction, in which he lists the proposed chapters and a synopsis of each. Over the next 18 months or so, watch for Happy's chapters as regular columns in the I-Connect007 Daily Newsletter. (If you are not a subscriber, click here.)

Wrapping up this month's lineup is Karl Dietz with his Tech Talk column, discussing high-performance laminates. As always, Karl has provided an in-depth review, which doubles as a great reference document for anyone using or thinking of using these materials—no doubt nearly everyone reading this.

Now, getting back to medical electronics, with all the exciting advances going on, I am watching for the notorious inefficiencies in (especially) hospitals to start disappearing, beginning with the filling out of forms at every corner. Instead, they'll just scan my arm and have access to my medical history, medicines I'm taking, insurance info, address and phone number, along with next of kin. I'll sign an electronic form with my fingerprint…

I'm sure that in just a few years, when I am old and tottering (no smart comments!), I can have a fabulous array of services to protect and care for me—including that car with the virtual chauffeur—enabling me to stay in my home just as long as I like.

Moving on to next month, don't miss, "What's New in PCB Fabrication." Tune in, see what's new, and learn. **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. She has worked actively with IPC since 1981 and served as TAEC chairman, and is also the co-author of numerous technical papers. To contact Goldman, click here.

FEATURE

Robots, Wearables and Implanted Devices in the Age of Bionic Health

by Jason Marsh
INSULECTRO

If you are an electronics manufacturer and you ask your business bankers where their market research suggests growth will come to, they will almost certainly identify medical electronics as a key growth area. For the past five years, the segment has enjoyed something close to 6% CAAGR with acceleration predicted in the short term and remains one of the few areas where the U.S. is a net exporter of products. This results in a market size on the order of $120 billion in the U.S. alone with more than 6,500 companies participating, and analysts expect this figure to grow to $133 billion in the next two years. There are a series of drivers for this growth: demographics, technology advancements and, perhaps most importantly, remote monitoring.

The first and most obvious trend is that the population base is both aging and living longer (Figure 1). With an increasing number of prospective patients for more advanced procedures, the proliferation of medical electronics and technology advancement is a critical piece of the puzzle. The objective is to bring technology advancements such as wireless communication protocols, data analytics and robotics into the hospitals and operating rooms to improve success rates, reduce complications and improve patient comfort.

A visit to a hospital operating room in 2015 will provide ample evidence of the trends toward more and more advanced electronics adoption in the medical field. Technology is allowing more surgery to be done with fewer incisions, reducing scarring, risk of infection and other complications. 3D cameras and robotic surgical instruments allow doctors to operate from several feet to thousands of miles away avoiding the crowding of operating rooms and allowing specialists to work on patients who cannot travel to their physical location. The da Vinci® system manufactured by Intuitive Surgical is a great example of this enabling robotic technology (Figure 2) whereby the entire procedure can be precisely controlled from a remote operating

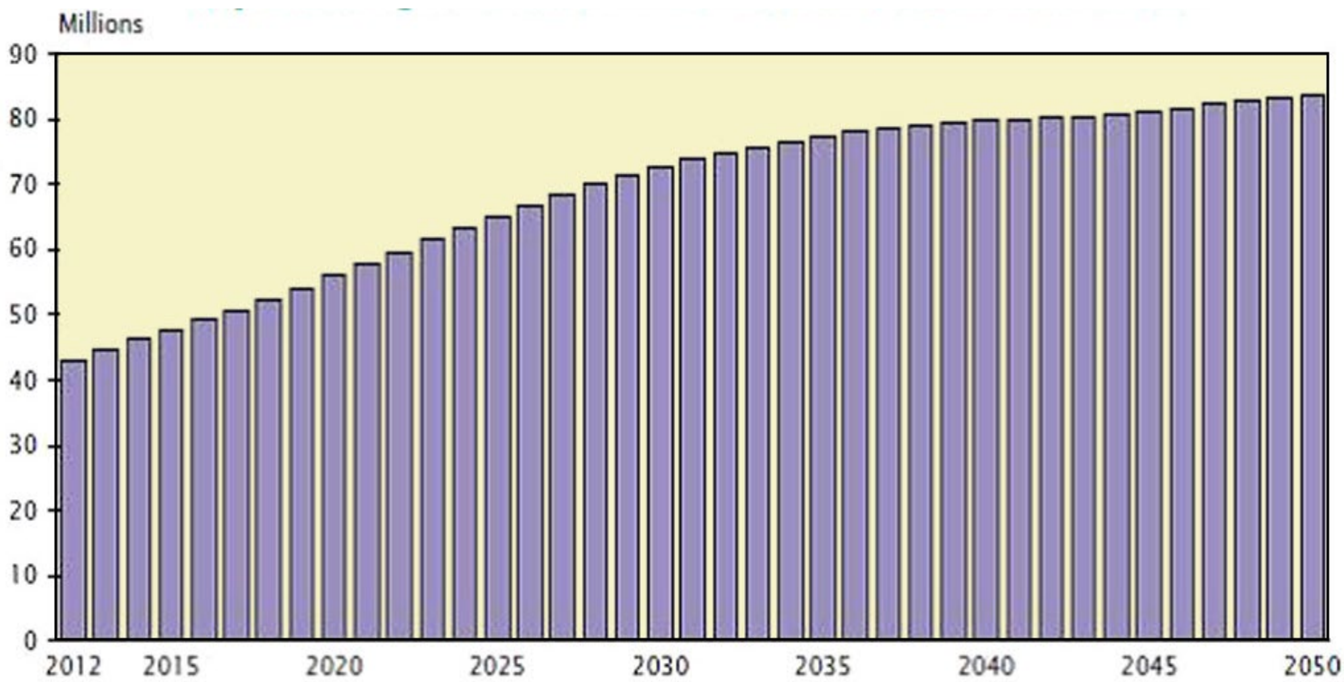

Figure 1: U.S. population aged 65 and older, 2012–2050. (source: U.S. Census Bureau)

location and multiple tools can be in the surgery area simultaneously.

Even traditional operating rooms use products like Stryker's 3D camera navigation system to magnify and clarify what is going on inside the body. Stryker, a major player in many medical device and equipment segments, has software systems that can image, map and even model the affected area both before and during surgery such as their Spine Map^tm and Nav3i^tm system for spinal and cranial surgery respectively (Figure 3).

A major electronics partner for both Stryker and Intuitive is Lenthor Engineering. Lenthor's president and owner Mark Lencioni recently invested significantly in a next-generation top technology facility including some specialized assembly capability (Figure 4). Lencioni explains how important the partnership is to both Lenthor and Stryker. "In the medical arena, reliability is critically important. Meeting these requirements is actually more stringent than many of the military specification operations Lenthor builds for. In order to achieve this, a high level of trust on both sides is critical. This is a really an 'open Kimono' relationship for us

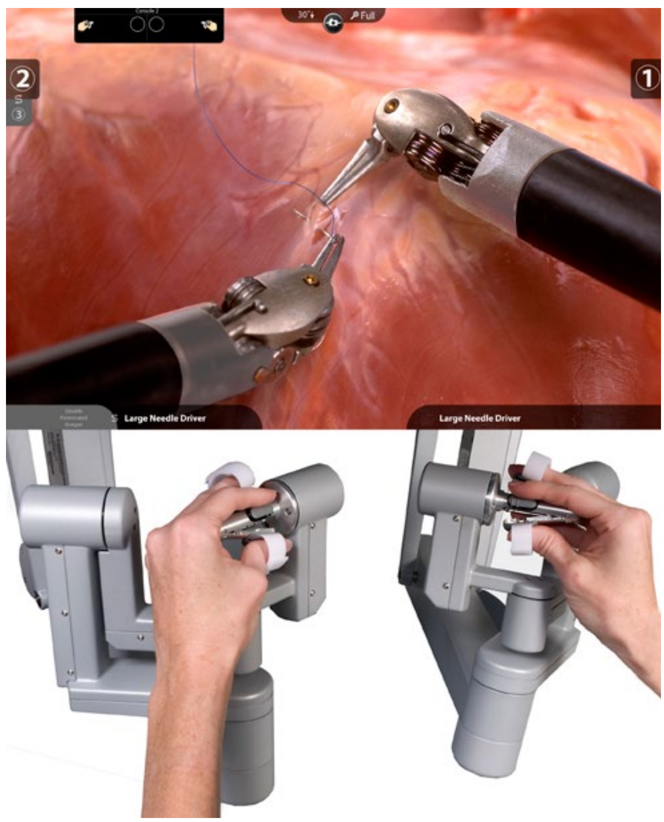

Figure 2: Da Vinci® robotic surgery equipment.

Figure 3: Stryker cranial mapping and surgery system.

Figure 4: Assembly department at Lenthor Engineering.

Figure 5: Various glucose test strips.

that many fabricators would not be comfortable with." Although there are no industry standards or specifications governing this, the customers each have their own very stringent systems and methods to ensure that they get reliable products into the field.

"The brand impact of failure in a medical product could be astronomical," explained Rich Clemente, general manager for Lenthor Engineering. "Stryker sent their people to encamp onsite during the [Lenthor] move to the new facilities and ensure that everything followed procedure." This is a very unique relationship between a supplier and a customer but is critical if you consider a simple calculation that based on the number of surgical tools produced and the average service-life, Stryker products are likely used in close to 10,000 surgeries per day.

The next major segment seeing medical electronics advances are the areas of skin contact, body fluid contact and implantable devices. In the printed electronics arena, a longtime favorite market has been the blood glucose test strips which are used daily by millions of patients. The disposable strips combine hydrophyllic polyester substrates with silver conductive inks to measure blood sugar and are manufactured by companies like GSI Technologies (Figure 5). GSI CTO Gordon Smith also points out that "GSI is in a good position in the medical device market, producing electrodes for in vitro diagnostic strips for glucose, cholesterol and other tests." Another popular printed electronics application are the EKG pads used in automatic external defibrillator devices which are commonly printed with carbon inks on adhesive pads and are produced by companies like Medtronic and Vermed.

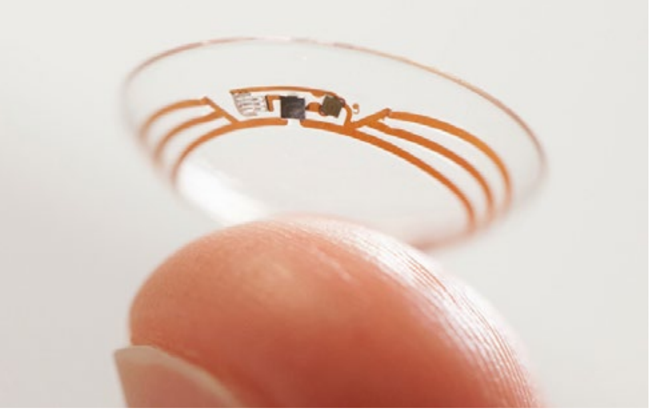

Figure 6: Google smart contact lens.

Figure 7: Nanovivo prototype.

These well entrenched technologies are already being overtaken by more novel technologies such as the glucose monitoring contact lens with wireless communication capability that was developed by the Google X team (Figure 6) which will be produced by Novatris' Alcon Division according to an interview with Novartis CEO Joseph Jimenez.

In addition, there are a myriad of new devices for remote monitoring, encompassing everything from traditional heart rate monitors, produced by Polar or even your Apple or Samsung watch and even new entrants like San Jose startup NanoVivo who is producing a prototype system that they claim can monitor chronic diseases, hydration, blood count testing, food/nutrition, digital cosmetics, diet monitoring, athletic performance, pregnancy monitoring and even food safety through a wrist watch type device that can connect to the cloud via Wi-Fi (Figure 7).

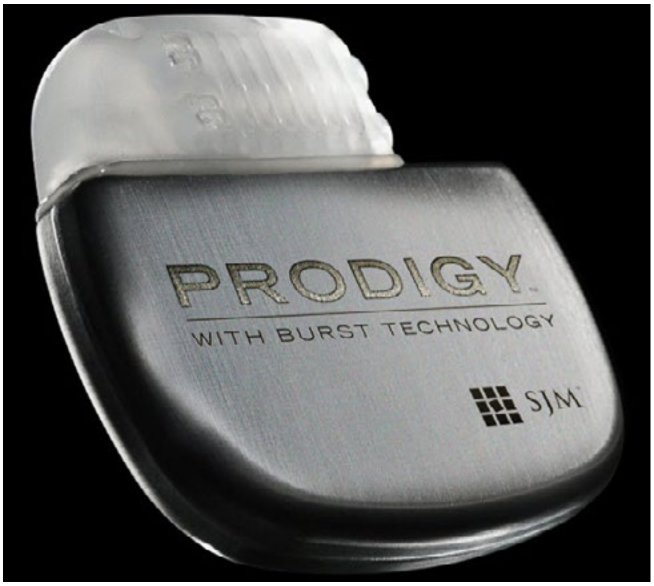

Figure 8: St. Jude Medical electro-stimulation pain managment device.

The next group are the implantable and semi implantable products. Some of the more straight-forward systems like the Prodigy™ device from St. Jude Medical provides electrical stimulation to pain areas in the lumbar and spinal region in patients (Figure 8). KCA electronics in Anaheim has long been a supplier to the St. Jude market, and they maintain special procedures for the products governed by the FDA. Classic systems like pacemakers are taking quantum leaps as well. Medtronic has moved the needle from its early devices that looked like something out of a Frankenstein short (Figure 9), to the significantly more modern and elegant systems like the Medtronic Micra™ and St. Jude Nanostim™ (Figure 10).

Another area seeing rapid advancement is that of hearing aids. Companies like Cochlear and Starkey have unique technologies that require microcircuits seen in very few other products (Figure 11). Another application we don't often think of in the medical implant space is

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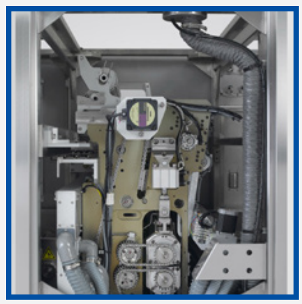

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Figure 9: First Medtronic pacemaker produced.

Figure 10: Nanostim pacemaker.

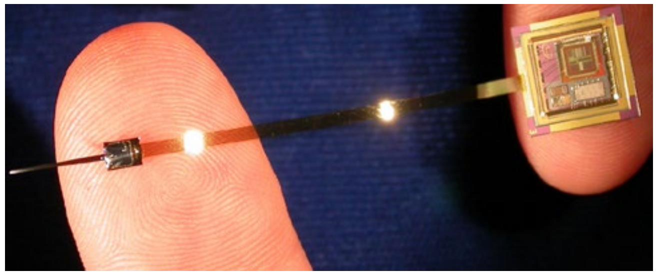

Figure 11: Cochlear hearing aid circuit.

