MEMS' Trends

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Magazine on MEMS Technologies & Markets

Top MEMS ranking: Shuffling the cards

YOLE Développement

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EDITORIAL

Above US $20B in 2017

This new issue of *MEMSTrends* is dedicated to our update of the MEMS markets and MEMS players' ranking. The MEMS market will continue to see steady, sustainable double-digit growth for the next six years, with 20% compound average annual growth in units and 13% growth in revenues, leading to a $21 billion market by 2017. Microfluidics and inertial MEMS will contribute largely to this growth, as will the "next big thing": combo sensors. The market for combo sensors started last year, with 6-axis accelerometer and magnetometer combo units shipped in volume. Six-axis accelerometer and gyro units are now starting to do so as well, often with only a small additional cost for the accelerometers. We believe that while the market for discrete inertial sensors will begin to decline, the growth of combo solutions will be huge. We estimate it is currently a less than $100 million niche, but we expect combos to be a $1.7 billion opportunity by 2017. New MEMS devices are also very close to volume production -- for example, autofocus components have taken somewhat longer than anticipated to reach the market, but they now have potential for quick adoption, with Polight and Tessera readying for production.

On the manufacturers' side, the big news is STMicroelectronics is now challenging Texas Instruments for top spot. In 2011, STMicroelectronics had an impressive 42% growth, which equated to more than $250 million in added business. In fact, most of the microphones and inertial MEMS companies achieved good growth in 2011, compared to 2010. Although the MEMS foundry business had a modest 5% growth, some companies did quite well: Silex Microsystems and Teledyne DALSA are both growing steadily in the $40-$50 million range, and could soon be contenders.

In conclusion, MEMS are definitely becoming part of our everyday lives. One day, they will contribute to form a ubiquitous sensor network, with processing power, wireless link, and smart energy sources to allow for a more sensitive world.

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Dr. Eric Mounier, Senior Analyst, MEMS Devices & Technologies, Yole Développement
Since 1998 he is a cofounder of Yole Developpement, a market research company based in France. Dr. Eric Mounier is in charge of market analysis for MEMS, equipment and material. He is Chief Editor of Micronews and MEMS'Trends magazines (MEMS Technologies & Markets). Dr. Eric Mounier has a PhD in microelectronics from the INPG in Grenoble.

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Courtesy of Benedetto Vigna, Group VP, General Manager MEMS and Healthcare Division Analog, Power, MEMS Group Industrial & Multisegment Sector STMicroelectronics and Jiri Marek, Senior Vice President of Engineering Sensors at Robert Bosch

EVENTS

- **Sensors + Tests**
  May 22 to 24 – Nuremberg, Germany
- **MEPTEC - MEMS Technology Symposium**
  May 23 - San Jose, CA
- **Sensors Expo & Conference**
  June 6 to 7 - Rosemont, IL

Five Impeccable Reasons to Attend…

"MEMS in Motion is a different way of doing business…you're going to see a lot more of these in the future. I'll attend again, and I'd recommend it to other companies in the MEMS field."

John Brashear, VectorNav Technologies
MEMS in Motion 2011 Participant

"I love MEMS in Motion. I will absolutely dedicate the time to make sure I attend next time."

Kevin Shaw, Sensor Platforms
MEMS in Motion 2011 Participant

"I am extremely pleased with MEMS in Motion. It was great and I am looking forward to next year's summit!"

Vincent Fortin, Teledyne DALSA
MEMS in Motion 2011 Participant

"Some conferences you have just speakers and listeners, presentation after presentation. Forums like MEMS in Motion force interaction between people which tend to be more productive meetings. I would recommend this event to other industry people—100 percent."

Tom Flynn, Coventor
MEMS in Motion 2011 Participant

"Overall, I was very satisfied with MEMS in Motion and I think I'll come away with some deals from this experience."

Mary Ann Maher, SoftMEMS
MEMS in Motion 2011 Participant

Industry leaders will gather for the second edition of the two-day MEMS in Motion event. Qualified attendees will enjoy exclusive plenary sessions; hours of one-on-one meeting opportunities, plus a variety of social activities.

Register today, and help shape the future of inertial devices.

To watch a video featuring comments by 2011 participants, and to learn about the 2012 event and how you can participate, visit www.MEMSinMotion.com.

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FINANCIAL BUZZ

InvenSense and Tessera lead the MEMS financial deals in Q1 2012

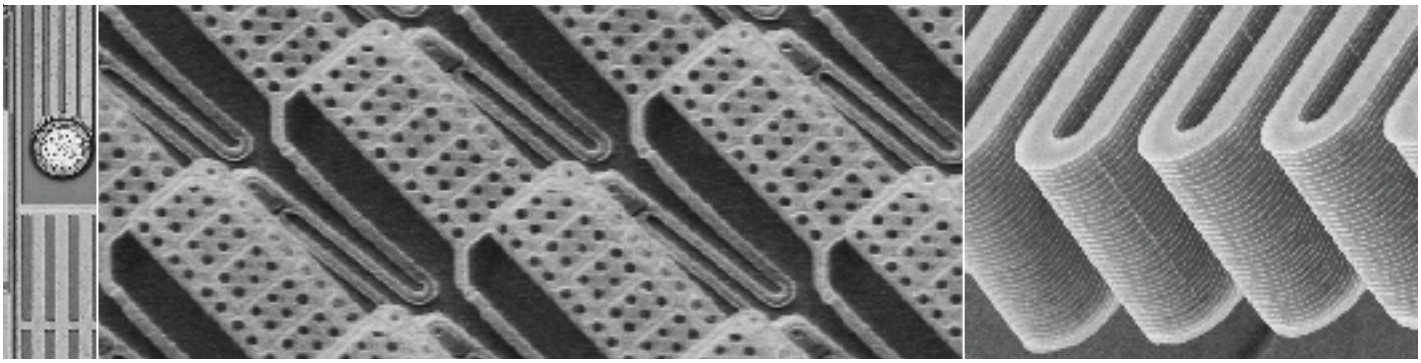
The first part of 2012 was rather quiet in terms of MEMS financial transactions, compared to the end of 2011, which was anything but! Among the deals made, we make special note that InvenSense managed a follow-up offering on its IPO, and also that Tessera became vertically integrated with the purchase of VistaPoint's camera module business, which is good news for DigitalOptics' MEMS Auto-focus development.

New investments (VC rounds, IPOs)

Company	Type of product	Type of investment	Level of new investment	Investors	Yole Développement Comment
Jan. 2012					
Senova Systems (US)	Carbon based solid state pH sensor	Series B financing	US$6.7M	Phoenix Venture Partners, Harris & Harris Group Inc. + existing investors	Senova Systems is developing products based on exclusive licensing of a technology developed in Oxford University
Owl biomedical (US)	Cell sorting platform based on MEMS	Equity	US$3.0M	NA	Incorporated in 2010, OWL Biomedical (previously "J2D BioMedical, Inc") is a spin-off of the MEMS foundry IMT. This equity is part of a $16.9M round
Feb. 2012					
MEMSCAP (FR)	Pressure sensors, Micromirrors for optical communication...	Capical increase	US$1.6M	Existing shareholders	We note that MEMSCAP's available liquidities amounted to 1.7 million euros at December 31, 2011, including cash and cash equivalents and liquid financial assets available for sale. Following the successful capital increase finalized beginning of February 2012, these liquidities will be increased by 1.2 million euros
Rheonix (US)	Microfluidic platform for the molecular diagnostics	3rd round	US$6M	Private investors	Located in the adjacent building of Kionix, Rheonix originally operated as the microfluidics division of Kionix. Rheonix is developing a low cost diagnostic platform based on proprietary polymer chips
Mar. 2012					
InvenSense (US)	MEMS gyroscopes, inertial combo solutions	IPO follow-up offering	US$96.5M	NA	6.5M shares are beeing offered, at a price of $14.85. Mainly VCs are selling part of their shares in InvenSense. We note that InvenSense will not receive any proceeds from the sale of shares by the selling stockholders. InvenSense had an excellent 2011 year thanks to gyroscopes and other motion sensing solutions integrated in mobile phones and tablets. InvenSense is the only company to challenge ST in this market.

M&A

Company	Type of product	Type of transaction	Value of the transaction	Acquirer	Yole Développement comment
Sept. 2011					
Hygrochip business from Hygrosens (D)	Humidity modules	Acquisition	NA	Innovative Sensor Technology IST AG	IST is a well-known manufacturer of capacitive MEMS humidity sensors. IST had close relationship with Hygrosens in the past since Hygrosens developed modules based on a custom IST sensor. With this acquisition IST goes a step forwards in the value chain
Mar. 2012					
Zhuhai Camera Module Business of Vista Point Technologies (Flextronics group) (CN)	Camera Modules	Acquisition	US$23M	DigitalOptics Corporation (subsidiary of Tessera)	Tessera is pushing its MEMS auto-focus technology to the market. Tessera MEMS actuator technology comes from Siimpel acquisition in 2010. The major drawback of this approach is that a lens element need to be changed in the middle of the stack of lenses (4 or 5 usually), which means that changes are needed at the system level. This is probably one of the reasons why Tessera decided to control the cameramodule assembly with this acquisition. We note that this is one of the first times that a MEMS component company gets vertically integrated by buying a system business
Tamarack Scientific (US)	UV projection lithography systems, laser micro-structuring tools	Acquisition	US$9.34M	Süss MicroTec	Süss MicroTec adds a new product line to its portfolio and gains access to a new core technology for equipments used in MEMS but also in advanced packaging and LED industries. We note that Süss is mostly involved in the front-end and mid-end types of equipments, where Tamarak was mostly involved in back-end tools. Consequently this transaction opens new markets for Süss.



Rapid progress in the chinese MEMS industry

Observations at SEMICON/Electronica China

Wenbin Ding,
Technology & Market Analyst MEMS Devices & Technologies,
Yole Développement

In March 2012, Yole Développement attended SEMICON China and Electronica China 2012 in order to follow the latest industry and market trends, evaluate disruptive technologies, and continue bringing the hottest news from both the Chinese and the global market to the entire MEMS/micro technology world.

In conjunction with Semicon China, CSTIC (China Semiconductor Technology International Conference) 2012 was also held in Shanghai. CSTIC is one of the largest and most comprehensive annual semiconductor technology conferences in China, and it is organized by SEMI and ECS, with co-organization from China's High-Tech Expert Committee. The show covered every aspect of semiconductor technology and manufacturing, including devices, design, lithography, integration, materials, processes and manufacturing, as well as emerging semiconductor technologies and silicon material applications. Hot topics, such as LEDs, III-V semiconductors, and MEMS were also included in the conference.

During CSTIC, many MEMS companies made presentations about their technology and their new products. For example, Horst Theuss from Infineon Technologies showed us the challenges and opportunities of MEMS sensors' packaging; Herb Huang, director at SMIC, revealed the manufacturing capability of their CMOS-MEMS platform; Andrea Onetti, Senior Director of STM's Audio and Sound Business Unit, revealed their newest generation of MEMS microphone products; and iNemos showed us the potential applications they can enable.

Yole Développement presented its latest analysis of the global MEMS market and emphasized two very hot products at the moment: inertial sensors and microphones. Participants were interested to learn about the latest technological and market trends, and of how the whole MEMS industry supply chain is changing.

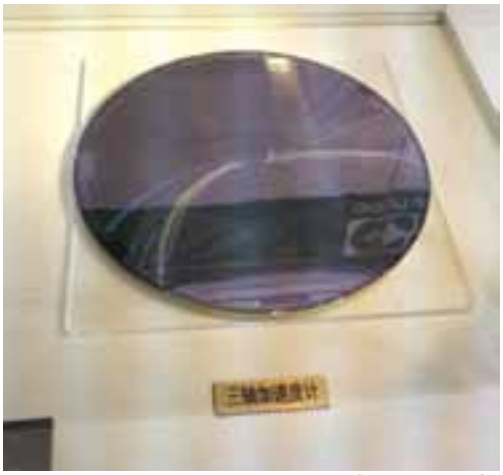
After the very interesting CSTIC came Semicon and Electronica China, two huge exhibitions taking place March 20 – 22 and where thousands of companies exhibited to an endless stream of visitors. Semicon China was divided into four pavilions: China Market IC Applications, TSV, LED manufacturing and secondary equipment services, and fab productivity solutions. Related forums were also organized for companies to present and exchange the latest technological information. Many familiar companies were present, such as ASMC, CSMC, Grace, and SMIC. Additionally, a host of other MEMS companies exhibited at Electronica China.

