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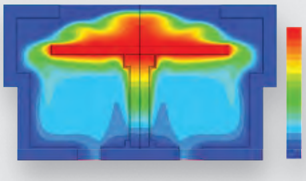

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The 450mm juggernaut

As expected the major manufacturers have instigated the move to 450mm and once again have moved in such a way that OEM and materials manufacturers have no choice but to join in or fear losing out on the next increase in wafer size. At least this is the case for most of the industry except one company whose bold moves have rewritten the way OEMs deal with manufacturers. ASML was one of the first companies I did a profile on when I joined this industry and a great deal has changed to enable the company to not only become the largest OEM supplier on the planet but to have enough clout to encourage manufacturers to invest billions of dollars in ASML to ensure that 450mm targets are made possible.

People should not underestimate the dynamic change that ASMLs dogged insistence that they would not be stumping up the research costs for 450mm and EUV without financial investments from the three major industry manufacturers. When the 300mm transition took place a number of OEM companies attempted to involve the manufacturers in covering the growing research costs on tools that may never see an ROI. One OEM even went as far as providing total solutions for the move to 300mm and the upcoming move towards 65nm but this was dismissed out of hand by the bigger players at the time. In fact much of the dialogue around 300mm was about the unfairness of how costs were distributed along the value chain.

At the time many companies stated they would not allow the manufacturers to dictate the rules at the next size transition. ASML was definitely not one of the companies back then and was not even the number one lithography company. The fact they are now able to dictate terms to the manufacturers shows how much of enabler lithography has become. Not just in terms of the technology but the sheer cost of new tools means they are taking an ever increasing part of the IC pie. A large enough section to be able to give manufacturers a taste of their own medicine.

This will not be the end of the changing dynamics and ASML's boldness only serves a warning that more of this is to come. Maintaining Moore's Law is no longer the right of the manufacturer to expect the required tools. The value chain is more integrated with fewer players so sometimes the choices are limited for manufacturers providing one lithography company the technical expertise required to force a cash up front scenario that would have been unthinkable only a few years ago.

As 450mm takes hold companies will need to ensure potential customers are truly aware of their skill and expertise as there will be richer and louder competitors jumping up and down trying to get the same attention.

David Ridsdale
Editor


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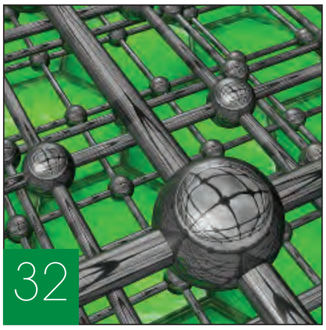

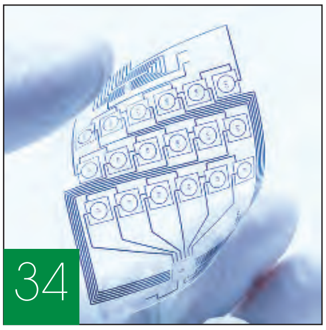

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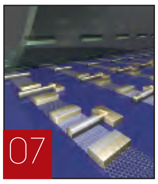

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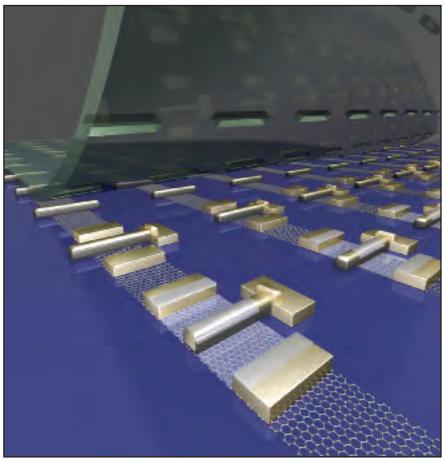
Graphene potential closer



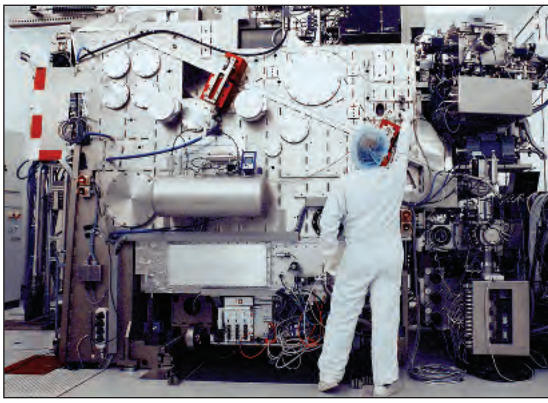
RESEARCHERS have developed a method of manufacturing transistors with graphene that could lead to a consistent and viable manufacturing process for a material that has been showing promise for many years. Graphene, a one-atom-thick layer of graphitic carbon, has attracted a great deal of attention for its potential use as a transistor that could make consumer electronic devices faster and smaller. But the material's unique properties, and the shrinking scale of electronics, also make graphene difficult to fabricate on a large scale. The production of high-performance graphene using conventional fabrication techniques often leads to damage to the graphene lattice's shape and performance, resulting in problems that include parasitic capacitance and serial resistance.

Now, researchers from the California NanoSystems Institute at UCLA, the UCLA Department of Chemistry and Biochemistry, and the department of materials science and engineering at the UCLA Henry Samueli School of Engineering and Applied Science have developed a successful, scalable method for fabricating self-aligned graphene transistors with transferred gate stacks.

By performing the conventional lithography, deposition and etching steps on a sacrificial substrate before integrating with large-area graphene through a physical transferring process, the new approach addresses and overcomes the challenges of conventional fabrication. With a damage-free transfer process and a self-aligned device structure, this method has enabled self-aligned graphene transistors with the highest cutoff frequency to date — greater than 400 GHz.

The research demonstrates a unique, scalable pathway to high-speed, self-aligned graphene transistors and holds significant promise for the future application of graphene-based devices in ultra–high-frequency circuits. Authors of the research include UCLA chemistry postdoctoral scholars Lei Liao and Hailong Zhou; UCLA chemistry graduate students Lixin Liu and Shan Jiang; UCLA materials science and engineering graduate students Rui Cheng, Yu Chen, YungChen Lin and Jinwei Bai (now a research scientist at IBM); UCLA associate professor of materials science and engineering Yu Huang; and UCLA associate professor of chemistry and biochemistry Xiangfeng Duan.

ASML announce results



ASML announced the investment in 450mm by manufacturers signalling a change in industry dynamics and now confirms its global strength with positive fiscal results. The company has confirmed steady sales for the remainder of the year and is on track for 2012 second half sales between EUR 2.2 and 2.4 billion.

"We executed H1 2012 as planned and expect sales to remain steady in the second half," said Eric Meurice, President and Chief Executive Officer of ASML. "The second half revenue level is expected to be between EUR 2.2 billion and 2.4 billion and looks sustainable by an increase of NAND memory critical layer systems shipments, stability of DRAM memory systems sales, and slower 28/32 nm Logic in the second half compared with the first half. The exact level of sales achieved in the second half will depend on the strength of NAND pick up, itself fueled by ultrabook PCs and smartphone ramps."

For the third quarter 2012, ASML expects net sales of about EUR 1.2 billion, gross margin of about 43 percent, R&D costs at EUR 145 million and SG&A costs at EUR 60 million. To date they have shipped 30 TWINSCAN NXT:1950i systems. Also in this quarter A TWINSCAN NXT:1950i has exceeded the productivity milestone of more than 5,100 wafers in a single day, 600 wafers more than the previous record.

"On the technology front, we expect to ship the first of the NXE:3300," Meurice said. "Our production-capable Extreme Ultraviolet (EUV) system, by the end of this year or early next year and the rest of our 11 unit order in 2013. These tools will be used for process development. We are furthermore making progress in preparing EUV lithography for 2014 device production, evidenced by customer commitment to purchase four additional production systems for delivery in 2014. This commitment is enabled by the data gathered on source power increase and by steady performance of the six units already in the field,".

The computational lithography unit Brion delivered enhancements to its leading Mask 3D models and applications, which are required at the 20 nanometer node and below. The full accuracy of the Brion Mask 3D models can now be realized with virtually zero incremental computational cost as well as substantially less accurate thin mask models.

With regards to productivity of the EUV source, 50 Watt power capability has been repeatedly demonstrated at a supplier and 105 Watt concept potential has been confirmed in lab experiments, supporting the roadmap to volume production systems starting at 70 wafers per hour. In situ experiments on the NXE:3300 will however still be necessary for full confirmation.

ASML announced a co-investment program in which customers will potentially contribute up to EUR 1.38 billion over the next 5 years to accelerate the development of 450mm wafer platform and the next generation of EUV systems, expected to enter volume production in the second half of this decade.

Inventory fall improves DRAM pricing

PRICING for dynamic random access memory (DRAM) is set to increase as a key indicator shows that inventory levels are falling relative to demand, according to an IHS iSuppli DRAM Dynamics Market Brief. The steady upturn of the DRAM market is reflected in the current Weeks of DRAM Inventory Index, which dropped to 11.6 weeks in the first quarter this year, down 4 percent from 12.1 weeks in the fourth quarter of 2011, as shown in the figure attached. It was the second consecutive quarter of improvement since the index hit 12.9 weeks in the third quarter last year. The decline also represents a significant turnaround from the major increases in the indices that ruled during most of 2011. Declining stockpiles of DRAM indicate that supply is coming into better balance with demand, resulting in stabilization of pricing.

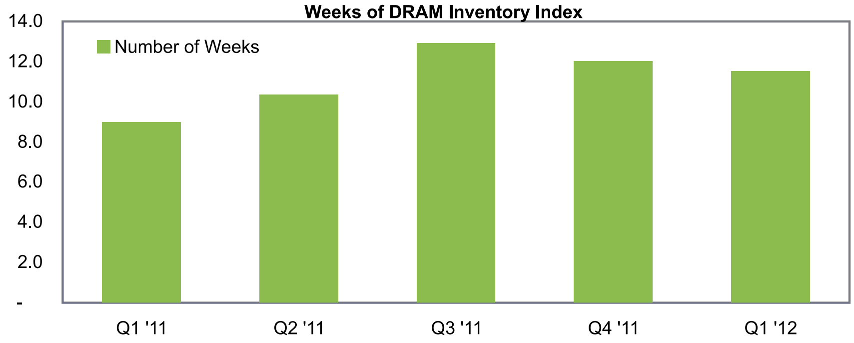
"The latest drop in the Inventory Index is due primarily to an aggressive stockpile burn-off from Japanese supplier Elpida, which declared bankruptcy in February," said Clifford Leimbach, analyst for memory demand forecasting at IHS. "The action taken by Elpida—and the resulting drop in overall inventory levels for the industry in the first quarter—is a one-time event unlikely to be repeated. Even so, the reduction in stockpiles in early 2012 means that pricing should continue to strengthen in the second half of the year."

Average pricing for DRAM in the 1 gigabit-equivalent density is preliminarily estimated to have risen by 1.5 percent in the second quarter, and is then set to climb by 7.7 percent and 3.5 percent in the third and fourth quarters, respectively.

IHS iSuppli Figure: Weeks of DRAM Inventory Index

	Q1 '11	Q2 '11	Q3 '11	Q4 '11	Q1 '12
Number of Weeks	9.0	10.4	12.9	12.1	11.6

Source: IHS iSuppli Research, July 2012



Source: IHS iSuppli Research, July 2012

This follows sharp declines of 24 percent and 12.4 percent in the third and fourth quarters of 2011, as well as a 5.9 percent decrease in the first quarter of 2012. Inventory in the first quarter could have declined to even lower levels were it not for the elevated DRAM stockpiles of two of the largest DRAM players. SK Hynix Semiconductor Inc. of South Korea and U.S.-based Micron Technology Inc. saw a modest 15 percent and 8 percent rise, respectively, in their inventories during the period, putting upward pressure on the index value that also prevented the drop from being larger in the first quarter.

Still, the inhibiting effect of SK Hynix and Micron should not be construed as a negative, IHS believes, because there is strong feeling throughout the industry that the DRAM average selling price (ASP) will strengthen in the second half of this year. Renewed optimism for PCs spurred by Ultrabooks, and the impending release of Windows 8, will likely translate into strengthened DRAM demand, bringing supply and demand into closer balance.

As DRAM prices rise because of these market forces, SK Hynix and Micron could be well-positioned to take advantage and sell the inventory that they have built up. Such favourable conditions point to a stronger DRAM market during the next few quarters and mean that the index will continue to decline. DRAM firms appear to be comfortable with their inventory levels overall, positioning themselves to reap the rewards of an expected increase in demand during the succeeding quarters. Despite the positive step forward for the market, the DRAM Inventory Index in the first quarter remained elevated above the 9.0 weeks recorded the same time a year earlier in the first quarter of 2011.

Furthermore, the index during the last four quarters has been above the long-term average of 9.5 weeks. Anything exceeding this threshold is considered undesirable because it indicates high inventories and weak DRAM demand. And with DRAM prices on the retreat, holding onto inventory costs money for firms as they are unable to sell product for revenue.

Large order for BSE Tech

BSE Tech, a BSE Group company announced it has sold diffusion equipment used in front end semiconductor production to Microchip Technology. The equipment will be used in Microchip's facility for production of its PIC microcontrollers.

"Adding Microchip as a customer is a significant development for BSE Tech," said Colin Scholefield, executive vice president, BSE Group, holding company of BSE Tech. "Over the last year, we have significantly invested in our BSE Tech business, which has contributed to growing our customer base with high quality companies like Microchip Technology."

"The secondary equipment market is a part of our overall equipment strategy to optimize our capital equipment budget," said Ed Lindstrom, manager, Supply Management, Microchip Technology. "BSE Tech delivers the high quality tools that are essential to realizing the value proposition in the secondary market."

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China PC growth

CHINA'S domestic PC shipments in 2012 are set to rise at three times the rate of the global market, driven by strong economic growth and demand from the commercial sector, according to an IHS iSuppli China Electronics Research report. PC shipments in China for 2012 are projected to reach 83.6 million units, up 13.1 percent from 73.9 million units last year. In comparison, global shipments are set to increase by only 4.4 percent this year.

Domestic shipments of both desktop and notebook PCs to the Chinese market have been growing at robust double-digit rates for several years, and the healthy pace of expansion is set to continue for at least two more years before the market moderates slightly to a 9 percent increase in 2015. Shipments will amount to some 129.4 million units at the end of 2016, as shown in the figure attached, equivalent to a five-year compound annual growth rate of 12 percent.

"A result of the country's fast-paced economic expansion, China's PC shipment growth is exceptional, especially when compared to the tepid growth anticipated this year in PC shipments for the rest of the world," said Elaine Zhi, analyst for China electronics research at IHS.