Figure 12: John Hopkins robotic prosthetic hand.

the area of active prosthetics. The Wounded Warrior Project has some hope at the hands of Johns Hopkins Applied Physics Lab who have created a robotic hand that can be controlled via electrodes attached to the wearer. It has the dexterity to handle an extremely delicate object like an egg without damaging it and can lift up to 43lbs. With a learning curve, it can restore an impressive amount of functionality to the user (Figure 12). Cirexx, a PCB manufacturer in Santa Clara, California, has been supplying this project for several years. Phil Mengus, president of Cirexx, says, “Nearly every flexible circuit in the system is manufactured by Cirexx here in California.”

The objective of all this electronics integration is to collect more data, reduce errors in diagnoses or treatment and improve the patient comfort level. A smaller form factor, but perhaps more ubiquitous area of technology growth is that of wireless communications. A recent report by Research and Markets values the wireless medical electronics market at $23.8 billion and is expected to more than double to $59.7 billion by 2018. The iconic photo of the patient struggling in a hospital bed amidst a tangle of tubes, wires and sensors will increasingly become a thing of the past (Figure 13).

On May 5, 2015, the Federal Communications Commission released the latest compliance documents for the allocation of a section of the broadcast spectrum for Medical Body Area Networks (MBANs) in hospitals, clinics, and doctors’ offices that would operate in the

Figure 13: Typical hospital monitoring equipment. (source: Forbes)

Figure 14: Mimo wireless baby monitoring suit.

2.36–2.4GHz Band. Adoption of these wireless systems will greatly reduce the clutter and complexity in operating and recovery rooms. Major players see this as a significant growth area. As an example, Qualcomm has created the Qualcomm Life Fund, an investment fund with the specific mission of accelerating global wireless health services and technology adoption. The key is its use in remote monitoring.

Qualcomm Life Fund Director Jack Young explains, "Patient monitoring is becoming a necessary measure for hospitals and doctors to measure their business." One reason all this matters is an example provided in a study by the Institute for Healthcare Improvement which found that patients who suffered a heart attack while being electronically monitored had a 48% chance of survival vs only a 6% chance for those not monitored. Now imagine if that could be rolled out in scale to patients who were not on site in a hospital but were connected to the cloud with remote monitoring devices.

The confluence of sensor technology, wireless communication protocols and pressure to reduce health care costs and improve success rates is creating a whole new field of non-FDA governed consumer level remote monitoring devices. Low-cost systems that use consumer grade protocols and do not require FDA approval are seen as a rapid speed to market opportunity for those who can produce such technology.

Figure 15: Printed electronics tattoo with diagnostic tools on board.

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Figure 16: Flex technology center showcasing wearable circuits.

Figure 17: Daft Punk wearing their trademark lighted helmets.

The springboard of MBAN and wireless communication protocols and the security standards developed for those allow for a proliferation of a new class of remote monitoring devices. Such devices can collect data like blood pressure, temperature, skin moisture content. These can include everything from wearable textiles like the Mimo baby monitoring night suit (Figure 14) or training suits for sports or fitness. There are even smart tattoos that can monitor skin conditions and upload them to the cloud (Figure 15). ABI Research estimates that 5 million disposable, wearable, medical sensors will ship by 2018. The potential growth in these areas is so significant that on July 23, 2015 industry heavyweight Flextronics has rebranded itself "Flex" in order to better position it to be considered a player in the wearables and flexible electronics markets and not just an assembly operation (Figure 16).

So the common thread is that remote monitoring technology is driving the consumer wearables and diagnostics market. A key takeaway from all of this is that if you have a board shop or printed electronics shop building medical devices, keep your quality up and deliver on time and you can expect consistent growth. If you are a patient for some of these devices, your comfort level and life expectancy will continue to improve. If you are an early adopter of wearable technology, you can expect an endless stream of new devices to try out. All this taken together ensures that in time we will all live to be two centuries old and will likely walk down the street dressed like Daft Punk (and if you don't know who Daft Punk is, perhaps you may be an early success case for longevity). **PCB**

Jason Marsh is vice president of product management at Insulectro. To read past columns, or to contact the author, click here.

Medical Research is Golden

by Tara Dunn
OMNI PCB

Recently, I was involved in a group discussion about flexible circuits and the role of this product in medical equipment development and medical research. We were having a lighthearted discussion over lunch, when I was asked about the most interesting flex application I had been involved with. The first thing that sprang to mind was an application from several years ago. In this application, flex was being used for purely aesthetic reasons.

A handheld piece of surgical equipment included wires that were visible to the patient. The wires were functioning perfectly, but the negative perception of patients when seeing these wires during a medical procedure prompted the equipment designer to replace the wires with a sleek, high-tech-looking flexible circuit. In terms of technology, this was probably one of the simplest flex designs to be manufactured: standard materials, single-sided, two big traces, and tolerances that weren't particularly critical. Needless to say, the group was amused. Of all of the possible medical applications that I have had the opportunity to be involved with, THAT was the first one I thought of? Honestly, I have always appreciated that unusual application!

But after giving that question more serious consideration, I realized that there truly has been a marked increase in flexible circuit designs in medical products over the past several years. Flex is the perfect solution for solving space, weight and packaging issues. A visit to the doctor's office or hospital clearly reveals that medical equipment has become much smaller, lighter-weight and more portable, all while increasing functionality. Flex and rigid-flex designs are becoming commonplace in this field. As we see an increase in the number of flexible circuit applications in this field, we also see an increasing need for finer lines and spaces, microvia technology and mixed material stack ups. This is not unlike the technology advancements we see with rigid printed circuit board technology.

Neural Probe Technology

If I had to choose one of the most interesting flex applications that I have been involved with recently, it would be applications that involve neural probe technologies. Developers working on research studies designed a sensor that required trace and space in the one mil range, which is not a simple technology to manufacture. Compounding the complexity of this unusual request was the need for those traces to be gold rather than copper. I did need to clarify that this was a need for gold traces, not copper traces with ENIG or gold plated traces! Wanting to learn more about the technology required to

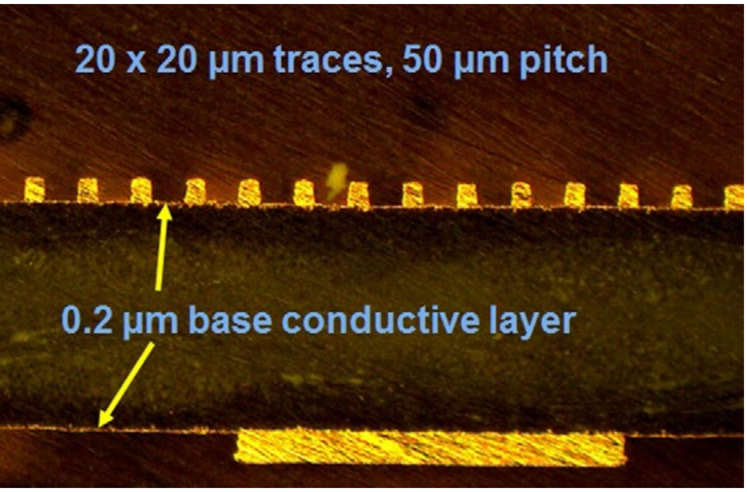


Figure 1: Cross-section of low-force, high-performance probe solution.

accomplish this combination, I reached out to Mike Vinson, with Averatek Corp., which manufactures using a patented innovative and additive metal "print and plate" process. This additive technology enables the creation of trace and space widths below 10 microns and enables the direct deposition of copper and other metals on a variety of substrates.

One of the first questions I wanted to answer was this: What would drive the need for gold traces rather than the traditional copper traces? What I have learned is that neural probes are being used in many clinical settings for diagnosis of brain diseases such as seizures, epilepsy, migraines, Alzheimer's and dementia. Microelectronic technologies are opening new and exciting avenues in neural sciences and brain machine interfaces. With this area of science and research, biocompatibility of the neural probes to minimize the immune response is critical. Copper, nickel and chromium can all adversely impact cells in the area of the electrodes. Flexible materials, such as polyimide, are commonly used in implanted devices to match the geometric and flexibility requirements of implants. Metallizing with gold provides further compatibility versus less noble conductors such as copper or nickel.

With a better understanding of the reasons behind the request for gold traces, the burning question was, how does the additive print and plate process enable both the fine lines and the gold metallization?

Fine Lines and Gold Metallization

The traditional PCB manufacturing process is accomplished by a subtractive etch process. The PCB manufacturer will start with a panel of copper-clad material. In other words, the full panel, often 18" x 24", is covered in copper. The traces and spaces are created with a develop-etch-strip process that essentially removes the unwanted copper from the panel leaving the desired trace patterns. Often over-simplified, this process is quite complex. After vias are drilled, electroless copper is deposited and resist is laminated prior to the photolithography process. Following the imaging process, panels are developed to remove resist that was not exposed, the copper is electroplated, and then tin is plated as a temporary etch resist. The remainder of the resist is stripped, the etch process removes the unwanted copper and the temporary tin plating is then stripped.

Additive technology is a reversal of this process. The manufacturer begins with the bare substrate. In the case of a neural probe, this is likely a polyimide material. The desired circuit pattern is then created by adding the metal layer to the substrate. Averatek has developed a proprietary nano-catalytic ink that enables a simplified five step process.

The bare substrate is prepared. Vias are drilled. The ink is coated and cured. The ink is then patterned with photolithographic imaging. Finally, metal is plated to this pattern. In this neural probe application, the metal is gold but metallization could also be copper or other metals. The key to this technology lies with the

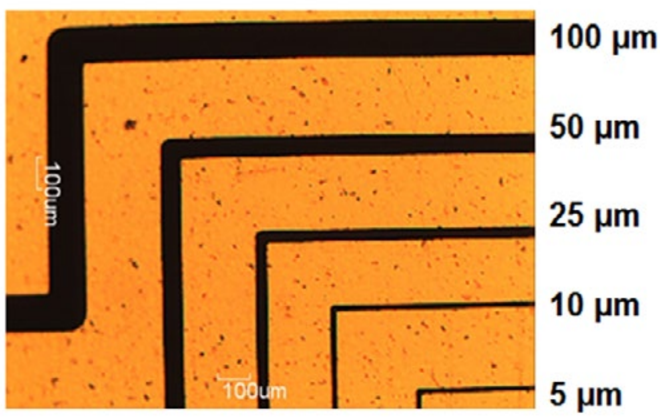


Figure 2: Fine lines on polyimide flex material.

catalytic ink. Precursor catalysts that are deposited in thin atomic layers have unique properties like so many other nano materials. Additionally, a catalyst that is deposited via a liquid or "ink" can fill in many areas, nooks and crannies that would not be touched by line-of-sight methods like sputtering. This provides a basis for electroless plating that will fill vias of all types with more thorough coverage than conventional methods.

Their semi-additive process works by applying a very thin electroless metal to the base layer, followed by photo resist and imaging allowing the plating of a thicker electrolytic metal when required. As with a traditional semi-additive process, the resist is then stripped and the unneeded metal is etched away forming the trace pattern. In the neural probe example, when working with gold rather than copper, a very thin layer of conductive palladium is applied electrolessly followed by the gold plating. Gold is a difficult metal to etch; the palladium is easily removed without impacting the gold plating. The key difference with the technology is the ability to work with thinner metallization than the traditional semi-additive process.

Without the technology barriers associated with the traditional subtractive etch process, the additive process enables both fine lines and spaces (less than 1 mil) and very thin metallization (less than 5 microns).

Medical applications using this technology are often single- or double-sided configurations that have been designed with fine lines and spaces. The ability to design features less than .001" adds a new flexibility to maximize breakouts and eliminate, or minimize, multilayer blind via constructions. When this is coupled with the ability to plate pure gold without nickel, chrome, or exposed copper layers, a unique offering emerges for applications where the circuits may need to be exposed in end use.

This same technology has applications in other medical applications as well. Conductive layers are often used for shielding. In some cases, minimal thickness is required for bulk and flexibility. Utilizing the technology for a semi-additive base layer, as noted above, enables a very thin, yet very conductive metallization on flexible substrates as well as insulation on wires and cables for coaxial type shielding. This thin

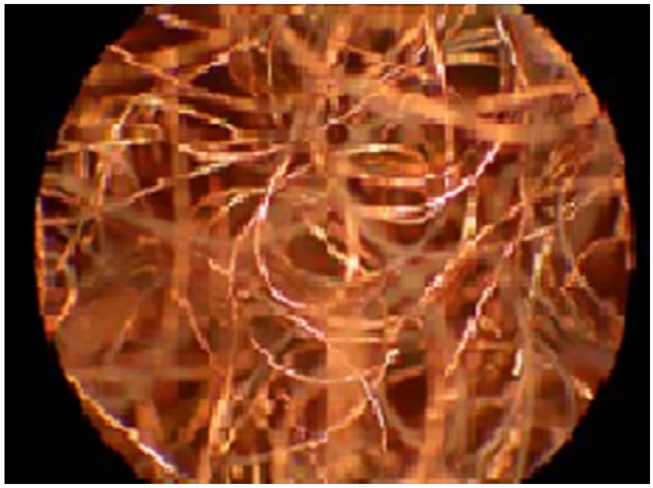


Figure 3: Metal-coated fibers (Velcro).

metalized layer can be cut to a specific size and installed around critical components in the final assembly. Many shielding applications require copper, but both gold and palladium can be used as required by the application.

Metallization of fabric is also an emerging market need. Using this additive technology, electrodes and other conductive paths can be formed by coating individual fibers in fabric, down to two microns in diameter, with thin metal layers. This has been demonstrated in gold, palladium and copper. The metalized surface can provide electrical, mechanical and chemical benefits.

Selecting the most interesting flex application related to medical field is not an easy task. There are just so many interesting applications and design developments to choose from. This field is moving at a rapid pace. At least for today, the neural probe technology, requiring both the traces to be metallized with gold instead of copper, and requiring those traces to be at or below .001", gets my vote. Not only does it push outside of standard technology in one way, but in two ways, simultaneously. **PCB**

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

MilAero007 Highlights

[New OEM Global Account Manager for Avionics & Automotive at Ventec International]

Ventec International Group, a world leader in the production of polyimide and high-reliability epoxy laminates and prepregs, is delighted to announce the appointment of Tamara den Daas in the role of OEM global account manager with a focus on opportunities within the avionics and automotive markets.

