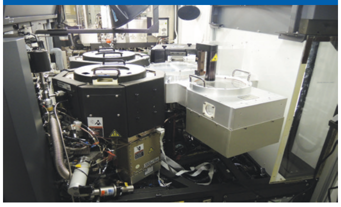
SiS
SILICON SEMICONDUCTOR
Connecting the Silicon Semiconductor Community

Volume 39 Issue 3 JULY 2017
@siliconsemi
www.siliconsemiconductor.net

Building a portable charger

Proactive asset management



Thin silicon implantable chips

Wireless charging going the distance

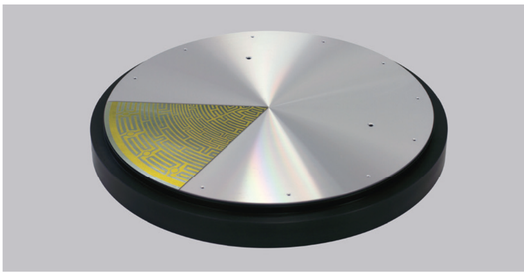
New power product solutions for NXP

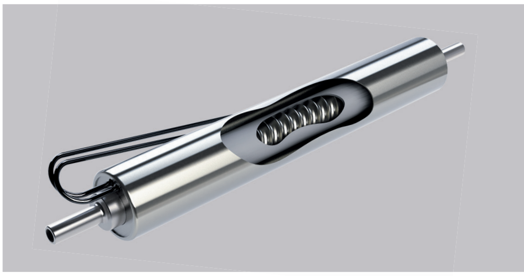
Linde

Rare gases in electronics: The nobility of the gases world

inside News Review, News Analysis, Features, Research Review, and much more...
Free Weekly E News round up go to: www.siliconsemiconductor.net

AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION





editor's view

By Mark Andrews, Technical Editor

Will industry see a 'Summer of Love' at SEMICON West?

SOME MAY SEE little similarity between the 1960s counterculture movements and today's semiconductor innovations. Look more closely. Technology enabled that now-fabled summer of rock and roll, tie dye jeans and hippy hair just as today it enables driverless cars, virtual reality and artificial intelligence.

Back in '67, just as today, one technological innovation bequeaths another. Missile technology from the 1940s became foundational to the 1960s space race. Radar that guarded our coasts spun-off 'Radar Range' microwave ovens. And more recently, analog voice-only cellular technology has evolved, becoming central to untold new digital RF products.

In 1967, electronic innovation centered on the transistor, the same building block we utilize 50 years later, save that today's devices have benefitted from generations of miniaturization. 2017 ICs are inexpensive enough to be disposable, but are more powerful computing tools than those aboard the Apollo 11 moon lander. Way back in what may seem like the Dark Ages of technology, solid-state transistors enabled the mass media age. Would thousands have flocked to San Francisco's Golden Gate Park for the 'Human Be-In' had it not been for radios and TVs? Would the music of the 1960s ever have become internationally popular without mass media? Would most who headed to San Francisco for a summer of love known to go without technology spreading the word? No, no and no.

SEMICON West celebrates the best of what industry creates for a world fascinated with what-comes-next.

The last two years have been tough on those still shaking off the Great Recession. But growth has returned, as seen in record high first quarter DRAM sales, topping (USD) $14 billion, according to the DRAMeXchange. While PC-related memory sales are expected to become more seasonal, server makers and other top memory consumers are expected to drive growth. Want other evidence? Globalfoundries is building a major memory fab in Chengdu, pouring billions with their partners into China's quest to become a major chip producer. Smartphone sales also grew 9 percent in 1Q, with Chinese insurgents taking sales from Samsung and Apple. Markets that previously consumed a fraction of the chips they use today, such as automotive, are poised for a driver assistance/autonomous driving surge. New markets, especially all things related to the Internet of Things, are also growth drivers.

Will 2017 be a new summer of love for chip makers? Time will tell. But on this 50th anniversary, any tie die fashions one sees in San Francisco, London, Mumbai or Shanghai might come equipped with embedded SoCs that give owners a personalized weather forecast synced to their smartphones while automatically posting updates to Instagram, Facebook and the owner's personal website. What's not to love?

Publishing Editor Jackie Cannon	jackie.cannon@angelbc.com	+44 (0)1923 690205
Technical Editor Mark Andrews		
Sales & Marketing Manager Shehzad Munshi	shehzad.munshi@angelbc.com	+44 (0)1923 690215
USA Representatives Tom Brun Brun Media	tbrun@brunmedia.com	+001 724 539-2404
Janice Jenkins	jjenkins@brunmedia.com	+001 724-929-3550
Director of Logistics Sharon Cowley	sharon.cowley@angelbc.com	+44 (0)1923 690200
Design & Production Manager Mitch Gaynor	mitch.gaynor@angelbc.com	+44 (0)1923 690214
Circulation Director Jan Smoothy	jan.smoothy@angelbc.com	+44 (0)1923 690200
Chief Executive Officer Stephen Whitehurst	stephen.whitehurst@angelbc.com	+44 (0)2476 718970

Directors Bill Dunlop Uprichard – EC, Stephen Whitehurst – CEO, Jan Smoothy – CFO, Jackie Cannon, Scott Adams, Sharon Cowley, Sukhi Bhadal, Jason Holloway.

Published by Angel Business Communications Ltd, Hannay House, 39 Clarendon Road,
Watford, Herts WD17 1JA, UK. T: +44 (0)1923 690200 E: ask@angelbc.com

Angel Business Communications Ltd, Unit 6, Bow Court, Fletchworth Gate, Burnsall Road,
Coventry CV5 6SP, UK. T: +44 (0)2476 718 970 F: +44 (0)2476 718 971 E: info@angelbc.com

US mailing information: Silicon Semiconductor is published four times a year for a subscription of $90.00 by Angel Business Communications Ltd, Hannay House, 39 Clarendon Road, Watford, Herts WD17 1JA, UK. Periodicals postage paid at Rahway, NJ. POSTMASTER: send address changes to: Silicon Semiconductor, c/o Mercury International Ltd, 365 Blair Road, Avenel, NJ 07001.
Printed by: The Manson Group. © Copyright 2017. ISSN 2050-7798 (Print) ISSN 2050-7801 (Online).

VOLUME 39 ISSUE III JULY 2017

CONTENTS

COVER STORY

Rare gases offer unique properties essential to advanced semiconductor manufacturing. Linde Electronics explains the role they play in everything from chip making to IoT sensors and beyond.

news

research

20 NXP reveals new power product line solutions

NXP has released a new line of processors and microcontroller solutions for the IoT, low power requirement designs and high performance multimedia applications

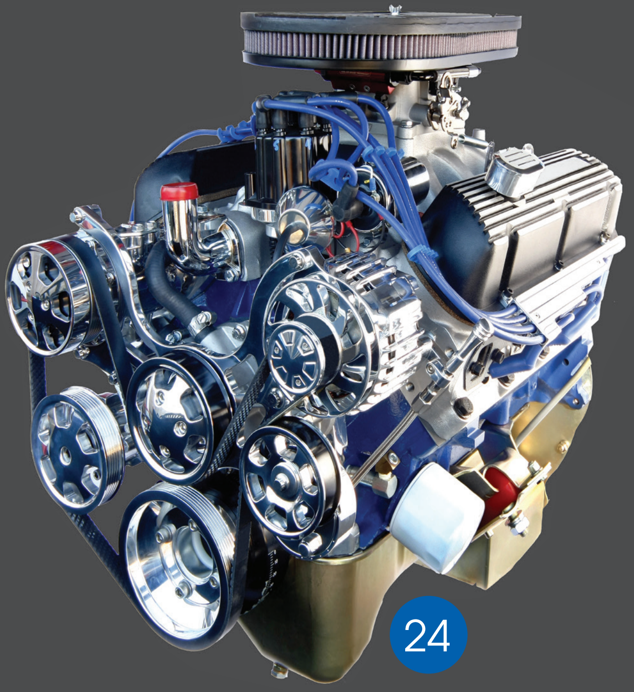
24 Mapping tilt and warp of internal and external component interfaces

Inside an automotive engine control module, a plastic-encapsulated microcircuit is about to fail because of an internal structural problem. The problem is not the usual void or delamination that eventually, by expanding or corroding, leads to electrical failure. Instead, it is mechanical stress within the die

28 Wireless charging poised to go the distance

The benefits of wireless battery recharging over a distance appeared about as likely as jet packs and flying cars until Dialog Semiconductor and Energous Corporation began their quest to cut the cords.


20


24

32 MES Migration: Don’t put your head in the sand

There are numerous reasons why manufacturers don’t change their Manufacturing Execution System (MES) but, in many cases, there are also many reasons why they should

36 EquipNet delivers proactive asset management

Dedicated asset managers offer a means to deal more effectively with the equipment implications of mergers, closures and start-ups across ever-changing global chip markets.

36

Imec and Cascade Microtech develop automatic probe for advanced 3D chips

IMEC, leading research and innovation hub in nano-electronics and digital technologies, and Cascade Microtech, a FormFactor company in advanced wafer-probe solutions, has announced the successful development of a fully-automatic system for pre-bond testing of advanced 3D chips. Pre-bond testing is important to increase the yield of 3D stacked chips.

The new system enables probing and hence testing of chips with large arrays of 40 μm-pitch micro-bumps, on 300 mm wafers. The relevance of this new tool is underlined by winning the 2017 National Instruments Engineering Impact Award yesterday at a ceremony in Austin, Texas. As an emerging technology, 3D IC stacking still has many open options and technical challenges. One of these challenges is probing of the individual chips, before being stacked, to ensure a good yield of the 3D stacked ICs. The inter-chip connections of 3D stacked ICs are made by large arrays of fine-pitch micro-bumps which makes probing these bumps a challenge. Until today, the probing solution is to add dedicated pre-bond probe pads to the to-be-stacked dies, but this requires extra space and design effort and increases test time.
Imec and Cascade Microtech have now developed a fully automatic test cell that can provide test access by probing large arrays of fine-pitch micro-bumps.

The system is based on a Cascade Microtech CM300 probe station and National Instruments PXI test instrumentation, complemented by in-house developed software for automatic test generation, data analysis, and visualization. The system allows testing of wafers up to 300mm diameter, including thinned wafers on tape frame with exposed through-silicon vias. After several years of intense collaboration between imec and Cascade Microtech, partly supported by the EU-funded FP7 SEA4KET project, good results were achieved with Cascade Microtech's Pyramid Probe® prototype RBI probe cards on imec's 300 mm wafers with 40μm-pitch micro-bumped chips.

"Imec provided us with unique early insights into the test requirements for 3D ICs, which drove the development of this system," said Jörg Kiesewetter, director of engineering at Cascade Microtech Dresden.

IBM Research Alliance builds new transistor for 5nm technology

IBM, its Research Alliance partners GLOBALFOUNDRIES and Samsung, and equipment suppliers have developed an industry-first process to build silicon nanosheet transistors that will enable 5 nanometer (nm) chips.

The details of the process will be presented at the 2017 Symposia on VLSI Technology and Circuits conference in Kyoto, Japan. In less than two years since developing a 7nm test node chip with 20 billion transistors, scientists have paved the way for 30 billion switches on a fingernail-sized chip.

The resulting increase in performance will help accelerate cognitive computing, the Internet of Things (IoT), and other data-intensive applications delivered in the cloud. The power savings could also mean that the batteries in smartphones and other mobile products could last two to three times longer than today's devices, before needing to be charged.

Scientists working as part of the IBM-led Research Alliance at the SUNY Polytechnic Institute Colleges of Nanoscale Science and Engineering's NanoTech Complex in Albany, NY achieved the breakthrough by using stacks of silicon nanosheets as the device structure of the transistor, instead of the standard FinFET architecture, which is the blueprint for the semiconductor industry up through 7nm node technology.

"For business and society to meet the demands of cognitive and cloud computing in the coming years, advancement in semiconductor technology is essential," said Arvind Krishna, senior vice president, Hybrid Cloud, and director, IBM Research. "That's why IBM aggressively pursues new and different architectures and materials that push the limits of this industry, and brings them to market in technologies like mainframes and our cognitive systems."

The silicon nanosheet transistor demonstration, as detailed in the Research Alliance paper Stacked Nanosheet Gate-All-Around Transistor to Enable Scaling Beyond FinFET, and published by VLSI, proves that 5nm chips are possible, more powerful, and not too far off in the future.

Compared to the leading edge 10nm technology available in the market, a nanosheet-based 5nm technology can deliver 40 percent performance enhancement at fixed power, or 75 percent power savings at matched performance. This improvement enables a significant boost to meeting the future demands of artificial intelligence (AI) systems, virtual reality and mobile devices.

"This announcement is the latest example of the world-class research that continues to emerge from our groundbreaking public-private partnership in New York," said Gary Patton, CTO and Head of Worldwide R&D at GLOBALFOUNDRIES.

"As we make progress toward commercializing 7nm in 2018 at our Fab 8 manufacturing facility, we are actively pursuing next-generation technologies at 5nm and beyond to maintain technology leadership and enable our customers to produce a smaller, faster, and more cost efficient generation of semiconductors."

IBM Research has explored nanosheet semiconductor technology for more than 10 years. This work is the first in the industry to demonstrate the feasibility to design and fabricate stacked nanosheet devices with electrical properties superior to FinFET architecture.

This same Extreme Ultraviolet (EUV) lithography approach used to produce the 7nm test node and its 20 billion transistors was applied to the nanosheet transistor architecture.

Using EUV lithography, the width of the nanosheets can be adjusted continuously, all within a single manufacturing process or chip design.

This adjustability permits the fine-tuning of performance and power for specific circuits – something not possible with today's FinFET transistor architecture production, which is limited by its current-carrying fin height. Therefore, while FinFET chips can scale to 5nm, simply reducing the amount of space between fins does not provide increased current flow for additional performance.

"Today's announcement continues the public-private model collaboration with IBM that is energizing SUNY-Polytechnic's, Albany's, and New York State's leadership and innovation in developing next generation technologies," said Dr. Bahgat Sammakia, Interim President, SUNY Polytechnic Institute.

"We believe that enabling the first 5nm transistor is a significant milestone for the entire semiconductor industry as we continue to push beyond the limitations of our current capabilities. SUNY Poly's partnership with IBM and Empire State Development is a perfect example of how Industry, Government and Academia can successfully collaborate and have a broad and positive impact on society."

Part of IBM's $3 billion, five-year investment in chip R&D (announced in 2014), the proof of nanosheet architecture scaling to a 5nm node continues IBM's legacy of historic contributions to silicon and semiconductor innovation.

They include the invention or first implementation of the single cell DRAM, the Dennard Scaling Laws, chemically amplified photoresists, copper interconnect wiring, Silicon on Insulator, strained engineering, multi core microprocessors, immersion lithography, high speed SiGe, High-k gate dielectrics, embedded DRAM, 3D chip stacking and Air gap insulators.

EV Group expands production capacity at corporate headquarters in Austria

EV GROUP (EVG), a supplier of wafer bonding and lithography equipment for the MEMS, nanotechnology and semiconductor markets, has announced that it is expanding production capacity at its corporate headquarters in St. Florian am Inn, Austria.

Representing a €20 million investment, the expansion will include the construction of a new building that provides additional production and test capacity for EVG equipment that meets the high cleanliness requirements of the semiconductor industry, as well as that allows for a significant expansion of warehouse space.