China's domestic PC shipments are also impressive when compared to global or other regional sums. The country's domestic PC shipments in 2012 are expected to be equivalent to 23 percent of the world's total of 368 million units, and they account for a staggering 63 percent of all PCs shipped in the Asia-Pacific region. Notebook PCs will lead China PC shipments this year, amounting to 42.5 million units, up from 35.8 million units in 2011. In comparison, desktop PCs will come in slightly lower at 41.1 million units, up from 38.1 million units.

The biggest PC maker in the country is Beijing-based Lenovo, projected to ship 29.9 million units domestically this year, equivalent to 36 percent of China's domestic PC market. Following Lenovo in the Top 5 are Acer with 11 percent market share; Dell with 8 percent; Hewlett-Packard with 6 percent; and Asus, also with about 6 percent.

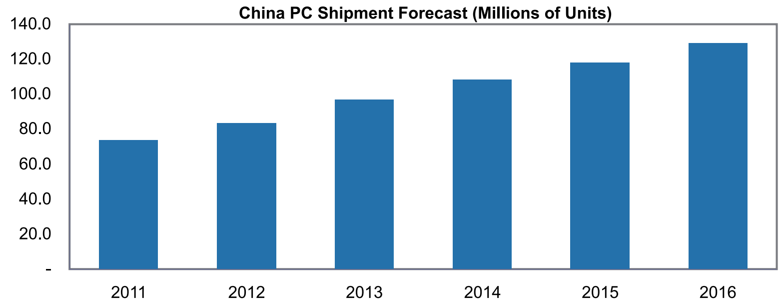
China's export PC sector is bigger than its domestic counterpart. Full projections for this year are not yet available, but Chinese PC makers last year exported a total of 234.1 million notebooks and 37.2 million desktops. Quanta Computer, Hon Hai and Compal Electronics were the country's Top 3 notebook PC exporters in 2011 with a combined market share of 64 percent; while Foxconn, Quanta and Pegatron were the Top 3 desktop PC exporters during the same time with a collective 53 % share.

Hon Hai and Foxconn are the same entities operating under different trade names, and the company as a whole is also among the world's largest providers of outsourced manufacturing services, with clients including Apple, Hewlett-Packard, Sony and Dell.

IHS iSuppli Figure: China PC Shipment Forecast (Millions of Units)

	2011	2012	2013	2014	2015	2016
Millions of Units	73.9	83.6	97.0	108.6	118.4	129.4

Source: IHS iSuppli Research, June 2012



Source: IHS iSuppli Research, June 2012

Panasonic commits to imec programme

IMEC and Panasonic have entered into the next phase of a collaboration agreement for joint R&D on healthcare, wireless communication, flexible electronics and advanced CMOS process technologies. The signing ceremony at the Panasonic Headquarters in Osaka was endorsed by the presence of His Royal Highness Prince Philippe of Belgium.

Panasonic has been a core partner in imec's research platform on advanced semiconductor process technologies since 2004. This collaboration has been fundamentally broadened in 2008, expanding the collaboration scope from advanced semiconductor process technology to also include various application areas of semiconductors.

Throughout recent years, Panasonic residents have been working closely together with imec's research teams both in Leuven, Belgium and Eindhoven, The Netherlands. Together, they have achieved breakthrough results in wireless communication, healthcare and next-generation CMOS technologies. The new agreement extends this collaboration for a period of 3 years and further expands to research on flexible electronics.

Luc Van den hove, President and CEO of imec, "I am very pleased that we will continue our strategic collaboration with Panasonic the coming years. The extension and expansion of our research collaboration is a confirmation of the value of our research offering to the industry. Through a collaborative approach of R&D, sharing resources and results, but also strongly protecting the generated IP, imec supports Panasonic already for 8 years to be at the forefront of innovation."

Yoshiyuki Miyabe, the member of the board, managing director and CTO of Panasonic, "Panasonic continued to keep good relationship with imec for these 8 years. We hope to strengthen our "win-win" relationship for both imec and Panasonic to prosper."

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Toshiba returns to top of NAND rankings

AFTER persevering through a devastating earthquake and two major revenue declines in 2011, Toshiba in the first quarter of 2012 made a comeback in the NAND flash memory business, achieving double digit growth that defied an industry wide contraction in revenue.

Toshiba of Japan posted NAND sales revenue of $1.71 billion in the first quarter, up 19 % from $1.43 billion in the fourth quarter of 2011.That growth performance gave the company a 34 % share of the worldwide market, up from 28 percent in the fourth quarter, according to an IHS iSuppli Flash Market Brief report.

In contrast, the overall NAND flash market suffered a 1 percent sequential decline in revenue, and all the other suppliers experienced sales decreases, most by double-digit percentages.

"Toshiba's improved performance in the first quarter came after a troubling 2011," said Dee Nguyen, memory analyst at IHS. "Last year NAND market share saw two major declines. The first drop because of disrupted production stemming from the Japan earthquake-tsunami disaster. The second decline arrived later when an uncertain market necessitated a carryover of inventory into the first quarter this year. Toshiba's strong results show that the company has regained its footing and has put a tumultuous year behind it."

The market for NAND flash in the first quarter was dragged down by weak pricing, which reflected the mismatch between an industry-wide growth in supply and a seasonally slow quarter for consumer demand. NAND flash is used in a wide range of products, including smartphones, tablets and solid state drives that form part of the storage systems of faster and thinner laptop computers, including the MacBook Air from Apple Inc. and ultrabooks championed by Intel Corp. But with the exception of Toshiba, NAND suppliers experienced revenue declines that ranged from a soft landing for Samsung to a steep drop-off for Powerchip Technology Corp.

Samsung maintained its lead with a 37 % share despite lower revenue in the first quarter of $1.86 billion, down sequentially from $1.94 billion. U.S.-based Micron Technology Inc., SK Hynix Semiconductor Inc. of South Korea and Powerchip of Taiwan rounded out the rest of the tightly held NAND market. Overall first-quarter NAND flash sales amounted to $4.99 billion, down 1 percent from $5.05 billion in the fourth quarter last year.

Samsung posted the highest total revenue among the decimated group, even though its quarterly share of the market inched down by a percentage point. Samsung's quarterly revenue decline was just 4 percent, compared to double-digit drops ranging from 14 % in Micron's case to a sharp 35 percent tumble for Powerchip, with Hynix somewhere in the middle with its 17 % contraction. Samsung's decline was due to a 10 % fall in the ASP of its NAND product, as well as because of the company throttling production in one of its fabs while preparing to transition to the firm's System LSI division that makes processors and chipsets. The company is optimistic about a stronger second quarter, as handset and PC manufacturers launch new products for the upcoming high-demand seasons.

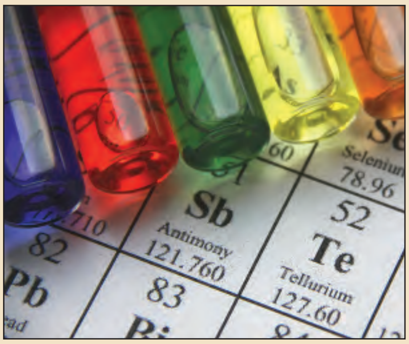
Micron maintained its place at No. 3 with revenue of $846 million, equivalent to a 17 percent market share. The only U.S. maker of memory semiconductors, Micron reported a 23 % retreat in its NAND ASP during the period. However, the Idaho-based maker should be able to grow market share in the coming quarter after purchasing the remainder of a joint-venture stake it holds with Intel Corp. in managing fabs in Virginia and Singapore.

At No. 4 was SK Hynix with revenue of $556 million for an 11 percent share of market. The company recorded tepid shipment growth of 2 percent, amid an ASP decline in of 16 % in light of weak seasonal demand. SK Hynix also has maintained a cautious outlook for the second quarter, guiding ASP declines in the midteens out of concern for possible oversupply as a result of industry capacity growth. The fifth-ranked player, Powerchip, had NAND revenue of $17 million for approximately 0.3 percent market share.

Overall, Toshiba continues to narrow the gap with NAND market leader Samsung, with the race for No. 1 expected to further heat up during this year. The battle for third place will also continue between Micron, currently comfortable in its lead, against Hynix, which now appears willing to spend its way to the top and tackle competitors head on to remain a viable player in the space.

Brewer Science founder appointed to SEMI board

DR. TERRY BREWER, founder and President of Brewer Science, has been appointed to the SEMI North American Advisory Board. With this appointment, Dr. Brewer joins a group of leaders in the nano- and microelectronics fields along with whom he will advise on global technology matters. Dr. Brewer's appointment to the board was announced by Karen Savala, president of SEMI Americas.



"It's important that the composition of the SEMI North American Advisory Board represents the breadth of SEMI membership, so we balance participation by industry segment served, product area, and company size. Dr. Brewer's election brings a Central US perspective, which is not currently represented, and therefore adds a new dimension to the Board. We're delighted that Dr. Brewer will join this esteemed group of advisors to SEMI," said Karen Savala.

"I am so pleased to be able to serve our industry as a SEMI North American Advisory Board member and hope to share in making a positive difference in difficult times," said Dr. Terry Brewer.

Self assembly accelerator for Tokyo Electron at imec

IMEC and Tokyo Electron (TEL) have announced that they will accelerate their Directed Self-Assembly (DSA) activities at imec's recent 300 mm fab-compatible DSA process line. Over the past two years, both companies have been actively engaged in DSA development. Based on results achieved on imec's 300 mm DSA process line, imec and TEL will expand their focus to explore DSA as viable patterning technique for 2x and beyond technologies.

Recent evaluations have demonstrated the feasibility of DSA to enable frequency multiplication through the use of block copolymers. Line features as small as 12.5 nm and 25 nm contact holes have been patterned on 300 mm substrates at imec using pre-patterned lithography followed by DSA. In recent experiments using pre-patterned EUV holes interfaced to ASML's NXE:3100, DSA repaired defective features, lowered line edge roughness (LER) and improved critical dimension (CD) uniformity.

For widespread DSA implementation, lower defect levels are required, and DSA needs to be integrated into existing flows. Imec and TEL are investigating various integration scenarios for line and hole patterning. Comprehensive evaluations to understand material and process interactions on CD uniformity, LER and defect levels are planned.

To push the capabilities of DSA beyond lab-scale environments, one of the world first 300 mm fab-compatible DSA process lines all-under-one-roof was recently implemented in imec's 300 mm clean room fab. In addition to TEL's especially configured DSA coater/developer managing gallon-sized quantities of block copolymers, and TEL's dedicated etch system supporting the DSA pattern transfer, imec has the necessary metrology, cleaning and pattern transfer toolsets. To complete the DSA process line and accelerate R&D on DSA at imec, TEL will provide imec with new hardware within the next few months.

"With specially configured DSA coater/developer and etch systems at imec, we have the capability to explore DSA as a potential candidate for next-generation patterning technology", commented Chung Gishi, Executive VP of Tokyo Electron Ltd. "We hope to understand the critical processes necessary to move early stage development into volume production to benefit our customers".

"DSA continues to show much promise as part of the toolbox for advanced sub-20 nm patterning. Our collaboration with Tokyo Electron has enabled us to rapidly implement DSA processing knowledge that has been developed in academia at the group of Prof. Paul Nealey (University of Wisconsin at Madison) into a representative manufacturing environment. We are excited to extend this effort to dedicated newly developed DSA modules.

imec looks at future gate options

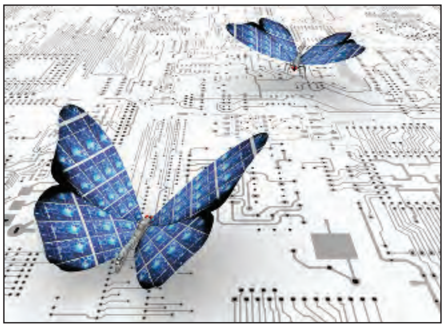
IMEC is successfully testing and evaluating various options for further transistor scaling using high-k dielectrics and metal gates in a replacement metal gate (RMG) integration schema. Although RMG technology is inherently more complex than gate-first integration, it has a number of advantages that allow increasing the device performance and that widen the choices in terms of high-k and metal gate materials.

One of the current challenges to enable further device scaling is the choice of gate dielectric and gate electrode. For the gate electrode, the key parameters to consider are the work function, resistivity and compatibility with CMOS technology. Further scaling also requires continued improvement of the channel mobility, adding the options for improved stress management and also reliability control as a first-order consideration in the choice of materials and processes.

In the industry, the RMG approach is rapidly becoming the integration scheme of choice, and an alternative for the gate-first approach. In RMG, the high-k gate dielectric is deposited in the beginning of the flow or just prior to gate electrode deposition and the electrode is deposited after the formation of the junctions.

A clear advantage is the enhancement of the channel stress in shorter devices because of the dummy-gate removal, an intrinsic step in RMG flow. RMG also allows metal gate processes with a lower thermal-budget, which broadens the range of material options for work-function tuning and reliability control. Advantages are a lower gate resistance compared to gate-first, important for RF CMOS, and more room for mobility improvement.

Imec and its partners have had an important role in the introduction of high-k metal gate processes, building a strong expertise and track record. With the eye on further scaling to sub-20nm technology nodes, they are now evaluating RMG



technology for different application, materials selection and engineering, and compatibility with advanced modules and device architectures, for which we collaborate with the major tool suppliers. For our partners, we conduct fair comparisons of options, and in-depth understanding of the physical mechanisms and techniques involved, and the chance to explore the limits in performance and reliability.

The research is performed in cooperation with imec's key partners in its core CMOS programs Globalfoundries, INTEL, Micron, Panasonic, Samsung, TSMC, Elpida, SK hynix, Fujitsu and Sony.

Platinum ALD films

Atomic layer deposition (ALD) is gaining traction as a viable manufacturing method for future devices and qualification continues on an array of materials and potential applications. Dr. Qi Fang and Dr. Tom Sharp of Oxford Instruments Plasma Technology, discuss results of both remote-plasma and thermal-ALD processing for the deposition of ultra thin platinum films.

Ultrathin metallic layers such as Platinum (Pt), Ruthenium (Ru), Palladium (Pd) and Copper (Cu) deposited onto oxide structural surfaces have wide applications in microelectronics, catalysis, photonics and chemical sensing [1-4]. Platinum films have a variety of potential applications in nanotechnology, microelectronics and energy technologies due to their chemical stability, catalytic activity, and excellent electronic properties [5-7]. During the past decade atomic layer deposition (ALD) has emerged as an outstanding technique to achieve accurate thickness and self-limiting control and is used to fabricate ultrathin and conformal thin film structures. This is useful for many potential applications in advanced high dielectric constant (high-k) gate oxides, electrode and connection materials, storage capacitor dielectrics and copper diffusion barriers in advanced electronic devices, as well as for solar energy and biological applications [8, 9].