After speaking with numerous companies and industry experts, we are happy to report rapid progress in the Chinese MEMS industry. While the country's inertial MEMS industry is still in its infancy due to immature technology, an announcement from MiraMEMS made our eyes light up: they've started production on China's first 3-axis accelerometer for consumer applications. Even though there may be room for improvement in the country's technology, this is a big step forward for Chinese MEMS players.

MEMS microphone is a hot topic in China, just as it is everywhere else. Chinese players are doing quite well thanks to the support of Infineon, which supplies MEMS dies to several companies. AAC Technologies is beyond a doubt the most successful at the moment - they supply to Apple for the iPhone 4 and 4S, and the new iPad as well. However, new challengers are growing very fast: Goertek, Gettop and the new company, NeoMEMS. All these companies are busy working on their own MEMS technology and trying to do everything in the package. Things are changing rapidly in China and we're excited to see what the future holds!

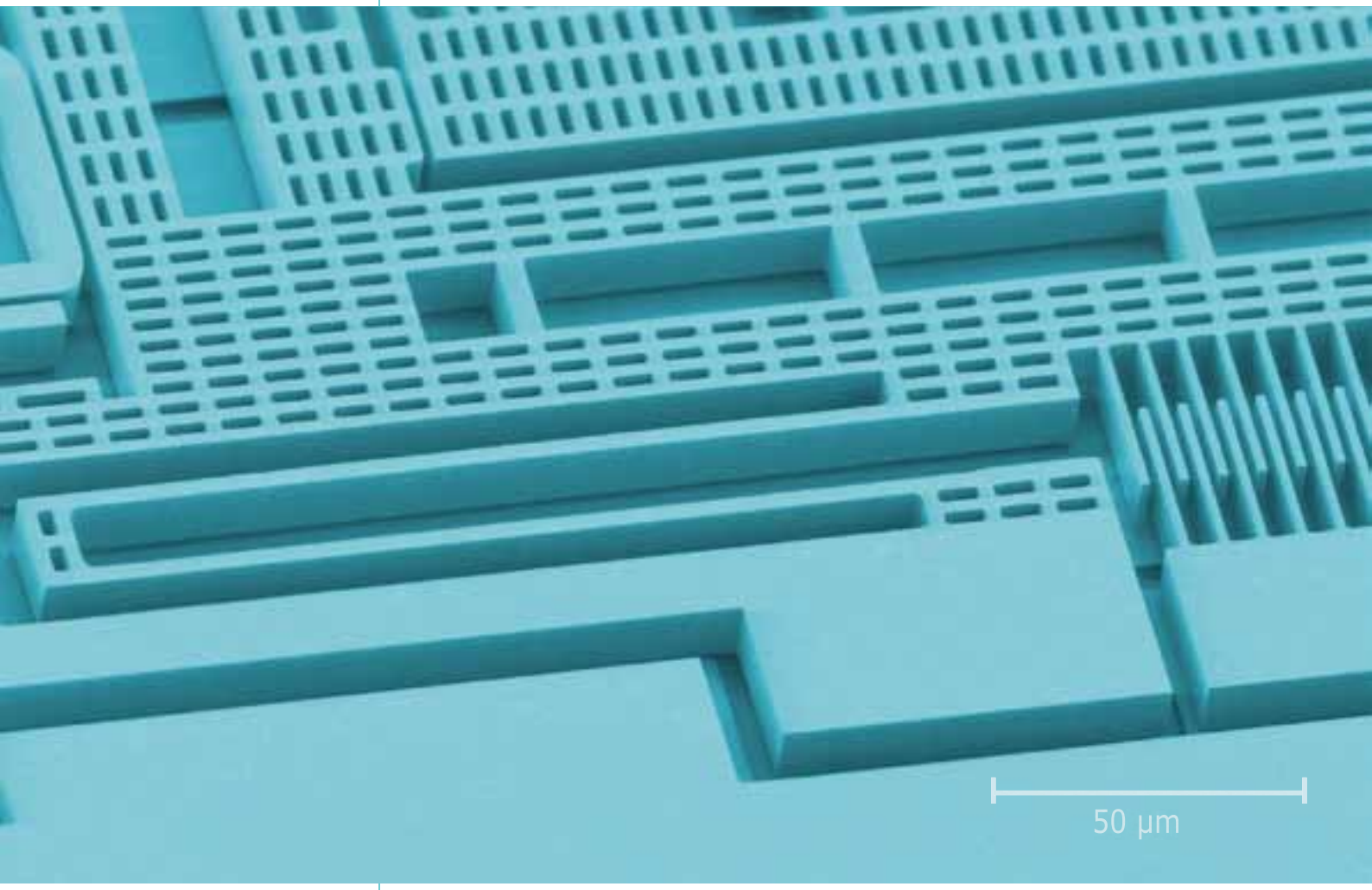
In closing, we expect to see more and more Chinese MEMS companies at different levels of the value chain: foundries, design houses, package/assembly companies, etc.

"Things are changing rapidly in China and we're excited to see what the future holds!"
says Wenbin Ding, Yole Développement.



3-axis MEMS accelerometer wafer (Courtesy of MiraMEMS)

www.yole.fr



Microelectromechanical components –Two billion Bosch MEMS sensors The MEMS structures of a yaw-rate sensor are many times finer than a human hair (Courtesy of Robert Bosch)

Top 30 MEMS companies 2011: Fast growing consumer markets continue to shake up MEMS sector

Smart phone market drives 17% growth in 2011, sending the MEMS market to $10.2 billion, and inertial sensors to almost a third of the total market.

"People talk about economic stagnation, but we see no signs of decreasing consumption," says Schaefer, Robert Bosch.

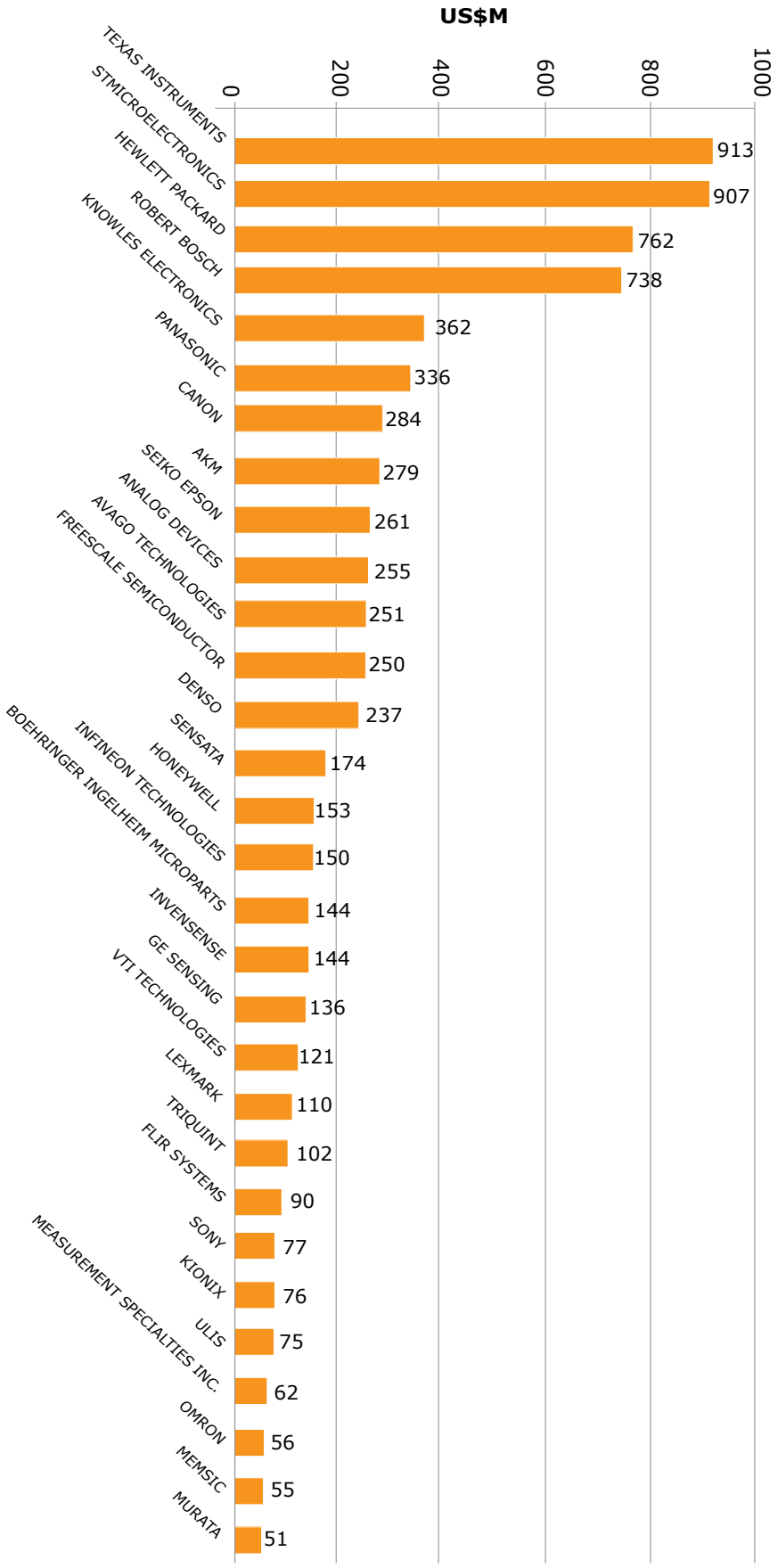
The rapid penetration of MEMS sensors into the smart phone market drove a 17% jump in demand for MEMS in 2011, creating a $10.2 billion total market, and propelling 40% and better growth across leading suppliers. STMicroelectronics challenged long time sector leader Texas Instruments for top position, as both companies closed in on $1 billion in sales. Robert Bosch similarly shouldered up against giant Hewlett Packard on the strong growth in inertial sensor sales, with a 17% increase to ~$738 million.

Smart phone demand drove whopping 20% to 80% growth across a whole range of sensor suppliers. ST achieved 42% growth, to total $907 million in MEMS revenues, climbing from fourth rank last year up to neck and neck with Texas Instruments, whose more mature micro mirror markets grew more slowly. Knowles Electronics moved up to fifth rank on 40% growth in MEMS microphones to $362 million. Magnetometer supplier AKM jumped 46%, to $279 million and eighth place. Though most magnetometers are not a purely MEMS technology, they are now so closely integrated with accelerometers that Yole Développement now tracks them with the MEMS industry. Fabless InvenSense jumped 67% to $144 million, thanks to its gyroscope and motion sensing offerings made at TSMC and now second sourced at Global Foundries, and pulled off the MEMS industry's first major IPO. MEMSIC reported better than 80% growth on the strength of its magnetometer and accelerometer sales, to enter the Top 30 ranks at $54 million. Triquint, Kionix, Analog Devices, and Sony also saw 20% or better growth, supplying phone makers with BAW filters, accelerometers, and microphones.

Other sectors did well too. Leading automotive suppliers saw 15% to 20% growth, as more government regulations worldwide required

Top 30 worldwide MEMS companies ranking 2011 Revenues (US$M)

(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)



electronic stability control units, and China massively adopted airbags. Infineon Technologies, Ulis and Sensata all achieved 20% or better growth in their automotive, microbolometer and industrial markets.

STMicroelectronics closes in on TI for sector lead, targets microphones next

STMicroelectronics' spectacular 42% growth meant more than $250 million in added business. "Motion sensors drove revenues, especially the increasing market penetration of the gryo," says Benedetto Vigna, EVP and GM of ST's Analog, MEMS & Sensors Group. "And ST grew more than the competition, because we had the manufacturing capacity in place, and because we were able to manufacture products with consistent quality and performance." ST reports it has shipped more than 350 million gyros since entering the segment in 2009. Vigna argues that this high volume production --with more than 2 billion inertial sensors made on the same technology platform to date—means tighter control of variability across units.

The company invested in expanding MEMS production in Italy, ASIC production in France, and assembly and test in Malta and the Philippines, to a reported planned capacity of 3 million die per day. The company doubled the capacity in the Agrate MEMS fab.