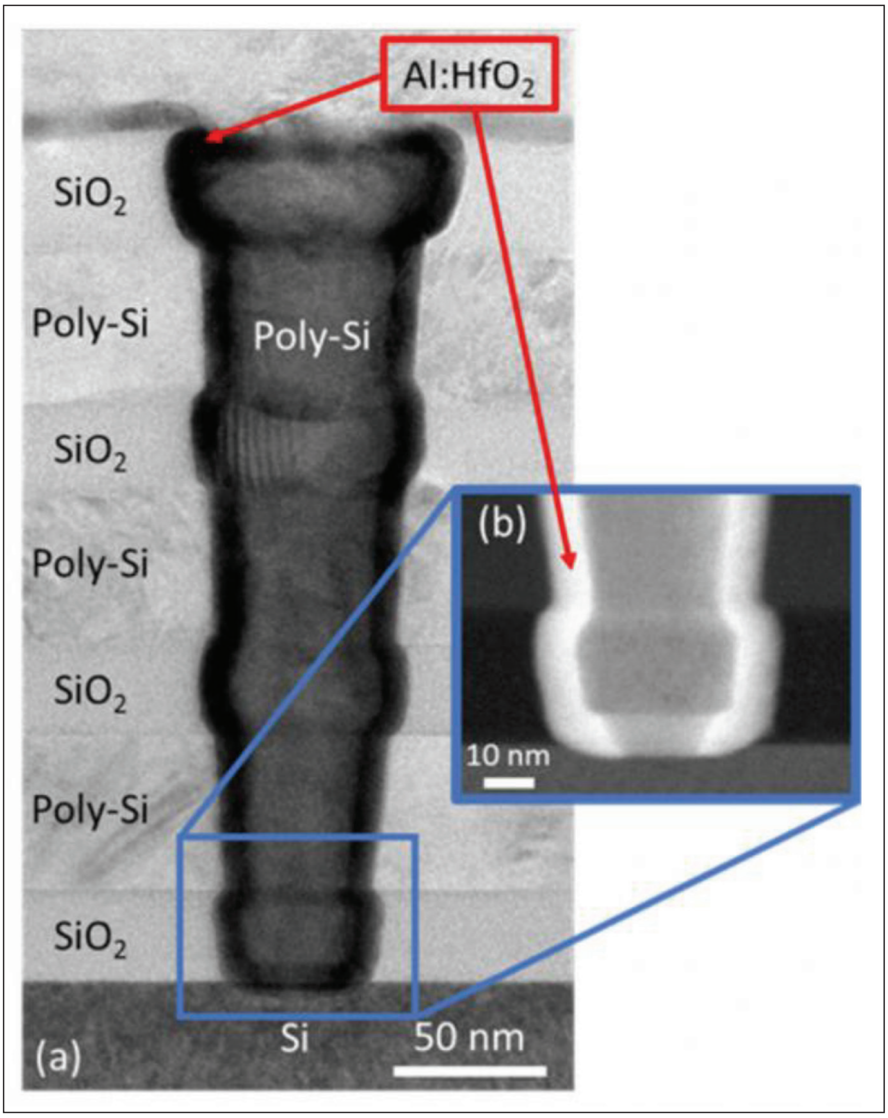
From left to right: Paul Lindner, Erich Thallner, Aya Maria Thallner, Hermann Waltl and Dr. Werner Thallner (EV Group Executive Board)

"With the new building adjacent to our existing manufacturing facilities, we will first and foremost create additional test rooms for the final assembly, software installation and quality assurance of our equipment and the technical source inspection by our customers," stated Dr. Werner Thallner, executive operations and financial director at EV Group. "This enables us to act on the significant increase in demand for our solutions in both existing and new markets, and pursue our mid- and long-term growth targets at the same time." The new building's to expand production capacity is set to open before the end of this calendar year.

Imec breakthrough in CMOS-compatible ferroelectric memory

IMEC, leading research and innovation hub in nanoelectronics and digital technology, has announced at the 2017 Symposia on VLSI Technology and Circuits the world's first demonstration of a vertically stacked ferroelectric Al doped HfO_2 device for NAND applications. Using a new material and a novel architecture, imec has created a non-volatile memory concept with attractive characteristics for power consumption, switching speed, scalability and retention. The achievement shows that ferro-electric memory is a highly promising technology at various points in the memory hierarchy, and as a new technology for storage class memory. Imec will further develop the concept in collaboration with the world's leading producers of memory ICs.

Ferro-electric materials consist of crystals that exhibit spontaneous polarization; they can be in one of two states, which can be reversed with a suitable electric field. This non-volatile characteristic resembles ferromagnetism, after which they have been named. Discovered more than five decades ago, ferro-electric memory has always been considered ideal, due to its very low power needs, non-volatile character and high switching speed. However, issues with the complex materials, the breakdown of the interfacial layer and bad retention characteristics have presented significant challenges. The recent discovery of a ferro-electric phase in HfO_2, a well-known and less complex material, has triggered a renewed interest in this memory concept.



"With HfO_2, there is now a material with which we can process ferro-electric memories that are fully CMOS compatible. This allows us to make a ferro-electric FET (FeFET) in both planar and vertical varieties," noted Jan Van Houdt, imec's chief scientist for memory technology. "We are working to overcome some of the remaining issues, such as retention, precise doping techniques and interface properties, in order to stabilize the ferro-electric phase. We are now confident that our FeFET concept has all the required characteristics. It is, in fact, suitable for both stand-alone and embedded memories at various points in the memory hierarchy, going all the way from non-volatile DRAM to Flash-like memories. It has particularly interesting characteristics for future storage-class memory, which will help overcome the current bottleneck caused by the differences in speed between fast processors and slower mass memory." Imec recently presented the first, extremely positive results to its partners. The research center is now offering further development and industrialization of the vertical FeFET as a program to all its memory partners, which include the world's major companies producing memory ICs.

"FeFETs can be used as a technology to build memory very similar to Flash-memory, but with additional advantages for further scaling, simplified processing, and power consumption," added Van Houdt. "With our longstanding R&D and processing experience on advanced Flash, we are uniquely positioned to offer our partners a head start in this exciting opportunity. They can then decide how best to fit ferro-electric memories in their products and chips."

NAND continues to sway the market

THE NAND FLASH MARKET remained in undersupply in the first quarter of 2017 as it had been in the preceding quarter, according to the latest report from DRAMeXchange, a division of TrendForce. Despite seasonality, the average contract price of NAND Flash chips in the channel market surged by 20~25% in the first quarter compared with last year's fourth quarter. Also, prices of mobile storage products such as eMCP, eMMC and UFS are still climbing. NAND Flash suppliers therefore can expect positive revenue outlook for the entire 2017.

"The overall production capacity for 2D-NAND has fallen during the industry-wide migration to 3D-NAND manufacturing," said Alan Chen, senior research manager of DRAMeXchange. "As the market has yet to regain its balance following this disruption, contract prices of NAND Flash chips will keep going up."

Despite this first quarter being the traditional slow season for end device shipments, the reduction in the 2D-NAND capacity was severe enough to result in tight supply during the period. Consequently, the NAND Flash industry saw just a slight revenue dip in the first quarter. With shortage being the overarching trend for the entire year, NAND Flash suppliers can also expect sequential revenue increases from the second to the final quarter.

Samsung

Samsung's revenue for this first quarter fell by 5.8% compared with the preceding three-month period, but the supplier saw a significant increase in its operating margin. In addition to the favorable market condition, Samsung has been optimizing its NAND Flash product mix to give more weight to SSD products. For the first quarter, SSDs accounted for more than 40% of Samsung's product mix. This contributed to Samsung's revenue during period as ASPs of SSDs rose due to supply shortages. Furthermore, Samsung has been enjoying strong sales of its high-capacity SSDs for the enterprise market.

SK Hynix

Demand from China's smartphone and SSD markets drove SK Hynix's first-quarter revenue. Furthermore, the general tight supply in the NAND Flash market resulted in an about 15% increase in SK Hynix's ASPs for NAND Flash products compared with the fourth quarter. Though SK Hynix's first-quarter NAND Flash bit shipments fell by 3% versus the prior quarter, but the supplier maintained healthy profit margins for all of its storage product lines.

Toshiba

Thanks to the overall market dynamics, Toshiba is in a more favorable position in price negotiations for its NAND Flash products. In terms of product strategy, Toshiba concentrated on supplying Apple last year. This year's first quarter, however, the company has adjusted its product mix as to distribute production capacity more evenly among its different product lines. Compared with the preceding quarter, Toshiba's first-quarter NAND Flash revenue fell by around 6.5% to about US$1.97 billion. Nonetheless, the supplier is maintaining a healthy profit level.

Western Digital

Western Digital reported a subtle revenue increase of 0.3% for the first quarter compared with the prior quarter. This increase was in line with the mild increases in Western Digital's bit shipments. At the same time, the supplier benefited from small hikes in ASPs of its NAND Flash products. The revenue growth also reflected the dominance of SSDs in Western Digital's storage business.

With the acquisition of SanDisk completed, Western Digital's strategic focus will be high-capacity storage solutions and the adoption of the 3D-NAND technology that is being jointly developed with Toshiba. Furthermore, Western Digital is going to streamline the overlapping businesses of SanDisk to help enlarge its revenue growth.

Micron

As with other suppliers, Micron's revenue rose due to the general undersupply. Another contributing factor was the company's adjustment of its product mix. Micron's first-quarter NAND Flash bit shipments grew versus the preceding quarter, while ASPs of its NAND Flash products remained stable. overall, Micron's first-quarter NAND Flash-related revenue rose by 11% compared with the prior quarter to around US$1.41 billion.

Intel

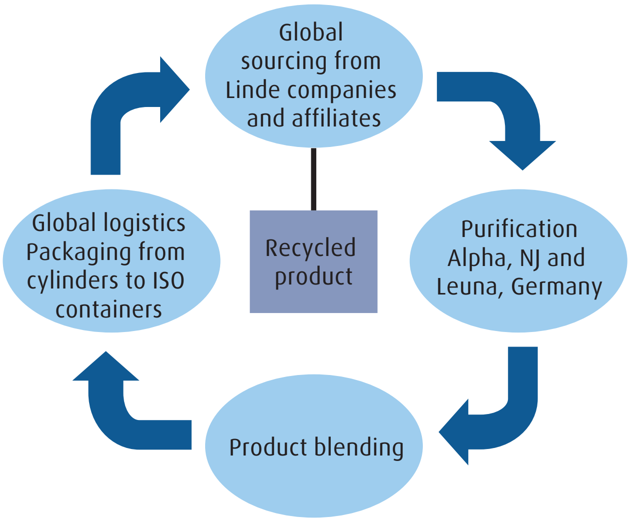
Intel's bit shipments for first quarter increased from the prior quarter as they rode on the growing server SSDs demand from enterprises and data centers. Consequently, the company's NAND Flash revenue for the first quarter grew by 6.1% compared with the previous quarter to US$866 million.

Leading the market with end-to-end rare gases supply chain

Investing in multiple-site rare gas production, blending, and purification facilities to assure long-term and secure supply worldwide

Linde is the only rare gases provider that can provide a robust supply chain including internal production and external partners, cryogenic production and purification technology, proprietary IP for the blending and analysis of laser gas mixes, in-house quality control capabilities, plant design and production, plus this product line:

- **Helium** – Most diverse portfolio of helium-producing assets
- **Argon** – Production off-site, delivery and on-site storage as liquid, and distribution on demand
- **Neon, krypton, and xenon** – Air separation units, purification, blending, and mixing
- **Xenon difluoride** – Global distributor and direct air shipment
- **Xenon and neon recovery** – On-site recovery and off-site reclamation, purification, and analysis
- **Complete portfolio of laser gases** – ArF, KrF, Kr/Ne, Ar/Xe/Ne, and HCl and BCl_3 mixes


Global sourcing from Linde companies and affiliates

Purification Alpha, NJ and Leuna, Germany

Product blending

Global logistics Packaging from cylinders to ISO containers

Recycled product

THE LINDE GROUP

Linde

www.linde.com/electronics
electronicsinfo@linde.com

imec introduces first thin-silicon implantable chip

Changing the future-generation of haptic prosthetics technology.

IMEC, leading research and innovation hub in nano-electronics and digital technology, has announced its success in fabricating a prototype implantable chip that aims to give patients more intuitive control over their arm prosthetics. The thin-silicon chip is a world's first for electrode density and was developed in collaboration with researchers at the University of Florida, as part of the IMPRESS project funded by the DARPA's HAPTIX program to create a closed-loop system for future-generation haptic prosthetics technology.

Today, arm prosthetics technologies have been shown to give patients the ability to move their artificial arm and hand to grasp and manipulate objects. This is done by reading out signals from the person's muscles or peripheral nerves to control electromotors in the prosthesis thereby conveying intent.

Although very helpful, these prosthetics still don't allow a fine motor control and don't give patients a feeling of touch. Future advanced prosthetics under development will provide amputees with rich sensory content from these artificial limbs by delivering precise electrical patterns to the person's peripheral nerves using implanted electrode interfaces.

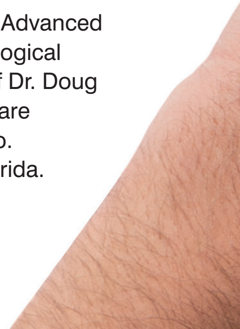
According to Rizwan Bashirullah, associate professor of Electrical and Computer Engineering, and director of the University of Florida's IMPRESS program (Implantable Multimodal Peripheral Recording and Stimulation System), "this effort aims to create such new peripheral nerve interfaces with greater channel count, electrode density, and information stability, enabled largely by imec's technological innovation."

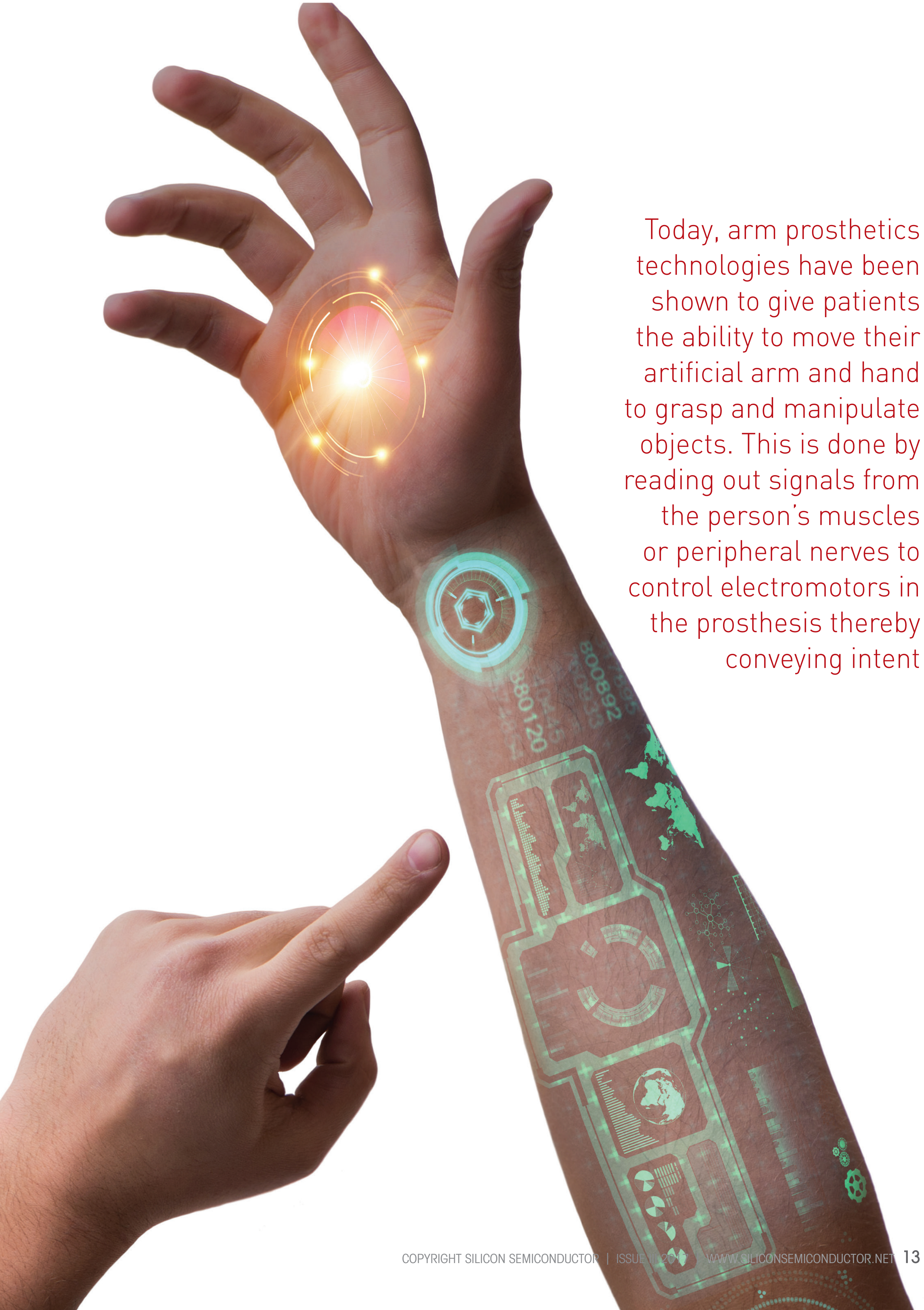
As part of IMPRESS, imec has now made a prototype ultrathin (35µm) chip with a biocompatible, hermetic and flexible packaging. On its surface are 64 electrodes, with a possible extension to 128. This exceptionally high amount of electrodes allows fine-grained stimulation and recording. Through a needle attached to the chip, the package can be inserted and attached inside a nerve bundle, further increasing the precision of reading and stimulation compared to current technology which has substantially fewer electrodes and is wrapped around the nerve bundle.