Eltek Receives Orders worth $1.4M from Customers in India

Eltek Ltd. announced today that since the beginning of the fourth quarter, it has received several orders for military applications from customers in India, amounting to US$ 1.4 million in the aggregate. The majority amount of these orders is expected to be delivered to the customers during 2016.

Dymax White Paper Explains Switching from Conventional Lamp to LED Light-Curing Sources

Dymax Corporation's new white paper, "Ensuring Success When Switching from Conventional Lamp to LED Light Curing Sources," discusses topics such as how LED curing works, the advantages to LED curing, and getting enough information to switch successfully.

Future Batteries Could Charge in 30 Seconds

Future cell phones and other electronics could have batteries that charge in less than a minute. This new capability will be in part thanks to a space experiment using hard, flexible material as a clean power source.

Honeywell Paper Investigates Avionics Vibration Durability

Dr. Joseph Juarez, principal mechanical engineer at Honeywell International, discusses his SMTA paper, which addresses avionics vibration durability between tin-lead and lead-free solder, the years of testing he conducted, the importance of doing a good soldering job, and some of the surprising findings of his research.

i3 Electronics Earns 'Preferred Supplier' Status from Raytheon

i3 Electronics has earned this "Preferred Supplier" status by continuously delivering a high level of performance and value-add to Raytheon. Designation of this prestigious "Preferred Supplier listing" will allow i3 to work even more closely with Raytheon and their world-class team of engineers, scientists and problem solvers.

NASA's SOHO Celebrates 20 Years of Space-based Science

After 20 years in space, ESA and NASA's Solar and Heliospheric Observatory, or SOHO, is still going strong. Originally launched in 1995 to study the sun and its influence out to the very edges of the solar system, SOHO revolutionized this field of science, known as heliophysics, providing the basis for nearly 5,000 scientific papers. SOHO also found an unexpected role as the greatest comet hunter of all time—reaching 3,000 comet discoveries in September 2015.

The Opportunities for Plasma Processing

Pete Starkey interviewed Andre Bodegom, managing director of Netherlands-based Adeon Technologies B.V., about their long relationship with Nordson MARCH, typical applications for plasma equipment, and what the most challenging materials are from the point of view of plasma processing in the PCB industry.

Graphic Plc Wins BAE Systems Gold Award

The award recognises continued commitment and support to BAE systems programmes and key business objectives. The award reflects Graphic Plc's achievements in demonstrating sustained excellence in delivery and quality performance.

NASA Selects New Technologies for Parabolic Flights and Suborbital Launches

NASA's Flight Opportunities Program has selected eight space technology payloads for reduced gravity flights on board specialized aircraft and commercial suborbital reusable launch vehicles (sRLVs).

Facing Incredible Times:

Robin Taylor's Vision of the Future

by Pete Starkey
I-CONNECT007

The highlight of the "Speakers' Corner" at the 2015 productronica trade fair in Munich was the presentation by Robin Taylor of Atotech entitled, "Facing Incredible Times Where the Only constant is Change," in which Taylor took a step back from his everyday marketing and technical sales management responsibilities to contemplate what might happen in the substrate business over the coming decade, in light of current trends and developments and drivers for the longer term.

"Technology is important—but cost is king!" was an inescapable reality as he delved into future packaging styles: small form factors and lightweight technology, and higher performance with lower cost. Glass and panel-based processing offered further opportunities for cost reduction. "Think sensors!" he advocated, in anticipation of a long-term market dominated by mobile, medical and wearable devices, and the Internet of Things. The semiconductor industry was currently going through an unprecedented period of consolidation, driven by increased cost of integrated circuit design and development and fab construction, as the technology node approached molecular dimensions. In parallel, there was increasing consolidation in outsourced assembly and test, substrate and PCB fabrication, and materials sectors.

Innovative techniques were extending the capability of optical lithography to reduce feature size much earlier than the semiconductor industry roadmaps had predicted, and package routing densities were approaching thin film dimensions. Although sub-1 micron line and space widths were achievable in foundries, there was still a gap to be filled by low-cost solutions and fan-out wafer level packaging concepts presented the prospect of high-volume substrate-less products.

The trend in mobile devices towards slimmer handsets, with larger screens and higher-capacity batteries left less room to accommodate packages and substrates, which consequently had to provide increased functionality in smaller and thinner dimensions, whilst the mechanical properties of their materials would become more critical, particularly in regard of warpage reduction. Copper-pillar and thermo-

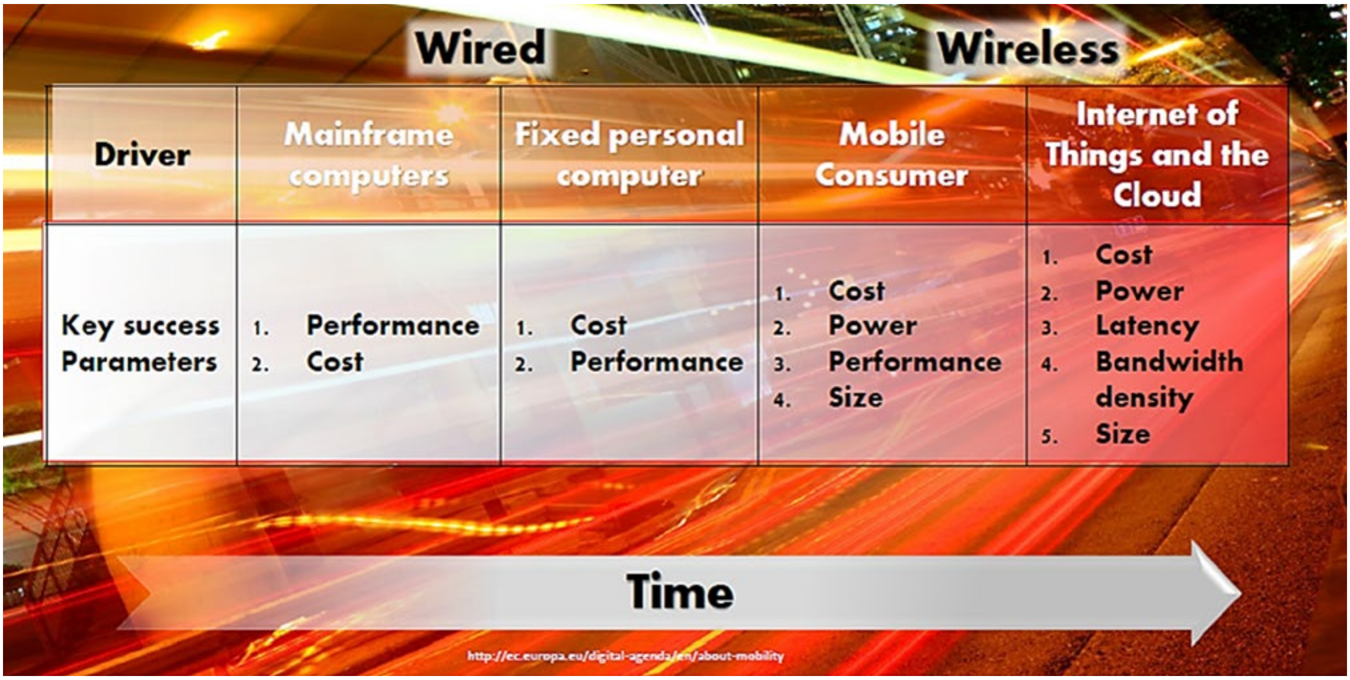


Figure 1: Technology is important—but cost is king!

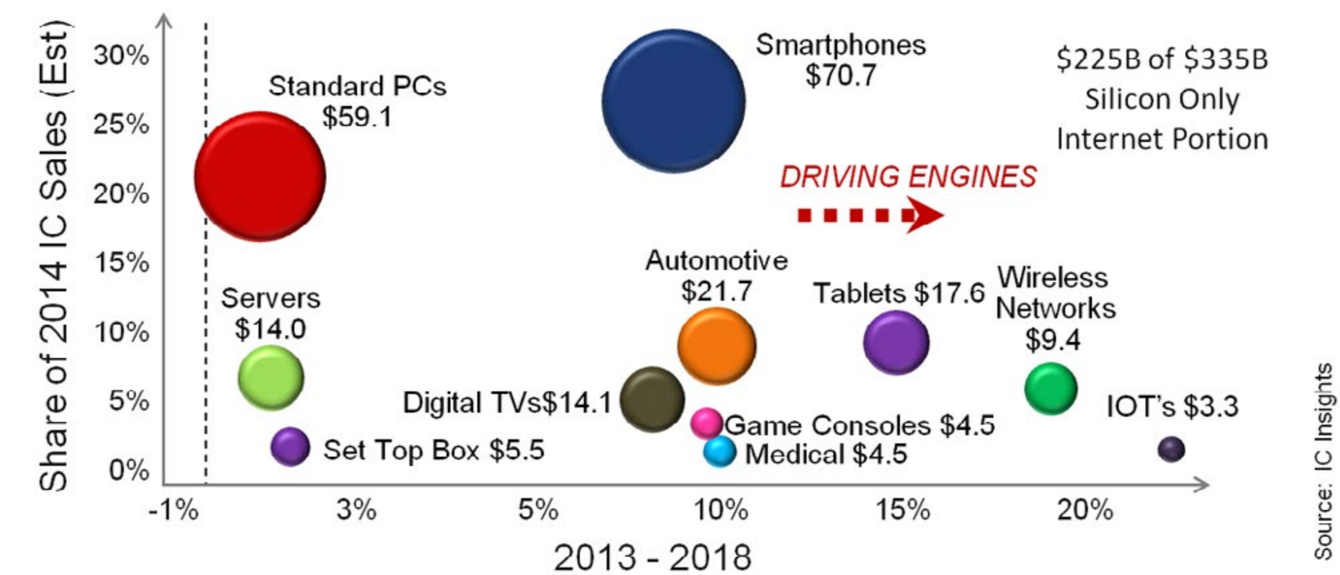


Figure 2: Long-term market growth will be dominated by mobile, medical/wearables and the IoT.

compression bonding was predicted to become the foundation for most of future advanced packaging platforms, essential for pitch reduction and offering cost savings and improved electrical performance. Technologies such as integrated fan-out package-on-package wafer-level packaging were expected to feature in next-generation smartphones, with the scope to incorporate processor and memory in one package. And developments in substrate-less packages posed a potential threat to the package substrate manufacturing industry, which was

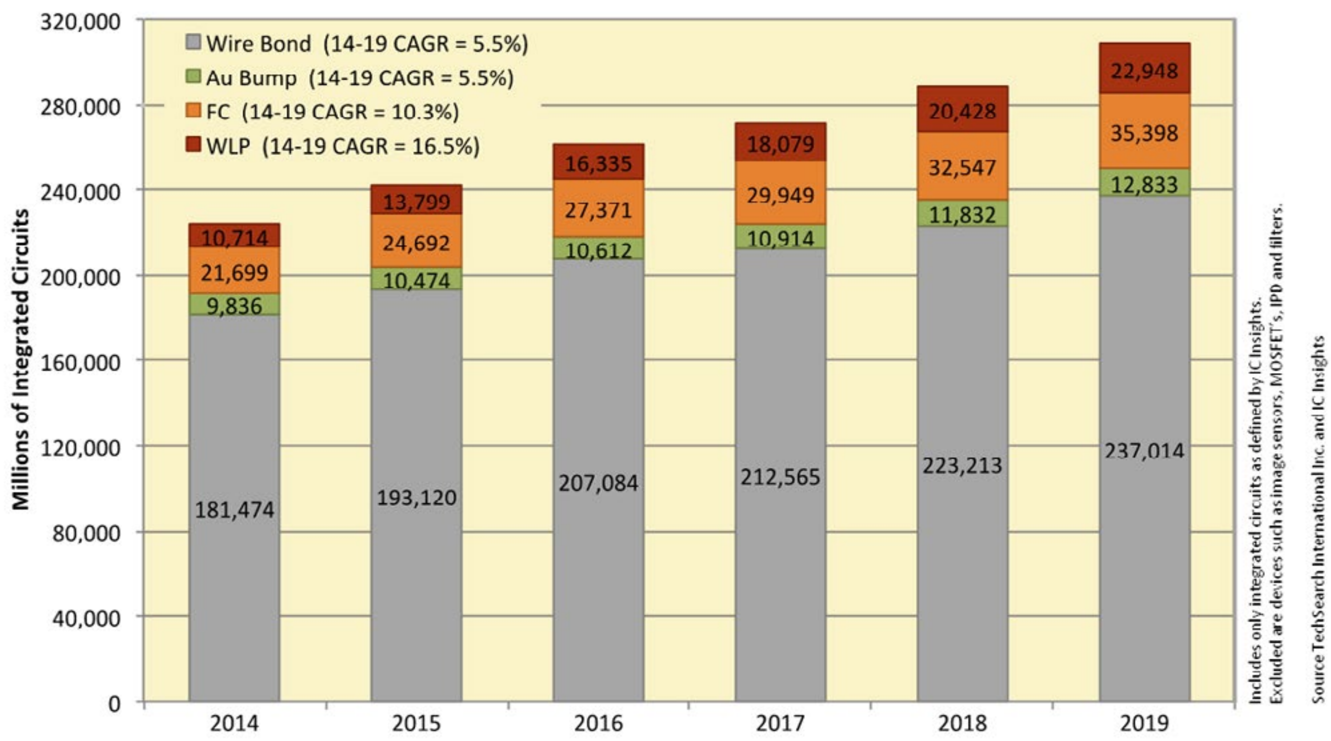


Figure 3: High growth rate for wafer level packaging (WLP)—what's ahead for IC substrates?

presently exploring embedded trace technologies and photoimageable dielectrics to shrink microvias to the 10 micron level and increase wiring density towards two to five micron line-and-space. Glass interposers offered high-modulus, low-warpage characteristics with high interconnection density. The flip-chip embedded interposer-carrier combined interposer and organic substrate, eliminating the solder joints between interposer and organic substrate and offering another alternative for high-density system-in-package.

Seemingly no end to the inventory of exponentially accelerating advances in semiconductor and packaging technologies, shrouded in a techno-language of acronyms and jargon understood only by the elite and incomprehensible to the majority, but what would be the outcome so far as humanity was concerned? Where would it all lead? What was Robin Taylor's vision?

He ran through a catalogue of scenarios, all totally plausible on the basis of logical projection from current state-of-the-art to a decade hence:

• Computers with processing power rivaling the speed of the human brain for $1000, an Internet of Everything with 100 billion connected devices, collecting data through a trillion sensors and driving a data revolution beyond our imagination generating a world of perfect knowledge about anything, anytime, anywhere, for eight billion connected people, five billion of whom would be potential new consumers added to the world economy.