With accelerometers already in almost all smart phones, and gyros and compasses also likely to reach close to 100% penetration this year, ST next targets sensors aimed at optical image stabilization and location-based service applications, and at improved acoustic sensing to be the next growth drivers. It counts on its dual core gyro to allow customers to use the same gyro concurrently for image stabilization and for motion sensing to save on size and cost. It counts on its accelerometer with microcontroller to serve the pedestrian navigation market, where it's working on solutions with wireless and location chip provider CSR, and expects that to also drive demand for its high resolution and accuracy pressure sensor. It counts on magneto-resistive compass technology for the better resolution and lower power consumption needed for these location applications. And it aims to provide higher performance MEMS microphones that provide better sound quality with lower power consumption for the growing market for voice interface and noise cancellation. "This year will see wider

adoption of sensors for location," says Vigna. "Then increased performance microphones are coming next. We want to become the leader in acoustic sensing too by the end of 2013."

Though the company says its 6-axis accelerometer and compass, or accelerometer and gyro solutions are in production for customers, most of the market is still integrating separate components, and also writing its own software for them. Vigna expects big volume adoption of combo modules is still about 18 months out.

Bosch adds another $100 million in business, enters full motion sensing fray with consumer gyro and magnetometer

Big IDM Robert Bosch's total MEMS business saw ~16% growth, to add more than $100 million in business to reach ~$738 million in 2011, very nearly catching up with long time giant Hewlett Packard. The company says it saw relatively balanced growth across its consumer and automotive portfolios. And now it expects its new consumer gyro and magnetometer to drive more growth in 2012.
"We expect a very good year in 2012 now that we have a complete portfolio and the sensor fusion software," says Frank Schaefer, senior manager for production planning and marketing, sensors, automotive division. "Making all the sensors means we can optimize them together. It is more difficult to make them smaller and integrate the software if you have two suppliers."

The company recently added a 3-axis gyro in a 3mm x 3mm package for the consumer market. It's also now making its own magnetometers, with a technology the company says provides better accuracy and uses less power than Hall-based devices. The Bosch approach uses two thin magnetic layers that change electrical properties when the magnetic field changes, in a 3mm x3mm package. When the magnetic film is reversed, the detector outputs a voltage pulse, and the time between the signals tells the strength of the earth's magnetic field there. The company expects the 6-axis accelerometer and magnetometer combo, and 6-axis accelerometer and gyro combo sensors to be the preferred choice for new platforms, for both lower cost and ease of use.

"Motion sensors drove revenues, especially the increasing market penetration of the gyro," says Vigna STMicroelectronics .

On the automotive side, demand was good for inertial sensors, and combo sensors penetrated the market further. Demand is continuing to grow for government mandated automotive safety requirements for electronic stability control, tire pressure monitoring, and more airbags in more cars in more countries. Lower cost is driving users to combo sensors. With the typical two-year automotive cycle, the combo sensor introduced in 2010 is now working its way into cars. "Many new platforms will be combo," says Jiri Marek, SVP of engineering sensors, automotive electronics.

Bosch expects the 2012 automotive market will continue on the same growth pace as 2011. "People talk about economic stagnation, but we see no signs of decreasing consumption," says Schaefer. Government mandates for ESC systems continue

LSM330D system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope (Courtesy of ST Microelectonics)

to spread until 2014 to USA, EU, Japan, South Korea, Russia, Canada and Australia. Demand also continues to grow for engine management systems to further improve control of emissions. China continues to add more accelerometers for more airbags to more cars, while stronger crash regulations in Europe, the US and Japan are also increasing the number of accelerometers and peripheral pressure sensors used per car. Further out, however, there is some question how many fewer engine control sensors hybrid and electric vehicles may use, as they reduce or eliminate their combustion engines.

Schaefer argues that the fast moving, high volume consumer business is helping drive new technologies and drive down prices on the automotive side as well. Both sectors use the same simulation models and process modules and contribute to fab volume, but the fast ramp to high volumes of the consumer products also builds manufacturing experience much faster --getting to multi million unit volumes in months instead of years. "The consumer business can push the limits of size and thinness much faster, so we know what the limits of the technology are, and can then adapt it to the automotive business as well," says Schaefer. Annual volume at Bosch is now up to almost 500 million die/year, or more than 1.3 million per working day.

The company's new automotive barometric pressure sensor for motor management uses much the same technology as its consumer pressure sensor, though with more complex electronics. Both use porous silicon to create the cavity, which allows growth of single crystal silicon on top for good quality signal, then heats the device to 1200°C to rearrange the porous silicon to form a thin 3µm vacuum chamber, for a small and robust device that is cheap to integrate in the CMOS flow.

Top growth: MEMSIC increases sales 80% with low cost devices for Asian markets

Fastest growing of all was MEMSIC, who achieved more than an 80% jump in MEMS revenues, on the strength of its low cost accelerometers and magnetometers in Asian mobile phone markets, for a ~$55 million business at the packaged die level, joining the ranks of the Top 30 MEMS companies for the first time. Total company revenues reached $68 million, including the systems value of the company's high end industrial and avionics products.

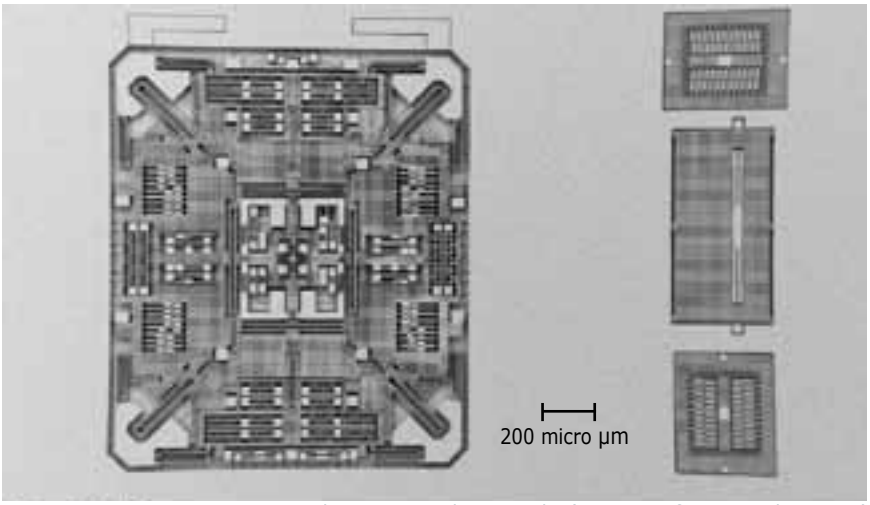
The company's low cost technology meets the needs of Asian fast-follower mobile phone makers, with major sales to Korean handset makers so far, and big potential to come in the China market. "There are 20-30 top companies in China, and maybe 1000 total, who aim to make a $200 phone with performance not that much worse than the leading $500 models," says CEO Yang Zhao.

Demand has been particularly strong for the company's low cost magnetometers, says Zhao, which use AMR technology that can be manufactured relatively simply with a single layer of magnetic thin film that changes resistance as the magnetic field changes, reportedly also more accurate than the Hall-effect sensors. Zhao hints that the key to cost reduction involves making the x, y, and z axes all in a single plane, but then bending up the z-axis component, allowing simple wire-bonding packaging to significantly lower costs.

MEMSIC's unique thermal accelerometer design also reportedly allows low cost manufacturing. The MEMS is made in 18µm CMOS on the same chip as the ASIC, then another 8-inch wafer is bonded on for wafer-level packaging, for a tiny 1.2mm x 1.7mm packaged device size. The thermal technology relies on temperature sensors to detect changes in the temperature profile as acceleration moves gas molecules instead of a proof mass. The company both fabs its own products and outsources production to TSMC to diversify risk, to meet customer expectations for dual location production for each step.

The company has no plans to join the gyro competition. "Why do you want to pay for a gyro in a phone?" wonders Zhao. "There is no killer app. There's almost no use except for games. An accelerometer and a magnetometer can simulate much of the function of the gyro, not 100%, but close enough for some games, and it's cheaper." MEMSIC stopped development of a consumer gyro when it figured it couldn't have a significant cost advantage over big IDMs who own their own fabs as gyro prices continue to plummet.

"There is no killer app. There's almost no use except for games. An accelerometer and a magnetometer can simulate much of the function of the gyro, not 100%, but close enough for some games, and it's cheaper," says Zhao, MEMSIC.



Gyroscope & accelerometer on the same die (Courtesy of ST Microelectronics)

Coming next from MEMSIC will be a more accurate accelerometer, says Zhao, and an accelerometer and magnetometer combo sensor that's smaller than the competition. Future growth, however, will have to come from software, systems, and from higher value-added markets. Accelerometer and magnetometer costs may be bottoming out, with silicon cost from the tiny die already down to pennies, and wafer-level and flat wire-bonding packaging wringing the cost out of the packaging side. "When hardware gets to the minimum, software and applications will become the driver," argues Zhao. MEMSIC now provides both the sensor fusion and the function software as well, which few mobile phone customers can do themselves. But going forward it looks to capitalize on the higher value added systems integration and sophisticated software expertise it acquired with its acquisition of Crossbow Technology, aiming both to expand its higher end systems business and to move this capability down market to consumer applications in simper systems with lower cost sensors.

Who's up and coming next?

Right behind the Top 30 are another ten or so companies in the $30 to almost $50 million range that could well move up into the top ranks in the next year or so. Silicon Sensing Systems is pushing $50 million, introducing a new generation automotive gyro, and doing very well in its foundry business in Japan. Silex Microsystems and Teledyne DALSA are both growing steadily into the $40-$50 million range and could soon be contenders. Epcos saw better than 50% growth to the $40 million ranks, thanks to its microphones and BAW duplexers. IR sensors supplier Excelitas also has some $40 million in revenues from its MEMS thermopile-based detector business. SiTime doubled its MEMS timing business as it continued to make inroads in that highly fragmented market. Though still less than $20 million in sales, fast growth is likely to continue, potentially bringing the company into the Top 30 in a few years.

Paula Doe for Yole Développement

Yole Développement defines MEMS as three dimensional structures made by semiconductor processes, with primarily physical or mechanical, not electronic, function. Typically these have moving parts or cavities, but also include solidly mounted BAW resonators and piezo and thermal devices where the physical response of resonating or expansion is more subtle, and non-moving structures like gratings and micro tips that may not have enclosed cavities but are made with the same technology. We also include magnetic sensors because they are now so closely integrated with MEMS inertial sensors. And we include microfluidics on polymer as well as on glass and silicon.
Yole Développement counts MEMS devices and revenue at first level packaged devices, separately from module and systems revenue. For companies that do not release MEMS revenues, we estimate the figures based on our data for product market size, market share, product teardowns, reverse costing, and discussions with the companies.

Since December 2003 Jiri Marek is Senior Vice President of Engineering Sensors at Bosch, Automotive Electronics Division, responsible for the MEMS activities at Bosch.
He studied Electrical Engineering at the University of Stuttgart, Germany and Stanford University, USA. In 1983 he received his PhD from University of Stuttgart and Max-Planck-Institut, Stuttgart for his work on the analysis of grain boundaries in large grain polycrystalline solar cells. After a post doctoral fellowship with IBM Research, San José, California he was a development engineer with Hewlett-Packard, Optical Communication Division. In 1986 he started his work with Robert Bosch GmbH in Reutlingen, Germany.

Benedetto Vigna
Group VP, General Manager MEMS and Healthcare Division Analog, Power, MEMS Group Industrial & Multisegment Sector STMicroelectronics
Vigna was a pioneer of micromachining activity in STMicroelectronics. After two years spent at the Berkeley Sensors and Actuator Center in California and a Business Management Course at STUniversity, he was appointed Director of ST's MEMS Business Unit, responsible for design, manufacturing, and marketing of ST's MEMS products.
In April 2008, Vigna was promoted to Group Vice President and his responsibilities were enlarged to include MEMS, Sensors, low-power RF, and devices for Healthcare applications.

Dr. Frank Schäfer is Senior Manager for Product Planning and Marketing Sensors
Automotive Electronics. Working with Bosch since 2003, he was before a researcher assistant with Prof. Forchel, Chair of Technical Physics at the University of Wuerzburg; where he presented a thesis about fabrication and characterization of III/V quantum dot lasers studied.

