MEMS' Trends

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INDUSTRY REVIEW
Emerging MEMS

ANALYST CORNER
Energy harvesting market will approach $250M in five years.

COMPANY INSIGHT
poLight readies production of optical MEMS autofocus

YOLE Développement

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EDITORIAL

Emerging MEMS: is the time right for new devices?

Although the MEMS market is currently very fragmented, with a number of high-volume MEMS applications still limited, every year brings new business to the MEMS landscape. In fact, the burgeoning market for smart phones seeking differentiated value may start to push some long-discussed MEMS devices into real commercial volume markets over the next few years.

Today, there are many MEMS devices which are close to "making the leap" from the development/qualification stage to market launch. We estimate that the total market for emerging MEMS devices will grow from ~$445 million in 2012 to $2.8 billion by 2017. An array of different devices is included here: PIR & thermopiles, microdisplays, micromirrors for mobile phone and tablet-embedded picoprojectors, auto focus, RF MEMS switch & varicap, oscillators, and others.

We estimate that the total market for emerging MEMS devices will grow from ~$445 million in 2012 to $2.8 billion by 2017...

Among these products, Micromirrors and RF MEMS switch & varicap will undergo a >150% CAGR over the next five years, driven by mobile applications such as smart phones and tablets. Also, a completely new batch of devices will emerge as well. For example, after years of development, we expect 2013 to be the year when MEMS auto-focus enters production, with at least three different players competing. Market growth will also be driven by "emerging" applications for established MEMS devices - for example, pressure sensors will expand into a new market space: altitude measurement for LBS in smart phones.

This *MEMSTrends* issue is dedicated to "Emerging MEMS". Inside, you'll gain insight into the different statuses of MEMS that are close to "making the leap". Among the numerous MEMS in development, we believe the time has come for at least three of them to break through to the next level: MEMS oscillators, picoprojectors, and tunable RF. To be honest, it would not be a surprise if these markets surpass the $100 million barrier in the next two to four years.

We wish you pleasant and interesting reading!

Dr Eric Mounier
Senior Analyst, MEMS Devices & Technologies
Yole Développement
mounier@yole.fr

EVENTS

- **MEMS Executive Congress**
  November 7 to 9 – Scottsdale - AZ, USA
- **Electronica**
  November 13 to 16 – Munich, Germany
- **Semicon Japan**
  December 5 to 7 – Tokyo, Japan

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JBBOX creation
(Courtesy of www.fotolia.com)

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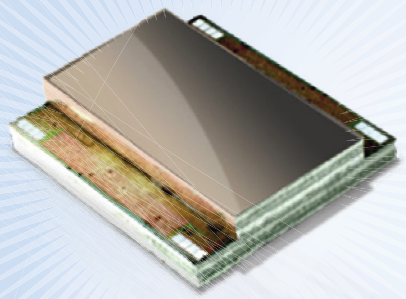