In practice, imec's solution will aim to give patients more control over their prosthetic arm and hand, and also the possibility of a finer haptic feedback. "Our expertise in silicon neuro-interfaces made imec a natural fit for this project, where we have reached an important milestone for future-generation haptic prosthetics," commented Dries Braeken, R&D manager and project manager of IMPRESS at imec. "These interfaces allow a much higher density of electrodes and greater flexibility in recording and stimulating than any other technology. With the completion of this prototype and the first phase of the project, we look forward to the next phase where we will make the prototype ready for long-term implanted testing."

"A new biocompatible chip encapsulation technology is used, based on the stacking of nanolayers with superior diffusion barrier properties, alternating with very thin polymer layers with excellent mechanical behavior," explains Maaike Op de Beeck, program manager at imec. "The final result is an ultrathin flexible electronic device with a thickness comparable to that of a human hair, hence ultimately suitable for minimal invasive implantation."

This work was sponsored by the Defense Advanced Research Projects Agency's (DARPA) Biological Technologies Office under the auspices of Dr. Doug Weber through the Space and Naval Warfare Systems Center, Pacific Grant/Contract No. N66001-15-C-4018 to the University of Florida.





Today, arm prosthetics technologies have been shown to give patients the ability to move their artificial arm and hand to grasp and manipulate objects. This is done by reading out signals from the person's muscles or peripheral nerves to control electromotors in the prosthesis thereby conveying intent

RARE GASES IN ELECTRONICS THE NOBILITY OF THE GASES WORLD

Rare gases offer unique properties essential to advanced semiconductor manufacturing.
Linde Electronics explains the role they play in everything from chip making to IoT sensors and beyond. By Sahir Khan (left), Global Product Manager, Linde Electronics and Paul Stockman (right), Head of Market Development, Linde Electronics

RARE – OR NOBLE – GASES, which constitute less than 1 percent of the total air in the earth's atmosphere, play an essential role in the world of electronics manufacturing. These chemical elements make up column 18 of the periodic table, which includes helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). The term rare denotes that they were first identified as being different from oxygen, while the term noble is an analogy to the inertness of noble metals like gold and platinum.

Chemists group rare gases in the last column of the periodic table because they all have completely filled outer electron shells. This renders them nearly non-reactive and means they exist as gases at ambient conditions, even for the heaviest among them.
Rare gases have unique properties that make them indispensable in electronics manufacturing processes. In this article, we will explore their history, properties and applications, production and supply chain, and market.

History

Sun god, New, Lazy, Hidden, Stranger: the direct translations from the Greek for helium, neon, argon,

Helium tube trailer

krypton, and xenon denote the elusiveness of these elements from discovery. Due to their evasive qualities – inert, invisible, gaseous, sparse – the rare gases remained undetected during much of the period of chemical enlightenment of the 18th and 19th centuries. In fact, the location of the first real identification of a rare gas in 1868 was not on the earth at all, but rather from the spectral discharge of helium in the sun.

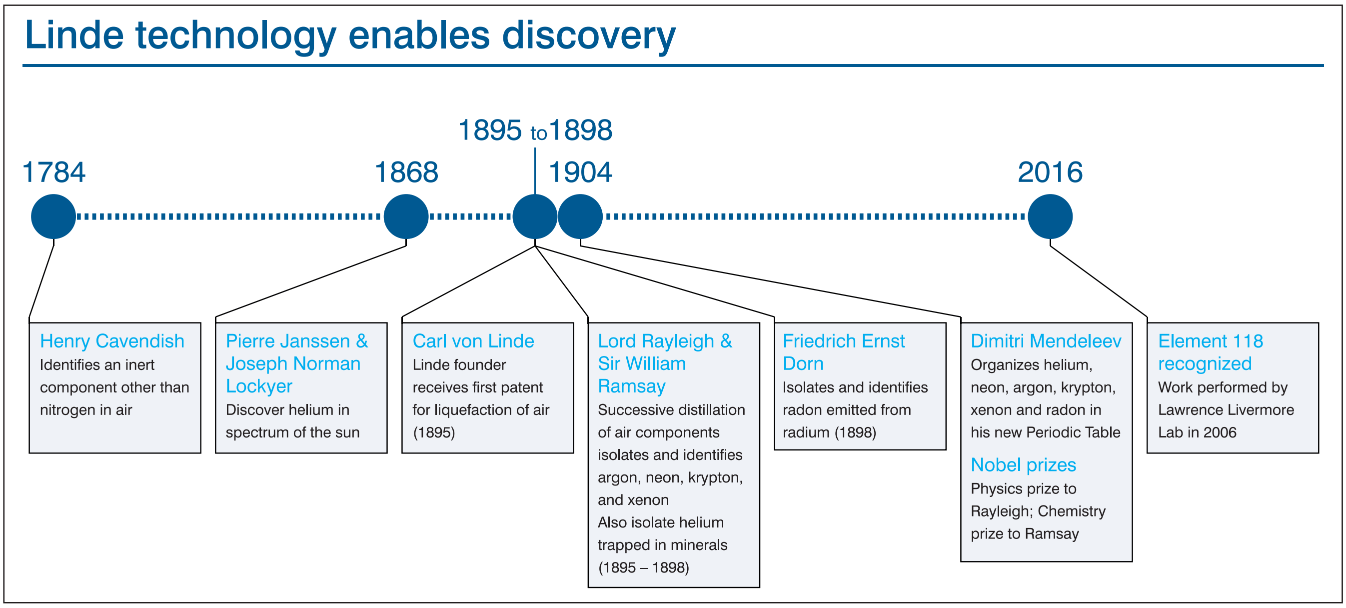
However, technology quickly enabled a rapid progress in understanding (Figure 1). Building upon earlier scientific and commercial successes with refrigeration, Carl von Linde developed the first apparatus for the liquefaction of air, which was patented in 1895.

While preserving the commercial benefits, Linde also realized the scientific impact of this technology, and distributed early prototypes to major academic centers across Europe. Within 10 years of this technical breakthrough, all five rare gases were isolated and identified, culminating in Nobel Prizes in 1904. Moreover, their discovery was essential to the formulation of the periodic table by Dimitri Mendeleev, and indeed modern atomic theory.

Properties and applications

Properties. The complete, outer electron shells of rare gases are not only an organizing nomenclature for the periodic table, but they also underlie the physical source of key properties associated with these molecules. Essentially similar electronically, rare gases are differentiated among themselves by their mass. Here, we describe four properties important to supporting electronics manufacturing.

- **Inertness:** Foremost among the properties utilized from rare gases is their inertness to chemical reaction. This is why the analogy to noble metals was made by early researchers, noting their lack of oxidation under the most extreme conditions. The complete electron shells mean that these molecules are already at their lowest chemical energy potential, and no reactions with other atoms will improve upon their energy state. Because many of the applications in electronics manufacturing are highly energetic, rare gases are relied upon as an inert medium for conductance of mass, heat, and light.
- **Ionization potential:** Ionization is the removal or addition of electronic charge to an atom or molecule; ionization potential is the energy required to accomplish this charging. Relative to similarly



Henry Cavendish
Identifies an inert component other than nitrogen in air

Pierre Janssen & Joseph Norman Lockyer
Discover helium in spectrum of the sun

Carl von Linde
Linde founder receives first patent for liquefaction of air (1895)

Lord Rayleigh & Sir William Ramsay
Successive distillation of air components isolates and identifies argon, neon, krypton, and xenon
Also isolate helium trapped in minerals (1895 – 1898)

Friedrich Ernst Dorn
Isolates and identifies radon emitted from radium (1898)

Dimitri Mendeleev
Organizes helium, neon, argon, krypton, xenon and radon in his new Periodic Table

Nobel prizes
Physics prize to Rayleigh; Chemistry prize to Ramsay

Element 118 recognized
Work performed by Lawrence Livermore Lab in 2006

Figure 1. The development of air liquefaction technology by Carl von Linde catalyzed a decade of rare gas discovery, culminating in the organization of the periodic table by Mendeleev and the award of two Nobel Prizes.

massed atoms, rare gases have very high ionization potentials due to their complete electron shells. This allows them to remove or conduct electronic charge efficiently to other atoms and molecules. Helium has the highest ionization potential of any atom or molecule.

- **Thermal conductivity:** Atoms and molecules have different rates at which they conduct heat energy, and this is quantified by their thermal conductivity. Helium, as well as hydrogen, have the highest thermal conductivity among gases, which is due to their low mass. Because of the high-energy reactions of many electronics manufacturing reactions, the combination of high thermal conductivity along with inertness means helium is often used to quickly change the temperature of objects.
- **Mass:** Mass itself is an important property for rare gases. Matching the mass of the rare gas to certain mechanically-enabled applications, again along with their inertness, means the selection of a specific rare gas can optimize outcomes.

Applications. Rare gases are used throughout the wafer substrate and device manufacturing process chains. Here we briefly describe some of the more common applications using rare gases, and show how they are associated with individual rare gases and their properties in Figure 2.

- **Backside wafer cooling:** Helium is often used to control the temperature of wafers and sometimes glass substrates in display manufacturing. This is becoming increasingly important as thermally sensitive, low temperature deposition and etch processes are adopted.
- **Loadlock cooling:** Likewise, helium is used to cool wafers between process steps.
- **Carrier gas:** Helium, and sometimes argon, are used to entrain and transport less volatile chemicals – ordinarily liquids at ambient conditions – into the reaction chamber.
- **Plasma:** Argon, and sometimes helium, are used to support plasmas in deposition and etch processes due to their high ionization potential and inertness.
- **Silicon ingot production:** Nitrogen is reactive to silicon at its melting point of 1414°C, and so argon is used instead to inert the surfaces of the molten silicon and newly formed ingots.
- **Cryogenic cleaning:** Microscopic aerosols of liquid argon have found use to clean delicate, high aspect ratio structures in advanced semiconductor manufacturing.
- **Excimer laser lithography:** Deep UV laser lithography has been used for 20 years in high-volume semiconductor manufacturing to pattern critical layers of devices. Laser gases are mixtures of 98+ percent neon with other rare gases (argon, krypton, and xenon) and halogen (usually fluorine).
- **Sputtering:** Sputtering is the direct removal, or indirect deposition, of material. The process is initiated by the physical impact of gas-phase atoms or molecules upon solid surfaces. By selecting a rare gas of similar mass, sputtering yields can be optimized.
- **Etch:** Rare gases are used to mediate etch reactions. Xenon is used in certain high aspect ratio etch applications for its combination of ionization potential and chemical inertness to adjust charge distributions in the etch reaction.

Production and supply

Cryogenic Distillation. Production and supply of rare gases are enabled by the same cryogenic distillation separation of air components pioneered by Carl von Linde more than 130 years ago.

The relative abundance of the components in air (Figure 3) and boiling points (Figure 4) indicate the cost to produce and availability to supply these critical materials to the typical 99.999+ percent purity.

Argon

Argon is the fourth most abundant gas in the earth's atmosphere. It is produced in air separation units (ASUs) alongside oxygen and nitrogen by means of secondary distillation of the liquid oxygen rather than from the primary distillation of air. Because the boiling point of argon is between that of nitrogen and oxygen, an argon-rich mixture is taken from a tray near the center of the distillation column and is further cryogenically separated. It can also be recovered from ammonia plant purge gas streams, which also process very large flows of air as an initial feedstock for nitrogen.

Neon, Krypton, and Xenon

Neon, krypton, and xenon are similarly obtained as by-products from the production of nitrogen and oxygen. Because the concentrations in air are miniscule, commercial quantities of crude products are obtained from only the largest ASUs with huge air intakes: on the order of at least 1,000 tons per day (tpd) oxygen capacity are needed. Neon has a much lower boiling point than nitrogen and oxygen and thus passes through the nitrogen distillation column unliquefied. This "light" stream is compressed and sent to secondary sites for further purification and packaging. Krypton and xenon conversely have much higher boiling points and are rejected from the oxygen distillation column as "heavy" waste. They are pre-purified at site to remove most of the oxygen before similarly being sent to secondary sites for further purification – including separation from each other – and packaging.