Yang Zhao
Chairman, President and Chief Executive Officer
Prior to founding MEMSIC in 1999, Dr. Zhao served in various management positions at Analog Devices, Inc. for seven years, where he was instrumental in developing ADI's MEMS product line and forming industry-wide strategic relationships.
He has been named as an inventor on 22 patents in IC circuit, processing, packaging and MEMS technology. Dr. Zhao holds a B.S. degree in physics from Peking University, as well as a master's degree and a Ph.D. in electrical engineering from Princeton University.

Top Foundries: Twenty players chase ~$600 million in foundry business

The small and highly diverse MEMS foundry business didn't get quite the same boost from the mobile phone business as the inertial sensor makers, as revenues for the Top 20 were up only about 5%, to more than $600 million.

These leading players account for the vast majority of the total MEMS foundry business, which remains a small fraction of the $10.2 billion total MEMS market.

Best growth came from Sony Semiconductor, who cashed in on the mobile business thanks to its production of microphones for Knowles Electronics, with a 145% jump in revenues to $49 million, to become the second largest MEMS foundry (Sony increase is in part due to Yole Dévelopement's under estimation of their 2011 business). That's still some ways behind number one ranked STMicroelectronics, whose $245 million in foundry business was a significant ~25% share of ST's total MEMS business, and an even more significant ~40% share of the total Top 20 MEMS foundry business. Contract production by MEMS IDMs for select partners accounts for more than half of foundry market, leaving the open, pure-play foundries to scramble over roughly $350 million in business.

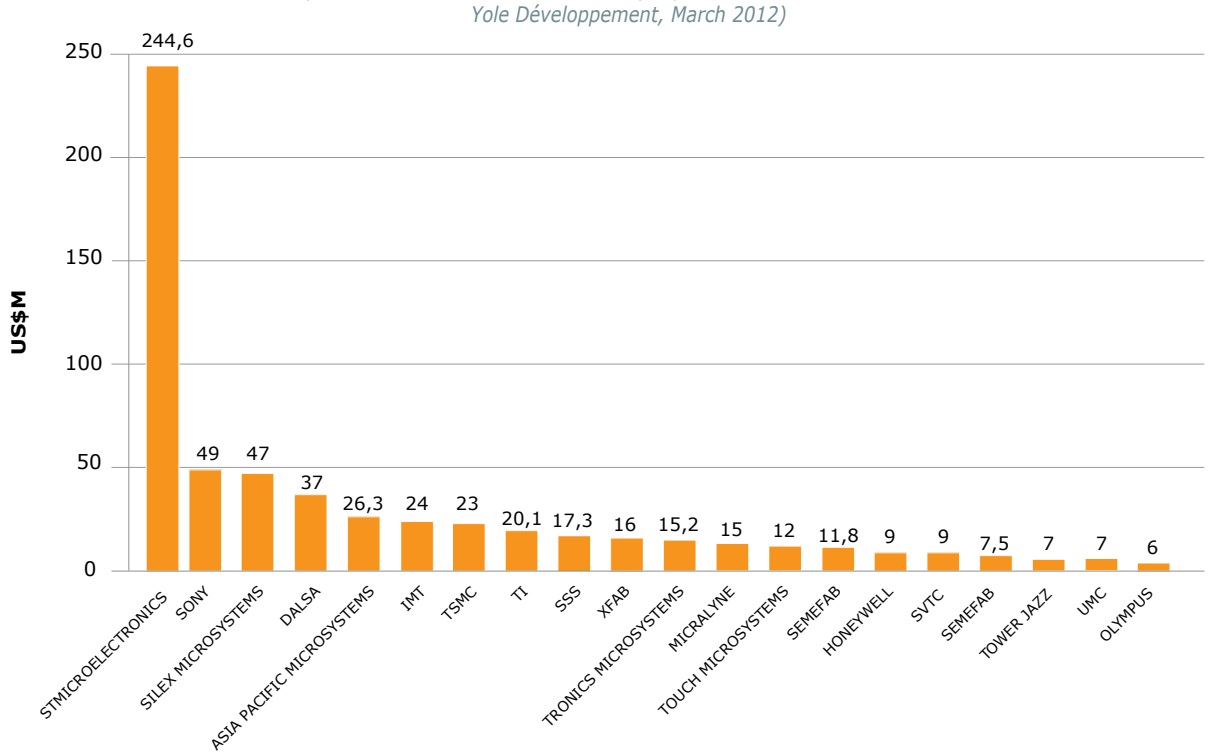
Silex Microsystems' (Silex) revenues jumped by 27% or $10 million, to $47 million, closing in on Sony and leading the pack of pure-play MEMS foundries, thanks to strong demand for its TSV technology. Teledyne DALSA was close behind with 23% growth, adding $7 million in revenues to hit $37 million, also outpacing most the crowd of smaller competitors, as it managed to carefully select customers with high value projects. APM, IMT and TSMC each also had $20 million or better in revenues. Another six players each sold at $10 to $20 million worth of foundry production or development services, including IDMs Texas Instruments and Silicon Sensing Systems. But nearly half the Top 20 players saw little to no increase in revenues in this increasingly competitive market, as the big IDMs captured much of the growth in the high volume mobile phone markets, venture capitalists funded fewer MEMS startups, and entrants from the IC side began to gain more customers. Several foundries saw double-digit declines, impacted by disruptions at Japanese end customers, by slowing in the inkjet sector, and by the increasingly volatile high volume MEMS market, where large chunks of business can come and go very quickly. We expect competition in the foundry market to continue to grow more intense, and some players may struggle.

Top pure- play foundry: Silex leads the specialty foundry crowd, with 27% growth to $47 million

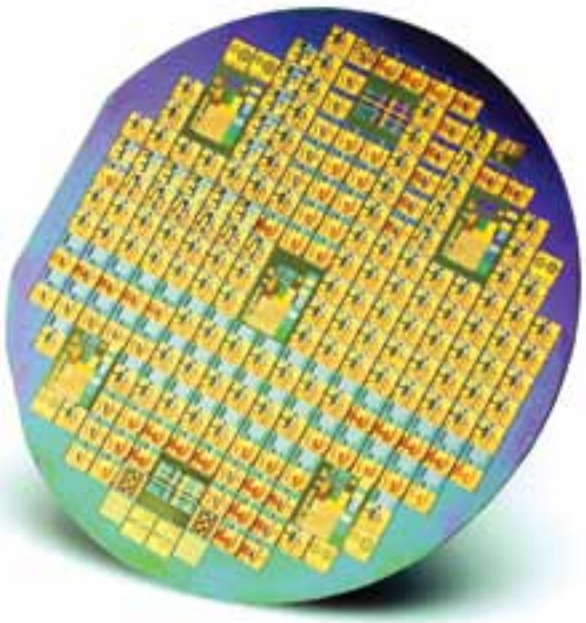
Silex led the pure-play specialty MEMS foundries, with a $10 million jump in business in 2011, to

Top 20 MEMS foundry ranking – Sales 2011 (US$M)

(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)



$47 million, neck to neck with second ranking Sony, almost big enough to make the ranks of the Top 30. Silex' business was fairly evenly split among its industrial, optical/telecomm, life science and consumer segments, and between new and existing customers, reports VP of marketing Peter Himes. He notes that the foundry customer base is changing, as there are few VC- funded MEMS startups anymore. Main customers instead now tend to be existing MEMS players making their next generation product, or OEMS making MEMS devices for their own system needs. The company's TSV technology has been a draw, with its now established cost and performance, and ability to solve some design problems. And Himes argues the company targets not just boutique manufacturing, but high volume products as well.



MEMS wafer (Courtesy of Silex Microsystems)

While foundry customers tend to come with a wider variety of product and manufacturing challenges than the typical IDM has to deal with, Silex aims to re-use well characterized process blocks as much as possible to speed development for new devices, though at best that's likely to be only 60%-80% of a new design. "The biggest challenge to the MEMS industry is time to market," says Himes. "And the solution has to be re-usable standard blocks to shorten the development cycle. MEMS can take up to three years to develop, but markets are on one-year cycles, tops. Standard process blocks are our best bet for now."

Silex is seeing more multisensor integration, with stacks of three or more wafers, SOI or bonded. Coming next is a more advanced metal TSV solution, out of the European-funded joint development programs, for smaller pitch or RF frequency needs. It's also working on R&D in the magnetic space, to be able to offer ferro magnetic materials capability to customers to integrate magnetometers with MEMS.

Paula Doe for Yole Développement

Peter Himes, VP of marketing, Silex Microsystems has over 25 years' experience in helping startups and public companies establish their strategic direction and industry position. Experienced in IC and MEMS alike, Peter has held VP of Sales and/or Marketing positions at QuickSil, SiTime, and Winbond Corporations. Earlier in his career, Peter spent 15 years at National Semiconductor in various engineering, marketing and corporate strategy roles in National's Analog Products division.

ANALYST CORNER

MEMS market will continue double digit growth, to double by 2017

Fast growing inertial sensor and microfluidics demand will drive a doubling of the MEMS market to $21 billion by 2017, as total unit shipments ramp at a 20% CAGR.

Eric Mounier,
Senior Analyst
MEMS Devices
& Technologies
Yole Développement

Laurent Robin,
Activity Leader
Inertial MEMS Devices
& Technologies,
Yole Développement

MEMS will continue to see steady, sustainable double digit growth for the next six years, with 20% compound average annual growth in units and 13% growth in revenues, to become a $21 billion market by 2017. That's a slight slowdown from the industry's 17% jump in 2011, as the initial rush of adoption of inertial sensors in smart phones cools a bit, inertial sensor prices continue to fall, and demand for inkjet heads slips a bit more. We expect continued strong growth in motion sensing and microfluidics means those sectors will increasingly come to dominate the MEMS market totals, making up almost half of the overall market in 2017, with accelerometers, gyros, magnetometers and combos accounting for about 25% of the total, and microfluidics for 23%.

Strong growth to continue in inertial sensors, 3-axis gyro remains the hot consumer product

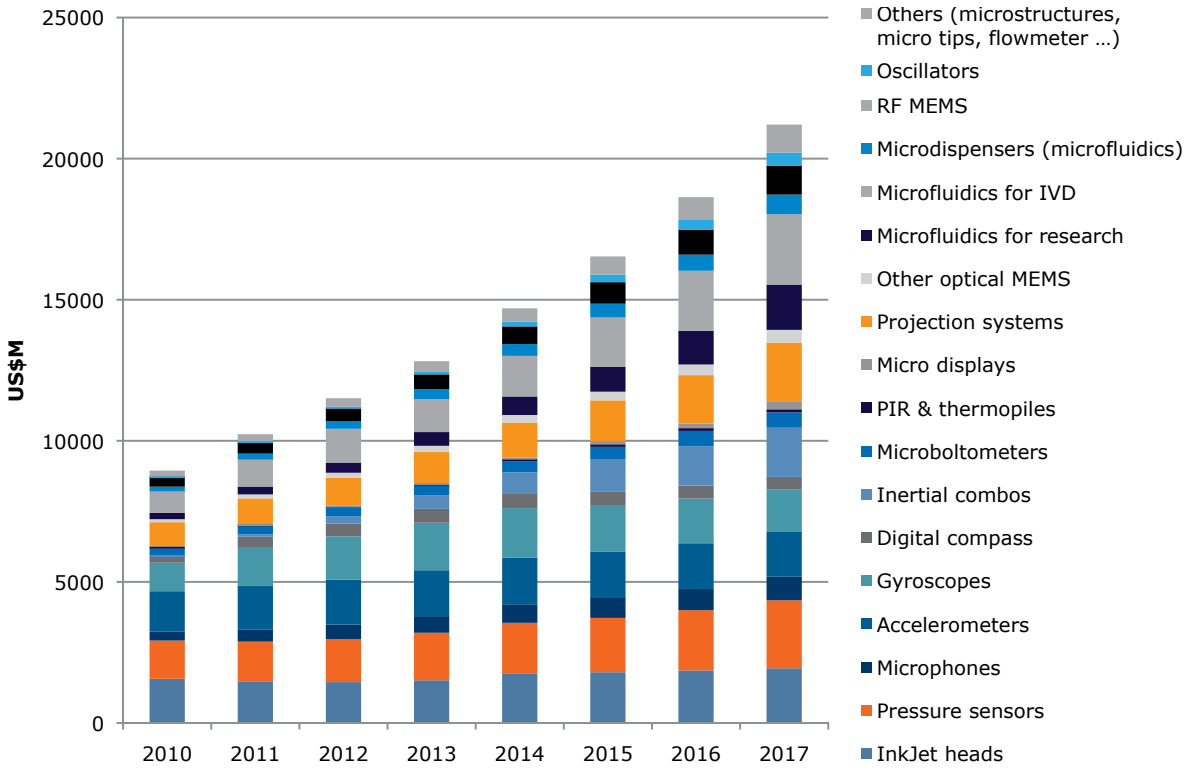
There's plenty of room for the motion sensor market to grow for at least the next three years, as penetration increases in growing end markets, for a $5.2 billion opportunity by 2017. But competition, falling prices, maturing markets and increasing integration also mean overall CAGR in this large market will be held to about 8%.