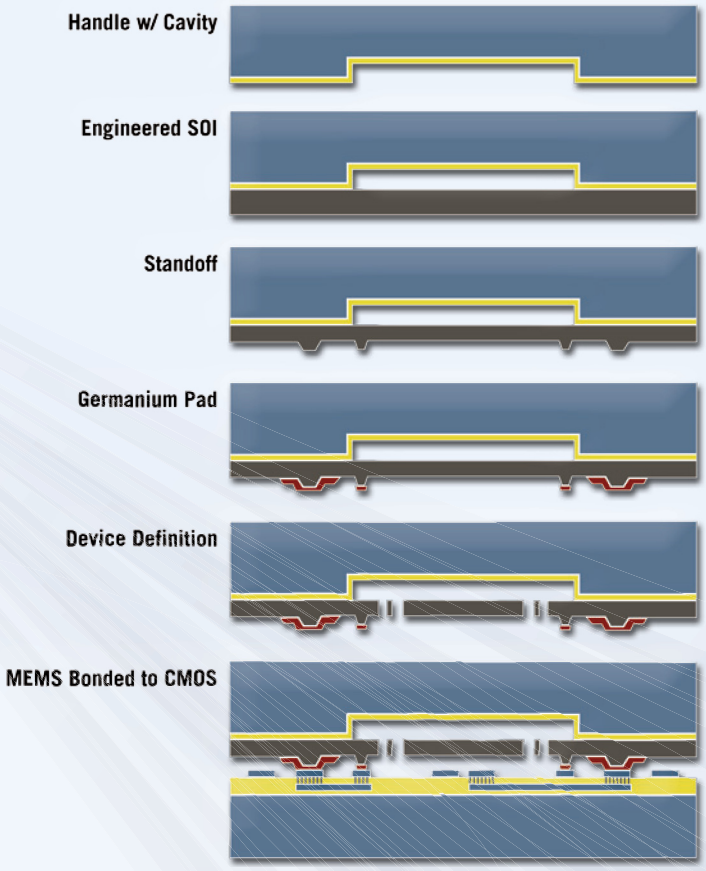

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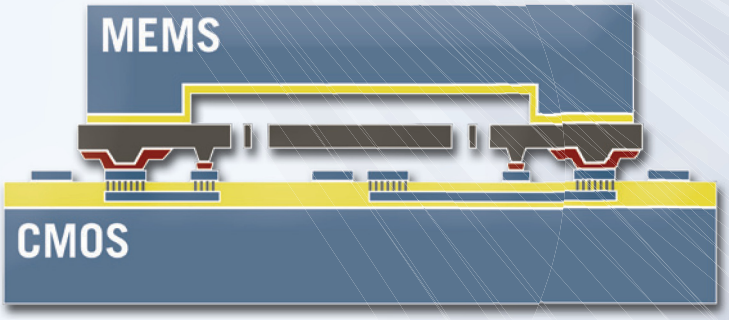

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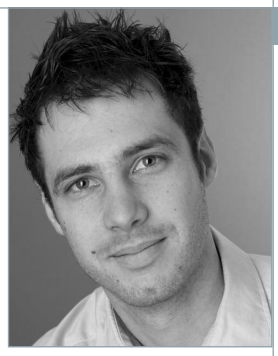
FINANCIAL BUZZ



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

Investors bet on the diversity of MEMS

Although a limited number of MEMS devices usually makes the headlines, Yole Développement always highlights the fact that the MEMS industry is highly fragmented. We expect that the growth in MEMS will come from many different types of MEMS sensors and actuators over the coming years. The financial transactions in Q3 2012 well illustrate this trend, as it concerns 9 very different MEMS market segments: software, modules, optical sensors, energy harvesting, fuel cells...

New investments (VC rounds, IPOs)