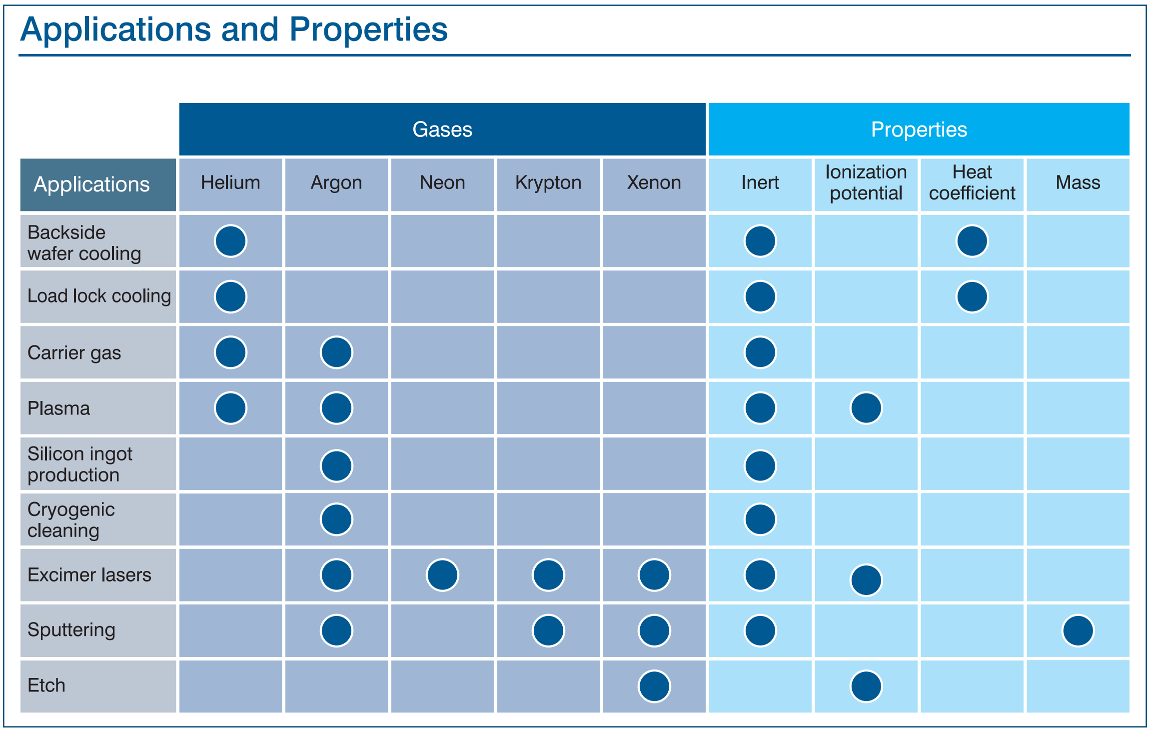
Helium

Helium is the most abundant element found in the universe after hydrogen, but it is relatively rare on earth. Helium is formed on earth as a result of the radioactive decay of thorium and uranium in the crust. It rises through geological fissures and accumulates in the same rock formations as natural gas. However, only certain deposits have concentrations high enough to be commercially viable, but which are less costly than distillation of air.

Commercial production of helium began in the United States as a strategic material spurred by the military applications for observation blimps during World War I. The primary commercial source for much of the 20th century was the Hugoton gas basin spanning parts of Kansas, Oklahoma, and Texas. During this period, the US government continued to treat the material as strategic, and excess crude material obtained as the by-product of natural gas extraction was stored by returning it to depleted reservoirs of permeable rock. Known as the Federal Helium Reserve and managed by the Bureau of Land Management (BLM) the reserve is in the process of being sold off under the Helium Stewardship Act of 2013 and this erstwhile primary supply will be tapered to negligible commercial impact in the near future. Meanwhile, significant new sources have been developed over the past few decades across the globe. The potential development of large sources in Siberia promises to continue to meet growing global demand.

Recovery

Due to their inert property, rare gases are not consumed, either by chemical change or incorporation into the finished product, during electronics manufacturing. Consequently, they are available in the waste streams from fabs, albeit highly diluted and contaminated. The technology to recover



Applications and Properties

	Gases					Properties			
Applications	Helium	Argon	Neon	Krypton	Xenon	Inert	Ionization potential	Heat coefficient	Mass
Backside wafer cooling	●					●		●	
Load lock cooling	●					●		●	
Carrier gas	●	●				●			
Plasma	●	●				●	●		
Silicon ingot production		●				●			
Cryogenic cleaning		●				●			
Excimer lasers		●	●	●	●	●	●		
Sputtering		●		●	●	●			●
Etch					●		●		

Figure 2. Specific and often extreme properties of rare gases result in their roles for essential electronics applications.

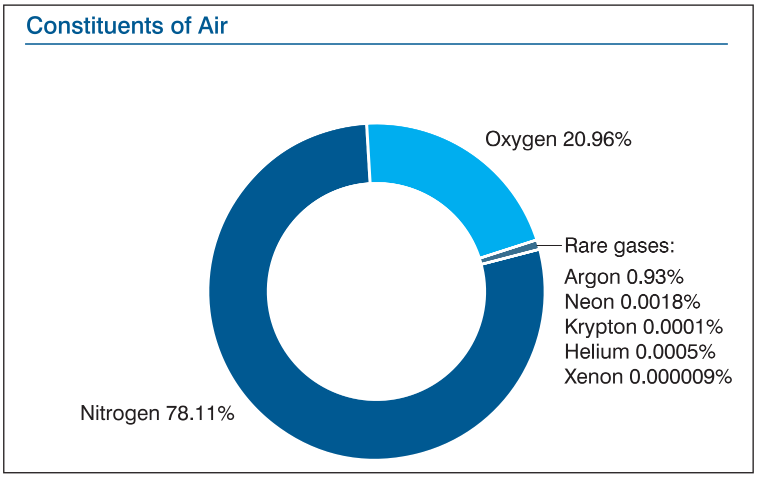


Figure 3. Rare gases are a small part of the atmosphere.

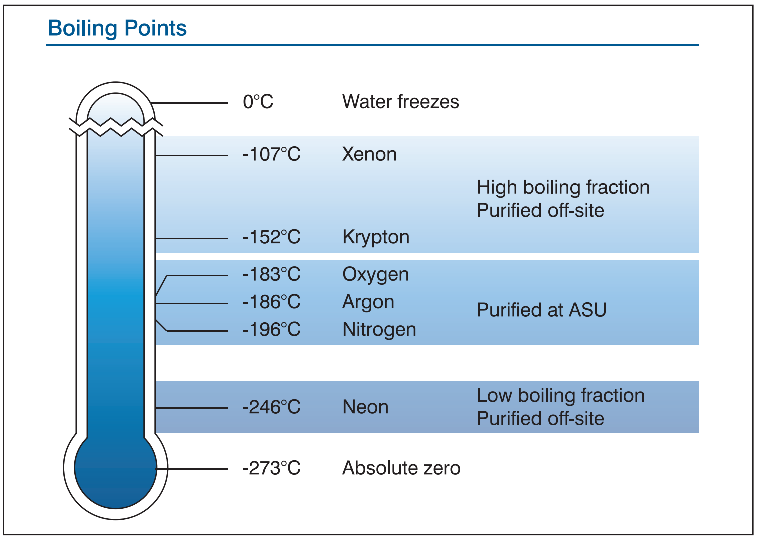
these materials is straightforward, with the potential to recycle them for electronics or other applications. However, as with most recovery processes, the choice to recover vs. supply with new material is made on the relative costs of the whole supply chain. Only the very largest use applications are candidates for commercially successful recovery.

Supply Modes. Rare gases are available in a variety of gas and liquid packaging, as indicated in Figure 5. These span from lecture bottle cylinders holding a few liters of gas to liquid bulk trucks for land and ISO containers for sea shipment of millions of gas-equivalent liters of product. Like most materials, the commercially viable transport cost is directly related to the value of the material (Figure 6). Because most rare gases are truly scarce, they are commonly distributed globally and generally independent of the geographic location of the source. The exception is argon, which is relatively inexpensive, and is produced in many geographies at large ASUs. However, it can be shipped regionally as supply imbalances dictate.

Market

The demand for rare gases has grown substantially in the past few decades on the back of new applications both for electronics and non-electronics markets. Moreover, while the overall demand for these materials has experienced a more-or-less smooth upward trend, the underlying application basis has sometimes changed dramatically. For example, the development and rapid adoption of LED lighting has quickly eroded the market for halogen lighting and display signage. Likewise, the market for plasma displays as a successor to cathode ray tube televisions was short-lived and eclipsed by the introduction of LCD technology. Below, we take a brief look at the electronics market demand, as well as significant non-electronics applications. These market shares are summarized in Figure 7.

Figure 4. Extracting rare gases requires cryogenic distillation of large quantities of air.



Helium

- **Electronics:** Electronics usage, which represented less than 1 percent of total global demand for helium, has grown exponentially to constitute more than 15 percent of the market demand today. The total demand for helium for a single fab can now exceed 200,000 m^3 per year.
- **Non-electronics:** Non-electronics applications include cooling in metal production and adoption of MRI scanners, whose superconducting magnets require liquid helium as a refrigerant. Fiber optic manufacture can also benefit from using helium as a coolant to speed the manufacturing process.

Neon

- **Electronics:** Dominated by DUV laser lithography, usage continues to out-scale wafer start growth as the complexity of leading-edge chip designs drives adoption of multi-patterning lithographic techniques. Laser annealing and lift-off for new display technologies will further accelerate demand.
- **Non-electronics:** Dissolution of signage applications has quickly reduced the non-electronics demand and ceded supply availability to electronics.

Argon

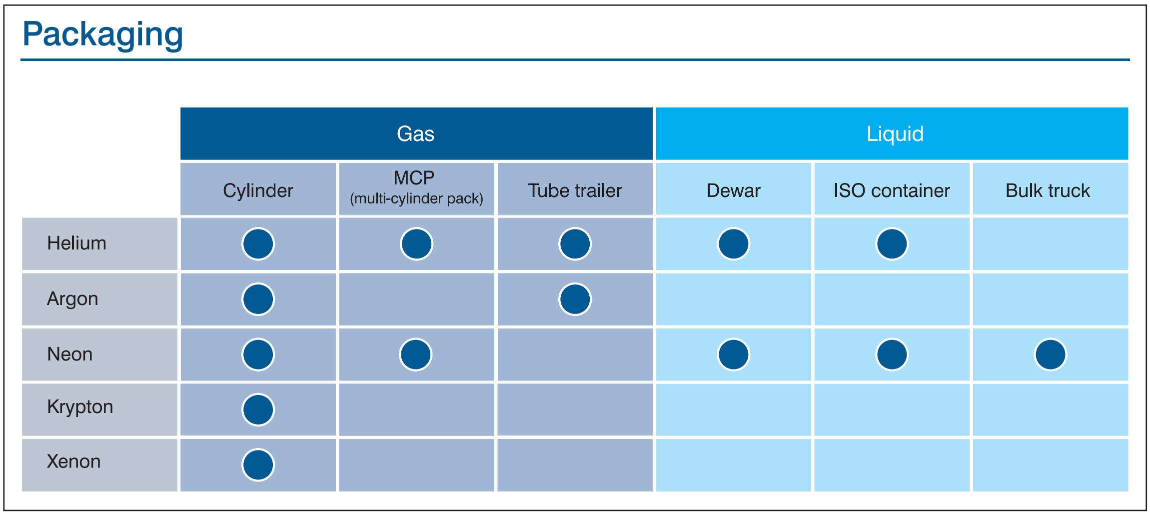
- **Electronics:** Argon is the primary inert gas used in the fab due to its relative inexpensive cost to supply. Usage continues to trend with process complexity. Geographic supply imbalances occur sometimes when large wafer or ingot fabs are built in regions lacking in ASU-intensive industries like steel and chemical production.
- **Non-electronics:** Usage is widely varied for inerting of high-temperature material processing, like the manufacture of stainless steel and as a plasma gas for welding.

Krypton

- **Electronics:** Usage in electronics is co-reactant in DUV excimer lasers and sputtering account for the relatively small electronics demand.
- **Non-electronics:** In these applications, krypton is used as an insulator between panes of glass.

Xenon

- **Electronics:** Long used in R&D as an etch enhancer for high-aspect ratio etch, xenon is finding



Packaging

	Gas			Liquid		
	Cylinder	MCP (multi-cylinder pack)	Tube trailer	Dewar	ISO container	Bulk truck
Helium	●	●	●	●	●	
Argon	●		●			
Neon	●	●		●	●	●
Krypton	●					
Xenon	●					

Figure 5. Rare gases are supplied in a wide range of gas and liquid packages.

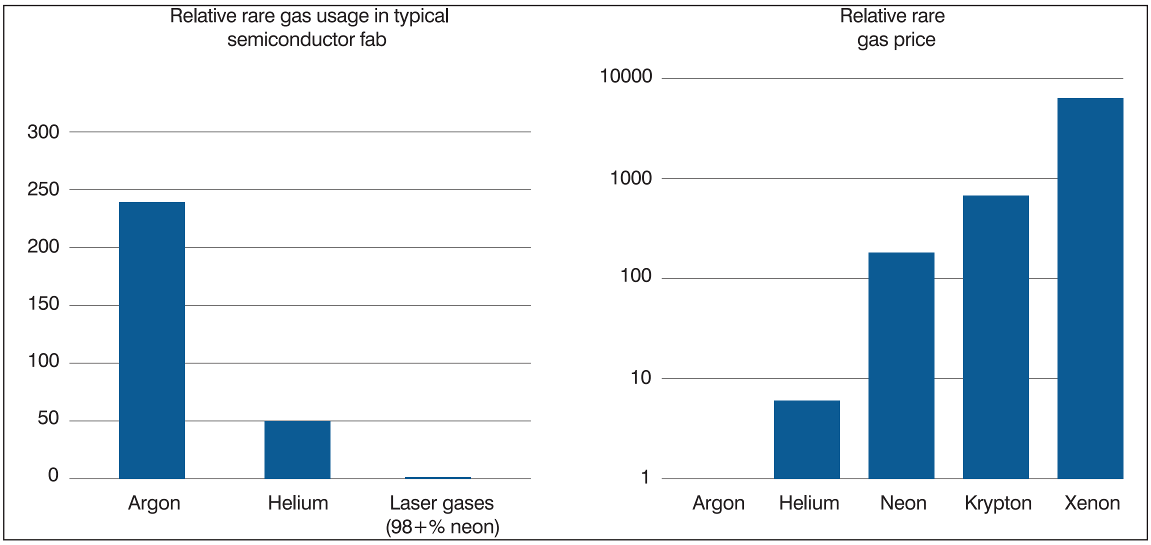


Figure 6. Rare gas usage and price are inversely proportional.

high-volume commercial adoption for such etch applications in new 3D semiconductor structures.

- **Non-electronics:** LED adoption has reduced xenon use for halogen lighting to one third its former demand in the span of the last three years. However, its use as the propellant for space satellites in non-military launches is growing rapidly, which is replacing lighting as the demand driver.

Conclusion

Long invisible to us although they surround us in the air, rare gases were quickly discovered after the enabling invention of air liquefaction by Carl von Linde. The technology to produce these molecules is advanced and the sourcing and production of rare gases is a specialist niche field. Scaling of ever larger ASU plants have made supply of these gases commercially viable, along with exploration and development for geological sources of helium.

From the beginning of semiconductor processing, rare gases have been important for the inerting properties they provide. As the industry has developed in technical complexity, rare gases have filled an ever widening matrix of essential applications. And now, electronics applications form a significant share of the market demand for all of these with the exception of argon.

Linde is the leading supplier of the technology to extract these needed gases. Using the world's largest portfolio of its own production plants as well as contracts with third-party producers, Linde manages the full supply chain of rare gases to meet the volume and quality demands of its electronics customers. Linde anticipates its customers' developing requirements by continuing to be the innovator in its field.

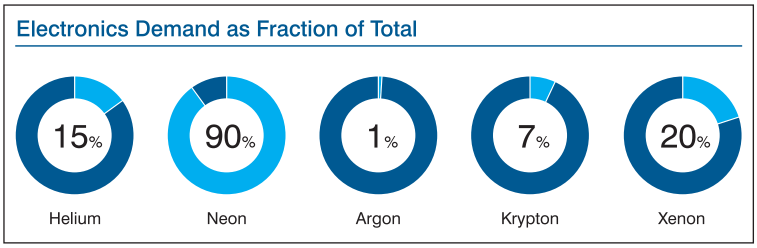


Figure 7. Electronics application demand makes up widely varying fractions of the total market for each of the rare gases.

NXP reveals new power product line solutions

NXP has released a new line of processors and microcontroller solutions for the IoT, low power requirement designs and high performance multimedia applications. Silicon Semiconductor's Mark Andrews spoke with NXP's Ron Martino, VP and GM of the company's i.MX product line, about their new solutions and the company's nod towards FD-SOI technology.