On the consumer side, accelerometers are already in almost all smart phones, but the overall cell phone market is still growing quickly, projected to grow by another 1 billion units by 2017. More of these phones will also be smart phones, the total likely doubling from 450 million to 900 million within the next three years, and MEMS are also now starting to be designed into more feature phones as well. The penetration of gyros jumped from 9% of smart phones in 2010 to 36% in 2011. Within two to three years, however, every smart phone will have a gyro.

Many phones may in fact start to have two gyros, as phone makers increasingly see image stabilization as a key way to differentiate their products with better photo quality. InvenSense

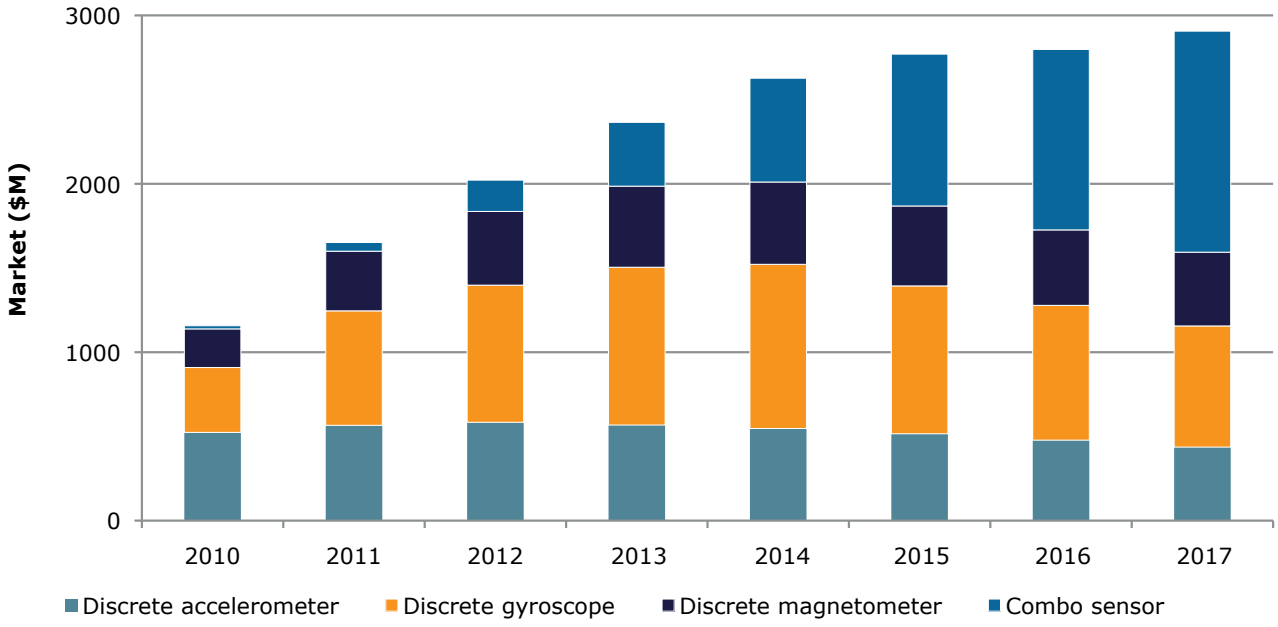
MEMS market forecast 2010 - 2017 (US$M)

(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)



2010-2017 MEMS consumer motion sensor market (US$M)

(Source: Yole Développement, April 2012)



"We believe that the market for discrete sensors will begin to decline, but the growth for combo solutions will be huge,"
says Eric Mounier, Yole Développement.

targets the camera module suppliers with for its precision gyro for image stabilization, arguing it makes things easier for the phone maker. STMicroelectronics offers a dual core solution instead, with both a high precision sensor for image stabilization and one more suited to gaming in a single package, but as this requires a more complex ASIC it may not necessarily be the cheaper solution.

AKM still dominates the magnetometer business with some 78% market share with its Hall-based device, and tight integration into the InvenSense modules and software. But other suppliers, from STMicroelectronics and Robert Bosch to MEMSIC, argue that their alternative technologies are more accurate and use less power, and that they can better integrate the devices they make themselves.

The market for combo sensors started in 2011, with 6-axis accelerometer and magnetometer combo units with a single ASIC shipped in volume, and 6-axis accelerometer and gyro units now starting to do so as well, often for only a small additional cost for the accelerometers. Stand alone components are still by far the biggest business, but in two to three years successful companies will be selling 6X or 9X devices.

To better track these important developments, we have broken out a separate category for combo sensors in our market data and forecasts this year. We believe that the market for discrete sensors will begin to decline, but the growth for combo solutions will be huge. Though currently less than a $100 million niche, we expect combos to be a $1.7 billion opportunity by 2017.

Microfluidics on fast growth path, to $4.8 billion in 2017

Though development has taken a bit longer than originally expected, the microfluidics market is now poised for strong 23% compound average annual growth. We project that demand for fab-level microfluidics devices (without chemistry) will reach some $4.8 billion in 2017, accounting for some 20% of total MEMS demand, to become the second largest sector of the industry. Major investment from big players is pouring into the field, producers from other large volume polymer industrial markets are bringing their sophisticated volume polymer manufacturing technology to the business, and major suppliers are ready to introduce elegant new commercial solutions for low cost, fast response microfluidic screening and diagnostic tests that provide real benefit. Biggest growth will be for ongoing screening of food and water quality, but the clinical laboratory testing, point-of-care diagnostics and pharmaceutical research applications are also poised for strong increases.

Optical MEMS and pressure sensors headed to >$2 billion markets

Optical MEMS should outpace the overall market with 16% CAGR, to reach $2.6 billion by 2017. The projection market remains the main driver, but the emerging pico projector market made real progress this year, with embedded cellphone prototypes from major players being widely demonstrated. DLP technology now dominates over LCOS, but laser-based systems should start to see improvement now that first direct green lasers have started sampling, though their need for two large ASICs brings size and cost issues.

MEMS is also increasingly taking over the telecommunications switch market, both ROADM and VOA. Autofocus components have taken somewhat longer than anticipated to reach the market, but they now have

potential for quick adoption, with Polight and Tessera readying for production.

We expect continued steady growth in demand for pressure sensors, for automotive applications, and also increasingly for cell phones for indoor navigation and location information services, to total 8% CAGR to $2.2 billion by 2017.

RF MEMS to reach $1.0 billion level

The market for RF MEMS switches and tuners is also heating up, with the first cell phone incorporating tunable RF MEMS from WiSpry hitting the market last year. Opinion is divided over how widely this technology will be adopted, but we take an intermediate view that there is indeed big potential for antenna tuners and other tunability in 4G phones, but MEMS will likely get only a part of this market. Paratek has also shipped a first device to Samsung, using a competing non-MEMS technology based on a thin film dielectric with variable capacitance. RIM's recent purchase of Paratek suggests RIM sees it as a strategic component in the next few years. Peregrine is shipping competing silicon-on-sapphire products as well, and SOI alternatives could also have potential. Other big MEMS players could also enter the market.

We see growth in the silicon MEMS oscillator business starting to accelerate as well. This conservative and fragmented timing market has been slow to adopt the new devices, but the technology is steadily gaining credibility. SiTime sales are likely to keep on their fast track, and major players NXP, SiLabs, VTI and Sand9 expect to enter the market this year.

We expect RF MEMS, including these switches and variable capacitors, silicon MEMS oscillators, and BAW filters and duplexers, to see 16% CAGR to a $1.0 billion MEMS market by 2017.

www.yole.fr

Laurent Robin is in charge of the MEMS & Sensors market research. He previously worked at image sensor company e2v Technologies (Grenoble, France). He holds a Physics Engineering degree from the National Institute of Applied Sciences in Toulouse, plus a Master Degree in Technology & Innovation Management from EM Lyon Business School, France.

Dr. Eric Mounier
Since 1998 he is a cofounder of Yole Développement, a market research company based in France. Dr. Eric Mounier is in charge of market analysis for MEMS, equipment and material. He is Chief Editor of Micronews and MEMS'Trends magazines (MEMS Technologies & Markets). He has a PhD in microelectronics from the INPG in Grenoble.

COMPANY INSIGHT

InvenSense sees 65% growth as motion processing becomes must-have for handhelds

The fabless startup capitalized on the growth of the motion interface market to see ~65% growth, to ~$144 million in sales in CY 2011, vaulting into the top 20 MEMS companies, and pulling off the MEMS sector's first major IPO.

Steve Nasiri Chairman, CEO & Founder

InvenSense caught the wave of mass market demand for motion processing –and gyroscopes—as applications moved beyond the gaming niche to wide adoption in smart phones and tablets last year. "Motion sensing is as transformational as wireless and cameras for the mobile phone market," argues CEO Steve Nasiri, noting that strong traction for motion interfaces is also now expanding into wearable sensors and smart TV controls. That's helped the company to rapidly diversify beyond its early dependence on the gaming market, which accounted for more than 70% of its sales in its last fiscal year. But non-gaming applications accounted for more than 50% of its revenue in the most recent quarter, and are on track to be well over 60% of revenues for its current fiscal year through March.

In 2011 the company also expanded to full high volume production at TSMC, entered the accelerometer business, brought its first 6-axis device into production, and made considerable progress on educating customers on the advantages of buying integrated sensor units instead of discrete accelerometer, gyroscope and compass components. "It's not reasonable to buy components from separate vendors and throw them into a phone and expect them to work together," says Nasiri, noting the need for calibration, and how performance variation on one component can throw the whole sensor system out of specification. "Customers expect it to be like an IC, you put it in and it works," he says. "By educating customers that integrating the components provides a single device that meets the spec, we've converted the majority to the 6 axis device."

The other big event of 2011 was of course the company's high profile IPO, raising $75 million with 10 million shares at $7.50. The stock price then climbed to the $18 range. The initial offering was apparently motivated more to meet customer needs for stability and employee needs for liquidity than for cash. "More than anything else, it was a branding event," explains Nasiri. "Customers worried about having one of their major suppliers be a private company that might be acquired by someone else, so we took that concern off the table. The option value was getting up there, so it was hard to hire good people. And some employees who had been with the company for years and now had families needed to get some money out of the company to be able to buy a house and the like."

(Courtesy of InvenSense)

Maintaining margins by aggressive decrease in die size, increase in integration

InvenSense counts on its aggressive roadmap towards smaller, more integrated sensor units that are easier for customers to use for motion processing functions to maintain its ~25% net margins as inertial sensor prices continue to fall sharply. "The only way to maintain margins is by innovation," asserts Nasiri, arguing that the company's technology platform that bonds the ASIC directly to the MEMS chip with conductive connections more easily allows continued reductions in die size and integration of more components than do the more conventional wire bonding or poly layer interconnect technologies used by competitors, with their higher input/output burden. He also argues that being fabless allows the company to focus on the software and marketing to extend motion processing to ever more applications, not on selling components to keep the fab full. The company focuses particularly on the software side as the most cost effective way to improve performance, by such features as temperature tracking and self calibration in use.