Company	Type of product	Type of investment	Level of new investment	Investors	Yole Développement comment
July 2012					
Pyreos (GB)	MEMS -based infrared sensor array	4th round	$9.71M	Robert Bosch Venture Capital, (lead investor) + other investors including Siemens Technology Accelerator, Scottish Investment Bank's Scottish Venture Fund and clients of Perth-based Braveheart Ventures	Pyreos is a spin-off of the Scotland Microelectronic Center. Pyreos has acquired granted patents and related IP around a unique thin film pyroelectric infrared sensor technology developed by Siemens over many years in their corporate research facilities in Munich. Many developments are ongoing with MEMS-based infrared sensors. Yole Développement expects the market for commercial applications of infrared sensors to grow quicky in the coming years.
Movea (FR)	Motion sensor software solutions	Series C Funding	€6.5M (= $7.4M)	Intel Capital (lead investor) together with existing Investors iSource and GIMV	Founded in 2007, Movea now counts 45 employees and is a leader in motion sensing solutions based on MEMS inertial sensors. Yole Développement sees Movea in good position to benefit from opportunities to develop revenues from 6 axis and 9 axis motion sensors. Indeed there is a growing need for applications / software as sensors become ubiquitous in mobile applications.
Aug. 2012					
Fluidigm (US)	Microfluidic tools for DNA sequencing	Public offering	$52.2M	NA	Fluidigm is recognized as one of the leaders in DNA sequencing tools for research. The company has recently set up a research center for single-cell genomics. The proceeds will be used to pursue the developments of systems for research and possibly to expand in new areas such as diagnostics (currently dominated by Illumina). We note that Fluidigm has done a successful IPO in February 2011.
Sept. 2012					
Microgen (US)	Piezo MEMS energy harvester	Serie A	$2.6M	XTRION N.V. + contract from NY State Energy Research Development Authority	This is one of the first significant financial investments for MicroGen, which raised a few $M in grants and equity so far. While manufacturing agreement have been established with XFAB for using a 8-inch line with AlN capability earlier in the year, we note that this investment comes from XTRION which specializes in semiconductor investment and is the major owner of XFAB, among other companies. MicroGen is the leading start up developing energy harvesters based on piezo MEMS technologies. In the energy harvesting sector it is challenging for the tiny MEMS devices to compete against non-MEMS technologies in many applications. However Microgen has a breakthrough technology and we expect to see production ramp-up next year.
Sand 9 (US)	Silicon MEMS timing devices	6th round (Serie C)	$3M	Ericsson	This new investment follows the $23M round in June led by Intel Capital. This new corporate investment highlights that Sand 9 is close to introduce its disruptive silicon MEMS timing technology in the market.
Lilliputian Systems (US)	MEMS-based solid oxide fuel cell	8th round	$40M (out of $60M round)	RUSNANO (Lead Investor), Altira Group LLC, Atlas Venture, Fairhaven Capital Partners, Intel Capital, Kleiner Perkins Caufield & Byers, Stata Venture Partners	Many efforts on microfuel cells failed in the past few years. However Lilliputian Systems is working on a "game-changing" technology which should enable weeks of charge with a single cartridge. The technology is based on licenses from the MIT. This large round of investment is expected to enable scale manufacturing and market introduction of Lilliputian first product.
CrossFiber (US)	MEMS-based photonic switches	Serie D	$13.3M	Southern Cross Venture Partners (lead investor), New Venture Partners, Arsenal Venture Partners, Back Bay Management, PacifiCap	CrossFiber is developing optical switches for data center application. The technology is based on 2D and 3D MEMS mirrors and originate from OMM company, inventor and pioneering manufacturer of the world's first Telcordia-qualified MEMS-based photonic switch modules. We note that a few days after this fund raising announcement, CrossFiber has announced the acquisition of key OMM assets, including the IP portfolio.

M&A

Company	Type of product	Type of transaction	Value of the transaction	Acquirer	Yole Développement comment
Aug. 2012					
BTendo (IP and staff) (ISR)	Picoprojector modules based on MEMS scanning mirrors	Acquisition	NA	ST Microelectronics	This acquisition is in line with the strategy of ST to be the largest one-stop MEMS solution provider worldwide. ST started a strategic collaboration with BTendo in February 2011, while BTendo was in difficult position. At that time BTendo was counting about 15 employees. Yole Développement understanding of the ST deal was the following: co-design partnership / ST acting as foundry for the MEMS and the driver / BTendo doing the optical assembly /both ST and BTendo selling the solution but ST having the exclusivity for large customers. ST is now able to produce the MEMS mirrors internally and to market the picoprojector modules to large potential customers. We note that this market is still limited to few camcorders and DSCs today. But the long term market potential for picoprojectors is very appealing given the high value of such module in the system and the expected integration in smartphones. We note that Samsung has recently done its first massive launch of a smartphone embedding a picoprojector (Galaxy Beam model). At the MEMS level, TI is today leading the market with a specific version of its DLP MEMS mirror array.
Sept. 2012					
Microstrain (US)	MEMS-based inertial modules (AHRS...) + WSN + energy harvesting + displacement sensors	Acquisition	NA	LORD Corporation	Microstrain activity should be merged with LORD "Vibration & Motion Control" products. Microstrain end-markets are in-line with those of LORD: Aerospace/Defense and Industrial. We do not expect significant change in Microstrain business and roadmap as LORD is a group of diversified activities, each of them being rather independent. However this acquisition provides "muscles" to Microstrain which faces an increasing competition in low cost MEMS-based inertial modules in particular. Indeed with the progress of MEMS technology, many new players have recently appeared on the market and are able to develop new applications by using low cost consumer or automotive-grade sensors: XSens, SBG Systems, Senlution, VectorNav, InterSense...
MicroProbe (US)	Wafer test probe solutions	Acquisition	$116.8M	FormFactor	Formfactor has its own MEMS-based probes technology, which is integrated in his solutions. This acquisition is a sign of consolidation in the semiconductor test industry.