FlexAL, Oxford Instruments Plasma Technology

A unique attribute of ALD is that it uses sequential self-limiting surface reactions to achieve control of film growth in the monolayer or sub-monolayer thickness regime. Therefore, ALD is receiving wide attention for the ultrathin layers grown onto micro- and nano-devices with three-dimension in a high aspect ratio. Furthermore, ALD can also be used for any advanced technologies that require control of film structure in the nanometer or sub-nanometer scale due to its capacity for self-terminating conformal layer formation.

Most Pt ALD processes reported used thermal ALD process using methylcyclopentadienyl trimethylplatinum ($MeCpPtMe_3$) and O_2 gas [10-12]. This process is based on the dissociative chemisorption of O_2 on the Pt surface for oxidative decomposition of the precursor ligands [13]. However, this oxidative decomposition becomes extremely difficult in the initial stage of a thermal ALD process (before formation of Pt nano-particles), leading to a nucleation delay. Knoops and his co-authors reported on the Pt and Pt O_2 processes by using both remote plasma ALD and the thermal ALD of Pt. Their work shows that the remote plasma process leads to immediate growth without substantial nucleation delay, while the thermal ALD process leads to no growth at all unless a Pt starting surface or a high O_2 pressure is employed [1]. In the O_2 plasma, O radicals are created, providing atomic O to the surface directly from the gas phase, enhancing oxygen chemisorption on the surface and oxidation of the precursor ligands. [14]

However, despite its successful Pt depositions, the ALD process lacks a detailed atomic-scale understanding of the formed interface structure and the effect of substrate used on the Pt growth, which is extremely important for microelectronic applications. In this work, platinum films were grown on Si wafers, SiO_2, Al_2O_3 and high-k dielectric HfO_2 ALD films on Si substrates by both remote plasma and thermal atomic layer deposition (ALD), using methylcyclopentadienyltrimethyl platinum ($MeCpPtMe_3$) and O_2 as precursors. The Pt ALD growth behaviours with precursor dose times, O_2 or O_2 plasma exposures and substrates are investigated. Furthermore, the Pt ALD process on various oxide substrates, Pt nucleation process, electrical property and chemical impurities of the Pt thin film are also discussed.

Experimental

The Pt films were deposited in an ALD system with load-lock delivery (FlexAL, Oxford Instruments Plasma Technology). The deposition system was connected to an in-situ ellipsometer and an inductively coupled plasma (ICP) source, which gives the ability to run both thermal and remote plasma ALD modes within a single system.

The pump unit consisted of a turbo molecular pump and a dry pump reaching a base pressure of 1 x 10^{-6} mbar. Trimethyl (methylcyclopentadienyl) platinum(IV) ($MeCpPtMe_3$) (SAFC, Sigma-Aldrich) in a stainless steel bubbler, heated to 70°C, was used as Pt- precursor and vapor drawn into the chamber.

The deposition of Pt films was carried out by both thermal and remote O_2-plasma ALD at 300°C, using methylcyclopentadienyltrimethyl platinum ($MeCpPtMe_3$) and O_2 as precursors. The $MeCpPtMe_3$ precursor was vaporized at 70°C using the vapour-draw method without bubbling gas and using 200sccm of Ar gas flow as purge gas.

To maximise precursor usage, the first half-cycle consisted of $MeCpPtMe_3$ precursor dosing with the bottom valve closed (no pumping) a holding for 5-10 seconds, in the process investigation. Si (100) with native oxide layer was used as the substrate. For the oxide samples, Si (100) substrates were first coated prior to the Pt metal ALD with 10-20 nm of ALD Al_2O_3, HfO_2 and SiO_2 using alternating ALD processes of TMA(trimethylaluminium)/O_2-plasma, TEMAH [Tetrakis(ethylmethylamino) hafnium]/O_2-plasma and TRDMAS [tris(dimethylamino) silane]/O_2-plasma, respectively. Table 1 shows the details of the four types of substrates used, namely: Si wafers, SiO_2, Al_2O_3 and high-k dielectric HfO_2 ALD films on Si substrates. ALD chamber pressure was varied from 10 to 40 millitorr during the process steps. Not only the wafer holder stage was heated but also the chamber wall and delivery line were heated to a temperature of 120°C and 80°C, respectively, to prevent the precursor condensation and make the sample surface temperature the same. The remote O_2 plasma was generated by a radio frequency (rf) induction-type plasma generator (ICP). The plasma power was 300 W.

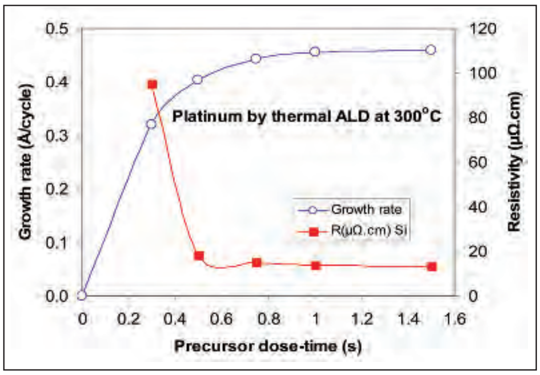


Figure 1, growth rate and resistivity of platinum films by thermal-ALD at 300°C vs precursor dose-time for 600 cycles

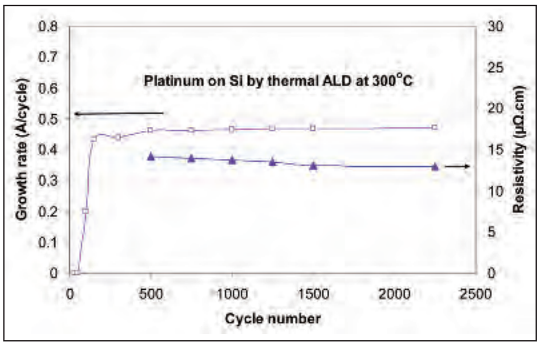


Figure 2, growth rate (GR) and resistivity of platinum films by thermal-ALD vs cycle number and it is found that a GR of Pt thermal-ALD is around 0.45-0.47Å/cycle and the resistivity range of 14.1 to 12.8 μΩ-cm from 500 cycle to 2250 cycle

The thickness and the refractive index of the ALD films were measured using a J.A. Woollam M2000V spectroscopic ellipsometer (370nm-1000nm wavelengths) and also confirmed by cross sectional SEM (Zeiss, SUPRA-25). Energy dispersive X-ray (EDX) (INCA-7426, Oxford Instruments) and Auger Electron Spectroscopy (AES) were used for determining the chemical composition and element profile of the ALD films.

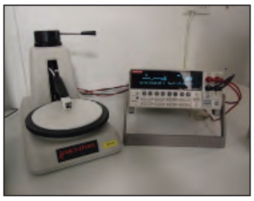
A 4-point probe (Signatone 4 point probe with a Keithley 2410 Source) was applied for testing the electrical property of the film.

Outcomes

Figure 1 shows the growth rate and resistivity of platinum films by thermal-ALD against the precursor dose-time for 600 cycles at 300°C. The growth rate of 0.45-0.47 Å/cycle and the resistivity of platinum films of about 13.5μΩ-cm from 600 cycles were obtained. To confirm the growth rate and to investigate the relationship of resistivity and film thickness of the platinum films by thermal-ALD,

Substrate	ALD-oxide process	ALD oxide film thickness (nm)	ALD process temperature (°C)	ALD precursors
Si(100)	/	/	/	/
SiO2/Si	Plasma-ALD	10	200	TRDMAS
Al2O3/Si	Plasma-ALD	18	200	TMA
HfO2/Si	Plasma-ALD	10	290	TEMAH

Table 1, the substrates used for ALD-Pt film deposition



Signatone 4-point probe connected to a Keithley 2410 Source meter

Figure 2 gives the growth rate (GR) and resistivity of platinum films using ALD cycle numbers up to 2250. It is found that GR of Pt increases slightly for long deposition, but is still around 0.45-0.475Å/cycle. The resistivity of Pt films are in a range of 14.1 to 12.8μΩ-cm from 500 to 2250 cycles and the resistivity of the Pt layer on Si was found to be slightly reduced with increasing Pt thickness, the lowest resistivity of 12.8 μΩ.cm were measured with a Pt thickness of 100nm on Si substrates. The Pt nucleation and growth in ALD processes was investigated by SEM.

The nucleation delay in thermal ALD of Pt was found to be approximately 70 cycles from Figure 3, which has been confirmed by SEM observations. Elam reported the nucleation behaviors of Pd and Pt on various substrates. [15, 16] They found that the Pt films deposited concurrently on Si (100) substrates showed Pt particles that increase in size with the number of Pt ALD cycles performed such that the Pt film is nearly continuous after 75-100 cycles. [16]

Platinum by plasma-ALD

Figure 4 shows the growth rate of platinum films by plasma-ALD against precursor dose-time at 300°C. The growth rates of 0.43-0.45 Å/cycle were obtained, which is comparable to that of thermal ALD.

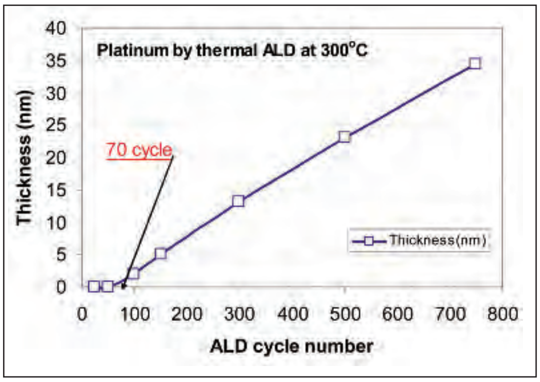


Figure 3, thickness of platinum films by thermal-ALD vs cycle number at 300°C and the nucleation delay of Pt thermal-ALD to be found is around 70 cycles

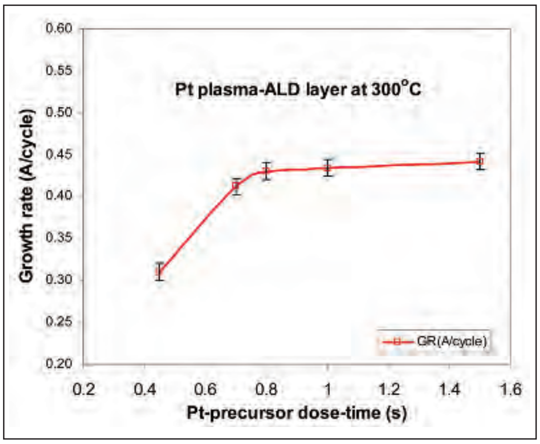


Figure 4, growth rate of platinum films by plasma-ALD at 300°C vs precursor dose-time

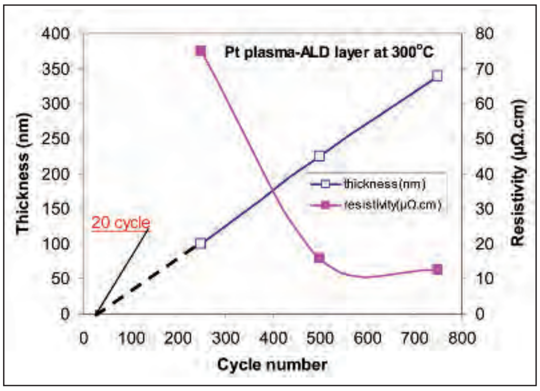


Figure 5, thickness and resistivity of platinum films by plasma-ALD vs cycle number at 300°C and the nucleation delay of Pt plasma-ALD is around 20 cycles. Comparing to the nucleation delay of Pt thermal-ALD of 70 cycles, it shows that plasma-ALD can reduce nucleation delay of Pt

The thickness and resistivity of platinum films by plasma-ALD with cycle number at 300°C are shown Figure 5. The resistivity of the platinum films is below 14.5 μΩ.cm after plasma ALD of 500 cycles and the nucleation delay of Pt plasma-ALD is around 20 cycles. Comparing to the nucleation delay of Pt thermal-ALD of 70 cycles, it shows that plasma-ALD can reduce the nucleation delay of Pt.

The remote plasma enhanced ALD Pt films showed a short nucleation delay on all the different types of substrates, and an active nucleation behaviour which resulted in a very smooth film surface morphology. AES profile scanning and EDX testing were applied for the elemental analysis in the film and interfaces. AES studies revealed high quality Pt films deposited by both thermal and plasma ALD with carbon impurity less than 1.5% and oxygen found only in the interface (Fig.7).

Pt islands and nucleation delay

Our initial Pt thermal ALD experiments on Si surfaces revealed nucleation and growth behaviour of forming Pt nanoparticle islands. Figure 8(a) and 8(b) show a similar SEM cross-section thickness of Pt-ALD films grown by using plasma and thermal ALD for 500 cycles at 300°C. The particle-size measurement was based on SEM and SE.