Though the company started offering motion fusion software early on to work with its gyroscopes and input from others' accelerometers, it is steadily integrating more sensors on the chip or in the packaging to bring down costs. The 6-axis accelerometer-gyro combo unit is in production for customers, and production of the 9-axis device is targeted for the second half of 2012 for several customers. That device adds a compass from AKM wire-bonded on top of the 6-axis unit in the same package and integrates the compass calibration in the software for a single output. A 10- axis unit that also adds a pressure sensor is on the roadmap, with a reference design and small evaluation board available to get it into the hands of apps designers, but there is as yet no specific date for production. The more discrete information from the pressure sensor doesn't require such tight coupling, but including it in the same software suite makes it easier for designers to use in applications.

Lower prices and improving ease-of-use open new markets for motion processing

Lower prices do enable more applications in the highly price-elastic consumer market. Motion has become one of the check-the-box features for new vendors of smart phones and tablets, like the camera, with the accelerometer already included for landscape/portrait control, and a compass for using maps. "The gyro is becoming the next level. It's affordable so there's no reason to hesitate," says Nasiri, who counts on the ability to easily incorporate motion functions to spur lots of diverse ideas from a variety of customers, and more than 2000 third-party application developers working with the company's motion processing solutions, rather than any one killer application.

One big pull, however, looks likely to come for adding image stabilization to cameras in phones, as a very visible way to differentiate the product by sharper picture quality, as people increasingly use their phones as primary cameras, and as the cost for gyros comes down. Camera module vendors likely will buy and include the tested and calibrated 2-axis gyros for image stabilization, so the phone makers don't have to worry about it, potentially increasing the gyro count in the phone.

Lots of interest is also coming from makers of wearable motion sensors, for sports and health monitoring, using battery powered motion sensing units that wirelessly connect to a smart phone. InvenSense recently introduced a development kit with these features for developers who have ideas to add more useful motion sensing information to running shoes, golf clubs, ski goggles, and watches, both to track sports performance and to supply health information on things like calorie burning, activity level or range of motion.

Location based services will also likely drive significant demand for inertial sensor units, as major companies who see major money in the business are developing the necessary infrastructure to enable location-specific advertising. "It's not as far away as you might think," says Nasiri.

The company also reports seeing increasing interest in the assortment of other motion based features it continues to demonstrate, from simple shake and tap controls that could often be more convenient than touch screens, to complex systems of augmented reality, any of which could take off with consumers if some industry thought leader promoted a compelling application.

www.invensense.com

"Motion sensing is as transformational as wireless and cameras for the mobile phone market,"
says Steve Nasiri, InvenSense.

Steve Nasiri, Chairman, CEO & Founder
Steven Nasiri is the founder of InvenSense and has served as our President, Chief Executive Officer and Chairman since our inception in 2003. Prior to founding InvenSense, Mr. Nasiri held various positions as a co-founder and executive of several MEMS companies, including SenSym (acquired by Honeywell), NovaSensor (acquired by General Electric), Integrated Sensor Solutions (acquired by Texas Instruments) and ISS-Nagano GmbH. He also held key management and operations positions at several semiconductor companies, including National Semiconductor, Fairchild Semiconductor and Maxim Integrated Products. Mr. Nasiri is an inventor in over 50 patents and patent applications, and has authored many published papers and articles on MEMS technology.
Mr. Nasiri earned an M.B.A. from Santa Clara University, a M.S. in Mechanical Engineering from San Jose State University and a B.S. in Mechanical Engineering from the University of California, Berkeley.

GLOBALFOUNDRIES starts product ramp, credits IC-industry manufacturing practices

The chip maker says it ramped its MEMS fab from equipment install to risk production for its first few customers in the 18 months through the end of 2011, thanks in part to IC-industry style process control.

Rakesh Kumar, Director of MEMS program

"With volumes increasing, MEMS is becoming more like semiconductor production, with process control at every step," says Rakesh Kumar.

Since first installing equipment for its MEMS foundry in the summer of 2010, GLOBALFOUNDRIES made its first functional devices in the spring of 2011, and produced customer qualified devices by the end of the year. It's now in risk production for its first few customers and readying to ramp to large volumes over the next three to four months, reports Rakesh Kumar, director, MEMS, 200mm. It expects to finish development and process qualification for another two or three customers by the end of this year. InvenSense has announced that GLOBALFOUNDRIES is now fully qualified for as a second source for volume production of its inertial sensors.

The company targets a limited number of customers making inertial, optical or RF MEMS in high volume, preferably those who offer complete solutions, with the sensor and the control and the firmware for ease of use by systems makers to drive adoption. "In this industry dominated by the IDMs, we target the same areas as the IDMs," says Rakesh Kumar. "In fact, we will have to work with the IDMs and gain a share of their outsourced production." And like the big IDMs, GLOBALFOUNDRIES aims at using a limited number of well controlled standard process modules, for a limited set of product platforms, to speed the development of new products to enable fast growth for its customers.

Though some CMOS foundries have been playing in the MEMS area for some time, the industry's maturing technology base and its growing production volumes may finally be reaching levels where the IC industry's strengths begin to be useful. High volumes and fast growth unavoidably require well controlled standard processes, with monitoring, feedback and control at every step of production, argues Kumar. "MEMS people says MEMS is more art than science, but with volumes increasing it's becoming more like semiconductor production, with process control at every step," he says.

GLOBALFOUNDRIES aims to focus on standard process modules, such as cavity SOI wafers and wafer-level packaging. If a customer comes with its own process, the fab tries to match the results with a process of its own. And it particularly aims to apply CMOS-type process control to these standard process modules to speed the ramp to volume and improve yields. The fab, with capacity of a few 1000 wafers per month, shares some tools with the CMOS facility, to reduce capital cost and thus cost to customers. And with MEMS volumes getting to levels where statistical process controls start to make sense, the company uses its same CMOS manufacturing system for the MEMS production as well--the same monitoring, feedback and control at every level, the same methodologies for QA and yield defect control. It calls upon the same CMOS engineers to diagnose yield issues, who apply their experience in correlating the inline data to the tool process to control results. The company uses offline SEM metrology profiles of high aspect-ratio cross sections as part of its regular statistical control of the etch process, uses a semiconductor backend optical inspection tool for inline defect scanning of all critical layers, and has IR inspection tools in house. "We are looking for high volume inspection tools for MEMS," says Kumar, noting that some are under development for the growing market, but few are yet available. The company is also trying to add test structures for electrical test, or for metrology, aiming to assure quality without functional test, or even without electrical test.

Higher MEMS production volumes also mean more resources from suppliers can go into developing better tools and supporting infrastructure for better control of MEMS processes, argues Kumar. Equipment makers are seeing enough market potential to invest in making improvements to their legacy equipment, such as improved ability to handle the different thicknesses and topography of MEMS wafers. Layout/topography simulation tools can now help identify problems before making the device, and the larger market may spur development of better data bases of material properties and simulation tools, even if the volume foundries, like the big IDMs, have to develop their own.

"We believe MEMS manufacturing will become more standard, because standard processes and modules help speed time to market," argues

A GLOBALFOUNDRIES employee loading MEMS wafers into an automated wafer bonding system (Courtesy of GLOBALFOUNDRIES)

Rakesh Kumar. "And that will also drive the industry towards more foundry production. Of course it is not so easy for MEMS as for CMOS, because of the difficulties of getting a design into volume production. But it will happen, because of cost savings on the investment in high volume 8-inch capacity, and because MEMS manufacturing is becoming more standardized, and will become more mainstream, and less of a core competence. IDMs will turn their focus more to design and marketing."

"People think it is just a fad for CMOS companies to enter the MEMS business, but we have seen a very big interest to work with us because of the capabilities we bring," says Kumar. "IC foundries will start to grow fast in the MEMS business."

www.globalfoundries.com

Rakesh Kumar, Director of MEMS program
Rakesh Kumar received his B.S. (Hons.) and Ph.D. degrees in electrical engineering from Punjab Engineering College, India and Nanyang Technological University, Singapore, respectively. He is currently Director of MEMS program (200mm Business Unit) at GlobalFoundries, Singapore. Prior to this, he was deputy director of Semiconductor Process Technology Lab at Institute of Microelectronics, Singapore where he was responsible for MEMS process development and technology transfer. His areas of interest include advanced copper interconnects, 3D wafer level packaging and MEMS technologies. He has authored and co-authored more than 90 research publications in journals and conferences.

CEA-Leti solves problem of making MEMS smaller without compromising performance

Working demonstrators of a 3-axis accelerometer, 3-axis magnetometer and 3-axis gyrometer have already been built, paving the way for 9-axis sensor fusion in less than 5mm² (MEMS chip dimension), which importantly uses the same analog electronics for all the different gauges.

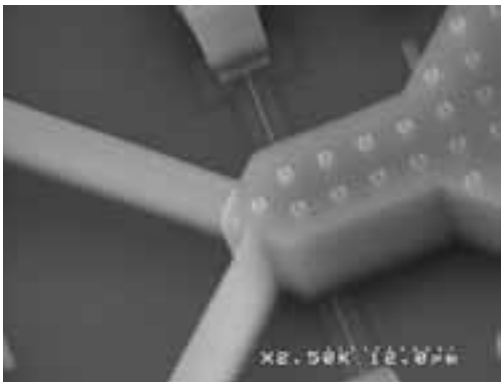
Philippe Robert, PhD MEMS sensor group Manager

"M&NEMS will dramatically reduce the cost of MEMS sensors to meet the ever increasing demand for sensor awareness to add functionality and features to devices," says Philippe Robert.

In electronics, if you can make it smaller, usually the cost decreases. Unfortunately, signal-to-noise ratios (SNR) can also decrease because various device parameters, such as mass and capacitance, reduce and that lowers the performance. CEA-Leti, the French research giant, has developed a novel way to solve this problem in the case of MEMS sensors that uses standard bulk CMOS production techniques, except for the last magnetic layer deposition in the case of the magnetometer.

Micro- and Nano-Electro Mechanical Systems

Their patented solution combines Micro- and Nano-Electro Mechanical Systems (M&NEMS). A thick MEMS layer provides the inertial mass, which is suspended by one of its extremities by a hinge anchored to the substrate. Attached to this is a NEMS part that forms a suspended, silicon nanowire, strain gauge with a 250nm x 250nm cross-section.



Scanning electron microscope image of silicon nanowire gauge (Courtesy of CEA-Leti)

These nanowires function as piezoresistive transducers and the motion of the MEMS mass creates mechanical strain that results in a measurable change in the nanowire's resistance. The nanowire transducers occupy much less area than capacitive transducers as there are no bulky capacitive comb structures. They offer a perfect linear response compare to the highly nonlinear readout of the capacitive transducers and their performance trend improves as their cross-sectional area is reduced. Thus, for example, a reduction from 2.5 x 2.5µm2 to 0.25 x 0.25µm2 amplifies the output signal by two orders of magnitude because the strain is concentrated over a smaller area.

The suspended nano-gauge is orthogonal to the symmetric axis of the sensor (defined by the straight line passing through the rotation axis of the hinge and the centre of inertia of the mass). One end is fixed to an extremity of the mass such that this fixed point of the gauge is slightly offset from the symmetric axis of the sensor and the rotation axis, and the other to an anchor. This nano-gauge can be a simple, silicon suspended beam that is used as a piezoresistive gauge or as a vibrating beam in the case of a resonant accelerometer - either transduction methods are equally effective. The piezoresistive interface is much less sensitive to parasitic capacitance, greatly simplifying the electronic interface circuitry and the packaging.

An acceleration will induce a rotation of the mass around the hinge axis, which creates a stress in the nano-gauge. A high degree of sensitivity can be obtained because the stress is concentrated by the very small cross-section of the silicon nanowire gauge, and also by the lever arm effect of the accelerometer design. Another important point is the very high efficiency of the transduction. With a traditional implanted or deposited piezoresitive gauge, the major part of the stress induced by an external force is dissipated in the flexion of the beam or in the membrane leaving only a small fraction of the stress to be detected by the gauge. By comparison, in the M&NEMS design, all the stress produced by the acceleration is concentrated into the piezoresistive nano-beam, giving greater sensitivity.

The M&NEMS approach also provides the ability to have an in-plane and out-of-plane detection of the inertial mass movement on a same chip. In this case, a vertical acceleration causes the mass to rotate around the two hinges. As the nano-gauge wire is thinner than the mass, this rotation applies an axial stress, which is also amplified by a lever arm effect.

3-axis accelerometer

The 3-axis accelerometer has given very good results in term of sensitivity, a resolution with a dynamic range of 6000 for a 1 kHz BW, and good stability, i.e. only small drift over time of the nano-gauges.