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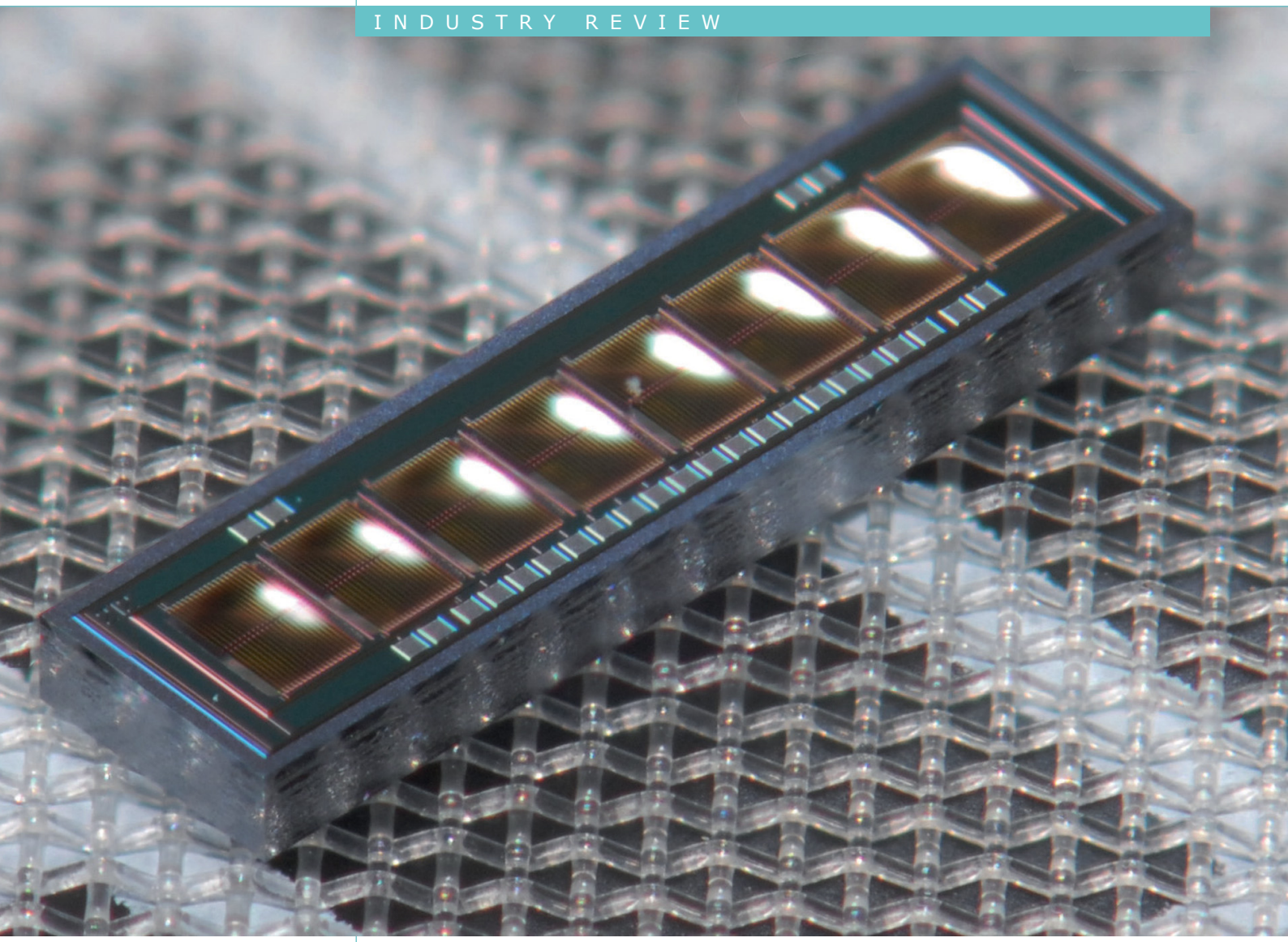