One example of average Pt-size of 5.5 nm grown on Si by thermal ALD for 150 cycles at 300°C is shown in Figure 8(d). The detailed measurements showed that the average nano-particle island size of Pt

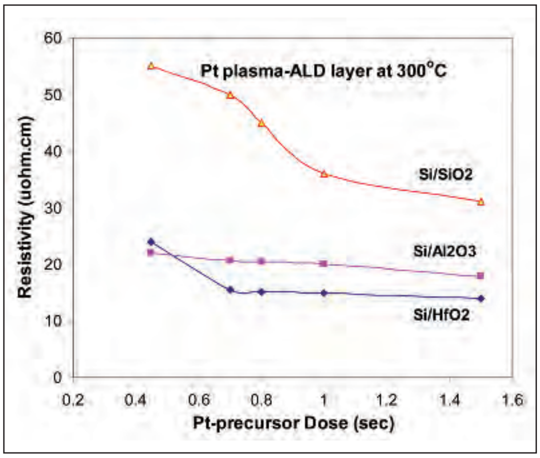


Figure 6, resistivity of platinum film on various oxides by plasma-ALD at 300°C vs precursor dose-time. It is clear that the order of resistivity of Pt film grown on oxides is Si/SiO_2 > Si/Al_2O_3> Si/HfO_2

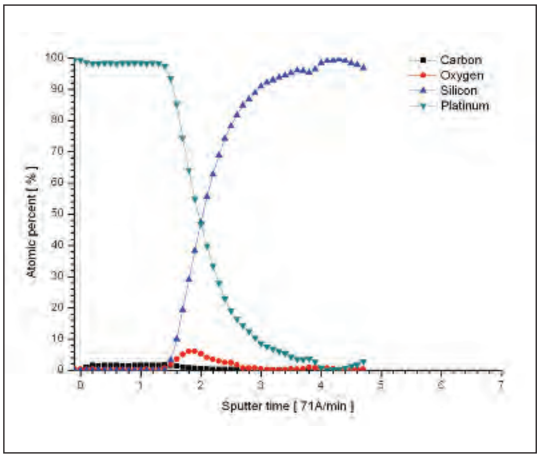


Figure 7, AES of 30nm Pt film grown by plasma-ALD

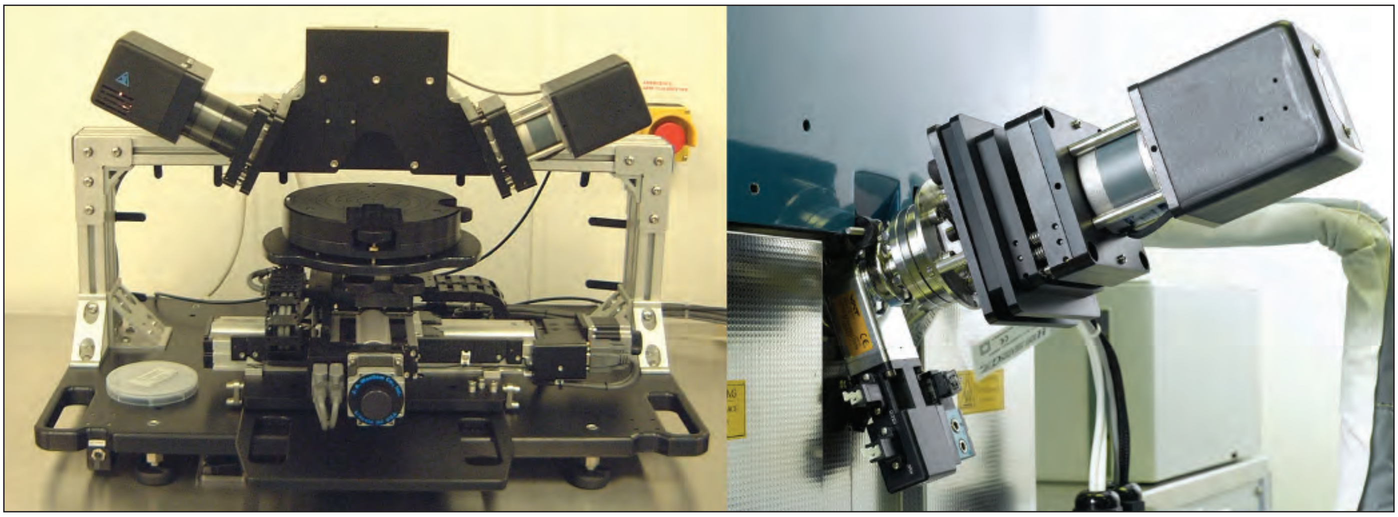
grown on Si by plasma ALD is bigger than that of thermal ALD at same cycle numbers.

Table 2 gives a short summary of Pt particle-size at 50 and 100 cycles, respectively, and the process data of Pt films on the surface of Si, SiO_2, Al_2O_3 and HfO_2 deposited at 300°C by thermal and remote plasma ALD for 500 cycles. The growth rate and resistivity of Pt plasma-ALD layers on various oxides is shown in Figure 9.

HfO_2 shows the highest growth rate and the lowest resistivity of them. It is believed that surface functionalisation by plasma-ALD and rich-absorbed oxygen radicals on HfO_2 surface are the reasons.

From Fig.3 and Fig.5 we have found that the Pt films deposited on Si (100) substrates showed a Pt nucleation delay of 70 cycles and 20 cycles grown by thermal ALD and plasma-ALD before the Pt ALD process goes to a linear growth. Table 2 shows Pt particles increase in size with the number of Pt ALD cycles performed and it is also clear that the Pt particles grown by plasma-ALD are bigger than those by thermal ALD. It is believed that surface functionalisation by plasma-ALD plays a important role to shorten the nucleation delay. In the O_2 plasma, O radicals are created, leading to three effects on the Pt growth by reducing the nucleation delay:

1) providing active atomic O to the surface;



Left: Ex-situ M2000 ellipsometer with motorized X-Y mapping stage at Oxford Instruments
Right: the M2000 ellipsometer mounted in-situ on the FlexAL tool in OIPT's laboratory

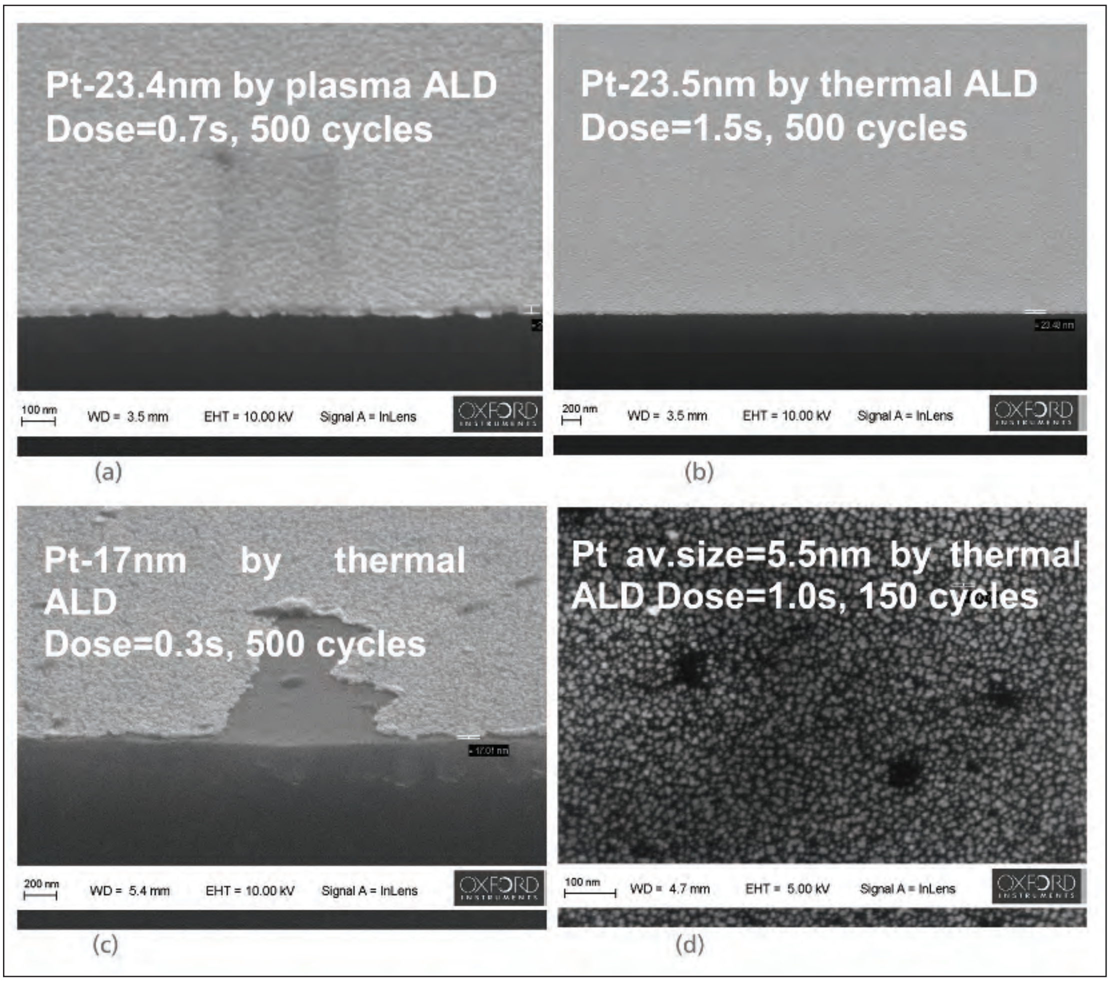


Figure 8, SEM of Pt-ALD films (cross-section of thickness and particle-size measurement)

2) increasing oxidation with the ligands of the chemisorbed precursor on the surface; and
3) increasing Pt nucleation by extra plasma energy.
Pt particle-size at 50 and 100 cycles on different metal oxide surfaces (SiO_2, Al_2O_3 and HfO_2) deposited at 300°C by thermal and remote plasma ALD also is shown in Table 2. It was found that the Pt particle-size on HfO_2 was quite big, 3.7 nm for 50 cycles and 5.6 nm for 100 cycles as compared to 1.6 nm and 2.1 nm on Si, respectively. Studies found that high work function metals such as Pt show instability in oxygen-deficient conditions. [19] As is well known, Pt ALD process relies on the dissociative chemisorption of O_2 on the Pt surface for oxidative decomposition of the precursor ligands. [17, 18] Therefore the absorbed oxygen on surface of oxides might be a controlling step for the initial step of the Pt ALD process.

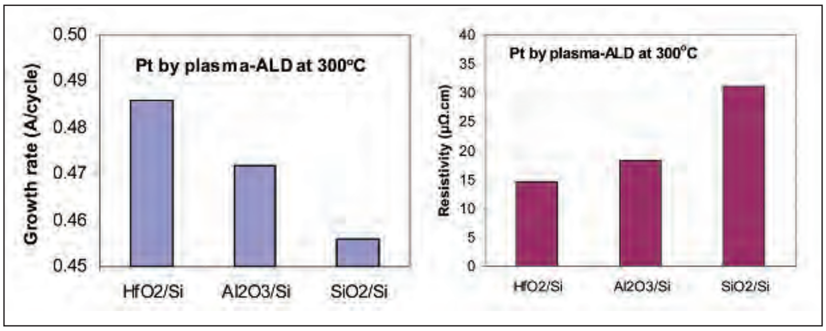
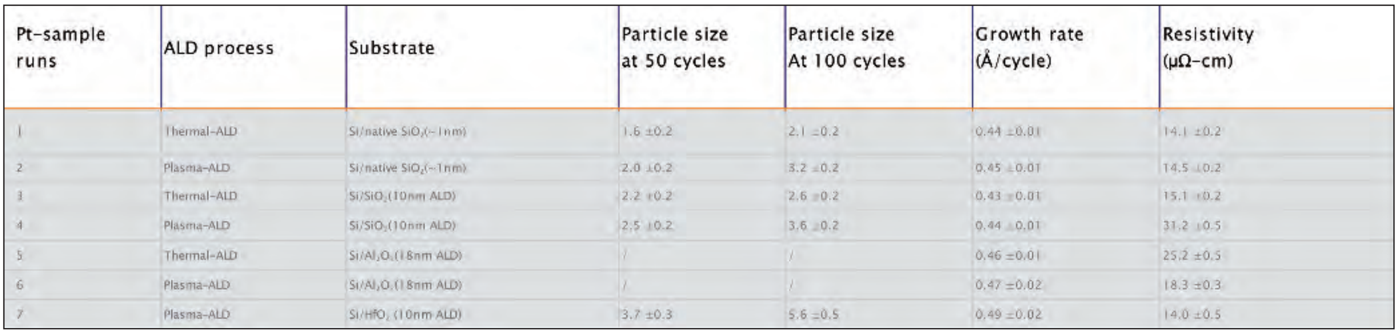


Figure 9, Growth rate and resistivity of Pt plasma-ALD layers on various oxides. HfO_2 is shown the highest growth rate and the lowest resistivity of them. It is believed that surface functionalisation by plasma-ALD and rich-absorbed oxygen radicals on HfO_2 surface are the reasons

Considering Fermi level pinning in terms of oxygen vacancies, these appear to exist in sizable amounts in HfO_2 film, [20] which is named high temperature oxygen ion conductor and allows oxygen transport across the HfO_2 layer. [21, 22]. The remote plasma enhanced ALD Pt films showed bigger Pt particle-size and a short nucleation delay on HfO_2 films. Both active atomic O species generated from oxygen plasma and their absorption and diffusion on the HfO_2 surface resulted in increasing growth rate of Pt layers on the HfO_2 by plasma-ALD.

Conclusions

Platinum films were deposited by both remote plasma and thermal atomic layer deposition (ALD) using methylcyclopentadienyl- trimethyl platinum ($MeCpPtMe_3$) and O_2 as precursors on oxide materials. The ALD Pt-films deposited were



Pt-sample runs	ALD process	Substrate	Particle size at 50 cycles	Particle size At 100 cycles	Growth rate (Å/cycle)	Resistivity (μΩ-cm)
1	Thermal-ALD	Si/native SiO_2(~1nm)	1.6 ±0.2	2.1 ±0.2	0.44 ±0.01	14.1 ±0.2
2	Plasma-ALD	Si/native SiO_2(~1nm)	2.0 ±0.2	3.2 ±0.2	0.45 ±0.01	14.5 ±0.2
3	Thermal-ALD	Si/SiO_2(10nm ALD)	2.2 ±0.2	2.6 ±0.2	0.43 ±0.01	15.1 ±0.2
4	Plasma-ALD	Si/SiO_2(10nm ALD)	2.5 ±0.2	3.6 ±0.2	0.44 ±0.01	31.2 ±0.5
5	Thermal-ALD	Si/Al_2O_3(18nm ALD)	/	/	0.46 ±0.01	25.2 ±0.5
6	Plasma-ALD	Si/Al_2O_3(18nm ALD)	/	/	0.47 ±0.02	18.3 ±0.3
7	Plasma-ALD	Si/HfO_2 (10nm ALD)	3.7 ±0.3	5.6 ±0.5	0.49 ±0.02	14.0 ±0.5

Table 2, the process data of Pt films on the surface of Si, SiO_2, Al_2O_3 and HfO_2 deposited at 300°C by thermal and remote plasma ALD using $MeCpPtMe_3$ and O_2 gas or O_2 plasma (500 cycles)

homogeneous and resulted in a low resistivity of 12.8 μΩ-cm.

AES studies revealed high quality Pt films deposited by both thermal and plasma ALD with carbon impurity less than 1.5% and oxygen found only in the interface. SEM and EDX investigations of Pt nucleation and growth in ALD processes showed that the plasma ALD can form bigger size Pt particles in the early stage and reduce the nucleation delay. Pt on HfO_2 has shown the highest growth rate and the lowest resistivity of the oxides. It is believed that surface functionalisation by plasma-ALD and rich-absorbed oxygen radicals on HfO_2 surface are the reasons. In the O_2 plasma, O radicals are created, leading to three effects on the Pt-growth by reducing the nucleation delay:
1) providing active atomic O to the surface;
2) increasing oxidation with the ligands of the chemisorbed precursor on the surface; and
3) increasing Pt nucleation by extra plasma energy.

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A changing landscape

The annual Semicon West show in San Francisco was dominated by news about 450mm and the future of lithography. Despite concerns of the future for many in the industry David Ridsdale found that although financial dynamics have changed, Moore's Law continues to direct industry goals and aspirations.