3-axis gyrometer

The 3-axis gyrometer uses a tuning fork structure and the Coriolis force is measured by means of suspended nano-gauge instead of the classical capacitive detection. This concept enables extremely compact, single-chip 3D gyroscopes to be made while maintaining high performances. Performances for consumer or automotive applications have been obtained with a size of the mechanical part of 0.5mm²/axis (standard gyroscope sizes are larger than 1-2mm²/axis). First measurements show a noise of 0.02°/s/√Hz (the measurement was limited by electronics) and a quadratic bias of few 100°/s for the Z-axis gyro.

3-axis magnetometer

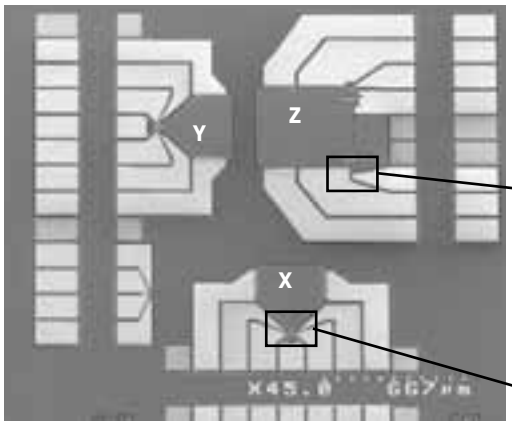
In the 3-axis magnetometer, the silicon mass is used as carrier structure for magnetic material. Inside a magnetic field, the structure is subjected to the magnetic dipole moment that induces a rotation of the silicon carrier structure around its fulcrum leading to a deformation of the nano-gauges.

Three individual silicon structures are used in order to achieve 3D detection of the magnetic field. Two of them detect the X and Y magnetic field components by rotation in the chip plane, and a third structure rotates out of plane for detection of the Z component. Sensitivity to all three spatial axes is achieved by integration of two perpendicular magnetization directions within the plane.

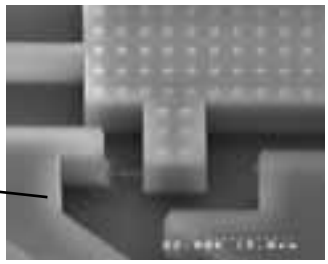
Main advantages of this magnetometer are 3-axis integrated on the same chip, very low power consumption (few tens of µW), a resolution of around 100 nT/√Hz and that it is a multi-range sensor with the range being set by the MEMS design.

More sensors using M&NEMS

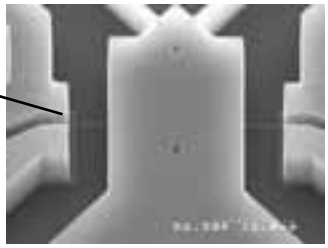
CEA-Leti is currently researching into additional sensor designs that use this M&NEMS platform such as a microphone and a very high performance and ultra-miniaturized pressure sensor so that all the key sensors required for most applications can be simultaneously created on the same chip. This will dramatically reduce the cost of MEMS sensors to meet the ever increasing demand for sensor awareness to add functionality and features to devices.



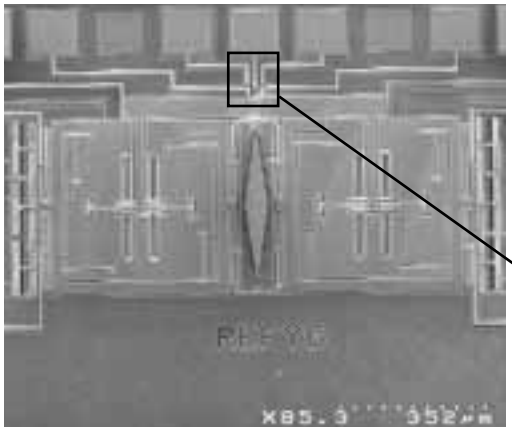
3-axis M&NEMS accelerometer with a sensitive element of less than 1mm² (Courtesy of CEA-Leti)



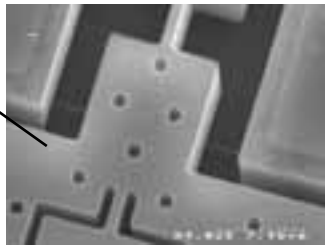
Focus on Z-axis accelerometer



Focus on X-axis accelerometer



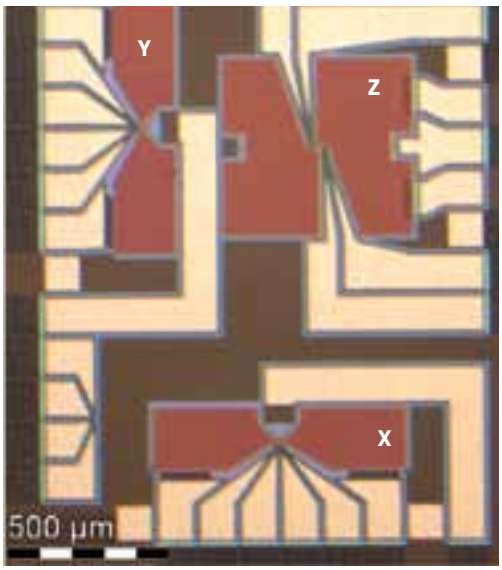
Y-axis M&NEMS gyrometer. (Courtesy of CEA-Leti)



Focus on Y-axis M&NEMS gyrometer

Last but not least, the M&NEMS technology is already being transferred to Tronics Microsystems who will industrialize it and bring it to the market in the coming years.

www.leti.fr/en



M&NEMS 3-axis magnetometer with integrated AF/F permanent magnet (Courtesy of CEA-Leti)

Philippe Robert, PhD, after different positions in the industry, is now the manager of the MEMS Sensors group at CEA-LETI. He has authored or co-authored about 40 journal papers and conference contributions, and holds more than 40 patents dealing with MEMS and NEMS. He was member of the IEEE-MEMS Technical Committee in 2007 and 2008. He is European co-chair of the ITRS-MEMS Technology Working Group. philippe.robert@cea.fr

HANKING GROUP

Hanking Electronics starts construction of major MEMS fab

Hanking Electronics aims to become China's first major MEMS IDM as it starts product development and construction of an 8-inch fab to supply the domestic industry with low cost, locally made MEMS components.

Doug Sparks, Executive Vice President

The MEMS subsidiary of the Hanking Industrial Group started construction in March on an 8-inch MEMS fab with capacity of 40 million die (3000-4000 wafers) per month when the first phase ramps in 2013, with two more phases of construction to follow. The company website says investment will total $4.5 billion. The plant is located on a 127 acre site in the Fushin economic development zone of Shenfu new town in Liaoning province. Hanking Electronics EVP of development Doug Sparks says the company is also starting to specify and get quotes for equipment in parallel with construction, targeting the shell to be completed and equipment installation to start in about a year.

The plant will start with 8-inch equipment, but will be designed to be able to transition to 12-inch, perhaps as soon as in three to five years. "That is a lot of volume, but China is a big market, and we may eventually move into India and Indonesia which together have a population of 1.2 billion," says Sparks. The company aims to do packaging as well as die fabrication, and also intends to do some of its own ASIC design and embedded software, and extend into production of systems with high MEMS content for or with its partners.

"The plant will start with 8-inch equipment, but will be designed to be able to transition to 12-inch," Doug Sparks, Executive Vice President.

The strategy is to offer Chinese systems makers lower cost Chinese-made components, thanks to low labor costs. The company will target high volume consumer, automotive and medical markets. But Hanking also aims to make inertial sensors, initially for consumer markets, pressure sensors, and microfluidics. It has talked publicly about making tire pressure monitoring systems for the automotive market. "This is a new page for MEMS in China," says Sparks. "Everyone who imports MEMS is excited."

The Hanking Industrial Group's annual revenues of ~$550 million come largely from mining and processing iron ore and nickel, though it also makes bearings and owns shopping malls. It currently has no other semiconductor or electronics experience.

Hanking is working on licensing technologies and designing its own first products, doing development work at the fab facilities at the University of Michigan and Purdue, near its US headquarters in Cleveland and where Sparks has connections, as well as working with commercial MEMS foundries. First products are likely to be relatively basic sensors for consumer products.

Though the plan is to primarily be an IDM, the company will also offer foundry services to fill the fab with perhaps 30% of its capacity, for which it's looking for partners who want to manufacture high volume products for the Chinese market, or who need a second source foundry. It also intends to support the small scale foundry business with some facilities, to nurture development of new products in China.

Hanking Electronics headquarters building (Courtesy of Hanking Electronics)

Doug Sparks is the Executive Vice President of Hanking Electronics. Prior to joining Hanking he was the founder and president of NanoGetters and the Executive Vice President of ISSYS where he oversaw its microfluidic product line. He also worked at Delphi Automotive System's/Delco Electronics in the area of MEMS and integrated circuits. He has published over 100 technical papers, has more than 40 patents and holds a Ph.D. in Material Science and Engineering from Purdue University.

www.hanking.com

From smart systems research to value creation: the success stories to follow

Miniaturized smart systems are structures composed of small units which constantly interact with their environment.

Géraldine Andrieux-Gustin, COWIN Coordinator, Yole Développement

Analogous to cells in the human body, these systems work together on a microscale in order to convert energy, produce electrical signals, communicate with each other, or respond to environmental influence. Thanks to innovative technologies, miniaturized smart systems provide functions such as Feeling, Evaluating, and Acting.
These smart systems are not only able to feel, evaluate and act, but can use foresight to communicate with their environment and to help final users in taking decisions. They are capable of self-diagnosis and acting autonomously, behavior which is comparable to cognitive abilities.
In enabling such different functions, miniaturized smart systems have applications in a broad range of fields, as illustrated in figure 1.

As shown in this figure, the miniaturized smart systems market is growing, with a mean annual growth rate expected at 13% from 2011 to 2017 (Source: Yole Développement, March 2012).
Miniaturized smart systems thus represent a real market opportunity, and it is interesting to analyze how value creation operates in this business. The best way to analyze it is to take a closer look at key success stories.

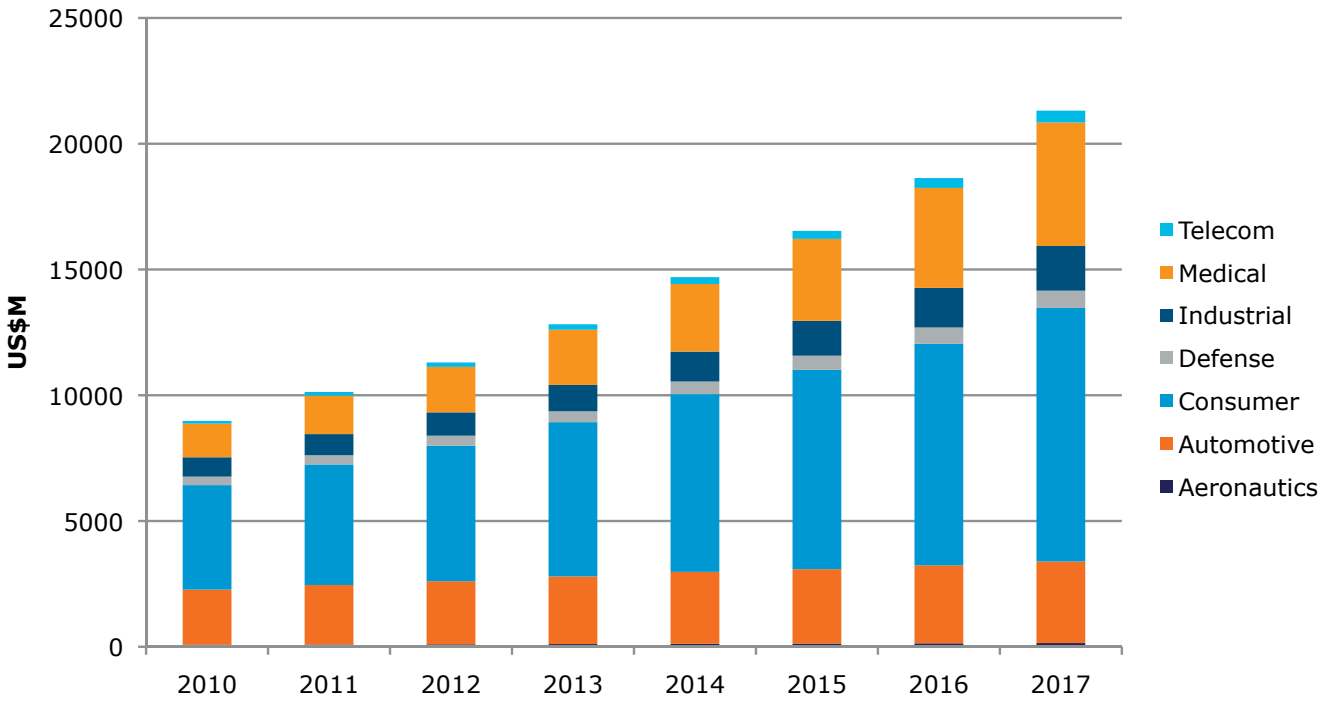
Choice of business model is key.