• Dematerialisation, demonetisation and democratisation of today's inefficient business systems, with protocols such as Blockchain, enabling secure digital transfer of assets and information, decentralised cloud storage of sensitive data, smart, unbreakable contracts and digital IP.

• Disruptive digital innovations in healthcare, with genomic sequencing and machine learning revealing the root causes of disease, biometric monitoring enabling timely diagnosis and robotic surgery routinely and cost-effectively available.

• Developments in augmented and virtual reality resulting in dramatic changes to user interfaces

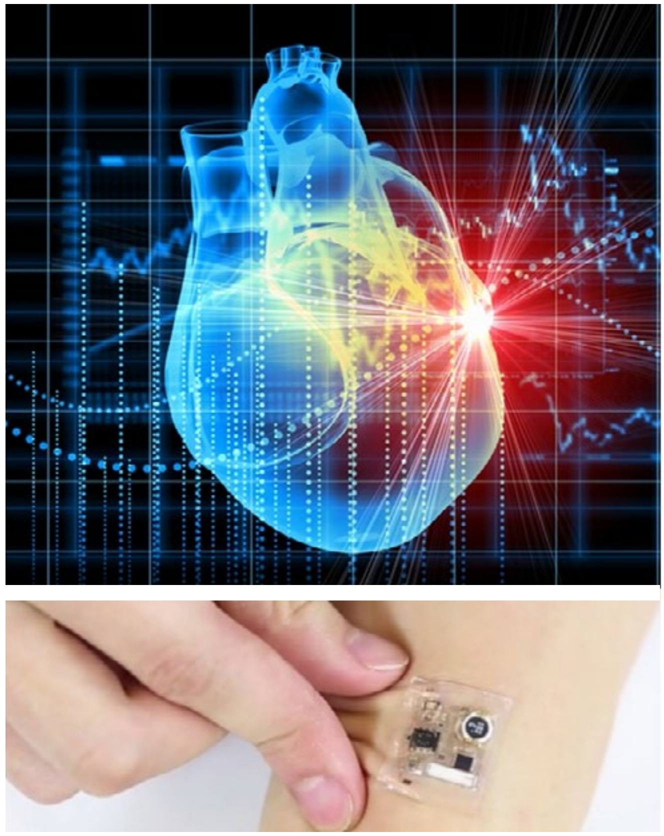
FACING INCREDIBLE TIMES: ROBIN TAYLOR'S VISION OF THE FUTURE

Figure 4: By 2025 a $1000 computer should have the processing speed of a human brain. (source: eng-csr.edu)

and displays, and the disappearance of computer, phone and TV screens to be replaced by a whole new generation of displays and user interfaces, with impact upon business-to-business, consumer retail, education, travel and entertainment.

- Advances in artificial intelligence, with expanded capabilities to understand and analyse, and cognitive computing simulating human thought processes and mimicking the way the human brain works—immense technological and practical capabilities, but at what risk?

With all this in prospect, Taylor's bottom line was that we live in the most exciting times ever! But what were the concerns? How could security and privacy be maintained? How could the Internet of Everything be regulated? Would global internet connectivity be a hacker's wonderland? What could be the consequences of mobile devices knowing the location of both the user and all of his connected contacts? Would artificial intelligence be a blessing or a risk? Would cognitive computing be a global game changer? Would "Digital Everything" equate to "Digital Minefield?"



Source: Shutterstock

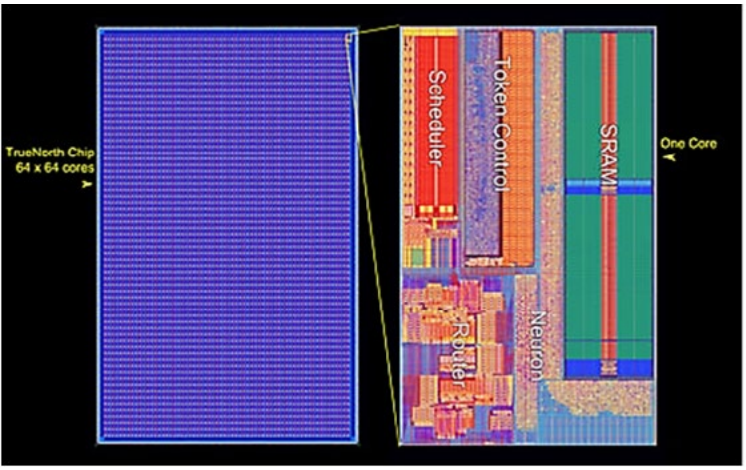
Source: ctvnews.ca

Figure 5: Healthcare benefits from disruptive, digital innovations.

Talking to Taylor after his presentation over a beer, I asked him a few questions, including what had been the motivation for his presentation.

It was a kind of a look outside of Atotech, which was quite interesting to do. We normally talk about our own products and services. The idea was to have a look at what's happening in the market today—what are the trends and what are the areas where we see some developments in the substrate business that may or may not be interesting to us, and also what may happen during the next 10 years. It's a very interesting subject to look at because normally we're more Atotech-centric. It's very useful for us to take a step back and actually have a look at really what we think is happening in the market.

I tried to add a little bit of humour at the end because when we look at all the stuff that's happening with artificial intelligence, cognitive



Source: IBM Research

Figure 6: IBM's TrueNorth chip core array, capable of 46 billion synaptic operations per second.

computing, and Google buying all the robotic companies in the world, it reminded me somehow of the Terminator movies. This is not my conclusion, but it's a possibility that this is how the world could end. It's a kind of light-hearted look at what's happening in the market with some serious overtones because clearly some of the things that are happening just now in packaging could be a significant threat to our business. We have to be very aware of what's happening so at the very least we can try to participate and find some solutions for the future.

I also inquired what the main points were that he sought to bring over:

In general, looking at the market and then looking at what's happening in the mobile market, as we see it is being driven by mobile. Also, wearables, the Internet of Things, and the Internet of Everything are unknown segments, but there are a lot of predictions for growth in them, as well as the growth of wafer level packaging, especially for fan out wafer level packaging. Of course, since we actually wrote this paper, there has been some announcements in this field, like TSMC with their InFo wafer level package that is rumoured will take all the Apple business for the A10 processor, or most of it. This eliminates the package substrate, which is of course of significant interest to us. Looking at all the trends and then looking at what the substrate guys are doing to try to compete in this brave new world,

Source: Telefonics

Source: cs.injit.edu

Figure 7: Security/privacy remains a concern: Digital Everything = Digital Minefield?

then just a kind of semi-light-hearted look at what we might think might happen, with some serious overtones, for the next 10 years.

The IBM TrueNorth chip core for cognitive computing is actually a fantastic achievement. Artificial intelligence is being pursued by a number of companies who previously had no tangible interest in it. All the advances in health care with the IoT, so that we can become CEOs of our own health—you can monitor your body, it can be automatically uploaded to your doctor, and he can advise you immediately if something is amiss. Even things like block chain where you have the potential for digital secure voting—things that we couldn't dream about in the last few years. Also, very interesting for me is the internet revolution from space.

You have the OneWeb consortium in conjunction with Virgin media and Qualcomm which is already up and running. OneWeb has a disaster recovery system where, for example, if you have a massive explosion in a city you can put a hub on the ground and you get 4G LTE and 100 megabytes per second WiFi to coordinate rescue efforts. Then you have SpaceX, which is funded also by Facebook and Google, who also want to get in on the act. By doing this on a global basis they can add billions of new consumers.

The whole world is moving to digital. For me it's very interesting. How do we control it? How do we regulate it? These are all things that really haven't been thought out. In terms of the rate of change, for me, it seems to be moving faster than we can control it and regulate it. Some of the paper is very light-hearted but there is a serious overtone behind it because I don't know how we can control and regulate this stuff. And with the prospect of the Internet of Everything, I don't think anybody knows yet how this will turn out.

Robin Taylor

I agreed with Robin Taylor, sharing his concern that things were moving so quickly that we will struggle to keep them under control, and thanked him for a presenting such a thought-provoking, albeit rather frightening, vision of the future. **PCB**

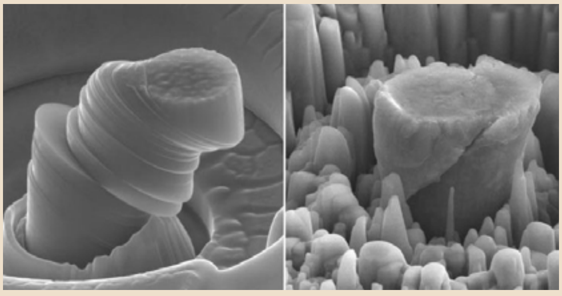
Pete Starkey is technical editor for I-Connect007 and based in the U.K. Starkey has more than 30 years of experience in the PCB industry, with a background in process development, technical service and technical sales. To contact Starkey, click here.

UCLA Researchers Create Exceptionally Strong and Lightweight New Metal

A team led by researchers from the UCLA Henry Samueli School of Engineering and Applied Science has created a super-strong, yet light structural metal with extremely high specific strength and modulus, or stiffness-to-weight ratio. The new metal is composed of magnesium infused with a dense and even dispersal of ceramic silicon carbide nanoparticles. It could be used to make lighter airplanes, spacecraft, and cars, helping to improve fuel efficiency, as well as in mobile electronics and biomedical devices.

The research was published recently in Nature.

"It's been proposed that nanoparticles could really enhance the strength of metals without damaging their plasticity, especially light metals like magnesium, but no groups have been able to disperse ceramic nanoparticles in molten metals until now," said Xiaochun Li, the principal investigator on the research and Raytheon Chair in Manufacturing Engineering at UCLA. "With an infusion of physics and materials processing, our method paves a new way to enhance the performance of many different kinds of metals by evenly infusing dense nanoparticles to enhance the performance of metals to meet energy and sustainability challenges in today's society."



Magnesium, at just two-thirds the density of aluminum, is the lightest structural metal. Silicon carbide is an ultra-hard ceramic commonly used in industrial cutting blades. The researchers' technique of infusing a large number of silicon carbide particles smaller than 100 nanometers into magnesium added significant strength, stiffness, plasticity and durability under high temperatures.

Flex: Just What the Doctor Ordered for Medical Devices

by Dave Becker
ALL FLEX FLEXIBLE CIRCUITS LLC

Medical devices represent one of the fastest growing electronic markets in the United States. The drive for reduced space and weight, added functionality, and reduced cost has driven the adoption of a wide array of custom flexible circuits. The design freedom offered by this three-dimensional interconnect supports the packaging design requirements for a myriad of diverse applications within the medical electronic market.

The adoption of flexible circuitry in medical devices goes back to the early 1970s, when companies like Cardiac Pacemakers and Medtronic used flex circuitry for implantable pacemakers and implantable defibrillators. As electronics and packaging advanced, medical products enjoyed a tremendous growth both in the U.S. and overseas. This growth will most certainly continue as new and innovative products, with increasingly demanding electronic requirements, challenge product designers to add functionality within smaller and smarter devices.

Today flexible circuits are found in many medical applications:

- **Implantable medical devices:** These include pacemakers, defibrillators, neurological implants and cochlear implants (hearing). These devices are surgically implanted in the human body. Product requirements are extreme reliability, long life cycle, light weight, biocompatibility and compact size.
- **Non-implantable medical devices:** Hearing aids, drug dispensing systems, and external defibrillators (attached to patient) are examples of this medical application. These devices are generally worn or attached to the skin of the patient.
- **Monitoring devices:** These products include portable and wearable electronics that monitor heart rate, blood pressure, body temperature, and blood sugar rate. Also included in this category are bedside monitoring devices.
- **Diagnostic equipment:** This category includes equipment for ultrasound scanning, magnetic resonance imaging (MRI), computed tomography scanning (CAT scan), X-rays and a variety of other types of equipment to aid in detecting and diagnosing health problems.

• **Surgery tools:** These include electronic saws, screwdrivers and cauterizing scissors for clamping and closing blood vessels while performing surgery.

• **Single-use devices (SUDs):** Applications include ultrasonic scalpels, electrode recording catheters, biopsy instruments, electric biopsy forceps and other applications where sterile requirements dictate one time use.

The variety of uses and applications is continually expanding with innovative new designs or redesigns of existing equipment. During the past several years the medical industry has certainly become one of the fastest growing segments for flexible circuit applications. A number of important factors make flexible circuitry ideal for the medical industry:

Reliability: As early as the 1950s, flexible circuitry was used in the military and avionics industry, with both applications demanding extraordinary reliability. Years of proven performance in these demanding applications provided the medical industry with confidence in flex circuitry's reliability and robustness. Flexible circuitry has inherent advantages because it eliminates connection points. This can be accomplished by designing out the need for connectors, soldered wires, and/or rigid circuit boards. Integrating these components into a single flex circuit assembly is a common adoption of the technology. This often helps simplify the assembly and can reduce the chance of human error.

Space and Weight: Electronic applications within the medical market drive demand to make devices smaller and lighter. This feature is typical of why flexible circuits are often adopted when weight and space are a premium. Flexible circuitry is very thin, can be easily bent for assembly, and connects components across multiple planes. While implantable devices may be fully sealed to eliminate contamination, non-implantable devices are frequently used in applications requiring contact with human skin.

Feature Density: Flexible circuits can be built with narrow lines and spaces (conductor trace and space widths less than .005» are quite common) and are often constructed with multiple conductive layers. Resistive metals are sometimes added as a layer that can be designed as a heater element. This becomes increasingly important as designers continue to reduce volume while increasing functionality.

Dynamic Flexing: Flexible circuitry has often been employed for dynamic bending or movement. This includes applications to provide interconnection through a hinged device or for maintaining connection through devices that expand, contract or telescope during use. Material construction and circuit layout are particularly important in dynamic flex applications. Consulting with a flex vendor or other industry expert is recommended when moving parts need to be connected.

Supply Chain: Materials used to make flex are widely available. A good supply chain infrastructure exists as the market growth has attracted the attention of multiple vendors. This helps create a foundation of technical resources available for application and design support in the USA, including capable and experienced applications engineering talent. Organizations such as IPC have helped support the cross fertilization of technology and knowledge. The variety of applications has created a wealth of experience and has spawned innovation within the industry.

The demand for flexible circuitry in the medical industry will remain robust as electronic medical equipment continues as one of the hottest growth areas for the electronics industry. The aging population, longer life expectancy, demands for more affordable and less invasive health care, and the continued advancement in technology are some of the factors driving growth in this market segment. Increasing possibilities for the use of flexible circuitry in medical electronics will grow rapidly as designers identify additional ways to take advantage of the utility offered by this three-dimensional interconnection technology. **PCB**

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

Electronics Industry News

Market Highlights

Frost & Sullivan: Five Big Technology Predictions for 2016

Frost & Sullivan's Audrey William, Head of ICT Research, Australia & New Zealand, shares her insights for the five big technology predictions going into 2016.