San Francisco once again hosted the annual Semicon West conference and exhibition and although organisers highlighted the increase in booths, they down played the reduction in companies attending despite 51 new players joining the show. As the conference is co-located with Intersolar it is also hard to get a handle on the number attending. SEMI was hoping for 31,000 but post show figures suggest a couple of thousand shy of this. As registration to one show included the other it becomes difficult to determine the true level of attendance. The benefit for the two shows is that everywhere looks busy which helps set a mood at any such event.

Despite an impressive array of speakers and pre-planned events the show was immediately overshadowed by the announcement that Intel was investing as much as US$ 4.1 Billion into ASML to accelerate research and development into EUV and 450mm as the company scales towards its 14nm goals while moving to the larger 450 mm wafer size. Intel will spend an initial US$ 3.1 Billion for up to a 15 % stake in the company and add another billion to the R&D pot at ASML. Whilst most pundits are applauding Intel for their shrewd investment I feel it is ASML who has led a game changing coup.

The semiconductor industry began the transition to 300 mm wafers 14 years ago although some will say dragged to the transition. Some companies have announced they are only now seeing a return on investment and of course many companies saw no return if they survived at all. The transition to 300mm was the time when manufacturers pushed upstream price pressures down to tool and materials suppliers. It was the main reason that many companies began to complain when 450mm was first raised a few years ago. The initial public response from toolmakers was they would not foot the bill for the 450mm transition whilst privately stating that they expected the 450mm transition to occur regardless of what they thought.

This is exactly what has been happening. The major IC manufacturers began to talk of future plans and road maps and suddenly companies began to work on 450mm projects. That or be left out of the loop. A number of pilot lines began to be mooted and some built and the momentum was with the industry. Except ASML who chose to only talk about the evolving Extreme Ultra Violet (EUV) lithography and insisted they were not looking at 450mm stating they could not work on both projects.

Ten years ago it would have been inconceivable that any tool company could exert the influence over its customers that ASML has demonstrated with this pro-active investment from Intel and now Samsung and TSMC have followed suit. Ten years ago it would have been unlikely that a company focusing on one area of technology would be the biggest tool manufacturer in the world. In fact ten years ago ASML was barely in the top three lithographers

making their achievements all the more impressive. The truth is that lithography is now the key enabler of scaling and the costs involved to develop EUV lithography as well as 450mm platforms will cost billions. ASML has stuck its ground and avoided the 450mm issues for some time. No surprise that their 450mm road map appeared after the Intel announcement. Other major tool suppliers were turning envious eyes to the agreement but realise their fight is just to be involved in the 450mm pilot lines and qualification processes. Or else miss out on the next technology node completely. Nikon has been the only true competitor to ASML of late and the new arrangements will be seriously concerning the company.

Almost every discussion following the announcement involved 450mm and the technology challenges below 28nm. The main focus being lithography and 3D IC integration. In other words the enablers of Moore's Law. There is plenty of discussion concerning the changing financial nature of the industry with concerns the Moore's Law supposition has reached its limits but the events of the show demonstrate that the desire to maintain the doubling of transistors at half the price every two years still dictates technology goals. With estimated costs for 450 mm in the billions, let alone for lithography and packaging, the real concern is that it will not be technology that sees the end of Moore's Law but the financial costs of continued scaling. The cost per transistor equations will be where the real story will be told.

Less players, more opportunities

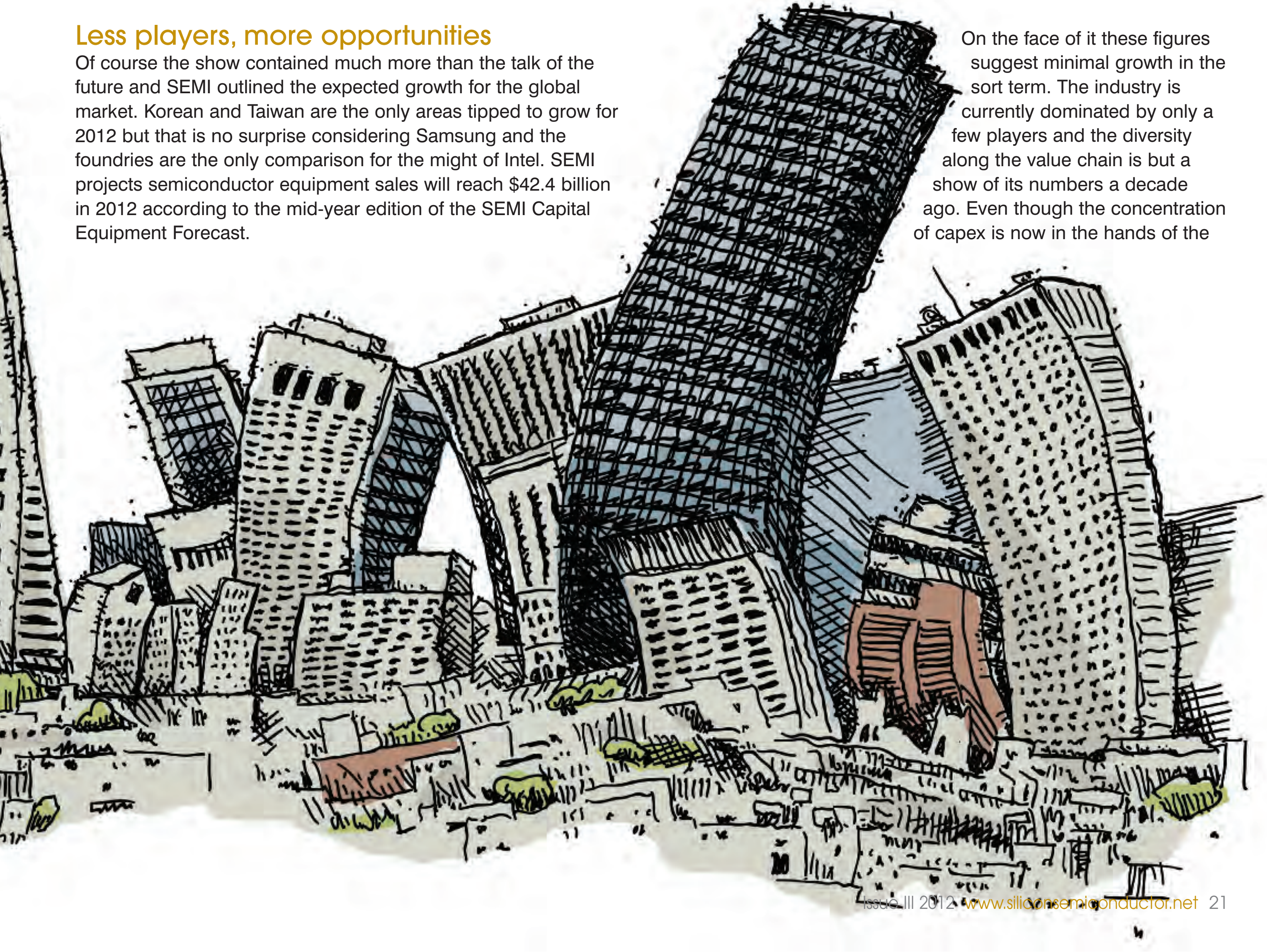
Of course the show contained much more than the talk of the future and SEMI outlined the expected growth for the global market. Korean and Taiwan are the only areas tipped to grow for 2012 but that is no surprise considering Samsung and the foundries are the only comparison for the might of Intel. SEMI projects semiconductor equipment sales will reach $42.4 billion in 2012 according to the mid-year edition of the SEMI Capital Equipment Forecast.

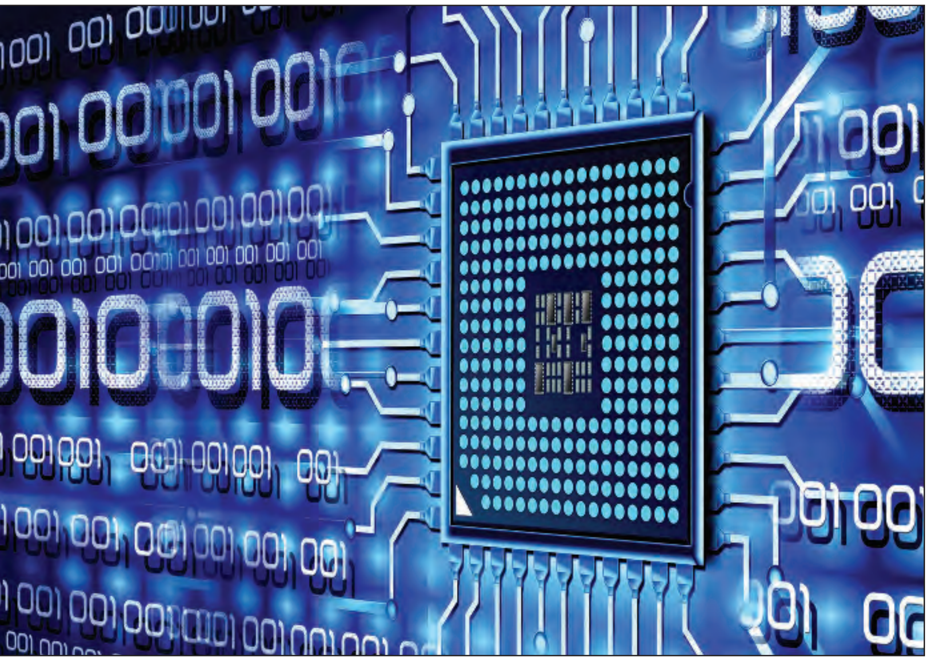
Driven by consumer demand for tablet, smartphone, and mobile devices, chipmakers will continue to purchase manufacturing technology equipment. The forecast indicates that, following a 9 percent market increase in 2011, the equipment market will contract by 2.6 percent in 2012. The year 2012 is likely to be the fourth highest spending year in history, with higher spending only in 2011 ($43.5 billion), 2007 ($42.8 billion) and 2000 ($47.7 billion). With $33.0 billion for 2012 forecasted for wafer processing equipment, it will be the second highest spending year ever for this segment, surpassed only by the $34.3 billion spent in 2011.

"We expect 2012 to post one of the highest rates of global investment for semiconductor manufacturing equipment. Following a multi-year market expansion, sales will again exceed $42 billion — just one billion short of last year's spending rate as the industry absorbs new capacity," said Denny McGuirk, the new president and CEO of SEMI. "We also forecast accelerated spending to exceed $46 billion in 2013."

Wafer processing equipment, the largest product segment by dollar value, is expected to decrease 3.8 percent in 2012 to $33.0 billion. The forecast predicts that the market for both Test ($3.8 billion) and Assembly & Packaging ($3.4 billion) equipment will remain essentially flat (increase of 0.2 percent and 0.9 percent, respectively).

On the face of it these figures suggest minimal growth in the sort term. The industry is currently dominated by only a few players and the diversity along the value chain is but a show of its numbers a decade ago. Even though the concentration of capex is now in the hands of the





few there are more emerging opportunities within the industry than most give credit to. Nearly all the innovation that has been introduced into the semiconductor industry has come from small ventures. Those focused on providing a solution to a particular industry challenge. There are many companies out there with potential solutions right along the value chain. Many of them are realising they need to be able to get to potential customers and educate them on the possibilities. Explain how new ideas can be introduced with minimal disruption but provide improvements in product or cost.

Twelve years ago all companies wanted to ride the wave of success that led to the billion dollar companies we have today but the ride has changed and although the gradient not as steep the roller coaster nature of the industry provides entry points for new comers with new ideas. The companies I meet that seem to have the solidest approach are those who are looking at maintaining profitable companies and are not over extending themselves at the whim of share holders. A number of larger OEMs are losing their shine as the focus is on shareholder quarterly returns with no sense of longer term technology goals.

The technical and financial challenges of continued scaling are changing the industry landscape to such an extent that companies can no longer rest on their laurels. Companies who believe they will maintain or improve their large market share in the next technology node may be in for a shock. I would expect changes in the top companies over the next 18 months that may not be obvious now.

Moving forward collaboratively

The rising cost of the technological challenges in the industry have forced a collaborative approach to technology that was unexpected a few years ago. Shekhar Y. Borkar, Intel Fellow and director of extreme-scale technologies at Intel Corporation grace the first key note speech and focused on energy demands of computing today and the rapid increase expected in energy needs. Borkar stated that the industry requires a new approach to energy consumption pointing out that once again the industry will need to work together to ensure this does not become a brick wall to innovation.

While manufacturers are looking at different transistor architecture to tackle the growing problem of energy usage such as Intel's tri gate approach but the improvements are available throughout the value chain. It could be a materials solution or a new IC design. Form factor continues to be a major issue as interconnections and packaging are required for ever smaller devices. System on a chip and an array of other options all have contributions to make to the future technology and the opportunities exist along the entire manufacturing chain from design to final text.

The industry will also witness the continued consolidation of companies and technologies that has been occurring the last ten years. The LAM Novellus merger/takeover is the highest profile consolidation of late and despite the excellent synergies of technologies one can only hope that LAM executes the merger better than the recent SEZ acquisition. The early indications are that the company learnt from the speed of the Austrian takeover and are taking their time to meet integration targets this time. If done well, the new venture will be a serious contender for Applied Material's market share in the next technology node.

The semiconductor industry is its most fascinating when facing technical challenges. I don't mean the ones they face daily but those moments when people feel they are facing a brick wall. Sometimes even perceived physical limitations. Each times they find a way forward and I would expect the same of this innovative industry despite the overwhelming challenges facing them. I have covered the industry long enough to know that the solutions will come from unexpected quarters and the eventual winning companies may not appear to be in such a position. This industry proves that number one today means very little tomorrow.

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Making a success of MEMS

MEMS has being regarded by many as a future opportunity but there were those who recognised the diverse potential that was on offer. Tony McKie, General Manager of memsstar provides an OEM perspective how an approach that supports MEMS development, process integration and manufacturing has led to success.

Data from ABI Research indicates that strong growth in the MEMS market over the next five years will result in nearly five billion MEMS being shipped during 2016.[1] MEMS growth will likely come from consumer applications driven by mobile computing and gaming.

Today, MEMS are found in smartphones, netbooks, media tablets, eReaders, games consoles, handheld gaming platforms and cars. Novelty applications for MEMS devices, bioMEMS are an example, are also becoming increasingly popular. Devices are getting even more feature rich, adding secondary capabilities to functions already in place. More often than not, more than one MEMS will reside in any given consumer device. For example, instead of just one silicon microphone, you now have a minimum of two, one for voice recognition and one for background noise reduction.

As MEMS become vital components in an increasing number of devices, the market is entering a transition phase from R&D to volume manufacturing where high yield and cost-effective manufacturing become increasingly critical. Successful development of full-scale manufacturing lines remains a work-in-progress that will involve identification of best practices, standardization of manufacturing technologies and best-in-breed equipment and process technology that can make production more cost-effective, even as products become increasingly complex.