NXP Semiconductors (Eindhoven, Netherlands) announced in March that it was bringing new processors and microcontroller solutions to market based upon FD-SOI (fully depleted silicon on insulator) technology, supplanting CMOS in wide-ranging applications. The company also announced new development frameworks and SoCs.

NXP subsequently announced that Amazon was utilizing i.MX products in next-generation 'Alexa' devices. In a separate announcement the company said that its Android Things platform, utilizing i.MX applications processors, supports the new Google Cloud IoT Core, which is a managed service for securely connecting and managing devices at a global scale.

NXP previously announced that its i.MX 7ULP design would deliver 'deep-sleep' suspended power consumption of 15 uW or less: about 17 times better than its previous low-power i.MX 7 devices. Dynamic power efficiency for the new device family is 50 percent better in real-time domains, said the company.

Although NXP's new product line offers superior performance compared to earlier generations, some industry watchers found the news of NXP's commitment to a long-range plan broadly migrating design of general purpose processors and microcontrollers from CMOS nodes over to FD-SOI as most significant. What proved to be deciding factors for the company are the capabilities they find in FD-SOI to deliver designs that can provide low power consumption, high efficiency and scalability. NXP indicated that it sees prospects for developing a variety of processor families all from one FS-SOI process node.

NXP's embrace of FD-SOI began two years ago after Samsung announced 'dramatic improvements' in power, performance and

efficiency in their process recipe. Earnest development began shortly thereafter; qualification came early in 2016, with the first devices arriving at NXP offices late last year.

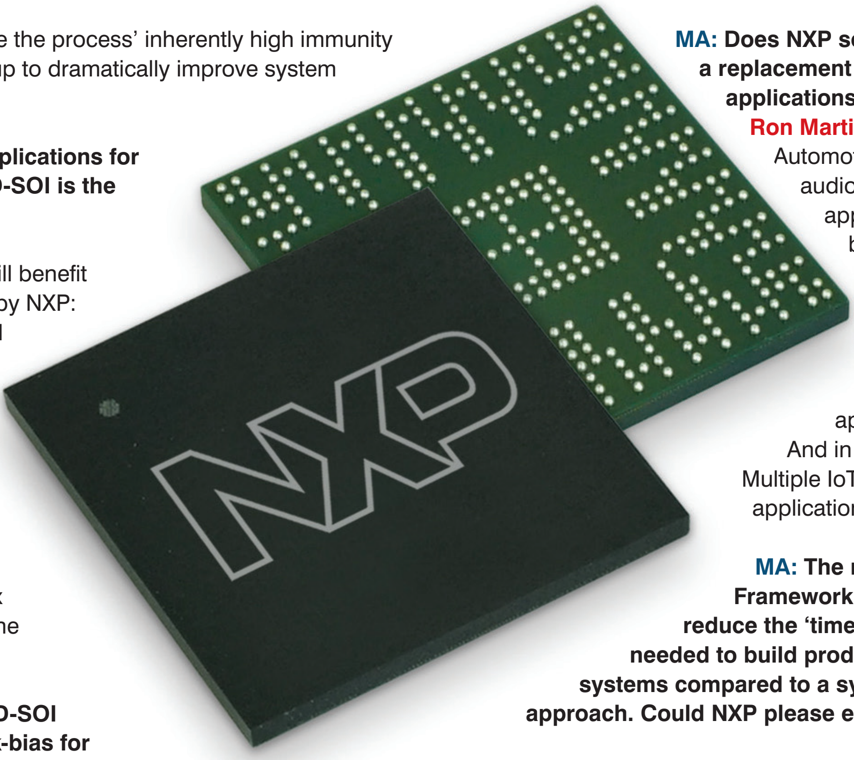
For NXP, FD-SOI technology represents what some might characterize as an easy transition from SOI—technology with which their design engineers were already well experienced. Key advantages include the flexibility brought by its back-biasing and forward-biasing techniques.

In a nutshell, 'forward back-bias' is an ideal way to increase performance, while 'reverse back-bias' is an excellent way to reduce leakage.

Power Electronics World's Mark Andrews spoke to Ron Martino, VP and GM of NXP's i.MX product line about the new solutions and his company's commitment to FD-SOI technology.

MA: Does the switch to FD-SOI for i.MX devices indeed signal a shift to that technology for low-power solutions overall, or primarily for IoT-related applications?

Ron Martino: The choice of 28nm FD-SOI for next-generation i.MX offerings signals a new paradigm (for the) applications processor -- optimization of power, performance and integration for a diverse set of applications. Our low power solutions (i.MX 7ULP), delivering power efficiency for battery operated devices, will concentrate the transistor design and mix to minimize the leakage through Reverse Body Bias (RBB), as well as lowering dynamic power through Forward Body Biasing (FBB). The performance solutions (i.MX 8 and i.MX 8X), targeting optimized power-performance for wired operated devices, will leverage Forward Body Bias for high performance modes, as well as having the ability to achieve extremely low power wait states for efficient system design and operation. In addition, multiple applications will leverage the process' inherently high immunity to soft errors and latch-up to dramatically improve system reliability.



MA: Are there other applications for which NXP believes FD-SOI is the ideal tech?

Ron Martino: FD-SOI will benefit many markets targeted by NXP: consumer, industrial and automotive. All three markets require the power-performance benefits. The industrial market will benefit from the significantly improved Soft Error Rates (SER), which can go up to 100x versus bulk, as well as the immunity to latch-up.

MA: Does NXP favor FD-SOI due to its forward back-bias for a performance increase, while its reverse back-bias is a superior choice to reduce leakage?

Ron Martino: FD-SOI enables a significantly wider range of RBB and FBB compared to bulk technology alternatives. Lower Vmin operation is achievable without the need of additional devices, which add cost and complexity to the technology and integrated circuit development. The basic technology integration has fewer masking steps compared to alternative bulk options, so short cycle times can be achieved in development and manufacturing of product.

Lower failure rates can be achieved based on superior immunity to latch-up and SER. Device oxide is thicker than some alternatives in the industry allowing for more reliable solutions for automotive and industrial applications. Analog and RF integration significantly benefits from superior characteristics in gain, noise, and switching.

In addition to the above which link to product attributes, there are benefits to internal development efficiency. The wide dynamic range of FD-SOI enables the broadest range of scalable solutions on a single technology platform.

MA: Does NXP see other benefits that FD-SOI technology offers?

Ron Martino: FD-SOI offers the ability to deliver a full range of new leadership products across the continuum of microcontroller, microprocessor and connectivity offerings. The future integration of disparate technologies such as novel NVM, innovative analog leveraging benefits of FD-SOI and RF capability with leadership low power capability enables NXP to apply its innovative culture to create impactful safe, secure and connected solutions for its customers.

MA: Does NXP see FD-SOI as a replacement for CMOS in applications outside IoT?

Ron Martino: We do in key areas: Automotive: Cluster, display audio, telematics and V2X applications processor benefits. Also in Industrial: Industrial control, Point of Sale (POS), robotics, industrial transportation application benefits. And in consumer products: Multiple IoT and wearable/portable application benefits.

MA: The new NXP IoT Framework is said to drastically reduce the 'time, effort and expertise' needed to build production-ready IoT systems compared to a system integrator approach. Could NXP please elaborate?

Ron Martino: In addition to the leadership embedded processing and connectivity products that NXP has introduced to the market, it also delivers leadership enablement and solutions around these offerings to improve time-to-market and reduce development efforts for its customers. In particular, NXP is delivering an Integrated Development Environment (IDE) that simplifies system development requiring connectivity (Thread, ZigBee, Wi-Fi Ethernet, NFC), security (secure element, integrated hardware security), embedded processing reference design, and smart device/cloud computing enablement and interoperability.

MA: How does the NXP time-sensitive network (TSN) benefit Industry 4.0 applications?

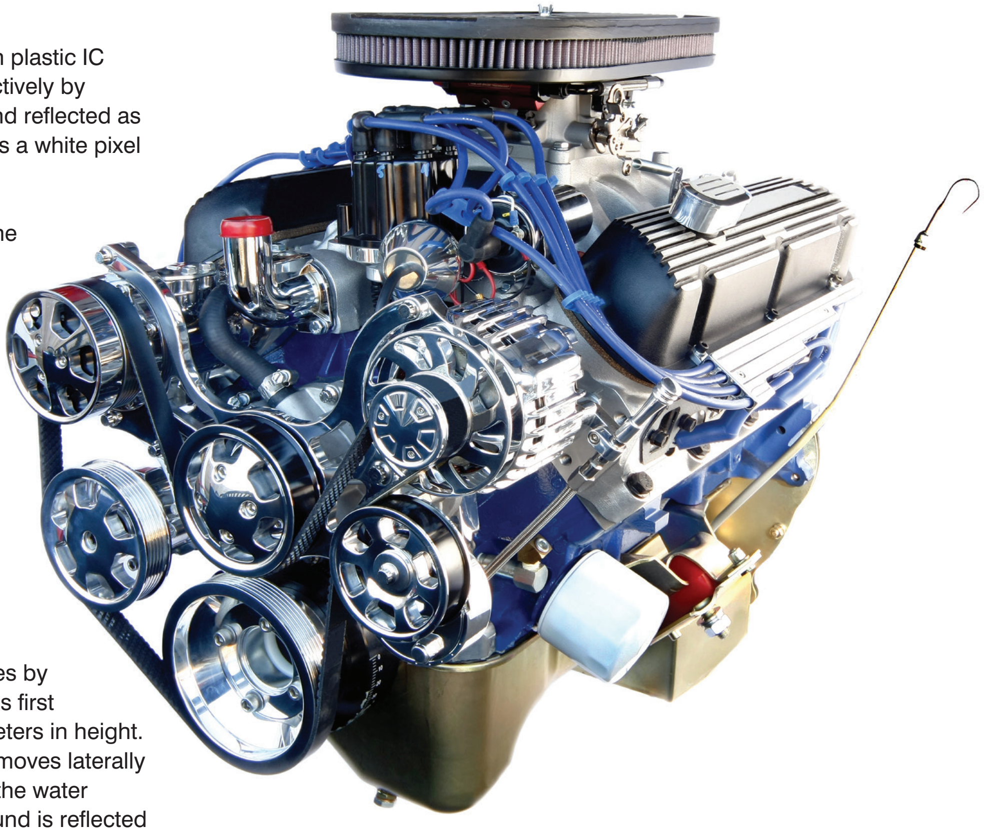
Ron Martino: NXP's TSN offering extends its leadership in networking solutions by providing the next-generation of IEEE AVB which converges OT /IT traffic in a single network; (it also) provides determinist Ethernet at gigabit speeds, reduces network delays and improves network robustness of industrial applications.

MA: Intel has released its 22nm FinFET process to foundry customers, saying it offers simplified design rules compared to FD-SOI, that it provides simpler interconnects and that it is a 'technology for the masses.' How does NXP feel FD-SOI compares to Intel's offering?

Ron Martino: NXP reviews all competitive technology offerings in the industry in order to make the best selection for its portfolio. In general, a subset of NXP products with very high digital content and performance requirements will benefit from FinFET at more advanced nodes. FD-SOI is a planer technology with simpler integration. Both are fully depleted solutions, however, FD-SOI has the buried oxide which gives better latch-up immunity. Finally, FD-SOI has a large power-performance dynamic range enabled by the body-bias capability.


3D MICROMAC

VOIDS, NON-BONDS and other gaps in plastic IC packages can be examined nondestructively by acoustic micro imaging tools. Ultrasound reflected as an echo from any air-filled gap becomes a white pixel in the acoustic image.



Even though no gap may be present, the stresses that are causing the control module failure could have been found by an acoustic micro imaging tool such as the C-SAM® tools from Sonoscan. The telltale signs of stress are external or external surfaces that should be flat and horizontal, but which instead are warped or tilted. Warped or tilted component surfaces are mapped by the C-SAM's Time of Flight mode, while internal interfaces are mapped by the Time Difference mode. Both modes produce contour maps.

The ultrasound pulsed at or into samples by tools in Sonoscan's C-SAM® line travels first through a column of water a few millimeters in height. The transducer pulsing the ultrasound moves laterally at speeds that may exceed 1 m/s, and the water column moves with it. Because ultrasound is reflected only by material interfaces, a portion of the ultrasound is reflected by the water-to-sample interface.

Mapping tilt and warp of internal and external component interfaces

Inside an automotive engine control module, a plastic-encapsulated microcircuit is about to fail because of an internal structural problem. The problem is not the usual void or delamination that eventually, by expanding or corroding, leads to electrical failure. Instead, it is mechanical stress within the die.

By Tom Adams, consultant, Sonoscan, Inc.

From here the rest of the pulse travels into the sample, where it may strike and be reflected by a second interface. If the pulse strikes only solid-to-solid interfaces, it may be reflected by several of the interfaces. But if it strikes a solid-to-air interface, it goes no deeper and there are no further echoes. The pulse -echo sequence occurs several thousand a times a second as the transducer is moving. Each echo (or the absence of an echo in a homogeneous sample with no internal interfaces) represents one x-y location at depth z and becomes one pixel in the acoustic image.

Time of flight mode

The Time of Flight mode measures the time required for a launched pulse to travel back to the transducer from the top surface of the sample. If the surface of a sample is perfectly flat, the transducer will read the same time, measured in nanoseconds, at each of the thousands or millions of x-y locations where a pulse

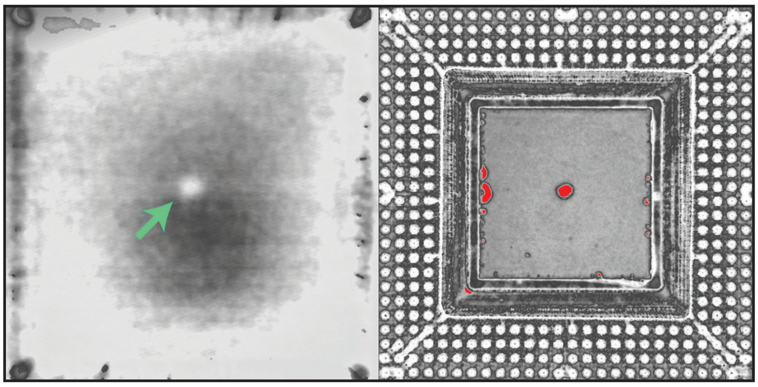


Figure 1. The bump (white, at left) at the surface of this plastic BGA package was caused by a void (red, at white) between the die and the mold compound.

was launched. On a perfectly flat sample, all locations will report the same Time of Flight, and the image of the surface flatness will have pixels all the same color (or the same shade of gray). Variations in elevation will produce a map displaying multiple colors.

Slight variations in surface flatness are not likely to be significant, so why map the component surface at all? Because some variations in surface elevation are caused by internal anomalies such as voids, or by internal stresses other than gaps. Either of these items may change during the component's service and cause an electrical failure. Local mechanical stress may blossom into a crack. A small innocent-looking gap may grow and break a wire bond.

The user may employ reflection mode imaging and limit the return echoes used to make the acoustic image to a specific depth of interest. This process is called gating, and a gate may be wide (vertically) or narrow. If a void appears bright in a reflection mode acoustic image, the void must lie within the gated depth, .

Figure 1 left is the Time of Flight image of a plastic BGA package. The image shows the relative elevation of the top surface of the package: lighter colored regions are higher, darker colored regions are lower.