Portable Device can Quickly Determine the Extent of an Eye Injury

An engineer and an ophthalmologist are developing a portable sensor that can quickly and inexpensively determine whether an eye injury is mild or severe. The device, called OcuCheck, measures levels of vitamin C in the fluids that coat or leak from the eye.

Smart Grid Data Analytics Market to Triple by 2022

According to a new market report published by Transparency Market Research "Smart Grid Data Analytics Market—Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015– 2022," the smart grid data analytics market was valued at US$1.6B in 2014 and is estimated to reach US$4.6B by 2022, expanding at a CAGR of 13.4% from 2015–2022.

A Battery Revolution in Motion

The first prototype of a sodium-ion battery has just been revealed by the RS2E, a French network bringing together researchers and industrial actors. This technology, inspired by the lithium-ion batteries already used in portable computers and electric vehicles, could lead to the mass storage of intermittent renewable energy sources.

Flat Camera Invented at Rice University Looks into the Future

How thin can a camera be? Very, say Rice University researchers who have developed patented prototypes of their technological breakthrough. FlatCam, invented by Rice labs' electrical and computer engineers Richard Baraniuk and Ashok Veeraraghavan, is little more than a thin sensor chip with a mask that replaces lenses in a traditional camera.

TrendForce Anticipates 4K TVs to Reach 23% Market Penetration in 2016

Global LCD TV shipments for 2015 will total 216 million sets, according to the latest estimation by WitsView, a division of TrendForce. This year's shipments will represent a slight annual decline, for the first time since the shipment slide in 2013.

Researchers Find New Phase of Carbon, Make Diamond at Room Temperature

Researchers from North Carolina State University have discovered a new phase of solid carbon, called Q-carbon, which is distinct from the known phases of graphite and diamond. They have also developed a technique for using Q-carbon to make diamond-related structures at room temperature and at ambient atmospheric pressure in air.

Future Batteries Could Charge in 30 Seconds

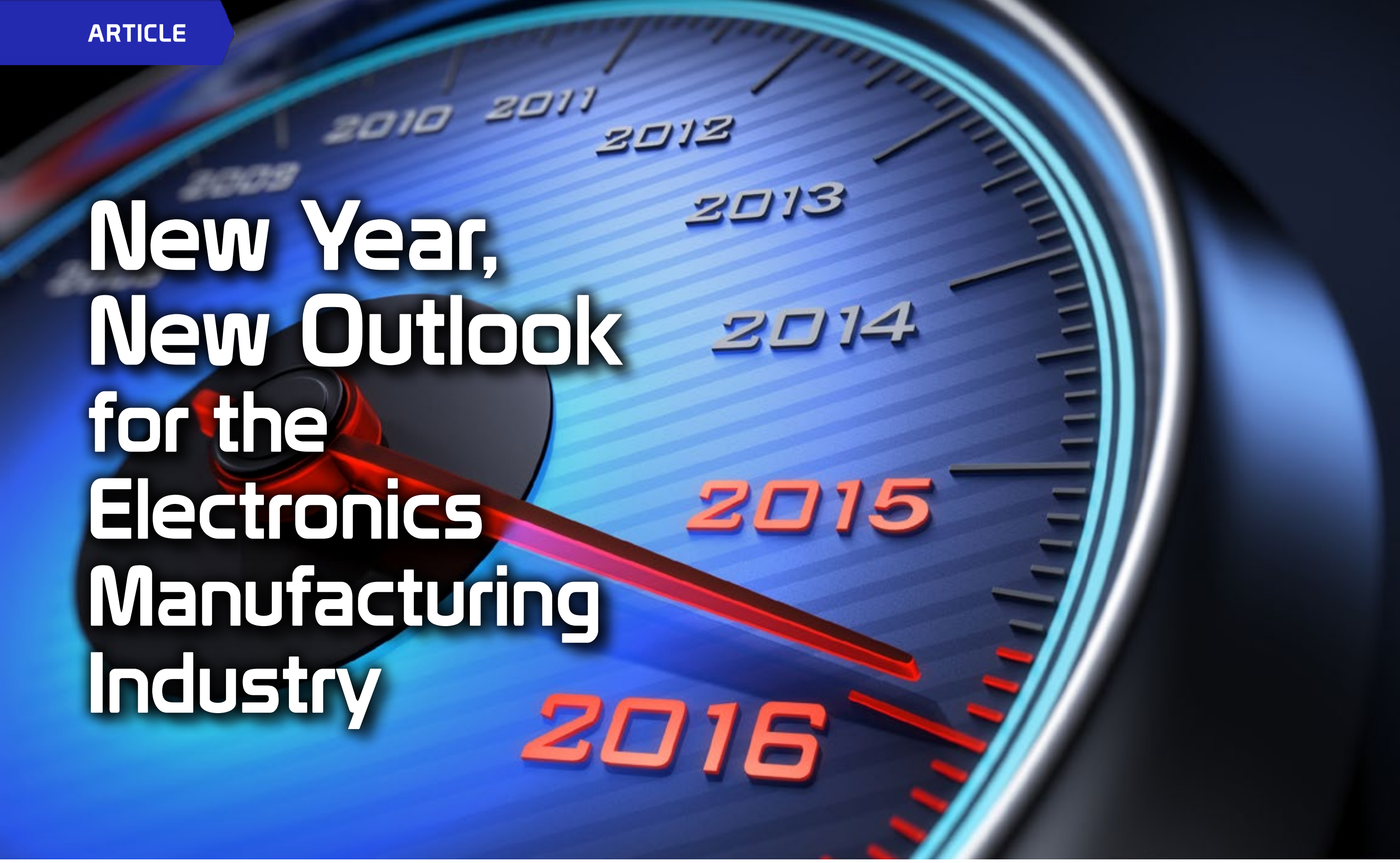
Future cell phones and other electronics could have batteries that charge in less than a minute. This new capability will be in part thanks to a space experiment using hard, flexible material as a clean power source.

Intel Takes Integration Down a New Path

In its latest teardown report, ABI Research, a leader in technology market intelligence, discerns that the Intel Atom x3 Platform, the company's second integrated communication platform, includes the highest integration mobile platform transceiver to date.

Teaching Machines How to Learn

Machines will become not just more intelligent in the future, but also more capable of learning. To promote research in this field, ETH Zurich and the Max Planck Society officially opened the Max Planck ETH Center for Learning Systems. The scientists want to understand the theoretical principles of learning and how these can be applied to real machines.



New Year, New Outlook for the Electronics Manufacturing Industry

by John Hasselman
IPC—ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES

January is traditionally a time to reflect on how to build on the successes of the past year, with the added excitement of looking ahead to setting priorities and goals for the new year.

As an advocate for the electronics manufacturing industry, my job is to educate and encourage policymakers to create a favorable legislative and regulatory environment for advanced manufacturing to grow and succeed. From that perspective, I think we should be proud of the significant progress we made in several areas in 2015.

For example, in the United States, the National Network for Manufacturing Innovation (NNMI) launched several new institutes aimed at accelerating innovation in advanced manufacturing. Most recently, U.S. Secretary of Defense Ashton Carter announced $75 million in federal funding to establish NextFlex[1], America's Flexible Hybrid Electronics Manufacturing Institute, in San Jose, California. More than 160 companies, associations, universities and other organizations, including IPC, are backing the new institute, which will focus on catalyzing the flexible electronics ecosystem through investments in new materials, thinned-device processing, device/sensor integrated printing and packaging, system design tools, and reliability testing and modeling. IPC played a leading role in the industry coalition that secured congressional authorization for these institutes, and we will continue to advocate for full funding and aggressive implementation in 2016 and beyond.

Also, IPC hosted IMPACT, its annual Washington, D.C. "fly-in," where industry executives met with federal policymakers and advocated for public policy priorities that affect our industry. IPC also organized more than a dozen events across the country, in which member companies welcomed their elected representatives for policy discussions and tours of their facilities.

Furthermore, IPC launched a new website[2] and recruitment campaign for the IPC Political Action Committee (IPC PAC) to open a new phase in our long-term efforts to educate policymakers and address issues that affect our industry. Political action committees are transparent, regulated entities in which U.S. citizens and

Figure 1: Representative Paul Ryan touring Creation Technologies.

individuals lawfully admitted for permanent residence, may join together to make political contributions to candidates. The IPC PAC is non-partisan and supports pro-manufacturing candidates.

In Europe, IPC convened a conference in Essen, Germany on EU policy issues. The event provided attendees with an in-depth look at pending EU regulations on conflict minerals, along with updates on critical regulatory programs affecting electronics, including Registration, Evaluation and Authorization of Chemicals (REACH) and Restriction of Hazardous Substances (RoHS). For much of 2015, IPC members worked to educate EU policymakers about the risks of onerous conflict minerals regulations.

In Asia, IPC worked to influence the emerging Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains. Additionally, in a move that will enhance IPC's ability to serve its members in the government relations and business development arenas, we promoted Philip Carmichael—a 30-year veteran of doing business in China—to the position of IPC President of Asia.

As we continue to advance our efforts in 2016, our industry needs to build on these successes, and set new advocacy goals to drive advanced manufacturing worldwide. Here are a few of the IPC Government Relations team's New Year's Resolutions, drawn from IPC's Global Policy Framework:

Supporting Innovation and Advanced Manufacturing

IPC will continue to advocate for stepped-up public-private collaboration to promote innovation and advanced manufacturing all over the world. Efforts such as NNMI in the United States and the Fraunhofer Institutes in Germa-

Figure 2: Representative Dold with IPC's John Mitchell and John Hasselmann at IMPACT 2015.

Figure 3: A meeting between a member of Congress and IPC-member executives at IMPACT 2015.

ny are great models that should be emulated in other regions and nations.

Advocating for Smart Regulation

Manufacturers in many parts of the world face a complex and overwhelming regulatory compliance burden, negatively impacting their abilities to develop innovative technology, create jobs and compete in a global marketplace. IPC members favor a regulatory environment that justly balances risks, costs and benefits based on the best available scientific research. Specifically, that means we will be engaging in the conflict minerals debate in all of our regions, and working for sensible updates of environmental regulations such as the Toxic Substances Control Act in the United States.

Promoting a 21st Century Economy and Workforce

Above and beyond policies that directly affect manufacturing, IPC encourages governments to support broad-based economic growth and competitiveness. For example, IPC advocates for corporate tax rates and incentives that stimulate business investment, and we favor a reduction of trade barriers between countries. IPC—itself a provider of many education and training opportunities—endorses government-backed workforce development initiatives and strong programs in science, technology, engineering and mathematics (STEM) education. We also support immigration policies that allow for international mobility among highly skilled workers.

Those are just a few of IPC's New Year's resolutions to help our members and the $2 trillion global electronics industry survive and thrive amid many challenges. Aside from government relations, IPC is a leading source for industry standards, training, and market research, and we are one of the few trade associations that brings together all of the players in this industry: designers, board manufacturers, assembly companies, suppliers, and original equipment manufacturers.

If you or someone you know would be interested in joining IPC and getting involved in our government relations work, please contact me via LinkedIn, Twitter, or email. **PCB**

References

1. NextFlex.
2. IPC Political Action Committee.
3. IPC Global Policy Framework.

John Hasselman is VP, Government Relations for IPC—Association Connecting Electronics Industries.

Fabrication Drawings and Electrical Test—Reading the Fine Print

by Todd Kolmodin
GARDIEN SERVICES USA

When a new PCB design is born, designers envision what the product will provide when completed. Whether the product is for the consumer, aerospace, military, medical or countless other markets, the designers—or more likely, the customers—expect certain deliverables on the commodity they wish to purchase. To provide the desired functionality of the product design, engineers specify these deliverables on blueprints (prints) or fabrication drawings (fab drawings). These documents are the recipe for the manufacturing requirements of the given product.

A multitude of information is provided in these documents. In most cases the designers do not know the specific processes involved that satisfy their requirements, nor do they have to. They specify their requirements on the fab drawing and allow the PCB manufacturer to use the necessary processes to supply the final product, and herein lies the problem. Some complex designs could have fabrication drawings exceeding 20 pages, and may include requirements ranging from which raw materials are to be used to what type of anti-static packaging is required for shipping.

For this discussion, we will focus on how these documents pertain to electrical test (ET). In most fabrication drawings, many pages are graphical in nature and depict special dimensional or mechanical attributes, while others show drill/cutter requirements, plating requirements, special layup instructions, and almost always a note(s) page. Should ET read the entire package? Yes. Why? Because many times there can be mechanical attributes that will influence how the final product can be tested. However, there are some main topics ET will definitely be looking for:

Got Class?

The PCB industry has documented different performance classes for printed wiring boards. In ET this is very important to know. Testing a board with parameters to match or exceed its class requirement is mandatory. The performance class is always found on the fab drawing. Many times a reference to IPC-6012 Class I, II or III will be documented. From this information ET knows what parameters and test methodology are allowed.

Spec Check?

Above and beyond the IPC manufacturing specification, ET must also be aware of any proprietary specification that may be called out. If the proprietary specification has any specifics around ET, it is desirable that this information be on the print notes as well. If those requirements are not specified it could lead to a non-

> "Above and beyond the IPC manufacturing specification, ET must also be aware of any proprietary specification that may be called out."

conformance issue at the customer. Electrical test must also review for a military specification. If the ET department or contractor is granted suitability to test military product by the Defense Logistics Agency (DLA) they must test according to the specification and report product tested in the required annual report. Electrical test contractors or the internal ET department can only certify the product conforms to the electrical requirements of the specification unless the department has the final authority to write the certificate of compliance for the entire manufacturing process. In the scope of today's discussion, ET does not have the authority to certify the product is built to a certain specification. ET can certify the product was tested in accordance with the given specification.

Stamp it?

This is a subject that may require ET to review other pages of the drawing set other than the notes section. If a board passes ET it will usually receive a stamp or mark that shows it has passed ET. There are cases where the fab drawing states exactly where a stamp should be placed and conversely may also state the area(s) where it cannot be placed.

Is ET Special?

Another attribute ET should be looking for are special test requirements or parameters. These requirements will override the default specifications in most cases. This could be identification of buried passive components and capacitive attributes that may be present, which ET should know about so as to adjust equipment as necessary to avoid false failures and unnecessary delays.

Getting it Right!