Key Considerations for MEMS Manufacturing

Process integration is an issue of primary importance in MEMS processing, largely due to the lack of standards employed in MEMS manufacturing. The MEMS manufacturing industry appears to be following a similar path to that of the semiconductor industry, which migrated from a lack of standards to a state whereby all devices are manufactured using standard process techniques that are well-defined and characterized. The MEMS industry's ability to standardize, however, is considerably more complex due to the abundance of processing techniques and early stage IP protection.

In MEMS manufacturing, process integration is even more important than in semiconductor manufacturing due to the nature of the MEMS structures. The structure determines the suitability of the material and the processing technique. RF MEMS with metal, for example, need subsequent low temperature processes and processing techniques compatible with metals to avoid corrosion, etc. The complexity of a MEMS structure therefore leads to many variables. Performance in terms of uniformity, repeatability, etch/deposition rate, control, suitability to the structure being made and ease of manufacture are all key considerations for etch and surface preparation when developing a MEMS manufacturing process.

Processing technique remains a critical element within MEMS manufacturing. Successful process development requires extensive process and integration experience and equipment that is designed or optimized to maximize manufacturing performance. The suitability of various process techniques for the end structure must be identified during the device design phase, so as to significantly reduce the early-stage development of the structure. Process development is still required, but addressing manufacturing issues up-front ensures a more rapid and effective integration process.

Optimizing Equipment Processes

With MEMS manufacturers developing increasingly functional and complex devices, they stand to benefit significantly from process tools that can provide solutions for commercial MEMS R&D through to volume manufacturing utilizing the same process technology and hardware. This ability to achieve a seamless process transfer from R&D to production represents a challenge frequently overlooked in the MEMS market.

memsstar has designed and sold unique, patented processing systems for vapour phase isotropic etch and surface modification used in MEMS manufacturing since 2008. Its single-wafer platforms are fundamentally designed similar to semiconductor platforms, utilizing the same best of breed components. Also delivering process performance on par with standard semiconductor processes, memsstar provides a complete hardware and process solution for seamless integration into a manufacturing line.

With this approach, memsstar minimizes the requirement for specialist support within the customers manufacturing team. With zero consumables and extremely high uptime, memsstar equipment is available 24/7 for manufacturing.

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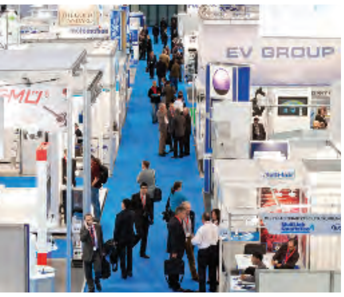

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Refurbished and Repurposed

The refurbished equipment market has seen strong growth over the past few years and is expected to remain a generally strong market, with increasing adoption of refurbished equipment for mature lines. Europe will likely lead the market in purchasing refurbished equipment, as it remains primarily a niche or specialty market that does not require leading-edge technologies.

memsstar's remanufacturing division is focused on refurbished and repurposed etch and deposition equipment for MEMS fabrication and R&D as well as semiconductor manufacturing in Europe. It offers an OEM-like solution to all its customers, with all systems built and/or reconfigured to the latest specifications and tested in accordance with the latest CE directives.

The systems are offered with process support, a full performance warranty and post sales support. memsstar is unique in offering repurposed systems with fully qualified and characterized processes for bespoke applications, as well as with standard semiconductor ones.

When looking to purchase refurbished equipment, the primary consideration is the processing technique of the equipment and the vendor's experience with the system and process. Value-add providers of refurbished equipment can impartially advise on suitable equipment from a range of suppliers that can be matched to an individual customer application.

For the MEMS market, process applications and a vendor's ability to develop and support these for MEMS manufacturing is a critical differentiator. For the generation of toolsets being adopted in MEMS manufacturing, most OEMs never developed MEMS processes at these technology nodes. In this case, the added value from a supplier like memsstar is the ability to develop processes for films better suited to MEMS devices, targeted primarily at mechanical properties. Another recent area of development has been for low temperature amorphous Si deposition, which requires a unique hardware and process set.

In terms of semiconductor manufacturing, capabilities such as upgrading chambers and reconfiguring platforms allow the company to supply systems that match current fab equipment sets, or facilitate migration to the next technology node. Many of the products manufactured on refurbished equipment sets are extremely price sensitive, so the market has the same drivers as leading-edge manufacturers, including more advanced technologies, more chips on the wafer and improved device or structure performance.

Business Model Outlook

The memsstar business model is working. Simply put, it's one based on providing a level of service and support that its customers want.

The company brings to market tremendous experience in the semiconductor industry, with well over 90 percent of personnel coming to memsstar with prior industry experience and a majority of those with over 15 years of experience in the capital equipment sector.

In total, memsstar has in excess of 100 man-years processing experience and over 400 man-years of experience with manufacturing hardware, which is fairly unique for a company of memsstar's size. It also demonstrates the company's commitment to advancing processing technology for MEMS manufacturers. This commitment to industry and process capability allows the company to provide a level of support that, at times, surpasses that of the OEM.

This expertise has provided memsstar an enviable position within its European market, retaining repeat business and expanding its customer base as a result of its quality. At the same time, MEMS manufacturers are increasingly adopting repurposed semiconductor equipment, marking another area in which memsstar has seen substantial growth. This demand led to the company's recent expansion of its Livingston, Scotland facility, doubling its cleanroom manufacturing space in order to reduce lead-time for refurbished OEM platforms.

memsstar sees a number of areas for potential growth in both its MEMS and refurbished markets over the next few years. The value-add available to manufacturers who utilize refurbished platforms will continue to be core business for memsstar. On the MEMS side, new product development and increased MEMS manufacturing capacity will drive sales. China also offers tremendous opportunity to MEMS suppliers generally, as it is widely expected that the country will increasingly move into technology development, which has the potential to create significant business there in the coming years.

1. MEMS in Smartphones and Consumer Electronics, ABI Research, Q1 2011.

Making sense of MEMS

MEMS technologies are the rising star in the sensors market. However, there are a number of misconceptions surrounding their capabilities, and conventional sensors continue to meet a much wider range of applications. Jesse Bonfeld of Sherborne Sensors examines the evolution of MEMS fabrication, microsystems, and MEMS devices, and their impact on the sensors market.

Micro Electro Mechanical Systems (MEMS) describes both a type of device or sensor, and a manufacturing process. MEMS sensors incorporate tiny devices with miniaturised mechanical structures typically ranging from 1-100 μm (about the thickness of a human hair), whilst MEMS manufacturing processes provide an alternative to conventional macro-scale machining and assembly techniques.

Also known as 'microsystems' in Europe, and 'micromachines' in Japan, MEMS devices have come to the fore in recent years with the wide-scale adoption of MEMS sensors by the automotive industry, and the growing use of accelerometers and gyroscopes in consumer electronics. Perhaps the most well known consumer electronics incorporating MEMS motion sensors include a number of the leading smart phones, and gaming consoles/controllers.

Rise of the micromachines

MEMS development stems from the microelectronics industry, and combines and extends the conventional techniques developed for integrated circuit (IC) processing with MEMS-specific processes, to produce small mechanical structures measuring in the micrometer scale (one millionth of a meter).

As with IC fabrication, the majority of MEMS sensors are manufactured using a Silicon (Si) wafer, whereby thin layers of materials are deposited onto a Si base, and then selectively etched away to leave microscopic 3D structures such as beams, diaphragms, gears, levers, or springs. This process, known as 'bulk micromachining', was commercialised during the late 1970s and early 1980s, but a number of other etching and micromachining concepts and techniques have since been developed.

Advances in IC technology and MEMS fabrication processes have enabled commercial MEMS devices that integrate microsensors, microactuators and microelectronic ICs, to deliver perception and control of the physical environment. These devices, also known as 'microsystems' or 'smart sensors', are able to gather information from the environment by measuring mechanical, thermal, biological, chemical, optical, or magnetic phenomena. The IC then processes this information and directs the actuator(s) to respond by moving, positioning, regulating, pumping, or filtering. Any device or system can be deemed a MEMS device if it incorporates some form of MEMS-manufactured component.

Demand for MEMS devices was initially driven by the government and military/defence sectors. More recently, a maturing of the semiconductor manufacturing processes associated with the microchips used within personal computers, and the intersection with the huge requirement in the automotive and consumer electronics sectors, has propelled MEMS sensors into the mainstream. The key MEMS sensors today are accelerometers, gyroscopes, and pressure sensors.

Innovation & limitation

All too often, MEMS technologies are perceived as being all-encompassing solutions made using standardized processes, when in actual fact, they remain a largely one product, one process business. A number of companies develop and produce MEMS devices themselves, and are defined as 'IDMs' (integrated device manufacturers), whereas some outsource production (fabless), and others operate both models. Much of the confusion in the market can be attributed to this diversity, and the way in which the various verticals subsequently interface make the MEMS market notoriously difficult to define.

At the point of fabrication, there are very few companies operating in the sensors market that offer MEMS together with another technology because of the high cost of market entry and the cost of packaging MEMS devices. Likewise, once a company has committed to manufacturing MEMS devices, it is difficult for that company to change focus, due to low margins, higher development costs, and greater complexity. That said, MEMS does enable high-volume production, due to the batch fabrication techniques employed, typically resulting in very low costs for each single device.

The shape of sensors to come

The advances in MEMS technologies and techniques means that manufacturers are now able to produce very capable MEMS sensors and devices, but many cannot be installed directly into an end application because they cannot survive the rigours of final assembly. Conversely, conventional sensors can survive just about any assembly process and any application, but are often perceived as being too big and too expensive. The challenge for the manufacturers of MEMS sensors that are to be used in commercial products is to take the MEMS price and form factor, and package it into something able to withstand harsh environments.

Indeed, it is this second level of packaging that must be envisioned and understood by specialist manufacturers moving forward to realise growth potential. Today, the majority of industry innovation and commercial opportunity is centred on the application of existing MEMS devices, in addition to new ways to package and integrate MEMS devices within a system that can be used directly by end users.

With the MEMS market returning to growth during 2010, the agile OEMs will be those that determine how to integrate conventional sensor fabrication technologies and performance capabilities with the emerging MEMS trends to overcome the limitations in material needs and processes. If the latter are addressed, then it is possible that MEMS will capture a larger portion of the overall sensor market.

The rise of chem-bio

One area of intense industry focus over the past five years is that of chemical-biological (chem-bio) sensors. Governments worldwide have been investing heavily in R&D, driven primarily by the heightened threat posed by a chemical or biological attack. Chem-bio sensors respond to changes in their chemical/biological environment and convert this response into a signal that can be read.

Suitable for national security applications, chem-bio sensors are able to quickly and effectively detect dangerous agents in their immediate vicinity – including chemical, biological, nuclear and explosive materials. San Francisco officials recently proposed to regulate the sensors on its buildings in order to detect such agents and, last year, the US Army demonstrated the feasibility of a sensor network to improve situational awareness and reaction time in the field during chemical or biological incidents.

The US Army demonstration used military standard formatted Nuclear, Biological and Chemical (NBC) messages from a sensor located on the soldier, to pass information via machine-to-machine data exchange up to the operations centre to be validated. If a sensor was triggered or an incident occurred, the soldier received an automatic audio alert based on the NBC message type, and an icon appeared on their 'heads-up' display. The system displayed the areas that needed to be contained or avoided, and helped to plan egress routes and notify soldiers when the area was clear. Further R&D will most likely see chem-bio sensors integrated into the smallest and most subtle of places, from an individual's clothing, to mobile phones. This will provide an instantaneous and automatic method of detection that can offer notifications of a chemical incident to the authorities, and may even combine GPS (global positioning system) to enable rapid location capabilities.

According to Frost & Sullivan, the biosensors market is expected to grow from \$6.72 billion in 2009, to \$14.42 billion in 2016 – driven largely by the biodefence and home diagnostic markets. However, it should be noted that in keeping with the diversity of the sensors market, a chemical sensor may only be deemed a 'biosensor' if it employs a biological element that detects chemicals (e.g. blood glucose testing, or screening for disease). Chem-bio sensors add a new dimension to MEMS, in that they call for development of somewhat exotic microstructures, such as cylinders within cylinders or those that are semi-permeable. Moreover, the challenge of how to ensure they become pervasive is one the industry has still to address.

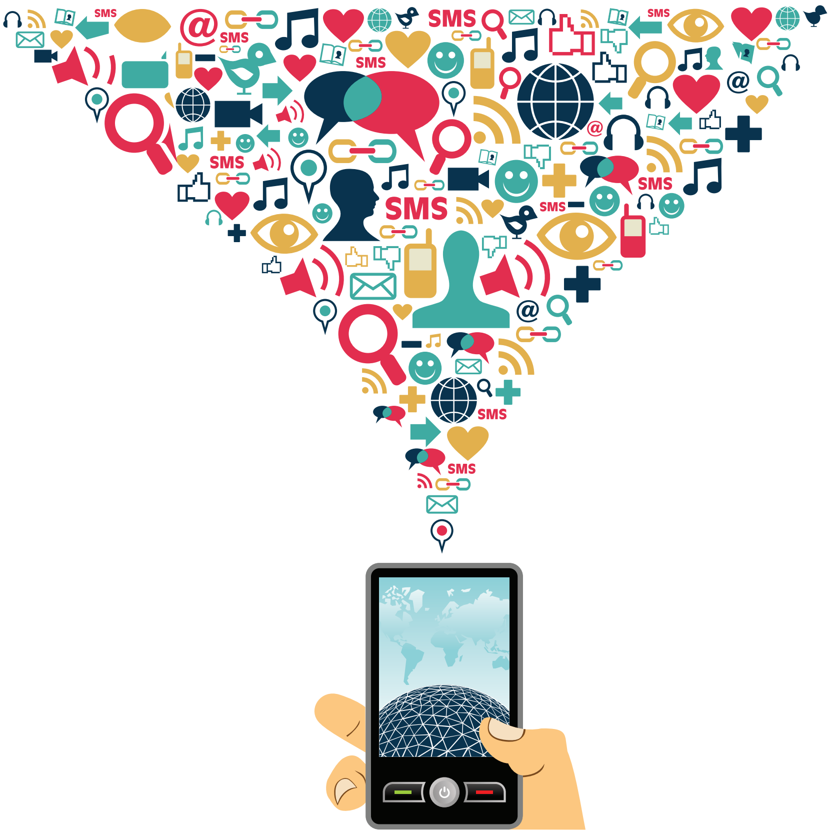
RF MEMS tipped for mobile growth

IHS iSuppli teardown analysis identifies first use of RF MEMS part

IHS has identified a radio frequency microelectromechanical system (RF MEMS) device in a new Samsung mobile phone, marking the first known use of such a part in a volume-shipping product and sounding the starting gun for an RF MEMS market that is set to grow by a factor of 200 by the year 2015.