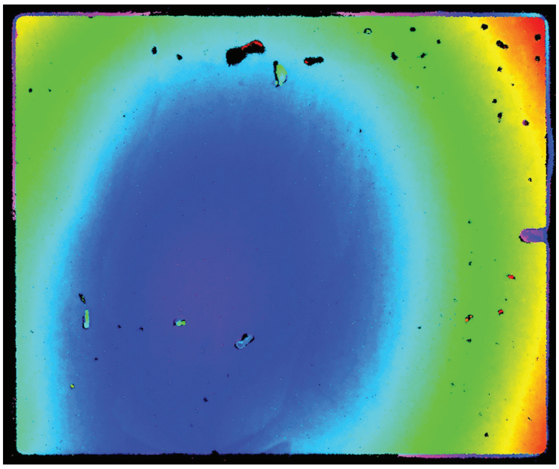


Figure 2. Colors display the contours of a warped ceramic raft, seen through the heat sink of an IGBT module.

Note four indented - and therefore dark - mold marks at the corners. Overall, the package surface is higher (lighter) near the edges and lower (darker) near the center. There is one significant anomaly - the small bright white spot marked by an arrow near the center of the package. Changes elsewhere are mostly gradual, but here the package surface spikes upward. Such an anomaly is typically caused by internal feature.

Figure 1 right is a reflection mode image of the same area of the package, gated on the die face - meaning that only echoes from the die face are used to make the acoustic image. Here colors display the degree of reflection from internal interfaces. The anomaly seen in the Time of Flight image at left was converted from white to red, the conventional color for defects, and is clearly a void between the die face and the overlying mold compound. This void has sufficient vertical dimension to cause the mold compound at the top surface of the package to be pushed upward, as seen in the contour map in the image at left. There are smaller voids near the periphery of the die, but these do not appear in the Time of Flight image and so have not significantly altered flatness at the surface.

Time difference mode

The Time Difference mode measures the difference in arrival time between two different echoes. Both may be from internal interfaces or one may be from the top surface of the component.

Time Difference is often used to map internal contours in IGBT (Insulated Gate Bipolar Transistor) modules. IGBT modules are high-power switches used in environments where high power loads need to be controlled. Mining equipment, ships, trains and wind farm generators are examples. A module typically contains multiple die mounted on ceramic rafts. The rafts are bonded, usually by solder, to a metal heat sink. The amount of heat that must be removed from IGBTs is usually large, with little room for error.

Anything that interferes with heat flow from the die is dangerous. Voids and non-bonds in the solder are the big problem, but tilting or warping of the raft may also impair performance and lifetime. Voids block heat, and can thus cause the die to overheat. Tilting and warping of the raft cause uneven heat loss across the die, and can lead to internal thermal variations that can cause the die to crack. Because failure of an IGBT module may be expensive, disruptive and dangerous, acoustic inspection is often performed to remove (or, before encapsulation, to rework) flawed modules. To avoid deposition of any residue at all on the die, IGBT modules must be imaged through the heat sink by an inverted C-SAM system developed by Sonoscan.

Figure 2 is the Time Difference image of one warped ceramic raft in an IGBT module. To make this image, return echoes were collected only from (gated on) the depth from the heat sink to those points on the the undulating surface of the raft farthest from the heat

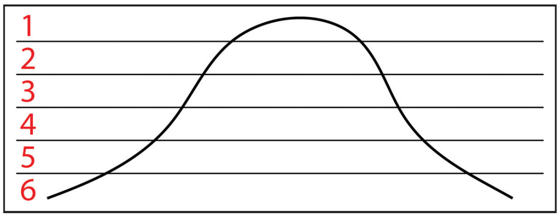


Figure 3. Gating the return echoes produced six depth-specific acoustic images.

sink. Colors indicate the distance from the raft surface at a given x-y location to the reference point (the heat sink). Those regions of the raft farthest from the heat sink are red. From that depth the surface of the raft moves upward (yellow, green) to dark blue, which is the highest point. The warped raft has formed what amounts to a low hill, with the top of the hill nearest to the heat sink. The solder is thickest in the red areas and thinnest in the dark blue areas.

There are gap-type defects here as well: the numerous small, mostly dark features are voids in the solder. Most appear black, probably because they are above the gate and above the top of the high point of the warped raft. Being outside the gate, they are not imaged directly. Instead, they block ultrasound returning from the raft and create a black acoustic shadow. A few of the voids (at lower left, for example) lie within the gate and are colored according to their distance.

What can we say about this raft? It is rather strongly warped, and its warpage will cause uneven heat removal from the die, and may lead to die cracking. The vertical distance between the red and dark blue regions is about 400 microns. In addition, the small voids will block some heat from reaching the heat sink. This IGBT module is probably not a good candidate for long-term use in a critical application. There are other acoustic methods for visualizing the warping of samples such as this raft. One method involves setting several to many gates. Each gate produces its own acoustic image. The result is that the sample may be viewed in a sequence of non-destructive horizontal slices.

The raft shown in Figure 2 was later imaged as six adjacent horizontal slices, as shown in Figure 3. Each gate was about 65 microns in its vertical extent. The colors represent distance from the reference point. Gate 1 was at the top of the ceramic, and gate 6 at the bottom.

The three topmost gates are shown in Figure 4. The center of gate 3 is dark because at this depth the center of the gate is in the bulk of the raft material and thus has uniform distance from the reference point. The outer colored regions of gate 3 represent the downsloping interface between the ceramic and the solder at this depth. In gate 2 the bulk ceramic material has nearly vanished because this slice is near the top of the warped area. In gate 1 there is no trace of the bulk ceramic. Gates 4, 5, and 6, lying below gate 3, looked much like gate 3 but with increasing areas of dark bulk ceramic.

Acoustic measurement of flatness is not limited to IGBT modules and BGA packages. Wafers are scanned to map their flatness before undergoing processes such as dicing that can damage non-flat wafers. Sonoscan has developed a system that, while scanning a wafer for defects, adjusts the transducer height to accommodate each die.

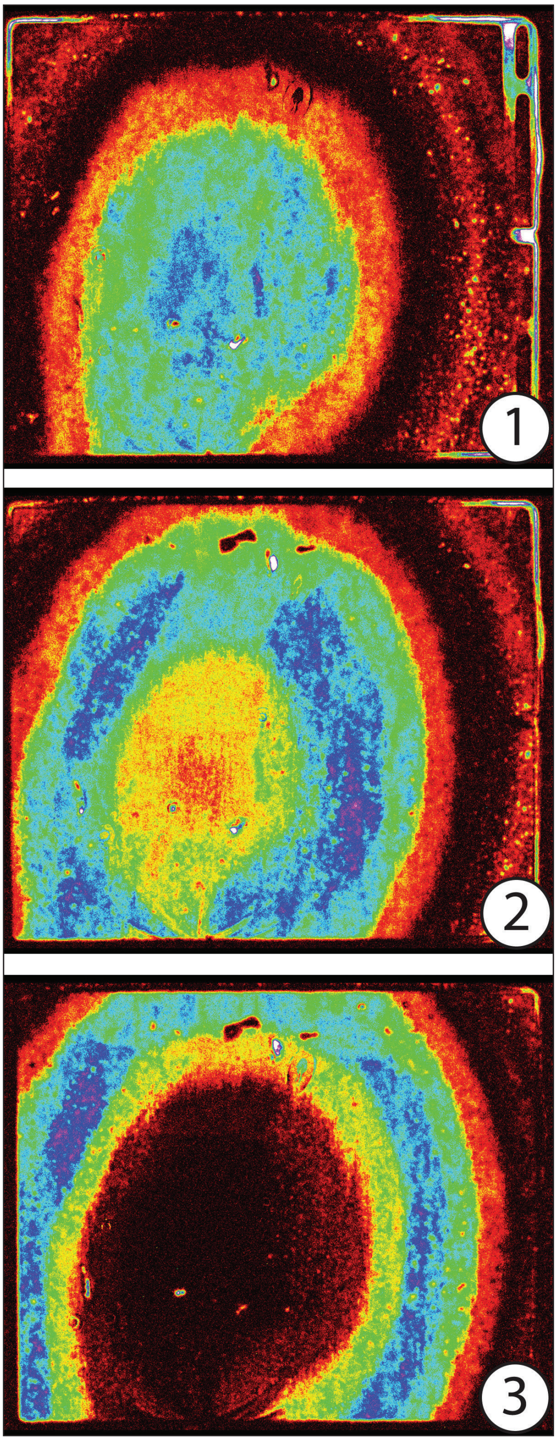


Figure 4. The top three gated depths.

WIRELESS CHARGING POISED TO GO THE DISTANCE

The benefits of wireless battery recharging over a distance appeared about as likely as jet packs and flying cars until Dialog Semiconductor and Energous Corporation began their quest to cut the cords.

WHILE CONSUMERS clearly love their smartphones, laptops and tablets, they equally detest the tangle of power converters and charger cables cluttering backpacks and briefcases from Bristol to Burbank. This love/hate relationship could be about to change if power technology companies Dialog Semiconductor and Energous Corporation successfully deploy their new WattUp® family of wireless charging solutions.

Wirelessly recharging mobile device batteries is hardly new. Existing wireless solutions typically employ coils to carry power to receiving devices; however, these have their limitations. According to Dialog Semiconductor's Senior Director of Corporate Strategy, Mark Hopgood, it is precisely those limits that make the solutions developed by Energous Corporation with support from Dialog so compelling. Without charger mats, precise alignment or other persnickety requirements, the WattUp solution offers benefits that Hopgood says consumers expect: no clutter, and more importantly, no wires.

"I think wireless charging has not lived up to a lot of consumers' expectations. In some cases it can be downright frustrating to find that your device has not charged because it wasn't placed quite right on the charging mat. We believe this new solution is much closer to consumer expectations – it will be a difference they appreciate when it comes time to buy," Hopgood said.

Dialog traces its roots back to 1981 and included times as a Daimler Benz AG subsidiary infused with CMOS and semiconductor technology from Silicon Valley's International Microelectronic Products company; its expertise in power management electronics later extended into smartphones incorporating ARM processors. Work with LED power technology and sensors were later added as the company grew to multiple locations in the UK, Europe, Asia and the US. Dialog's broad power-focused market appeal eventually led to a relationship with Energous Corporation that began in 2014 and was formalized with a partnership and cash infusion of (USD) $10 million in 2016 to support Energous' development of its WattUp wireless technology.

Energous developed its WattUp technology that provides over-the-air power at a distance as an alternative to existing wireless recharging techniques including those of other AirFuel Alliance members. Although Energous and Dialog stress the wireless

aspect of their technology enabling recharging at a distance, WattUp could be employed to create near field charging mats, but without the precise placement requirements some consumers find challenging. Both companies believe most consumers will realize additional benefits as longer-distance charging applications become available, such as deciding when a device is 'refueled.' Consumers can choose priority devices for recharging, or let anything properly equipped sip power as needed. WattUp receiver technology can be incorporated in a very wide range of consumer products that can ultimately be charged from various types of WattUp transmitters.

Even if WattUp devices are positioned in a wireless recharging mat in a near field application similar in appearance to existing systems, Hopgood said Energous' core technology has important advantages. "One of the things we looked at comparing coil based tech vs. Energous (WattUp) was the fact that the receiver coils tend to require a large diameter and an added physical dimension—a 'z' height thickness. Because of this, (coils) are often too big to be integrated into many products that could benefit from wireless charging. But if we reduce the footprint at the device level—which WattUp technology does, this translates into the antenna becoming nothing more than the tracking on a PCB; we can even use the same antenna for charging that you would use for Bluetooth," Hopgood said.

Besides eliminating the coil that other wireless charging technologies depend upon, Hopgood said Dialog and Energous have worked to move from discrete components to integrated semiconductors that further reduce space and increase efficiency. At the same time, WattUp software is designed to ensure that charging waveforms are dynamically directed, focused and controlled via proprietary algorithms; for mid field and far field charging applications consumers can choose various control options including recharging when electricity rates are lowest.

Dialog and Energous have moved forward with their plans to further miniaturize key component technology with the announcement in January of their first jointly produced integrated WattUp wireless power transmit (Tx) IC, the DA4100. This new System-on-Chip (SoC) integrates an ARM Cortex-M0 along with RF power generator, power management and secure element functionality into a single 7x7mm device. It also features on-chip DC-DC conversion and

M	=	a * p * v * t * + C						(y = mx + c)		
Material Removed (µm)	=	Constant	*	Processing Pressure (g/cm2)	*	Plate Speed (rpm)	*	Processing Time (mins)	+	Constant

embedded software, providing seamless integration to Dialog's SmartBond™ family of highly integrated, low power BLE SoCs. The new DA4100 minimizes board space needed to implement, enabling smaller charging transmitters and simplifying overall design-in requirements. Gordon Bell, VP of Marketing at Energous, said that the DA4100 is the backbone of all WattUp transmission designs including the near field transmitter that the US Federal Communications Commission (FCC) recently approved.

"We are engaged with a large number of product companies currently looking to incorporate the WattUp receiver technology into their devices. These companies would typically bundle a WattUp near field transmitter along with their product to offer devices that are charged wirelessly," said Bell.

Bell elaborated that while many end use designs are possible using WattUp receiver technology, Energous and Dialog expect that WattUp-enabled transmitters will most likely appear in future consumer markets focused on two primary applications: standalone and embedded transmitters.

"Standalone transmitters have a single function to allow for wireless charging to WattUp-enabled receivers. A standalone near field transmitter would likely be a small charging pad included inside the box of many small electronics (replacing the USB cord and power brick typically bundled inside today). A standalone mid field transmitter may be incorporated into the dashboard of a car or may be a small device that sits on your desktop, allowing for charging in the 2-3 foot range. A standalone far field transmitter may look similar to a Wi-Fi access point installed on the wall or ceiling, allowing for wireless charging at up to 15 feet," Bell explained.

"Embedded transmitters would be part of another product. For instance, the near field transmitter technology may be embedded into the top of a Bluetooth speaker, allowing you to charge small electronics simply by placing them on top of the speaker…. A desktop assistant type of product may offer mid field WattUp charging to other devices nearby. And the bezel of your TV may one day offer far field WattUp (utility), charging its own remote control, game controllers and other devices within 15 feet of your TV. All of these implementations would use the DA4100 as the backbone of the wireless charging function," he concluded. As the WattUp technology moves from development stages to design-in with lead customers, Dialog's Mark Hopgood said that the change from coil-based wireless charging approaches and other technologies to antennas working with directed RF signals will affect consumer purchasing. The degree to which a consumer has adopted mobile devices and uses them away from mains power supplies could be decisive.

"There are so many gadgets that are a slave to a socket; WattUp technology has the potential to change the way we use our battery powered devices…let's look at near field; at face value one might think that our technology doesn't really add much advantage, but actually when you go from a coil to an antenna based system, you dramatically reduce the footprint and the cost, so just doing that opens up a whole new category of devices. Also, RF is less precious about positioning the device on the charge mat.

"The paradigm shift may occur that when you are using a device, you are sending just enough energy over the distance (using WattUp technology) to keep the devices topped-up. This could be done constantly…so you can reduce the size of the battery, or you can simply not worry about charging them again by keeping them under a managed constant charge. That is where the paradigm shift will occur that the consumer will appreciate," he concluded.

While both Dialog and Energous could not share details regarding the original equipment manufacturers that are currently working to incorporate WattUp technology into future end user devices, they did indicate that product sampling and qualification tests were underway. The companies expect consumer devices incorporating WattUp wireless charging may begin appearing in some global markets later in 2017.