From the receipt of the new order the sales/tooling department needs to make sure all requirements are flowed down to every department involved. Missing information to any given department can cause delays. This is even more critical when independent contractors are used, whether in-house or external. Missing mechanical attributes such as layup or image array orientation are just as important to ET as missing electrical attributes. Missing information in these areas can cause costly delays, including wrong fixture tooling, incorrect programming for flying probes and incorrect parameters being used to test product. Diligence in all these areas can mean the difference between successful on-time delivery and costly restarts. **PCB**

Todd Kolmodin is the vice president of quality for Gardien Services USA, and an expert in electrical test and reliability issues. To read past columns, or to contact the author, click here.

Supply Line
Highlights

Navigating the Global Materials Supply Chain: A Roundtable Discussion
At SMTAI recently, I-Connect007's Andy Shaughnessy sat down for a roundtable discussion with some key players from the materials side of the supply chain. Participants included two executives from Ventec: Mark Goodwin, COO USA and Europe for Ventec International Group; and Jack Pattie, president of Ventec USA. Also participating in the roundtable were Schoeller Electronics CEO Michael Keuthen and Bob Willis, from the National Physics Laboratory (NPL).

MacDermid's Research Team Talks New Cyanide-free Immersion Gold at SMTAI
While at SMTAI in Chicago recently, I met with two of MacDermid's research team, Jun Nable, research project manager, who has been with MacDermid since 2007, and Cherry Santos, associate research fellow responsible for formulation work for metal plating solutions. We talked about the posters they were presenting and why they chose SMTAI.

Specialist Coatings for Specialist Applications
Taiyo America's Josh Goldberg agreed to spend a few minutes with I-Connect007's Pete Starkey at productronica recently, where he indeed climbed out of the box and explored the broader market for high-performance polymer coatings in the electronics industry.

productronica 2015: Schmid's InfinityLine Opens New Era in Etching Machine Technology
Schmid has combined the best attributes of their long-established CombiLine and PremiumLine in the development of their new InfinityLine family of modular etching machines, which offer an attractive cost structure without compromising performance, quality or durability.

MacDermid, Enthone, Alpha, OMG, and Compugraphics Now under One Roof
Platform Specialty Products Corporation, a global diversified specialty chemicals company, has closed on its acquisition of Alent plc. The closing of this transaction will prompt the launch of MacDermid Performance Solutions, a division of Platform that will combine the original MacDermid operations with businesses from Alent (Enthone and Alpha and their subsidiary company, Fernox), along with the recently acquired OM businesses.

productronica 2015: Rogers Scales up Production and Integrates Arlon's Product Range
John Hendricks gives a perspective on the European market for special-purpose laminates, and comments upon Rogers' acquisition of Arlon and the integration of their complementary product range into the Rogers portfolio.

productronica 2015: Electra's LDI Soldermasks for LED and Future Ink-jet Developments
Ashley Steers of Electra Polymers Ltd discusses with I-Connect007's Pete Starkey the continuing developments in LDI soldermasks, and how the challenges associated with highly reflective white soldermasks for LED applications are progressively being overcome.

productronica 2015: MicroCraft's EMMA Probe-tester Automated
Jesse Ziomek, sales manager at MicroCraft, discusses with I-Connect007's Pete Starkey their automated version of the EMMA probe-tester, which is capable of lights-out operation on multiple designs and panel sizes, at 6000 test-points per minute.

Saturn Electronics Chooses atg Flying Probe Technology for High-speed Electrical Test and Automation
atg Luther & Maelzer GmbH, confirms the order for high-speed bare board testing technology. The atg A5a, 8 head, double-sided, auto-load/unload system, for true "lights-out" operation has been ordered and installed by Saturn Electronics, Romulus, MI.

ARTICLE

25 Essential Skills for Engineers

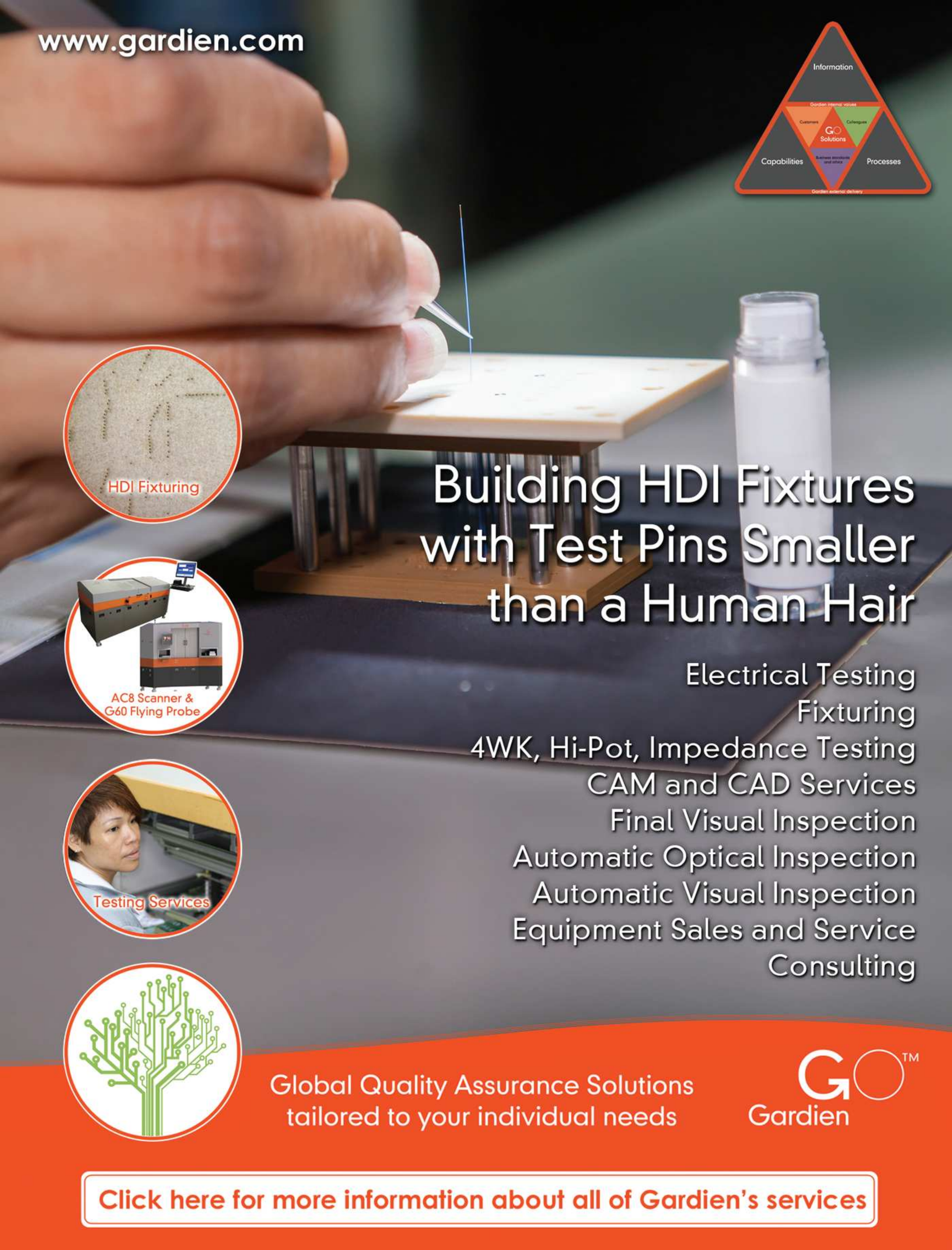
by Happy Holden

I have been working in electronics manufacturing for more than 45 years. I was fortunate to be part of this industry in its golden years, from 1972 to 2000! In this period, all the modern devices that we use today—calculators, mobile phones, tablets, medical devices and portable computers, etc.—were invented and went into production. Since 2000, after the Internet bubble burst, we have been mostly just enhancing those devices. The big boom has been with Internet software applications and the devices that they have inspired.

But this article, and the successive columns I will be writing for I-Connect007, is not about these wonderful devices; rather, it is about the engineering skills and capability that all those engineers demonstrated to have come up with these wondrous new devices. Throughout the years, I have concocted a list of 25 essential skills that I think every engineer should strive to master. Most are not taught in college engineering courses, but are acquired through company training or individual efforts. These 25 skills have led to many of these new devices or software and to the success of electronics in the last 50 years.

25 Essential Skills

The 25 engineering skills are just my opinion; they are what I have observed to be the essential tools that engineers, including myself, needed to complete a project, develop a product, meet a schedule, or solve a problem. These were the important skills that got me the promotion, or the opportunity for a challenging job. These 25 skills are subjects for my future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columns, and they are not necessarily listed here in order of importance:

1. TQC/Six Sigma/Statistics/Curve Fitting
2. Problem solving
3. Design of experiments
4. FMEA
5. Information research on the Internet
6. Technical writing
7. Product/process life cycles
8. Learning curve/learning theory
9. Figure of merit/shared vision
10. Design for manufacturing/assembly
11. Managing management time
12. Project/program management
13. Benchmarking
14. Engineering economics/ROI/BET
15. Roadmapping
16. Quality functional deployment (House of Quality)
17. Automation strategy/CIM
18. Computer aided manufacturing
19. Recruiting and interviewing
20. METRICS—dimensional analysis
21. 10-Step business plan
22. Programmed instruction/long distance learning
23. Lean manufacturing/JIT/TOC
24. Technology awareness
25. Predictive engineering

1. Total Quality Control/ Six-Sigma Quality/Statistics/Curve Fitting

Total quality control and Six Sigma (6σ) refer to the philosophy of continuous improvement through statistical techniques and a commitment to excellence. The PDCA process (Plan, Do, Check, Act) is a central theme using the Nine Basic Tools (cause-effect, process flow, pareto, scatter, histograms, process capability index, control charts, time-series, and check sheets). The useful Statistical *Engineering Handbook* is available from NIST as a free download. A fundamental place to start is selecting the right statistical tools (measurement system analysis, statistical process control, comparative methods, or design of experiment). Curve fitting is a further extension of the Nine Basic Tools because it permits the analysis of data to see if it conforms to any known mathematical model, linear or not.

2. Problem Solving

The seven-step problem solving method of TQC is a good place to start. But this has been refined and expanded by organizations such as Kepner Tregoe. KT's "Decision Analysis-Problem Analysis-Potential Problem Analysis" action sequence methods help engineers enhance their problem-solving skills.

3. Design of Experiments

DOE methods are employed by engineers during experimentations. Whether it is problem solving or process development, the DOE experimental methods provide the most efficient means of determining the correct answers or optimal conditions. It is an essential part of selecting the right statistical tools.

4. FMEA

Failure mode effects analysis (FMEA) is a simple method for finding out the real cost of potential failures in any product or system. FMEA can be used during design or later analysis of a product or process to help identify potentially significant failure risks. For example, an engine casing may be found to be at risk of cracking under harsh vibration or an order entry system may lose customer details if the wrong computer key is pressed. It is a scalable tool that can be used to examine failures in complete systems, subsystems or on individual components. The level and depth of analysis should depend on what is being examined and on the importance of finding all key risks.

5. Information Research on the Internet

There are more specific ways of researching a technical topic on the Internet than just using the Yahoo or Google Search engines. This covers the various locations to conduct specific searches.

6. Technical Writing

Technical writing can be a painful process for engineers, but it is essential as a communication tool and one that must be mastered. This logical and simple procedure may work for most engineers as it leverages off of their innate technical skills.

7. Product/Process Life Cycles

A life cycle provides the organizational framework for new product or process developments by breaking the creation process down into phases and tasks for design and marketing with strategic milestones of review.

8. Learning Curve Learning theory

The learning curve learning theory is a distinct model of yield prediction and useful for planning purposes as well as understanding learning.

9. Shared Vision/Figure of Merit

Figure of merit (FoM) is the third-level of metrics or "Measurement of Performance" and just below the highest (fourth) level. It is a powerful way to create a shared "scoring equation to evaluate any set of alternatives. The process is based on expert opinion utilized in an organized approach to reach a consensus on the important 'factors', their relative 'weighting' and the 'scale' of the factors.

10. Design for Manufacturing & Assembly

DFM/A is a specific design scoring method developed by Professors Dewhurst and Boothroyd to predict how easy or automatable a product will be to mechanically assemble. The score is based on the number of parts, fasteners and kinematic of assembly with tooling.

11. Managing Management Time/Coaching

MMT is a course taught by William Onken for managers about the skills of coaching and delegating to subordinates. It uses monkeys as the definition of problems and issues that employees have and how to keep them from "jumping to your back."

12. Project/Program Management

Program management tools like PERT/GANT charts, project scheduling, and critical PATH are used to plan and manage tasks in an efficient manner.

13. Benchmarking

Benchmarking may also be called reverse engineering and is the skill of dissembling a product to measure and collect metrics of performance about that product. It is linked to metrics and roadmapping.

14. Engineering economics/ROI/BET

Engineering economics is specialized to focus on ROI, net present worth and break-even time (BET), all used in determining design budgets, manpower and manufacturing investments over time. BET can help decide if more resources should be applied at the design phase in order to improve profitability and ROI.

15. Roadmapping

Roadmapping is a specific set of tasks that attempt to present a set of performance metrics for specific times in the future, providing a 'visible' future for planning purposes.

16. Quality functional deployment (House of Quality)

QFD was developed by Toyota to create an organized approach to converting "Customers' Needs and Specifications" into "Actions and Technologies." This is done through a four-step "House of Quality" analysis.

17. Automation Strategy/CIM

Automation (automatic + mechanization can be quantified into levels of systemization (information) and classes of mechanization (motions). Six levels of systemization and six degrees of mechanization creates a 36-matrix approach to automation planning and execution. Automation also has six key characteristics: superiority, simplicity, flexibility, compatibility, manufacturability, and reliability. Automation is key to any computer integrated manufacturing program.

18. Computer-Aided Manufacturing

The specific understanding and manipulation of product data is essential for an electronics or printed circuit engineer. This is the explanation and functionality of the various arenas in modern data-driven electronics manufacturing.

19. Recruiting and Interviewing

Social networking in your technical field is important, as well as establishing visibility in that community so that you have a ready list of capable people that you would like to have work for you. After recruitment, the interview is an important second step and one that requires some skill and practice.

20. Metrics—Dimensional Analysis

Metrics, or technical measures of performance, are key to engineering data and optimization. But too many independent variables makes analysis and optimization difficult. Dimensional analysis provides 129 dimensionless pseudo-variables (like the Reynolds number) that are used in engineering designs. These pseudo-variables provide simplifications like figure of merit can.

21. 10-Step Business Plan

The 10-step business plan is the format to present an idea or product in a fashion that will answer most questions that management has about a product or idea. It is how ideas and products come to reality.