Samsung's Focus Flash Windows smartphone includes an RF MEMS device from WiSpry Inc., according to the IHS iSuppli Teardown Service at information and analysis provider IHS .

RF MEMS devices like the WiSpry part can provide a range of benefits in mobile phones, including the reduction of signal interruptions and dropped calls, faster data transmission rates and improved design and power efficiency. This will pave the way for other mobile phones to adopt RF MEMS, causing global sales of such devices to rise to $150 million in 2015, up from just $720,000 in 2011.



"RF MEMS have been promoted by suppliers as the next big thing in mobile phones for nearly a decade," noted Jérémie Bouchaud, senior principal analyst. MEMS and sensors for IHS. "However, although they have been shipping since 2005 in low volume for instrumentation applications, interest among mobile phone makers in the use of RF MEMS didn't pick up until mid-2010, when users began to report problems with signal reception with the iPhone 4 after they held the device in certain ways. This so-called "death grip" problem can be alleviated through the use RF MEMS. When combined with the other benefits delivered by RF MEMS, the market for these parts is set for rapid growth in the coming years."

The IHS teardown of the Focus Flash revealed a MEMS-based antenna tuning module labeled A2101 in a die-on-LGA package near the antenna connectors. The tunable impedance match (TIM) device, as WiSpry calls it, consists of a network of inductors combined with WiSpry's CMOS-integrated, digitally tunable and low-loss MEMS capacitors. The WiSpry single-chip design integrates logic circuits/serial interface for control, on-board high-voltage charge pump and high-voltage MEMS drivers, together with fully encapsulated digital MEMS capacitors on a single chip.

Tuning in

There are multiple direct benefits of using RF MEMS to tune and match the antenna for the network operators, mobile phone makers and users. Beyond mitigating the signal dropout issue because of the death grip, RF MEMS can improve the antenna efficiency in mobile phones, which can increase transmission data rates. For example, in the U.S. long -term evolution (LTE) 4G standard, antenna tuning can boost data rates by as much as 40 percent.

Furthermore, RF MEMS enables mobile phones to employ smaller antennas that have the same or greater efficiency than larger ones. This can allow the design of thinner phones. The improved antenna efficiency also can allow network operators to achieve major savings on the deployment of the new wireless infrastructure, amounting to hundreds of millions of dollars.

Beyond reception issues, a major reason why mobile phone makers are adopting RF MEMS is their capability to efficiently implement the proliferating number of standards and rising data usage of mobile phones.

In conventional mobile phone RF architectures utilized today, multiple standards and functions coexist with multiple RF paths, which are set in parallel. This architecture is not adapted to the evolution of mobile handsets, since it raises the number of components, size and cost, as well as the power consumption of mobile handsets. New, reconfigurable architectures are required to increase the functionality of phones while keeping size, cost and power consumption low.

Several options are in development, including antenna tuning and antenna matching, as well as impedance-matching networks for the power amplifier and tunable filters. Antenna tuning and matching, which can be achieved with RF MEMS, is the most popular approach today, as it can provides the most significant improvement in terms of sensitivity.

MEMS at work

With its Samsung design win, WiSpry is leading the RF MEMS pack. However, other companies now are targeting this market, including TDK-EPC, Sony, Omron, RFMD, and the start-ups Cavendish-Kinetics and DelfMEMS.

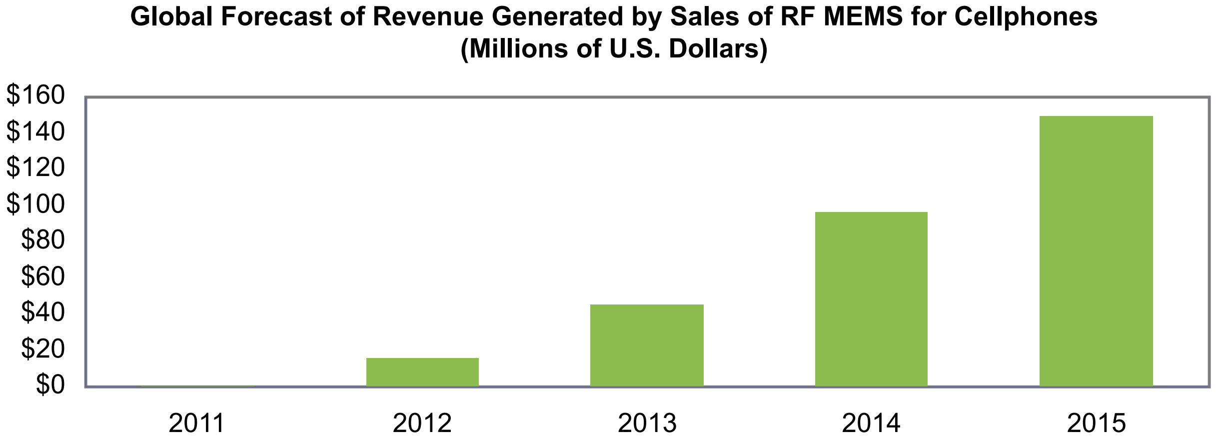
Beyond RF MEMS, other technologies are being offered for mobile phone antenna-tuning applications with varying applications noted at this stage but with the possibility of more applicaitons in the future. Current applications that are seen as promising in the industry include the following:

- Paratek Microwave Inc.'s barium strontium titanate (BST) tunable integrated circuits, which have been employed in a handful of phones starting in June 2011.
- Peregrine Semiconductor Corp.'s DuNE antenna tuning devices, based on its silicon-on-sapphire switch technology. These devices have been shipping in one mobile phone since December 2011.
- Gallium arsenide-based switches and tuners that are being sampled by other vendors.

IHS iSuppli Figure: Global Forecast of Revenue Generated by Sales of RF MEMS for Cellphones (Millions of U.S. Dollars)

	2011	2012	2013	2014	2015
Millions of U.S. Dollars	0.72	16.1	45.7	96.5	149.5

Source: IHS iSuppli January 2012



Source: IHS iSuppli January 2012

Many flavours on the menu for 22nm and beyond

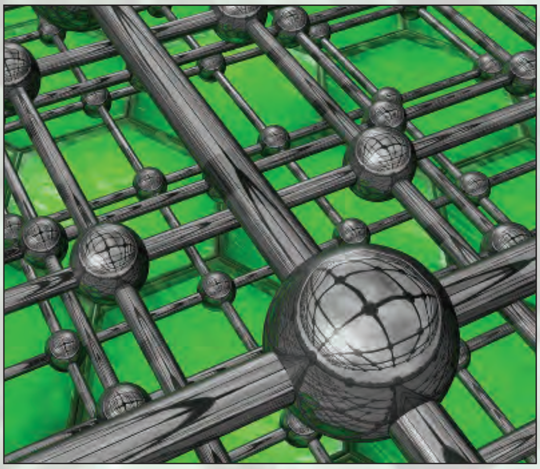
IC manufacturing has always had to look forward a number of nodes ahead to have any chance of instigating change in line with Moore's Law expectations. Beyond 22nm is where the industry currently sees challenges and Dr. An Steegen, Senior Vice President of process technology development at global research centre imec provides some insight into the manufacturing possibilities for these challenges.

In the majority of today's consumer electronics and handheld devices 65nm and 40nm technology is used while 28nm is being qualified for leading-edge products. To be able to provide consumers and businesses with ever faster computing, lower power consuming devices with smaller form factors, the technology development continues to follow Moore's law. To enable smaller dimensions, new device architectures, materials and litho techniques are needed.

To improve performance at lower operating voltage, fully-depleted device architectures are being introduced as early as the 22nm technology node and will likely be fully adopted by foundry for the 14nm technology node. Imec has a long history developing FinFET devices, but also ultra-thin SOI and implant-free quantum well devices are being benchmarked. By screening different technology options, imec helps its partners to make educated choices depending on their specific applications, the technology readiness, cost etc

To improve the transistor performance further, high-mobility channels for NMOS and PMOS will be co-integrated on a Si-substrate. Imec is accelerating the co-integration of germanium for pFETs (14nm) and III-V materials such as InGaAs for nFETs (11nm). Different integration routes are being investigated while the performance of these devices is being checked at 11nm dimensions.

Thanks to our partnership with ASML, we have access to the most advanced litho tools. We study immersion and EUV lithography in combination with advanced patterning solutions. High on our agenda is an intense exercise comparing EUV and immersion lithography for the 14nm node. This study will be help our partners to make choices on the introduction of EUV for 14nm or beyond.



Another challenge for further scaling is the changing landscape in which design and manufacturing of ICs is decoupled in fabless/fablite companies and foundries. At imec, we have set up the INSITE program, short for 'integrated solutions for technology exploration'. It is a framework of design exploration modules that allows fabless and fablite companies, foundries and EDA vendors to develop design and product information using emerging IC process technologies 1 to 3 generations ahead of IC manufaturing.

To conclude, I strongly believe that to maintain the tremendous time-to-market and innovation in consumer products, all parties benefit from working together in research communities such as imec. Designers and application developers get early insight in future technologies via initiatives such as imec's INSITE; chip manufacturers get an overview and can download selections of all technology options for future nodes. In this way, each company can make the right choices and is able to ensure its future in the tough but flourishing world of consumer electronics.

An Steegen

Senior Vice President process technology

Biography: Dr. An Steegen joined imec as senior vice president process technology development in December 2010.

In this role, she has the responsibility for the technical leadership and execution of imec's CORE program activities in the areas of devices, process, lithography and design and CMORE activities such as MEMS, Power, Sensors and Photonics.

These leadership technologies serve as the foundation of imec's successful growth and R&D leadership position in a wide variety of market segments.

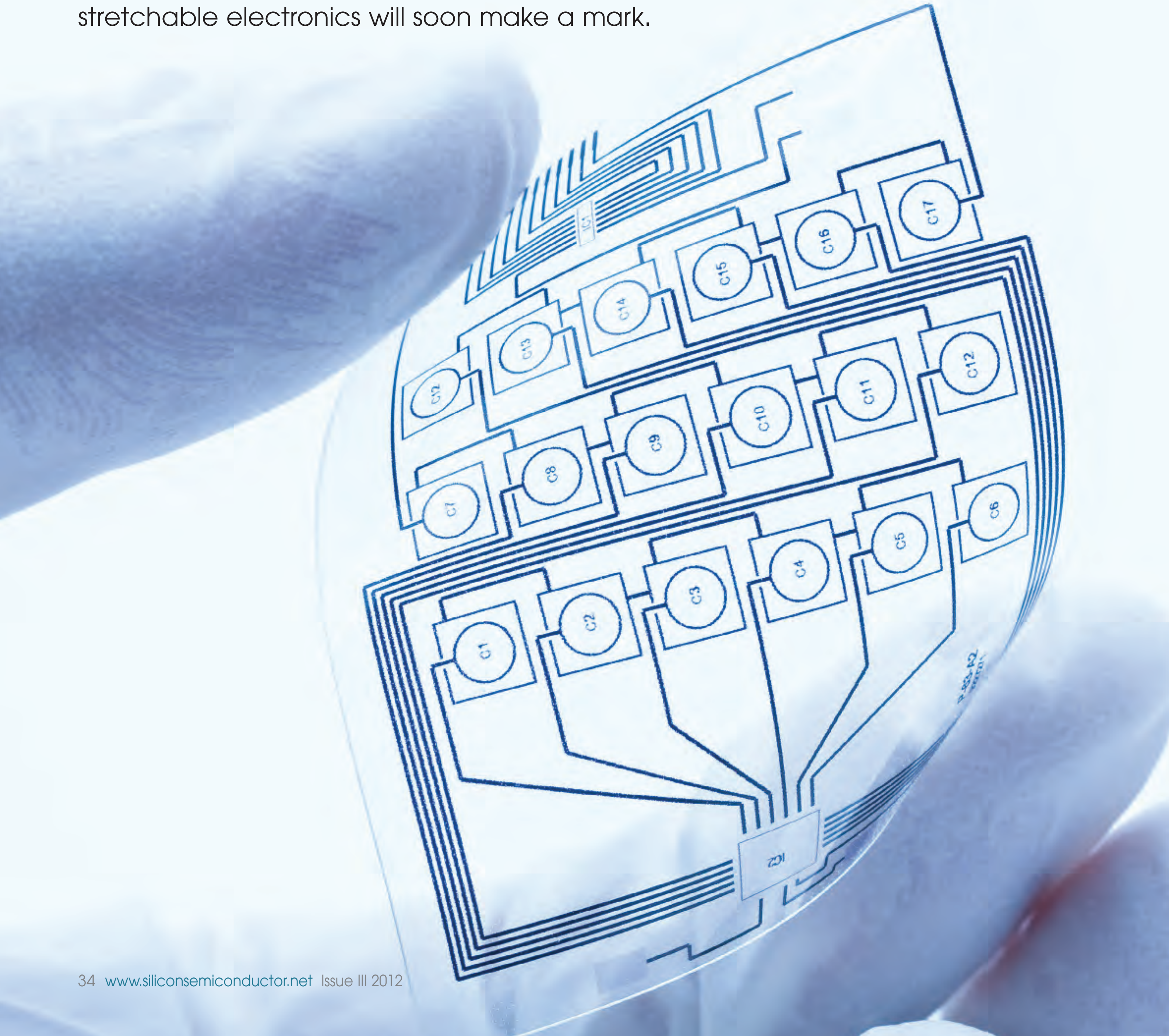
Dr. An Steegen holds a Ph.D. in Material Science and Electrical Engineering from the Catholic University of Leuven, K.U.Leuven, in collaboration with the Interuniversity Microelectronics Center, imec, in Belgium.

Throughout the years, Dr. Steegen has published more than 30 technical papers and she holds many patents in the field of semiconductor development. She joined IBM Semiconductor R&D in Fishkill, NY, in 2001, where she was the director of the bulk CMOS technology development division until 2010.

In that position, she served as the host executive in charge of IBM's logic International Semiconductor Development Alliance and was responsible for establishing strong collaborative partnerships in innovation and manufacturing as measured by power/performance, defect density and cost/complexity.

Stretchable electronics ready for market

Microelectronics is dominated by silicon based IC devices but there are many more options available. One area of growing interest is flexible electronics. Dr Peter Harrop, Chairman of IDTechEx discusses how stretchable electronics will soon make a mark.