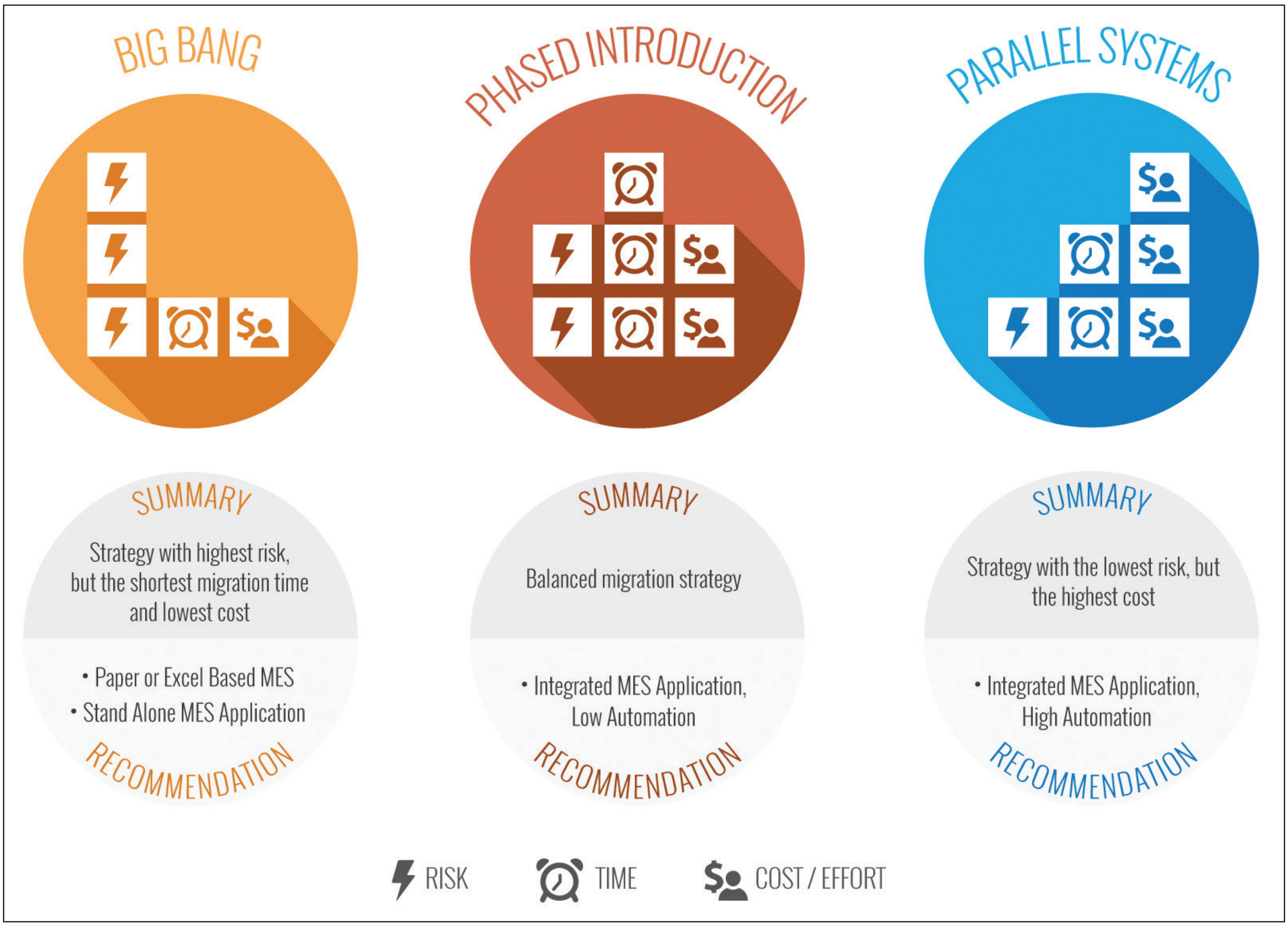

PM6

There are numerous reasons why manufacturers don't change their Manufacturing Execution System (MES) but, in many cases, there are also many reasons why they should. One of the biggest obstacles to change is risk. The very nature of an MES system means that it is at the heart of the manufacturing process. Francisco Almada Lobo, CEO, of Critical Manufacturing explains why companies should consider a change and what needs to happen for successful migration?

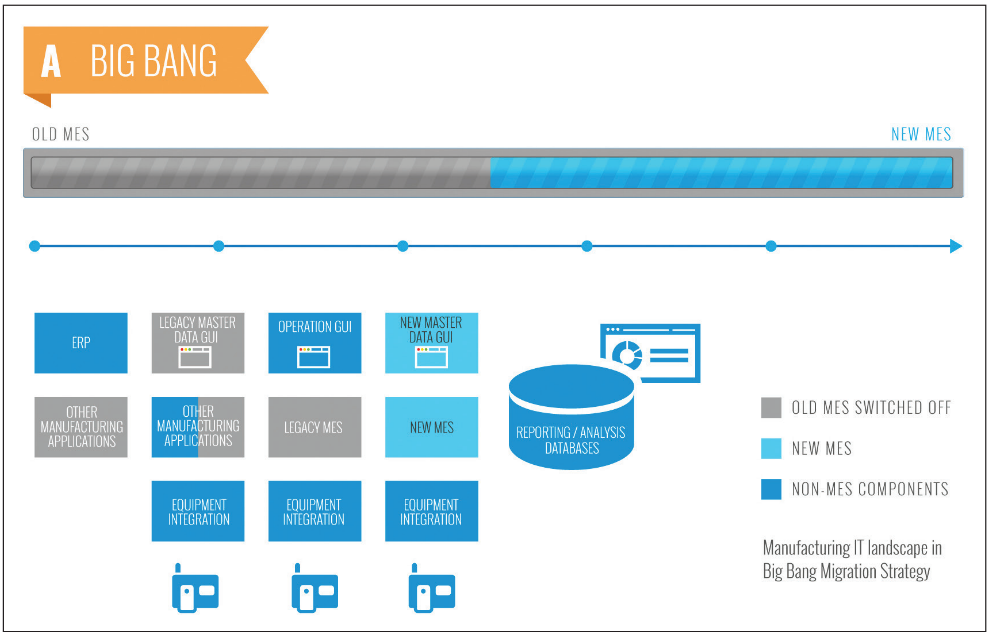
MANUFACTURERS in high tech areas of production, such as semiconductor, were early adopters of MES technology. The concept bought a great deal of benefit to their sophisticated manufacturing processes. As time has moved on, these systems have been adapted to changing needs with upgrades and add-ons that were often proprietary. This has left some production plants with a creaking MES based on hardware and software that is at the end of its life.

The system, however, is such an intricate part of the plant that the thought of replacing it is a very scary option with risk, time and overhead costs that may be perceived as unacceptable. But nothing lasts forever and not upgrading the system may bring real peril to the future of the business. An old MES solution may limit the ability of a company to be competitive today and into the future. Increasing overheads for maintenance will be accompanied by a growing inability to adopt new technology choices that can increase productivity, reduce costs and improve quality. With changing market trends towards the demand for smaller batches of higher mix products with more customised, individualised solutions; getting left behind could be a very costly mistake. In the semiconductor industry, most systems have been in place for over 10 years with some even dating back more than 20 years. Legacy MES constrain evolution and limit effectiveness with the main areas of concern being realistic modelling of the processes, comprehensive rule enforcement, functional coverage, integration and usability. These limitations can compromise traceability, precise control of processes, product quality and productivity. Old MES also inhibit producers from capturing the benefits of major technological advancements in recent years. These include mobile computing; 3D and augmented realities; advanced statistical process control models; advanced data analysis software with the ability to even predict production scenarios, and the use of 'Big Data' to gain greater understanding of processes, costs and issues. These technologies are driving production efficiency to new levels; increasing the speed with which new products can be introduced and fostering greater innovation.

For sure, production can be so dependent on an old MES that the thought of turning it off will give most production managers sleepless nights, particularly in high tech industries. However, the benefits of migration are huge and the cost of not changing equally risky. Staying with an old MES can only be a short term solution and can only lead to increasingly onerous end of life support, high maintenance, rising costs for modifications and a distinct lack of agility to meet changing production and market demands. With



the correct planning and support MES migration to a modern solution that will protect the future of a business can happen smoothly.

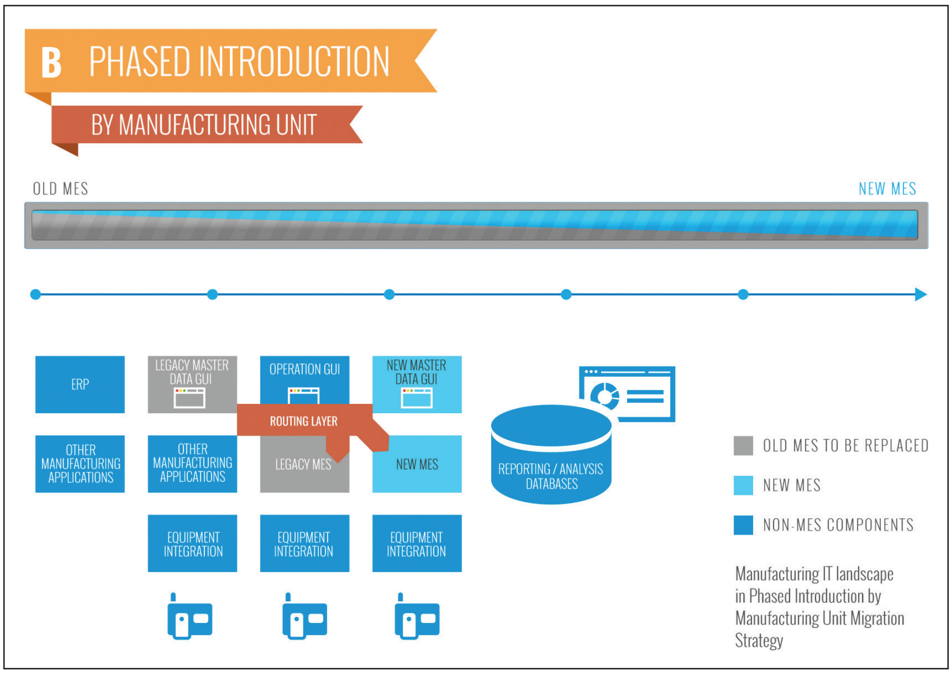


Manufacturing IT landscape in Big Bang Migration Strategy

MES selection

As with any project, the first step of considering a MES migration is to evaluate the return on investment. Along with understanding the costs and limitations of the legacy MES, this requires a definition of the migration scope, target and strategy. The process starts with selection of the migration project team and choosing the best MES system for the application. A project team needs manufacturing and MES knowledge but should also include someone with migration experience to help foresee and resolve challenges that the project may encounter. For system selection, shortcomings of the current MES need to be assessed and the functionality of new systems compared with the needs of the plant.

The new system should have high levels of flexibility to ensure it meets future as well as current business needs. It should include modelling possibilities for materials, equipment, containers, product structures, flows, steps, data collection. There is also certainly no point in upgrading a 15 or 20 year old system to a 10 year old one. A new system should support the plant for a minimum of 10 years. The ability of a new MES to help with the actual migration process by being able to mimic the legacy MES is also a consideration.

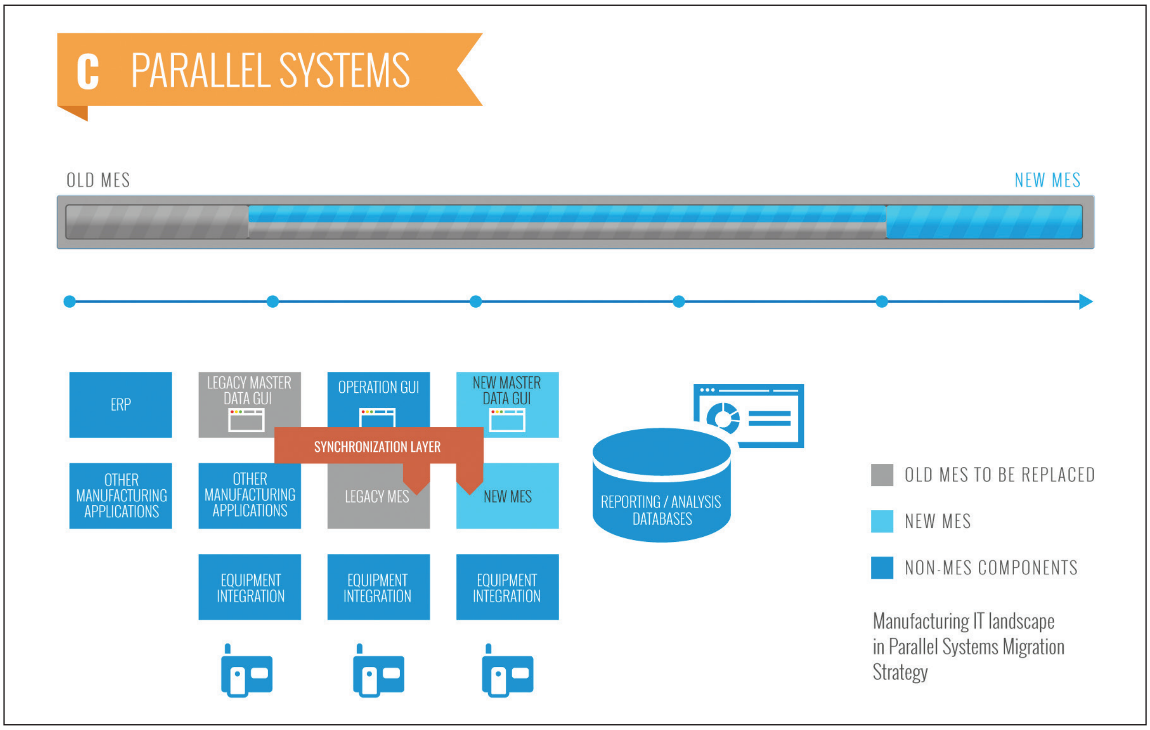


Manufacturing IT landscape in Phased Introduction by Manufacturing Unit Migration Strategy

Migration strategies

The migration to a new system can be carried out in a number of ways, each with varying levels of risk, cost and time. These include ‘Big Bang’, Phased and Parallel approaches. Big Bang is the fastest and lowest cost option with the legacy system being turned off and the new MES turned on. This single point switch over, however, also carries the highest risk as the offline testing phase of the new system may not re-create all live conditions of the plant or cover all inter-dependencies. Phased introduction of a new MES involves introducing the system into parts of the production process while leaving the old MES supporting other areas. These phases may be by manufacturing unit, MES function or by product lots. This approach reduces risk as confidence in the new system increases over time and parts that have been migrated can be rolled back if problems occur. This strategy does involve higher costs than the Big Bang approach, however, as routing layers and migration procedures are required to ensure the two systems work in harmony across the plant. It also costs the most in terms of time to fully implement the new system with many small migration phases.

Taking a Parallel approach puts both systems online at the same time, working in a master and slave configuration. When confidence is built that the new MES is operating successfully, it can be designated as the master and the old system switched off. This is the lowest risk approach as any problems that are encountered can be handled by the legacy MES. The time taken



Manufacturing IT landscape in Parallel Systems Migration Strategy

is also shorter than a phased approach. A parallel migration, however, carries the highest costs as synchronisation layers with orchestration logic need to be designed and implemented at application layer and, as data is duplicated in both systems, at the ETL (data extraction) routing layer.

There is no right or wrong migration strategy and the process selected is highly dependent on choosing one that fits the needs of the plant. This includes the level of risk that is acceptable and the amount of investment a business is willing to put into the project. Assessment of complexity of interdependence and interaction with other systems and applications; level of automation, and impact of downtime will also guide the choice of strategy for migration. While each migration project has its own individual challenges, and is highly dependent upon the application, in very broad terms the Big Bang approach is more suitable where there is no integrated MES (maybe a paper based system is still being used or the MES is a stand-alone application). A Phased migration may lend itself more to integrated MES with low levels of automation. A Parallel migration is a good option to consider where there is an integrated MES with high levels of automation.