SKILLS	Quality Leadership	Product/Process Innovation	Engineering Leadership	Sales Development
TQC / Six-Sigma / Statistics / Curve Fitting	X		X	
Problem Solving / KT	X		X	
Design of Experiments	X		X	
FMEA	X		X	
Information Research on the Internet	X	X	X	
Technical Writing	X	X	X	
Product / Process Life Cycles	X	X	X	
Learning Curve-Learning Theory	X	X	X	
Figure of Merit / Shared Vision	X	X	X	
Design for Manufacturing / Assembly	X	X	X	
Managing Management Time	X		X	
Project / Program Management		X	X	
Benchmarking		X	X	
Engineering Economics /ROI / BET		X	X	
Roadmapping		X	X	X
Quality Functional Deployment (House of Quality)		X	X	X
Automation Strategy / CIM		X	X	
Computer-Aided-Manufacturing		X	X	
Recruiting & Interviewing			X	
METRICS—Dimensional Analysis			X	
10-Step Business Plan		X	X	X
Programmed Instruction-Long Distance Learning			X	X
Lean Manufacturing / JIT / TOC	X	X		
Technology Awareness		X	X	X
Predictive Engineering		X	X	X

Figure 1: Breakdown of 25 engineering skills into areas of application.

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22. Programmed Instruction/Long Distance Learning

Increasingly more courses are now available over the Internet. To have this be effective there are specific requirements for a course taken or produced over the Internet in order for the user to have a positive experience.

23. Lean Manufacturing/JIT/TOC

Lean, agile manufacturing is the competitive basis for modern manufacturing. Lean is about eliminating waste from your process.

24. Technology Awareness

Technology continues to change and march forward. Electronics is one of the fastest of these technologies, but may be eclipsed by new technologies for the 21st century.

25. Predictive Engineering (PE)

Predictive engineering uses models and software to create a prototype in simulation only so that it can be optimized. The PE framework is the last software tool required to complete the next generation product development framework, with manufacturing (PCB fabrication, SMT assembly and test) all moving to Asia. While the majority of logical and physical design remaining in North America and Europe (concurrent engineering) along with the enterprise product data management, predictive engineering is the new framework needed to bring these two distinct product arenas into cooperation and optimization. Without PE, products will cost more, take longer to introduce, and not have the best performance.

Summary

I am still organizing my thoughts about all these topics. They are not of equal importance, nor needed at every stage of your career. In Figure 1, I attempted to classify them into four categories based on where I think they contribute the most. In my upcoming columns, I will draw on these topics and show how these skills contribute to your own future. Reader feedback will be appreciated. **PCB**

Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa/Westwood, Merix, Foxconn and Gentex. He is currently the co-editor, along with Clyde Coombs, of the *Printed Circuit Handbook*–7th Ed.

Graphene Proves a Perfect Fit for Wearable Devices

Cheap, flexible, wireless graphene communication devices such as mobile phones and healthcare monitors can be directly printed into clothing and even skin, University of Manchester academics have demonstrated.

In a paper in Scientific Reports, researchers show how graphene could be crucial to wearable electronic applications because it is highly-conductive and ultra-flexible. The research could pave the way for smart, battery-free healthcare and fitness monitoring, phones, internet-ready devices and chargers to be incorporated into clothing and 'smart skin' applications—printed graphene sensors integrated with other 2D materials stuck onto a patient's skin to monitor temperature, strain and moisture levels.

Examples of communication devices include:

• In a hospital, a patient wears a printed graphene RFID tag on his or her arm. The tag, integrated with other 2D materials, can sense the patient's body temperature and heartbeat and sends them back to the reader. The medical staff can monitor the patient's conditions wirelessly, greatly simplifying the patient's care.

• In a care home, battery-free printed graphene sensors can be printed on elderly peoples' clothes. These sensors could detect and collect elderly people's health conditions and send them back to the monitoring access points when they are interrogated, enabling remote healthcare and improving quality of life.

Using a mannequin, they attached graphene-enabled antennas on each arm. The devices were able to 'talk' to each other, effectively creating an on-body communications system.

High-Performance Laminates

by Karl Dietz
KARL DIETZ CONSULTING LLC

For the purpose of this column high-performance laminates are characterized as base materials that in one or more aspects exceed the performance of FR-4, CEM, or paper/phenolic laminates. The focus, however, is on low loss (Df), low Dk dielectric resin-based CCLs and prepregs. Included are laminates that distinguish themselves through higher Tg, better chemical stability, better dimensional stability, or some other performance factor. Polyimide-based flex laminates are covered briefly. Requirements for dielectrics specifically developed for HDI boards or flip chip packages, such as dielectric films for microvia build-up layers, laser-drillable prepregs, and various forms of RCC for rigid cores, are briefly mentioned to contrast these requirements to high-performance CCLs for second level packaging.

Market Overview—Applications

The applications for high-performance laminates are quite diverse and evolving rapidly. Low Dk and/or Df are common performance requirements in addition to many others that are shared with various applications. The high-performance laminate applications include:

- Cellular base station infrastructure (e.g., base station power amplifiers)
- LNBs (low-noise block down-converters)
- Cavity PCBs
- HF antennas
- High-speed digital backplanes
- High-speed routers
- High-speed servers
- High-speed test PCBs
- RF and HF microwave boards and modules
- High-speed chip packages
- Optoelectronic devices
- Satellite TV infrastructure
- Automotive collision avoidance systems

The automotive collision avoidance applications appear to be the highest frequency application at 40 GHz and above (current state-of-the-art radar chip systems, 77 GHz), and have a very high growth rate. It also demands dielectrics with very low loss.

Following is a list of commercial high-performance laminate constructions/compositions, as provided by the manufacturers:

- Woven E-glass/PPO
- BT/epoxy
- Woven E-glass/high-speed, low-loss epoxy
- Woven SI-glass, APPE thermoset resin
- Woven E-glass, ceramic filled thermoset hydrocarbon (polybutadiene)
- Woven SI-glass/high-speed, low-loss epoxy
- Woven glass, ceramic filled PTFE
- Woven glass, ceramic filled thermoset

Second Level Packaging: Material and Processing Requirements and Comparison to First Level Packaging

There are many electrical, mechanical, safety and environmental requirements for PCBs that translate into specific requirements for dielectrics, which is the focus of this column on high-performance dielectrics. Likewise, there are of course specifications for the conductors, typically copper, such as tensile strength, elongation, dimensional uniformity (height, width) and peel strength (adhesion to the surrounding dielectric material). Peel strength is of course a function of the nature of the chemical and mechanical interface between the copper and the dielectric and as such, affects the copper, as well as the dielectric and the preparation of such surfaces to achieve the desired peel strength.

Compared to first-level packaging requirements, the second-level packaging requirements typically don't include processability by the so-called semi-additive circuitizing process, and they are less stringent regarding low CTE, high chemical and dimensional stability. Requirements derived from PCB manufacture include desmear chemistry compatibility (i.e., the removal of resin smear from innerlayer copper with potassium permanganate chemistry) and the compatibility with conventional mechanical drilling as well as laser drilling. It should be noted that there is great reluctance in the industry to substantially change a process to accommodate a new material. Also, price/performance trade-offs are critical. A PCB fabricator will try everything to avoid replacing FR-4 with higher cost, high-performance laminate, including electrical redesign of the board, and will switch to high-performance laminate only as a last resort, especially if there are processing issues.

There is no single parameter of goodness for high-performance PCB materials. Performance parameters are driven by end-use requirements, processing needs, and by requirements derived from semiconductor characteristics, as specified by OEMs. Depending on the IC performance and complexity and depending on the end product, different performance criteria will make the "most critical" list.

Acceptance/performance standards and test methods vary for PCBs, and the most widely accepted standards and methods are developed and published by IPC.

The following is a list of performance parameters for dielectrics most often encountered:

- Low loss (low Df, loss tangent, or dissipation factor), i.e., a dielectric material that contributes very little to the attenuation of the electrical signal during its transmission
- Low Dk (dielectric constant)
- Low moisture absorption
- Low CTE (coefficient of thermal expansion)
- High Tg (glass transition point)
- Dimensional stability, stiffness
- Good thermal conductivity (heat dissipation)
- Flame retardancy
- Chemical stability
- Conductive anodic filament (CAF) resistance

There may be a single driver demanding one of these properties, or one performance property could be dictated by several requirements—requirements that might stem from semiconductor needs, assembly needs or end-use needs. Or one single end-use requirement may affect several performance parameters. The following list tries to explain these base material performance requirements.

Low dielectric loss is most important at high frequencies and where there is a long circuit path. The latter is obvious because loss is a function of transmission length and is usually stated as decibels per distance unit, typically dB/cm, whereby decibel is the ratio of the logarithms of the signal strengths at the beginning and the end point of the unit length. The former (high frequency) is not so intuitive. First, the trend to higher clock speeds and greater bandwidths to achieve higher data rates is well documented. The problem lies in the fact that the loss tangent (Df) of a glass-reinforced dielectric is not a constant but a function of the signal frequency, and, unfortunately, loss increases with frequency. Therefore, it is important to choose a dielectric that has a low Df that remains reasonably flat over a range of frequencies.

The dielectric resin's Df as a function of frequency varies: Df values may be fairly flat, or show an increase in a certain frequency range, or, more typically, decline slightly at higher frequencies, reflecting the frequency-dependent activation of chemical bonds. We find such low-loss dielectrics in microwave, radio frequency (RF), and radar boards and modules such as cell phone base station transmitters and receivers or cell phone RF modules. Without low-loss dielectrics, transmitters would lose most of their signal in the form of heat, and receivers could not maintain a weak incoming signal well above the background noise level. The issue is similar in digital applications where the trend is towards lower voltages. Very low-loss dielectric material such as PTFE (poly-tetrafluoroethylene) can also be found in high-end packages.

It is of interest to explore why FR-4 has a relatively high loss while PTFE is a low-loss material. This has to do with the molecular structure of the resin, of the composite or the ceramic. If the resin has predominantly chemical bonds that are characterized by charge separation (i.e., polar bonds or ionic bonds as opposed to covalent bonds), and if these dipole charges can easily move due to thermal or other activation, then such a resin will have a high dielectric constant and a high dissipation factor. On the other hand, a resin high in hydrocarbon domains (aliphatic and/or aromatic) with no or few polar bonds is likely to have a lower Dk and lower Df.

Low-loss resins comprise materials such as PTFE, polyphenylene oxides, functionalized polyethers such as allylated polyphenylene ether, building blocks such as butadiene, styrene, and maleic anhydride, and aromatic polyesters such as LCPs (liquid crystal polymers). The problem is that without functionalization these materials are thermoplastics (not thermosets), so that FR-4-type multilayer pressing with prepreg is not possible. The way out of this dilemma is the functionalization of the pure resin (e.g., with allyl-groups) and/or the construction of prepreg composites that contain some epoxy or similar thermoset; however, such maneuvers will dilute the desirable electrical properties to some extent. There is another ticklish matter: as the resin becomes more hydrocarbon-like in nature, adhesion to copper, or even to treated copper, becomes more problematic. Not only that, the resin itself is more prone to cohesive failure (i.e., the bonds between resin molecules are weaker than the polar bonds and hydrogen bridge bonds found in FR-4). It is of course possible to create multilayers with unadulterated non-polar resins by approaching the melt point in a melt-fusion lamination which fabricators, who are used to FR-4-like processing, don't embrace.

Low moisture absorption of the base material is desirable from several points of view. Moisture absorption has been linked to failure of solder joints in surface mount ("popcorning" in the pressure cooker test). Absorption of moisture also lowers the de-facto Tg, which is detrimental to dimensional stability and a problem with higher melting, lead-free solder compositions. This is not the end of the problem list. Moisture absorption generally leads to a deterioration of electrical properties (i.e., Dk and Df increase with increasing moisture content). The chemical approach to combat this problem is not unlike the one to gain better Dk and Df values in the first place: hydrophobic hydrocarbon-like structures are preferred. Cross-linked, dense structures or crystalline moieties with low water affinity and low moisture diffusion rates are useful (e.g., LCPs).

The need for ***high temperature dimensional stability (high Tg)*** stems from the advent of lead-free, higher temperature eutectic solders. Other drivers are the use of devices that generate a lot of heat such as chips that run at high clock speeds, larger sized chips, or optoelectronic components with heat generating

HIGH-PERFORMANCE LAMINATES

$C = f^*(kA)/t \quad Z_0 = \sqrt{L/C} \quad Z_0 = V/I$

$\text{Signal Speed} = \text{Speed of Light} / \sqrt{k}$

k = Dielectric Constant A = (copper) Area

t = (dielectric) Thickness Z_0 = (characteristic) Impedance

L = Inductance C = Capacitance

V = Voltage I = Current f = factor

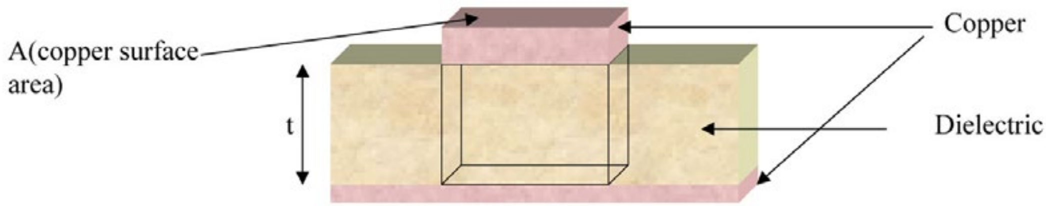

Figure 1: Interrelationships of electrical and dimensional parameters.

laser diodes. The ability to dissipate heat also becomes an important property in this context. Ceramic materials show an advantage here over organic materials.

Low dielectric constant materials play a role at high operating frequencies where controlled (matched) impedance is required and only small propagation delays can be tolerated. As layer thickness decreases one needs lower Dk dielectrics for controlled impedance. Figure 1 shows the interrelationships between capacitance, inductance, Dk, and the effect of Dk on the propagation speed in a medium. Compared to the propagation speed in a vacuum, the signal speed in a conductor surrounded by a dielectric is inversely related to the square root of Dk.

A low CTE dielectric, more specifically a dielectric with a CTE that approaches that of the chip (CTE of approximately four), is very important in direct chip attach (DCA) and becomes more important with increasing chip size. Ceramic materials have a more favorable CTE than organics. To reduce the large CTE of organics in the x/y-plane, ceramic fillers have been used successfully (e.g., in PTFE/ceramic composites) as well as aramid reinforcement fibers.