IR Sensor Chip 8x1 (Courtesy of Omron Electronic Components LLC)

Emerging MEMS: Leading suppliers say MEMS oscillators, picoprojectors and tunable RF are finally ready to take off

Leading suppliers say the time has at last come for MEMS oscillators, picoprojectors, and tunable RF to break through to the next level. Yole Développement thinks they may be right this time, with each of these markets now on track to pass the $100 million –- though it may still take two to four more years.

"First of these products to surpass the $100 million mark will likely be MEMS oscillators," predicts Yole Développement.

Maturing MEMS technology, maturing customer acceptance of MEMS technology, and the burgeoning market for smart phones seeking differentiated value, may start to push some long-emerging MEMS devices into real commercial volume markets over the next few years.

Yole Développement expects the total market for emerging MEMS devices to nearly double over the next two years, from ~$445 million this year to some $950 million in 2014, and to see 42% CAGR for the next five years to reach $2.8 billion. First of these products to surpass the $100 million mark will likely be MEMS oscillators, which we expect will reach that milestone in about 2014, followed by micromirrors for picoprojectors and autofocus devices in about 2015, and RF switches and variable capacitors by around 2016. Like the MEMS market in general, a major proportion of the rest of the emerging MEMS market consists of a widely diverse range of products in very small volumes, and we see growth potential in these newer products too, such as thermal sensors, audio speakers and force-sensitive sensors.

Suppliers of these devices say this growth is of course in large part enabled by improved technology that brings performance up to expectations, but also in part from market forces trending in their favor, from the enabling infrastructure of easily accessible video content for picoprojectors, to the LTE generation's dynamic frequency adjustment issues that may require tunable RF components. Now the key issues may move on to the business basics of marketing and distribution.

SiTime turns focus to designers' needs to grow MEMS oscillator sales to next level

SiTime plans a sharper focus on making designers' jobs easier with more applications support, speedier delivery of custom devices, and a stepped up effort to educate users on the performance and resilience advantages of MEMS oscillators. A partnership with established timing supplier Vectron should help reach more of its high-end customers. And lower power devices in development for the mobile phone market could finally turn the small size of the MEMS devices to competitive advantage.

"The game is changing from manufacturing to marketing," says SiTime VP of marketing Piyush Sevalia. "If every designer in the world just knew that MEMS was such a compelling alternative, they'd all use it.... Now it's a matter of who has the best market reach and who executes best on channel push, and pull with new technology."

It's perhaps a sign of maturity of the MEMS timing segment that growth now comes down to business basics of marketing and distribution. Over the last seven years, SiTime has mastered the manufacturability, overcome resistance to MEMS technology, then drastically improved the technology to meet performance requirements for more demanding markets, improving jitter by 300X to 0.5ps in five years, and frequency stability 250x to 0.1ppm. The company recently made a listing of the top 10 XO oscillator suppliers, with some 3% market share, and says it has shipped 120M units to date to 800 customers, as sales doubled last year. Still, total Yole Développement estimates revenues remained under $20 million for 2011 in this $6 billion market.

So in addition to developing technology for mobile and very high-end telecommunication applications, SiTime is investing in campaigns to get out the word about better MEMS product performance and resilience, based on data from a stepped up testing program. It's offering online tools for engineers to figure out the parameters for their designs, with online ordering and shipment of custom samples within 48 hours, with more such service improvements planned to come.