Let's first analyze the ULIS success story. ULIS manufactures uncooled infrared detectors and has become a leading player in the field. Their story starts with an attractive technology developed at CEA Leti. Few years after, ULIS was launched in 2002. Ten years later, the company reached 75 M$ turnover, with 120 employees.

The main ingredient for this success story is, of course, the emergence of an attractive technology in a demanding security market. But more important is the selection of a smart business model. At the time of ULIS's launch, no infrared detectors were available on the market. It was only a system/ camera business. With this new positioning, ULIS opened a window which has facilitated the growth of the company and the market.

Miniaturized smart systems market forecast by application (US$M)

(Source: Status of the MEMS industry report, to be released mid 2012, Yole Développement, March 2012)



Even in a growing and demanding market, great technology does not sell itself. Choice of business model is key.

Great technology isn't everything

To further this analysis, let's look at the example of the DRIE process. DRIE, which stands for Deep Reactive Ion Etching, is a structuration process used for the microsystems part composing miniaturized smart systems. This process enables achieving etch depths of hundreds of micrometers with almost vertical sidewalls.

The process was first developed by Robert Bosch, and thus it is also called the "BOSCH process". SPP, the equipment manufacturer, obtained a license from Bosch to exploit the technology, an agreement which has led to incredible growth of the DRIE market. First used for accelerometers production, the process is used today for production of inkjet heads, pressure sensors, accelerometers, gyroscopes, microphones, and microactuators (ex: auto-focus). Moreover, use of the process has become popular outside of the MEMS world, for advanced packaging applications.

The market penetration of the DRIE process is thus another great success story.

Great technologies do not sell themselves. They also require relevant equipment where it concerns production. Also, the choice of business model relies on a relevant analysis of the supply chain in order to drive market penetration.

A success based on new value proposition

Let's conclude this analysis with the example of smart systems for medical applications, which is one of the fastest-growing market segments.

Point-of-care solutions are attractive applications for smart systems. The first products were commercialized in the 1990's by the company i-Stat, which developed a hand-held blood analyzer associated with cartridges, providing real-time and lab-quality results. Today, more than 20 million of cartridges are sold every year.

The success of the company is based on a new value proposition. Traditionally performed in labs, blood analysis involves workforces that represent a large part of the cost of analysis. Automation performed in labs is one solution developed to reduce cost of workforces. But i-Stat has successfully proven its ability to perform rapid testing while decreasing workforces cost (see figure 2). For specific applications, i-Stat is a very attractive and added-value solution that has contributed to the growth of the point-of-care market.

The success of the i-Stat solution is thus based on a new value proposition which leads to new use and enables new organization.

The i-STAT new value breakdown

	Traditional method cost	i-Stat blood gas analyser
Labor	**72%**	12%
Equipments	14%	7%
Reagents & consumable	14%	**81%**

(Source: Yole Développement)

(Courtesy of i-STAT)

Success depends on building a relevant business case by setting-up a relevant process all along the technology development phase, which enables one to analyze how the exploitation of the technology will generate value.

If you wish to know more about how to build a relevant business case for your technology, or in other words how to ensure that the use of your technology will create value, please join us for our COWIN webinar, "Business case for my R&D project" - http://www.cowin4u.eu/events/cowin-webinar-business-case-for-my-r-d-project

www.cowin4u.eu

"Succeeding from smart systems research to value creation requires great technology but it is not enough. It is also based on a relevant business model taking into account supply chain organization and value breakdown."
COWIN coordinator, Yole Développement.

About COWIN
Launched in 2010 under the 7th Framework Program, COWIN is a support action dedicated to strengthening European competitiveness in miniaturized smart systems. The initiative is focused on the commercial exploitation of advanced technologies developed in the framework of European collaborative research projects. COWIN's mission is to facilitate take-up of those advanced technologies worthy of investment, in order to capture innovation, win new markets and make a profit.

Since 2003, Géraldine Andrieux-Gustin has supported many companies in their growth strategy and has been involved in several successful financial transactions in the MEMS and microfluidics industry. She earned an MBA from EM Lyon Business School.

EVENTS REVIEW

Q&A with Karen Lightman, Managing Director, MEMS Industry Group

Yole Développement interviewed Karen Lightman upon her return from hosting MEMS Industry Group's (MIG's) first MEMS Executive Congress in Europe. We spoke with Karen about growth in MEMS, the 'state of the state' of the US MEMS market, and about holding MIG's first major event in Europe.

Karen Lightman, Managing Director, MEMS Industry Group

Yole Développement: Why is the MEMS industry growing exponentially?

Karen Lightman: There are many reasons behind our growth. As an industry, we are solving some of the challenges with manufacturing, packaging and integration to develop a more robust and reliable supply chain that meets the requirements of even the most demanding high-volume customers. The MEMS industry proved years ago that we could satisfy demand for automotive airbag sensors. We moved on to laptops, cameras and video games and then to mobile handsets and tablets.

Here we are in 2012, and MEMS is ubiquitous in consumer electronics and mobile handsets. MEMS adds value to consumer applications in ways that consumers can discern. It's really not about processing muscle. It's about contextual awareness and application performance. MEMS inertial sensors and microphones, for example, so clearly improve the customer experience that manufacturers have been quick to adopt them.

All we need to do is look at Apple to see the consumer benefits of MEMS. And in my mind, we have just barely scratched the surface of what we can achieve through MEMS technology.

YD: How will MEMS add value beyond consumer products?

KL: If you can imagine it, MEMS can accomplish it. Some of the most exciting applications are in quality of life (QoL) and biomedical systems. Our QoL panelists at MEMS Executive Congress Europe (March 20, 2012 in Zurich) captivated the audience with their descriptions of commercially available MEMS-based QoL devices— such as Debiotech's miniature insulin pump, which mirrors the physiological delivery of insulin more closely than any other insulin pump on the market today.
At the Congress Europe, speakers from companies such as Audi AG and Continental Teves described a whole new class of intelligent automotive sensing systems that can make a car easier to drive, through sensor-enabled steering that senses the curvature of the road and accounts for torque and speed. But MEMS in automotive is really about safety. Enabled by MEMS, cars can tell if a child is in the street—and can avoid impact. MEMS can also ensure that a driver is not inebriated before getting behind the wheel. In addition, it can also improve energy conservation and utilization through energy harvesting.

Our "smart industrial systems" panelists at the Congress Europe, which included game-changing players such as Siemens and Schneider Electric, described just some of the ways that MEMS is making not just smart buildings possible— but also smart cities, leaving the audience both awestruck and inspired.

While consumer products are the volume leader for MEMS—and most likely will fulfill that role for some time—the other industry verticals that we explored at the Congress Europe are fertile markets for MEMS.

YD: Based on your answers, MEMS Executive Congress Europe made quite an impression! What was it like holding your first major MIG event in Europe? Will you return in 2013?

KL: MEMS is a global industry, and European innovation is responsible for so much advancement in mobile communications, energy conservation, automotive design and biomedical devices that it made perfect sense to bring MEMS Executive Congress to Europe.

In all honesty, I was expecting 100 attendees; we had 155. I thought that we would have a handful of sponsors; we had 30. By all accounts, the Congress Europe was a resounding success, and we will hold another event somewhere in Europe and possibly in Asia in 2013.

First, however, we will hold MEMS Executive Congress US in Scottsdale (November 7-8, 2012). We have already begun building the content for a full two-day event featuring panels on consumer, QoL/biomedical and other emerging technologies, as well as the crowd favorite: MEMS Tech Showcase.

YD: As you return your focus to the US in 2012, where are you seeing innovation in the US?

KL: The US has more fabless companies than any other global region. This includes InvenSense, the consumer electronics powerhouse, and WiSpry, which announced its first commercial design win for its RF MEMS tunable antenna in a Samsung phone during 2012 CES. We also have some very promising MEMS oscillator startups: SiTime, Discera, Silicon Clocks (now part of SiLabs) and Sand 9. And I would not count a new company out of the fast and furious world of inertial sensors. Qualtré has a very innovative approach to consumer gyros. It will be interesting to watch them in 2012 and beyond.

The US is home to the worldwide leaders in display technologies for pico projectors (Texas Instruments and Microvision – the latter of which is also fabless). Qualcomm MEMS Technologies is emerging strongly in e-reader and tablet displays. That's on the supply side of MEMS.

YD : How do you think the US ranks in terms of design influence of MEMS?

KL: The US is among the most influential global regions for MEMS designs— and for MEMS R&D and regulation as well. If you had to pick a champion design influence, it would be Apple. Other major influencers include Qualcomm, a leading wireless semiconductor company which affects the ways in which OEMs view and use MEMS.

Operating systems' providers like Google (Android for tablets, smartphones, televisions, etc.) and Microsoft (Windows-based mobile operating systems for all of the same plus video games) are very influential as well.

DARPA and the US Department of Defense (DoD) are funding MEMS devices like RF MEMS switches and varactors—which will eventually make their way into other non-military applications.

In terms of regulatory agencies, National Highway Traffic Safety Association (NHTSA) is responsible for safety regulations that greatly impact the world market for automotive sensors, including TPMS and vehicle dynamics.

MEMS Industry Group's next MEMS Executive Congress will take place November 7-8, 2012 at the Westin Kierland Resort and Spa, Scottsdale, AZ. For more information, please visit: www.memscongress.com/us

www.memsindustrygroup.org

Karen Lightman
Karen Lightman is managing director of MEMS Industry Group. She played a pivotal role in launching MEMS Industry Group (MIG) in January 2001. In June 2007 she became MIG's managing director. Ms. Lightman is active on the worldwide MEMS conference circuit as a keynote speaker and panelist promoting the commercialization of MEMS across global markets. She spearheads strategic growth for MIG, implementing a cohesive vision through programs, events and international partner programs which advance the MEMS industry.

Ms. Lightman joined MIG from Carnegie Mellon University's Center for Economic Development where she was senior policy analyst.
Ms. Lightman holds a BA from the University of Vermont and a MS in Public Policy from Carnegie Mellon University.

About MEMS Industry Group
MEMS Industry Group (MIG) is the trade association advancing MEMS across global markets. Nearly 140 international members and partners comprise MIG, including Analog Devices, Applied Materials, ATREG, Robert Bosch GmbH, Freescale Semiconductor, GE, Honeywell, HP, Intel, InvenSense, Nokia, Qualcomm, C2MI, STMicroelectronics, Texas Instruments, VTI Technologies and WiSpry. For more information, visit: www.memsindustrygroup.org.

About Yole Développement

Beginning in 1998 with Yole Développement, we have grown to become a group of companies providing market research, technology analysis, strategy consulting, media in addition to fi nance services. With a solid focus on emerging applications using silicon and/or micro manufacturing Yole Développement group has expanded to include more than 50 associates worldwide covering MEMS, MedTech, Advanced Packaging, Compound Semiconductors, Power Electronics, LED, and Photovoltaics. The group supports companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to develop their business.

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- Players & market databases
- Manufacturing cost simulation tools
- Component reverse engineering & costing analysis

More information on www.yole.fr

MEDIA

- Critical news, Bi-weekly: Micronews, the magazine
- In-depth analysis & Quarterly Technology Magazines: MEMS Trends – 3D Packaging – iLED – Power Dev'
- Online disruptive technologies website: www.i-micronews.com
- Exclusive and editorial webcasts
- Live event with Market Briefings

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