Migration planning

Whichever migration strategy is selected, the project will need to follow a number of steps. The phases of the project go through Definition, Preparation, Execution and Closure. Definition of the migration provides the groundwork for a successful project. Steps include capturing the current system landscape, defining the future landscape and determining how the migration will happen using the selected migration strategy. The Preparation phase then covers the tasks need for the following Execution phase to go ahead. This includes activities such as configuring, modelling and customizing the new MES; adapting applications to accommodate data migration; testing and validation of the new system, and even rehearsal of the migration execution. The Execution phase is highly dependent upon the effectiveness of the Definition and Preparation stages. It involves the roll-out of the new system as defined in earlier parts of the project, monitoring of the new system to ensure there are no glitches and shutdown of the routing and synchronization layers installed to enable the migration.

Finally, the Closure phase closes down the project and decommissions unnecessary hardware and software. It includes archiving data from the old MES and may incorporate the activation of new functionality in the installed MES.

Summary

Let's be clear – migration to a new MES is a complex undertaking, especially in highly automated industries. Where current MES are old and present a risk to the future of a business, however, ignoring the issues they have will not make them go away. Inevitably outdated MES will need to be replaced and leaving them in place for longer simply adds to the risk and complexity of a migration project. With the correct planning and expertise, MES migration can happen smoothly even in complex, high volume manufacturing environments. Although payback is not a short term view, modern MES systems can deliver enormous benefits to medium and long term business strategies. Their implementation should certainly be considered before legacy systems become critical and the competitiveness of a business is compromised.

EQUIPNET

DELIVERS PROACTIVE ASSET MANAGEMENT

Dedicated asset managers offer a means to deal more effectively with the equipment implications of mergers, closures and start-ups across ever-changing global chip markets. By: Mike Zunino, Director Semiconductor at EquipNet Inc.

COMPANIES across the semiconductor industry now more than ever are taking advantage of second-hand capital asset management to reap the benefits of identifying, tracking and redeploying equipment internally, as well as to buy and sell major assets. Using software programmes for the internal redeployment of capital assets helps to avoid the cost of purchasing new equipment and provides a return on the original investment of idle surplus equipment and support spares. The program also creates significant savings by buying secondary equipment. With the high demand and cost of new semiconductor equipment, purchasing assets from secondary markets can help to save time and money and still maintain the high-quality standards of having such machinery on production lines.

This article considers the revolution of tracking and redeployment systems within the semiconductor industry, as well as the wider benefits of proactive asset management. It will also focus specifically on the LED market as a perfect example of a key secondary user segment that has benefitted tremendously in cost avoidance.

The semiconductor market has been through a vast amount of change over the past few years in the form of mergers and acquisitions. In many cases merging companies find that assimilating capital assets creates a distraction from daily business responsibilities. This disruption comes from having to determine the machinery to keep and sell along with establishing the roles and responsibilities of executing sales or repurposing capital equipment. It is commonplace for an organisation to take several months to identify and sort through assets before this is finally resolved. The challenges they face include decision making, asset configuration and capability review, as well as financial responsibilities and buyer discovery as well as project management for excess equipment sales. This pull on the merged company's focus can become so distracting that leaders miss important marketplace opportunities. These challenges can be made more difficult when factory closures occur, which can often lengthen the process to up to a year or longer. So, at the time of a merger or acquisition, professional asset management is crucial to ensure a smooth transition. It allows full understanding of each company's capital asset inventory without having to commit resources from both the acquiring and acquired companies to obtain detailed information concerning all equipment now jointly held.

A revolutionary method

Asset management companies fully understand the issues of professional equipment and instrumentation management, with first-hand experience of work with major semiconductor companies. These professional asset managers have created an all-encompassing solution to this issue.

EquipNet's bespoke solution to managing complex equipment issues includes its Asset Redeployment Management System (ARMS). EquipNet deploys a trained and experienced team to a company's facilities to fully document all current excess equipment, including idle production, lab, metrology, test and measurement and even facility support equipment. All the information is uploaded to the ARMS software program (see Figure 1) that is fully customized to a client's requirements and only accessible internally by authorized departments and personnel. Clients are able to obtain full visibility of asset configuration details, location and a current status of their assets 24/7, allowing them to make real-time decisions for redeployment between sites, as well as list assets for remarket, sale or auction. With ARMS, once a decision is made about an asset's disposition, EquipNet's Global Logistics department can arrange crating, shipping, exportation and importation documentation for the final destination—all through the simple click of a button.

Furthermore, there are a number of important additional asset management requirements provided by EquipNet. For example, EquipNet assigns a dedicated Project Management team to each client. This team provides current market values to the client, as well as coordination of de-installation, rigging, relocation and installation, post sale management, as required, handling all requirements up to and including full site closures.

An example of how EquipNet is continuing to expand its support to clients is its acquisition of Quality Equipment Source, Inc. (QES), a refurbishment and repair facility in San Jose, CA. Additional end user requirements can now be performed through this newly acquired facility, and with the QES team joining forces with more than 170 EquipNet employees worldwide, the company is fully capable of managing any business's asset requirements regardless of size or location. EquipNet combines the skills of appraisal, brokerage, and auctioneering of instrumentation and equipment, as well as the de-installation and re-installation of equipment, rendering it a one-stop-shop for companies working in the semiconductor industry. Why use an asset management program?

In recent years, there have been a number of issues in the secondary equipment market due to the amount of start-ups and companies entering the instrumentation auction market. End users can often find themselves faced with conflicting information regarding equipment market values and the availability of instrumentation. 'Ghost markets' have been created, with multiple companies representing and advertising pieces of equipment that are owned by only one of these businesses. This can drive down the market value of equipment since the practice makes it appear that there are multiple assets available; this can also set future market value precedence for all similar makes and models of equipment.

EquipNet staff package and load process tools located in an Idaho (US) fabrication facility to another location in the United States

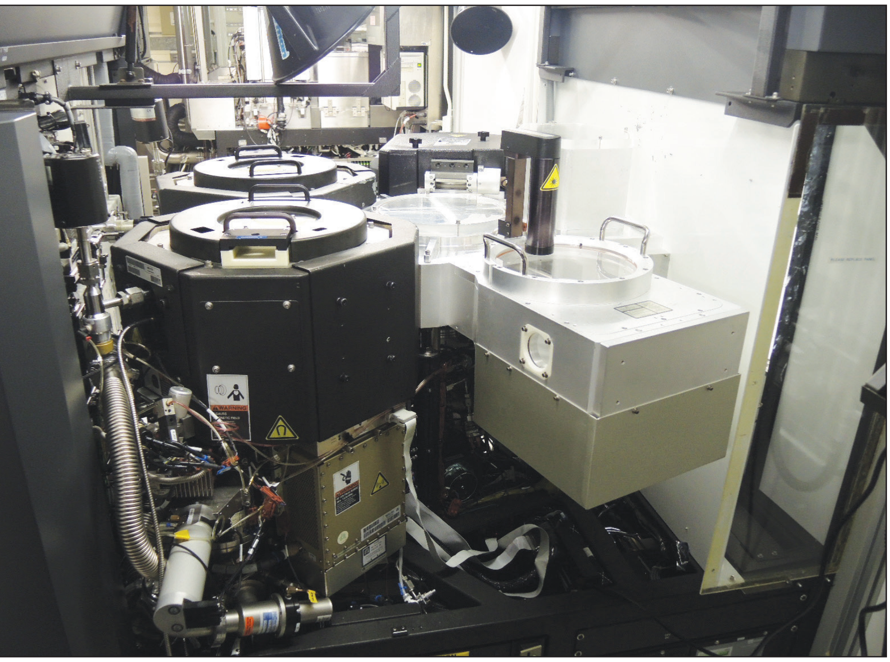
Ghost markets can also cause a problem for end users seeking to purchase a piece of equipment in the secondary market. Without direct access to the seller, companies find themselves paying over the odds for equipment and instrumentation. An example of the problems that buyers and sellers face include an end user that was purchasing a piece of equipment through the secondary market that later discovered they had purchased one of their own pieces of excess equipment from another of their sites.

Using an asset management program informs the buyer of the location of equipment that is for sale as well as identification of the seller. Programs also provide other critical instrumentation facts such as specifications and warranty details. Furthermore, Unfortunately, for some buyers many of the larger semiconductor companies have already scrapped a vast amount of their legacy equipment due to the limited buyer base prior to LED manufacturing's ascendency, which has often left manufacturers seeking quality, smaller format equipment scrambling for process tools at affordable prices

asset management providers implement critical services such as refurbishment and installation. It is therefore important that end users have the confidence to use an asset management provider, giving them the experience, transparency, reliability and trust they need when dealing in the secondary equipment market.

The LED solution

With the LED market growing worldwide, the demand for 4-inch (100mm), 5-inch (125mm) and 6-inch (150mm) manufacturing equipment has also increased dramatically. Because many of the largest semiconductor manufacturers converted to 8-inch (200mm) or 12-inch (300mm) wafer processing equipment, the process tools for handling smaller size wafers went into the secondary equipment market or were scrapped, which meant that with the advent of LED manufacturing and its smaller size wafer requirements, the demand for legacy 6-inch equipment has begun to increase. Unfortunately, for some buyers many of the larger semiconductor companies have already scrapped a vast amount of their legacy equipment due to the limited buyer base prior to LED manufacturing's ascendency, which has often left manufacturers seeking quality, smaller format equipment scrambling for process tools at affordable prices.



EquipNet staff relocated this Applied Materials P5000 chemical vapor deposition (CVD) tool in Wales (UK) to a manufacturer's facilities in China.

Today, the demand for legacy processing equipment is high, with more semiconductor products including power devices, MEMS and IGBTs using this technology. Proactive asset management companies, such as EquipNet, continually monitor and provide clients with real time market analysis and industry trends to help them handle both the buying and selling decisions of such legacy processing equipment. This can have a positive impact on their financial bottom line and help buyers to obtain rare and in-demand instrumentation.

Conclusion

Due to the current upsurge in semiconductor mergers/acquisitions, site closures and downsizings, it is crucial that companies have accurate asset information readily available to them. Asset management and redeployment services have been crucial to the success and growth of other industries including biotech, pharmaceutical and wide-ranging consumer product manufacturing over the past 15 years; those same services are now being offered to the semiconductor industry. A team of industry experts that understand the requirements of end user semiconductor companies can empower their clients with services including capital asset redeployment, logistics, refurbishment, repair, installation, purchasing, sales and market evaluations.

Asset management solution providers offer manufacturers critical services to maintain accurate information about the value and location of major capital assets. Programmes such as EquipNet's ARMS enables these businesses to focus on what they do best—producing products—without taking on the added responsibilities of managing excess capital or engaging directly with the secondary equipment market. Surplus asset management allows buyers to acquire good quality, second-user semiconductor equipment, whilst sellers can obtain a good return on their initial investment, hassle-free. With over 170 employees worldwide in North America, Latin America, Europe and Asia, EquipNet can directly support any company's requirements, regardless of size, to provide maximum returns without exhausting internal resources.

To promote your Products and Services contact:
Shehzad Munshi
T: +44 (0)1923 690 215
E: shehzad.munshi@angelbc.com

green pages directory

Flow Solutions

Total Flow Solution

KITZ SCT

http://kitz-sct.jp/english/

TEL +81-3-6404-2171
E-mail info@kitz-sct.co.jp

Furnaces

THERMCO SYSTEMS
A Division of Tetreon Technologies Limited

Furnaces for R&D applications

- Semi-auto and manual load options
- Choice of control system; simple temperature only or flagship PC-MUX PC based control system
- Small footprint with a 300mm flat zone
- High quality construction and components
- Global Service & Support Network

Thermco Systems
Tel.: +44 (0) 1903 891700 Email: info@tetreon.com
Fax: +44 (0) 1903 893888 Web: thermcosystems.com

Plasma Technology

Trymax
PLASMA TECHNOLOGY SOLUTIONS

When plasma matters

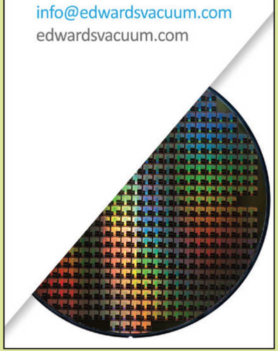
www.trymax-semiconductor.com

Vacuum Equipment

EDWARDS

EXPERIENCE MATTERS

info@edwardsvacuum.com
edwardsvacuum.com



Furnaces

THERMCO SYSTEMS
A Division of Tetreon Technologies Limited

T-Clean Solutions

- Fully automated, semi-auto and manual wet stations
- For semiconductor, industrial and medical applications
- Electroless metal deposition - Au, Ni, Pd, Cu, Ag
- Porous Si etching systems
- Single wafer cleaning and electroplating
- Custom wet chemical solutions for demanding applications
- Chemical delivery and distribution system design and manufacture
- Global Service & Support Network

Thermco Systems
Tel.: +44 (0) 1903 891700 Email: info@tetreon.com
Fax: +44 (0) 1903 893888 Web: thermcosystems.com

Materials, Processes and Equipment

brewer science

Advanced materials, processes, and equipment

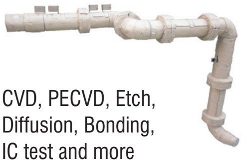
Lithography
Packaging / 3-D IC
Carbon Electronics
Emerging Technologies
Semiconductor Equipment

info@brewerscience.com
www.brewerscience.com

Pump Line Heaters

WATLOW
Powered by Possibility

Optimize the thermal performance of your process equipment



CVD, PECVD, Etch,
Diffusion, Bonding,
IC test and more

European Technical Sales Office
T: +49 (0)7253 9400-0
F: +49 (0)7253 9400-901
E: CCCKronau@watlow.de
W: www.watlow.com

Vacuum Equipment

Vacuum is nothing, but everything for us!

PFEIFFER VACUUM

Pfeiffer Vacuum
Headquarters/Germany
Phone: +49 (0) 6441 802-0
Fax: +49 (0) 6441 802-202
info@pfeiffer-vacuum.de
www.pfeiffer-vacuum.net

Furnaces

THERMCO SYSTEMS
A Division of Tetreon Technologies Limited

Industry Leading Furnace Solutions

- Full automation solutions with cassette to cassette transfer and back-to-back loading
- State-of-the-art computer control system with data collection and analysis
- Load sizes for PV of >500 cells back-to-back
- Characterised processes for PV, MEMS, LED, Nano and Semiconductor technologies
- Largest installed base worldwide
- Highest reliability and proven production systems
- System designs based on over 45 years' experience
- Wide product range from small R&D systems to large production tools
- Global Service & Support Network

Thermco Systems
Tel.: +44 (0) 1903 891700 Email: info@tetreon.com
Fax: +44 (0) 1903 893888 Web: thermcosystems.com

MFCs

Critical Flow Measurement & Control

- World's largest installed base of MFCs
- Factory-certified service
- Advanced diagnostic MFCs

BROOKS INSTRUMENT

www.brooksinstrument.com
888-554-FLOW

Solder Rework

SEMI GAS

ULTRA-HIGH PURITY GAS SOURCE, DISTRIBUTION, AND CONTROL SYSTEMS

(610) 647-8744
SALES@SEMI-GAS.COM
WWW.SEMI-GAS.COM

Wet Process

AP&S

WE ARE THE PARTNER FOR CUSTOMIZED WET PROCESS EQUIPMENT

www.ap-s.de

Tel.: +49 (0) 771 8983-0
Fax: +49 (0) 771 8983-100
E-Mail: info@ap-s.de