Flame retardancy of electronic devices is a basic safety requirement which basically affects the dielectric resin since other components such as copper, inorganic fillers, and glass fibers don't present a problem. The widely used FR-4 laminate typically derived its flame retardancy, as qualified by UL's V-0 Rating, by modifying the epoxy resin with tetra-bromobisphenol A. Concerns that this flame retardant may convert to dioxins upon combustion or during disposal by incineration, triggered the search for alternatives. Phosphorus-based additives are used as replacements but are not universally accepted. Resins containing aromatic rings (e.g., LCPs, polyimides) are inherently flame retardant, and so are PTFEs. Selecting epoxy resins high in aromatic moieties helps solve the flame retardancy problem, so does the selection and loading of inorganic fillers. The term "halogen-free laminate" has been used to describe flame retardant alternatives to standard FR-4, but it is a bit of a misnomer: The target specifically is the brominated bisphenol A, so bromine-free might be more accurate. PTFE is also not on the "undesirables" list even though fluorine is a halogen. The "free" in halogen-free is also relative, since trace amounts of chlorine or bromine that constitute natural impurities in the process of manufacture of dielectric resins are also not targeted.

Chemical stability is typically described in terms of percentage of material loss at a certain time and temperature (3–5% may be the upper

acceptable limit, depending on the laminate specifications). The reasons that chemical stability is important have to do with the expected, detrimental change of electrical properties and the notion that weight loss in the form of volatilized breakdown products may cause blisters, delamination, and conductor breaks. Studies have shown that the curing agent dicyanamide ("dicy") in epoxy resins appears to contribute to poor chemical stability performance, so that laminate fabricators switched to non-dicy curing agents such as phenol-based curing agents. However, other studies suggest that dicy can perform adequately with minor changes to the resin system.

Conductive anodic filament (CAF) is a defect that can lead to short circuits due to electromigration of copper ions, originating from metallic copper in metalized through-holes. Copper ions migrate along glass fibers, potentially forming a conducting path to another circuit. Such migration is facilitated by factors contributing to copper corrosion and migration such as moisture, and by small gaps between the glass fiber and the resin which may be caused by poor adhesion of the resin to the treated glass surface.

Current Material Technology

The following is a brief summary of the material components of laminates and their functions:

Metal Layers and Metal Coatings

Copper is the metal of choice for the circuit, power and ground layers, and through-hole metallization. In the case of CCL, the copper comes in a foil that is laminated to the dielectric layer(s). The copper foil is either formed in an electrodeposition process (ED-foil), or is so-called rolled/annealed copper—a copper form that is preferred in flex circuits because of its flexibility. Copper foils are typically treated for enhanced topography and chemical composition for adhesion to the dielectric resin. Such chemical modifications may include the deposition of zinc or brass and the coating with silane coupling agents. The copper surface facing the outside may be treated with anti-tarnish such as chromium for protection against corrosion, and it may be topographically and/or chemically modified for improved dry film resist adhesion as is the case with double-treat foil. The final, circuitized circuit board outerlayer may have a metal coating such as gold, nickel/gold, tin, nickel/palladium/gold, or tin/lead to protect the copper surface from corrosion and enhance solderability or wire bonding.

Reinforcements/Fillers

The most common reinforcement is woven glass, the surface of which is typically treated for better processability and for better adhesion to the resin (e.g., with silane coupling agents). Non-woven glass reinforcements as well as organic fibers such as aramids have also been used as reinforcements. They are used to improve dimensional stability and lower CTE. Fillers serve a number of functions (e.g., to modify Dk and Df, to lower CTE and to enhance thermal conductivity). In recent years there has been a demand for finer, more uniform glass weaves to improve impedance control and to enhance drillability, both mechanical as well as laser (UV, CO_2). The use of fillers requires dispersion know-how and surface treatment technology. The shape of filler particles is important too. To achieve low CTE in X, Y, and Z directions, one needs to employ fillers of near spherical shape.

Dielectric Resin

Historically, there has been a trend from low-performance resins such as phenolic/formaldehyde resins to epoxies and to non-epoxy high-performance resins to improve electric properties (lower Dk, Df), lower moisture take-up, improved chemical stability, and dimensional stability (modulus). Equally important to low Dk, Df values of the dielectric are the uniformity of these values across the entire surface of the board, and little change of Df, Dk as a function of temperature, frequency, and moisture contents. Low moisture take-up is desirable to avoid vapor formation (out-gassing) at high temperatures. Also, the presence of water typically deteriorates the electrical properties and changes Dk and Df values as a function of moisture content. High-performance resin examples are given in several tabulations of this study: PTFE, other fluoropolymers, BT, polyesters, polyimides, LCPs, hydrocarbons, rubbers, etc.

The Manufacture of Laminate and Prepreg (Bondply)

The manufacture of rigid base material is well known. It applies to high-performance laminates as well and is briefly outlined as follows: The resin is typically a thermoset resin. Resin and curing agent(s) are premixed and dissolved to low boiling solvents (ketones, esters, alcohols) and placed in a trough through which a continuous glass fabric cloth is guided. The dissolved resin, and dispersed fillers as may be the case, coat the glass fabric which travels up a treating tower through different temperature zones where the resin is thermally, partially cured to form the prepreg. The solvent is evaporated and the dry prepreg is then rolled up into large rolls. It is then cut up into sheets. It should be noted that a solventless prepreg process is also commercial. The prepreg is then laid-up by sandwiching it between copper sheets that have been cut from a large roll of copper foil.

Several of these packages are placed into the chambers of a lamination press where the copper clad laminate is formed by fully curing the resin and bonding it to the copper in a process specific time/temperature/pressure profile. After the lamination process, the large CCL pieces are routed into smaller panels. The edges of the panels are beveled for cleaner processing. Circuitized panels (innerlayer) may then be laid up to multilayers by alternating prepreg layers with innerlayers, topping the multilayer with a cap foil

Glossary

APPE	Allylated-polyphenylene ether, cross-linked upon heating
BT	Bismaleimide triazine
Bondply	Name for dielectric film, similar in function to prepreg, to build multilayer structures, typically used for polyimide flex circuits
CAF	Conductive anodic filament
CCL	Copper clad laminate (also: laminate, or base material)
CE	Cyanate ester
CEM	Composite epoxy material (i.e., cellulose paper/ woven glass/epoxy)
CTE	Coefficient of thermal expansion
Df	Dissipation factor (dielectric loss)
Dk	Dielectric constant
FPC	Flexible printed circuit
FR-4	Glass-reinforced epoxy resin (brominated bisphenol A epoxylated)
FR-5	Higher Tg FR-4
HDI	High-density interconnect (typically PCBs containing one or more microvia build-up layer)
LCP	Liquid crystal polymers (linear aromatic polyesters)
PCB	Printed circuit board, sometimes PWB (printed wiring board)
PEI	Polyetherimide
PPE	Polyphenylene ether (=PPO)
PPO	Polyphenylene oxide (=PPE)
Prepreg	Semi-cured (B-stage) glass weave reinforced epoxy used to build multilayer boards
PTFE	Poly-tetrafluoroethylene
PTH	Plated through-hole
Tg	Glass transition point

of copper. These multilayer lay-ups are separated by separation sheets and inserted into a multilayer press where the prepreg softens, conforms to the adjacent copper, bonds, and fully cures during the press cycle. After multilayer lamination, the multilayers are taken apart (broken down), their edges are cleaned, and multilayer processing continues (drilling, through-hole metallization, outerlayer circuitization, etc.).

Non-thermoset resins, or resins that have insufficient "pot life" after mixing the resin component with the curing agent, present a problem for multilayer manufacture. Such resins include PTFE, LCPs, polyimides and others. Bondplies for PTFE have been introduced that combine PTFE with thermoset resins. LCPs have been processed into multilayers using several different LCPs with different softening/melting points (i.e., a hierarchy of melting points) to avoid the softening (swimming) of completed, individual layers during the bonding process. Polyimides have used bondplies consisting of polyimide coated with acrylates. The high-performance, non-epoxy resins have caused concern because of special considerations in drilling and desmear operations. The desmear chemistry removes the resin drill smear from the copper of innerlayers. This chemistry has been pretty much standardized, consisting of alkaline potassium permanganate, and any other special chemical requirements are a barrier to entry. Special desmear chemistry for PTFE has been in use, based on complexed, metallic sodium (tetra-etch).

Flex laminates, for all practical purposes polyimides, are produced in a different processing sequence. The aromatic diamines and dianhydrides are dissolved on a solvent such as picoline, and cast onto belts or drums where the solvent is evaporated, and amidization, then imidization occur to form the polyimide film which is then peeled off and stabilized (stretched) for dimensional stability. The polyimide film can be treated by proprietary surface treatments for improved copper adhesion, and the copper clad laminate can be formed in sheets in a lamination press. Alternatively, polyimide film and copper foils can be continuously laminated to form rolls of flex base material. Downstream processing (resist application, exposure development etching, and stripping) can also be performed roll-to-roll.

PTFE-based high-performance laminates are also formed in a different process. The starting material is typically a PTFE aqueous dispersion. It may be mixed with fillers. The woven glass fabric is guided through a trough containing the dispersion where the glass cloth is coated with the dispersion. The coated glass cloth then travels up a treatment tower where it reaches a temperature at which the water evaporates and the PTFE dispersion sinters into a contiguous film. This process can be repeated until the proper resin/glass ratio is reached. The CCL roll stock is then cut up into sheets, interleafed with copper foil and laminated in a specialized lamination press which is capable of reaching the desired high lamination temperature.

A continuous fabrication process for CCL was developed by GIL Technologies and is worth mentioning here because of its technical merits, although the technology is not practiced anymore, according to the information available to the author. The process involves the use of a thermoset resin (thermosetting polymer alloy—TPA), the components of which are mixed in-line without the use of solvent. The resulting composition is coated onto a moving band of copper foil. A glass fabric is then rolled onto the resin coated copper, another coating of resin is applied, the second copper foil is then rolled on to cap off the laminate. The uncured laminate then travels through a curing zone and is wound up in a roll from where it can be processed into sheets. Some of the advantages of the process include low manufacturing investment cost (no prepreg manufacture, no treatment tower), and the ability to mix the dielectric layer components in-line (i.e., no resin shelf-life issues). **PCB**

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Recent Highlights from PCB007

1 TTM Technologies Unveils Global Operating Model

TTM Technologies Inc. announced changes to its operating model that will create individual business units focused on customer end markets. Effective January 1, 2016, TTM's PCB Segment will be comprised of three BUs: Communications and Computing; Automotive, Medical, Industrial and Instrumentation; and Aerospace, Defense, and Specialty. The Electro-Mechanical Solutions Segment will be a single BU.

2 IPC Standards Committee Reports—Component Traceability, Base Materials, Fabrication Processes, Assembly and Joining

IPC has released its standards committee reports from the 2015 Fall Standards Committee Meetings to help keep the industry up to date on IPC standards committee activities. The 2-19a Critical Components Traceability Task Group held its first face-to-face meeting to continue development of the working draft IPC-1782.

3 IPC Standards Committee Reports—Packaged Electronic Components, Flex Circuits, High-Speed/High-Frequency, Rigid Printed Boards

These standards committee reports from the 2015 Fall Standards Committee Meetings have been compiled to help keep you up to date on IPC standards committee activities. This is the third in a series of reports.

4 Flexible PCB: What's in a Name?

Flexible PCB is a common term that is synonymous with flexible circuits. While the term PCB is generally used to describe rigid printed circuitry, "flexible PCB" is a little contradictory because boards aren't really flexible. Some companies, like All Flex, design and manufacture flexible PCBs, but not rigid PCBs.

5 HKPCA & IPC Show 2015 Kicks Off in Shenzhen China

Barry Matties talks with Daniel Chan, executive director of the HKPCA, about the organization's expanded global outreach. They discuss what attendees can expect from this South China trade show that has become one of the biggest and most important shows in the PCB industry.

6 Catching up with Winonics' Mark Eazell

I have always thought of Winonics as one of the hidden gems of the North American PCB industry. Their well-equipped and well-laid-out facility in Brea, California is one of the more impressive looking PCB facilities in North America today.

7 AT&S Joins LEEN Network of Energie Steiermark

AT&S COO Heinz Moitzi is convinced of the purpose of this network and considers it a crucial lever to reduce energy consumption at AT&S even further: "For a globally producing industrial enterprise like AT&S, the reduction of energy consumption is of enormous economic and ecological importance."

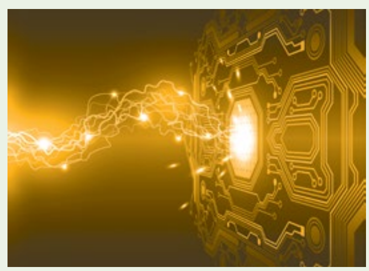
8 Help IPC Persuade U.S. Congress to Extend the R&D Tax Credit

IPC has long urged the U.S. Congress to enact a permanent research and development tax credit—or at least a multi-year extension, not just the usual temporary, one-year deal—and to provide that certainty sooner, not at the last minute.

9 Data Analytics through Statistical Techniques

Many companies get caught in data traps. They focus so heavily on cost and survival that they end up using data as merely a marketing and sales tool. In doing so, they fail to realize the true power of data: It can transform every aspect of a business.

10 Conducting Very High Currents through PCB Substrates at High Ambient Temperatures



One of the major challenges of our time is climate change and the associated need to reduce greenhouse gas emissions. The requirement to reduce CO2 emissions has brought about significant changes in the area of power generation, and also in the area of mobility.

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2016 EVENTS

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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.

DesignCon 2016
January 20–21, 2016
Santa Clara, CA USA

EIPC Winter Conference
January 21–22, 2016
Dresden, Germany

MD&M West
February 9–11
Anaheim, CA ISA

FlexTech Alliance
February 29–March 3, 2016
Monterey, CA USA

ICT-UK Evening Seminar
March 1, 2016
Tewksbury, England

IPC APEX EXPO 2016
March 13–17, 2016
Las Vegas, Nevada USA

25th China International PCB & Assembly Show 2016 (CPCA)
March 15–17, 2016
Shanghai, China

2016 Annual Foundation Course (ICT)
April 11–14, 2016
Loughborough, England

Thailand PCB Expo 2016
April 19–22, 2016
Bangkok, Thailand

JPCA Show 2016
June 1–3, 2016
Tokyo, Japan

IPCA EXPO 2016
August, 2016
India

IPC Fall Meetings
September 24–30, 2016
Rosemont, IL USA

SMTA International 2016
September 25–29, 2016
Rosemont, IL USA

electronicAsia
October 13–16, 2016
Hong Kong

Electronica
November 8–11, 2016
Munich, Germany

International Printed Circuit & Apex South China Fair (HKPCA)
December 7–9, 2016
Shenzhen, China

For additional industry events, see our other magazines.

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