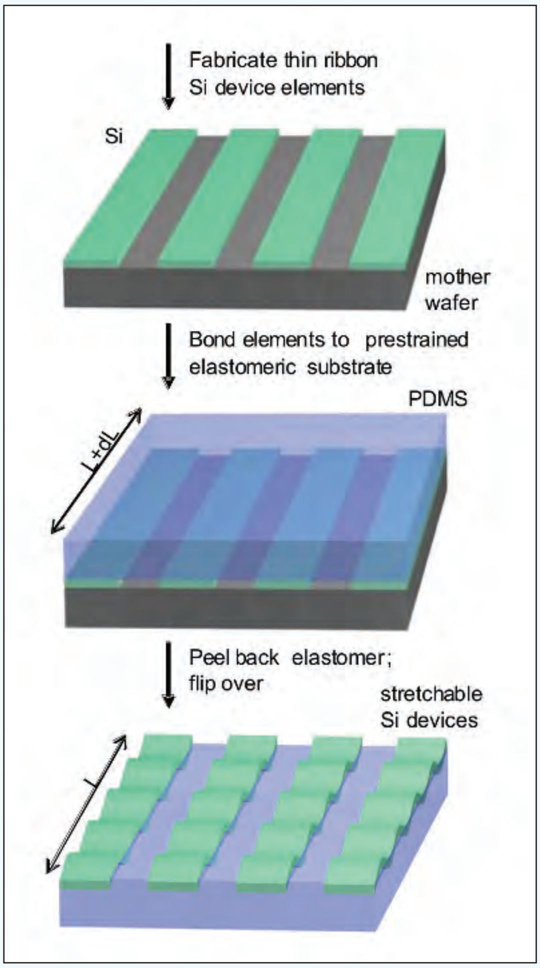
Stretchable electronics concerns electrical and electronic circuits and combinations of these that are elastically or inelastically stretchable by more than a few percent while retaining function. Usually the elastic versions must withstand repeated flexing without loss of function as with a patch attached to a living heart for diagnostics, energy harvesting to power implants and/or control, for that, they tend to be laminar and usually thin. No definitions of electronics and electrical sectors are fully watertight but it is convenient to consider stretchable electronics as a part of printed electronics, a term taken to include printed and potentially printed (eg thin film) electronics and electrics. This is because the cost, space and weight reduction sought in most cases is best achieved by printing and printing-like technologies.

Stretchable electronics has been one of the least exploited but most researched sectors in electronics over the past decade. Commercialisation has been elusive and a number of manufacturers have left the scene, though the participants see huge potential. A good example of this was seen this year when the University of Gent researching the subject wrote, "Mechanically stretchable electronics are virtually non-existing today."

Actually they are slightly underselling their industry because Artificial Muscle has commercialised electroactive devices employing elastic electrodes some years ago in haptic touch switches (you feel what you are doing) and promoted them for such things as energy harvesting and steerable serpentine camera lenses. Indeed the German giant Bayer AG has now snapped up this promising company. Nonetheless, it would be fair to say that the commercialisation of stretchable electronics has been disappointingly rare so far.

mc10 Inc in the USA is a rare example of a pure play stretchable electronics company. It works with partners in a joint development model to prototype and manufacture novel applications for consumer, military, medical and industrial applications, giving us a glimpse of where this nascent industry sees its products being used.

The value chain for printed electronics is unbalanced, with too little effort to commercialise the technologies, such as by designing innovative, amusing or useful new products, never before possible, created using the new toolkit. For example, the easiest commercialisation of stretchable electronics may lie in consumer goods, jewellery, fashion, toys and novelties but almost all participants are focussed on the slow-moving healthcare sector that is understandably more demanding in terms of safety and quality requirements and approvals. Certainly many very interesting things are being done to modernise sportswear, for example.



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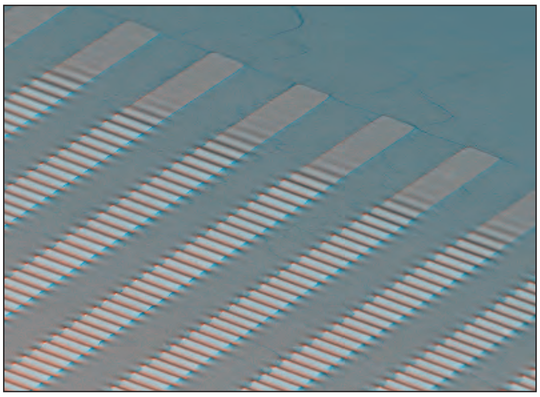
That said, it is particularly in healthcare that stretchability, bringing portability, disposability, error prevention, wearability and so on reads on to many of the big trends and needs today. These include how to cope with an ageing population that wish to stay mobile and how to respond to the fact that there will not be enough physicians, hospitals and carers to cope using old procedures and equipment. Stretchable implanted and skin mounted electronic and electrical patches will diagnose and respond earlier, delivering drugs with



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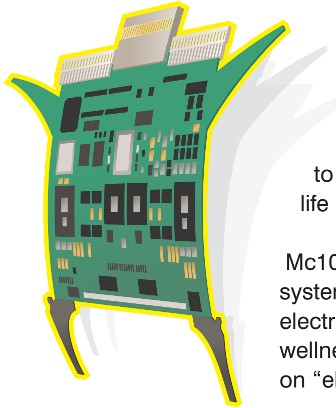
less error than when the patient had to remember times and doses. It facilitates the bionic man and woman and more. Indeed the longer term objectives are truly awesome, with talk of unintrusive electronics in the folds of the brain.

Future functionality

Taking the broader view that stretchable electronics makes a host of new functions possible we see investors sensing that this nascent industry is indeed at a tipping point. Too often the objectives have been engineering-led and unambitious. Add 100 creative designers and commercialisation will leap forward at a blistering pace.

Mc10 focuses on healthcare applications, commercialising the outstanding advances in the subject provided by the University of Illinois at Urbana Champaign. It completed a Series b fundraising bringing the round's total to $14.75 million in September 2011. mc10 takes electronics 'out of the box' to create thin, conformal systems that are able to move with the natural world. The company combines breakthrough technology with innovative engineering to develop exciting new consumer, medical, and industrial products. mc10 is headquartered in Cambridge, MA.



"Mc10 represents a game-changing technology for medical devices and health care electronics," said Adam Fine, Managing Director of investor Windham Venture Partners, experts in healthcare. "We are pleased to provide both capital and expertise to accelerate their products and partnerships in life science applications."

Mc10's ability to create bendable, stretchable systems out of otherwise rigid high performance electronics has immediate benefits for health and wellness products. For example, mc10 is working on "electronic skin", which can measure everything from heart rate to activity level to hydration, all in a thin, sticker-like package. This has enormous potential in the health, wellness, and health care markets.

The company's active partnerships, collaborations, and funding sources, including Massachusetts General Hospital, the US Navy, and Reebok, demonstrate the broad impact of mc10's platform. For mc10, Windham's support and involvement represents an ideal addition to the existing team.

"Windham complements the skills and interests of our other venture investors," said mc10's CEO David Icke. "They bring a driven, entrepreneurial approach along with a deep knowledge and far-reaching experience that will help us build our life science electronics business."

Now investors are alert for the mc10 of other sectors for stretchable electronics given that so much of the engineering is ready to move into pre-production. There is already origami electronics and car electronic and electrical parts that can mould into position as the vehicle is constructed.

However, tackling this calls for a completely different approach and value chain from traditional electronics and electrics with its focus on companies making different components and other companies that put them all together in a box and make them work.

Traditional electronics and electrics does not involve the paper and packaging, publishing or printing industry to any significant extent. It has input from the chemical and plastics industry but the new electronics turns all this on its head with totally new forms of collaboration becoming essential and much of the added value going to the chemical industry in particular.

Those that try to use the old approach of making and selling individual components by just printing them tend to go out of business because what the market and the economics demand is complete smart labels etc that perform a function at lowest cost. Even ink making comes centre stage as does the replacement of print and manual procedures before the replacement of electronics.

Excitingly, some of those inks will even include such exotica as carbon nanotube and graphene springs and transparent, not just stretchable and foldable electronics becomes widely possible.

Mobile MEMS market

Yole Développement tips 20% annual growth to reach $5.4B in 2017.

New MEMS devices will benefit from mobile device growth over the coming years. Phones and tablets will represent a 2.9B units in 2017 and most of them will integrate 5 to 10 MEMS devices, claimed Laurent Robin, Activity Leader, Inertial MEMS Devices & Technologies, Yole Développement. The analyst group believes 10 new MEMS applications in mobile applications will become $100M markets in 2017. MEMS devices are extremely popular in mobile applications. Despite this interest, only 3 categories of MEMS devices are in high volume production today.

Motion sensors including accelerometers, magnetometers and more recently gyroscopes is the hottest market segment. It is still growing quickly and many business and technical evolutions are expected. One of them is the launch of combo sensors which provide a higher level of integration and possibly embed sensor fusion algorithms.

MEMS microphones which are promised a bright future, driven by ECM replacement and by new functionalities that require multiple microphones

BAW filters and duplexers have been popular for years, especially in Band 2 and new opportunities will appear with some of the bands used in 4G standards

Yole is tipping novel MEMS opportunities that need to be watched:

- While limited to weather forecast applications today, pressure sensors are going to be used in combination with inertial sensors to provide location-based services
- RF MEMS switches had a successful start in 2011 and will benefit from the current hype for antenna tuning
- Oscillators is another hot area where silicon MEMS has a high potential, both for replacing TCXO quartz oscillators and for integration of resonators
- Another hot market is going to be MEMS auto-focus which provides significant added value compared to the existing VCM technology, but will face competition with other technologies as well
- Other types of emerging MEMS are microdisplays, microspeakers, touchscreens and joysticks

New players

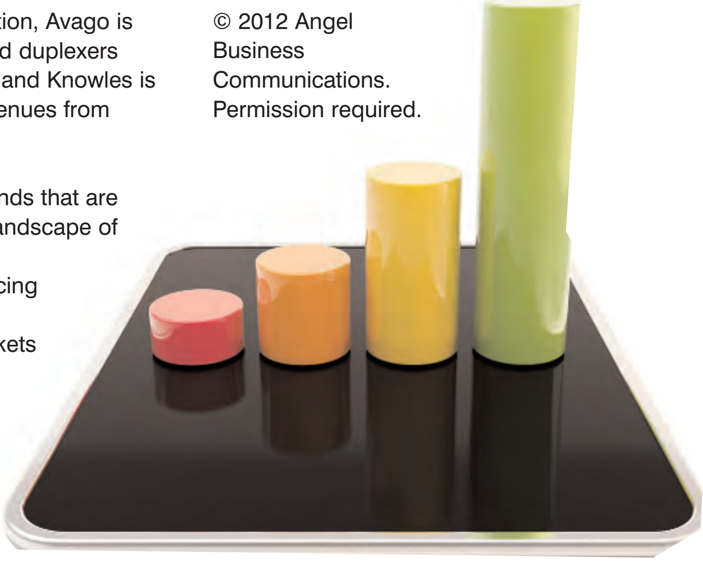
Opportunities are thus huge for MEMS device makers, as this market tripled from 2009 to 2011. The ranking of the top players has also evolved the past 2 years: ST Microelectronics was number 3 in cell phone applications in 2009 and is now the number one supplier by far with $477M cellphone and tablet revenue in 2011. ST Microelectronics still dominates the MEMS accelerometer market, had an impressive start with MEMS gyroscopes, only challenged by InvenSense, and continues to expand to many other MEMS devices to become a one-stop supplier.

ST Microelectronics major clients are Apple, Samsung, Nokia, RIM and HP. Other large players are very focused on their core markets: AKM is the number 2 with $260M sales of magnetometers for electronics compass solution, Avago is leading the BAW filters and duplexers market with $244M sales, and Knowles is number 4 with $233M revenues from MEMS microphones.

Yole sees a number of trends that are shaping the competitive landscape of tomorrow including;

- Many start-ups introducing disruptive technologies: both for emerging markets (RF MEMS switches and variable capacitors, scanning mirrors for picoprojectors, silicon timing devices, speakers, auto-focus…)
- Attracted by this growing market space, large semiconductor companies are now eyeing MEMS: Fairchild and Maxim have made the move through acquisitions, and others should follow
- New business models are being developed and it appears that some players specialize on a specific part of the value chain (MEMS manufacturing, signal processing…) while others are offering complete solutions (e.g. combo sensors which integrate MCU and software)

"The market for MEMS in cell phones and tablets will grow 19.8% to reach a $5.4B value in 2017", says Laurent Robin, Activity Leader Inertial MEMS Devices & Technologies, Yole Développement. The MEMS industry will be largely impacted by global trends in mobile devices: connected devices, video and music consumption, social networking, diversity of users and usages, mobile advertising. In the reverse way, Yole Développement also notes that the booming demand for smartphones and media tablets can be partly explained by the integration of MEMS sensors which provide new functionalities.



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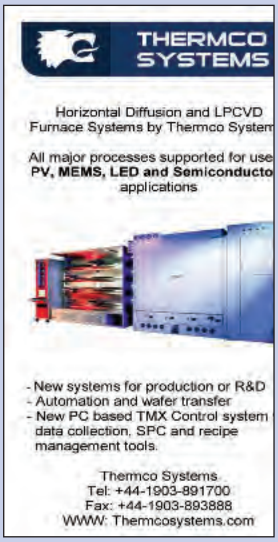

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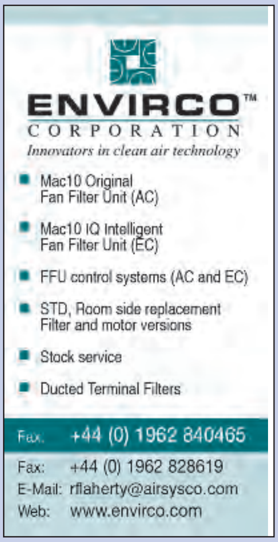

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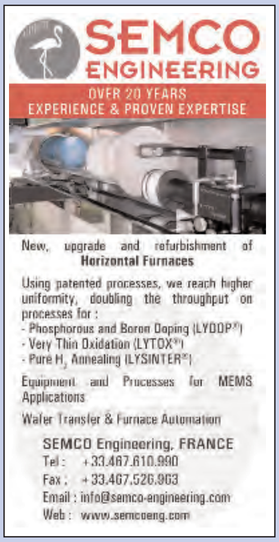

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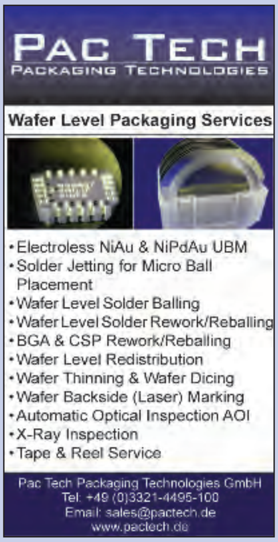

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