MEMS small size will likely become a competitive advantage going forward. It hasn't been so yet, as customers have typically preferred their MEMS devices in the same size packages as the traditional quartz devices for easy drop in replacement and interchangeability.

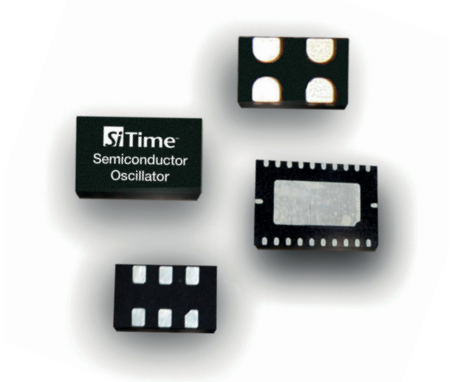
But the mobile phone markers will care about size, once MEMS can bring down power consumption enough for that market. "Look for an announcement in the next six months," says Sevalia. "Then MEMS will start to shine for its smaller size and enhanced feature integration."

Other users in the mobile segment have at least increased their trust in the reliability of MEMS enough to convert most orders to the smallest quartz package size available as the security backstop, even though actually replacing the MEMS with quartz in that size package would be much more expensive. The coming influx of other MEMS timing suppliers could also ease users' concerns with alternative supply of the smaller devices.

"More phones with the projectors are expected in the next six months," reports Frank Moizio, Texas Instruments.

TI reports more picoprojectors coming in next few months

Leading micromirror supplier Texas Instruments argues that improved technology, and the wide availability of easily accessible content are finally making the pico projector a compelling option. Now more real products that consumers can see in phones and retailers may start to spur demand.

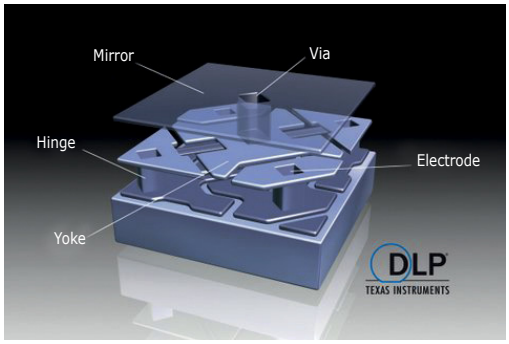


Oscillators in plastic package (Courtesy of SiTime)

Samsung's svelt Galaxy Beam pico projector phone out in multiple world markets is a major start. More phones with the projectors are expected in the next six months, and major retailers will stock multiple phone-accessory projectors by the Christmas season, reports Frank Moizio, TI business manager for DLP pico displays, arguing that this visibility will draw consumers. "Once you actually use the phone with the picoprojector, you really see its value," says Moizio, ticking off how he recently used his new Samsung Galaxy Beam phone for giving small group presentations, sharing pictures from events, and easily showing his parents his talks on YouTube.

The technology may at last be ready for prime time. On the MEMS side, major progress had been made in driving down the size of the DLP pixels, from the 10-12µm for TVs down to 7.5µm, to decrease the size of the array, reducing the power needed to drive the smaller mirrors, and allowing smaller die size, with simpler thermal management, to bring down costs. Major efforts have also gone into reducing the power usage of the rest of the chipset, and improving the efficiency of the LED illumination and the optics as well, to at last achieve enough brightness for good visibility with reasonable battery life and reasonable cost. The Samsung phone claims three-hour battery runtime for the 15 lm projector, at a price about that of other high-end smart phones, from ~$500-$550 alone down free on some contracts.

Besides the Samsung phone and others coming, Brookstone, Wal-Mart and Target are now stocking ~$200 accessory picoprojectors that fit around the phone like a sleeve, and multiple products will reportedly be available in multiple retailers this holiday season. Small stand-alone projectors, both plug-in and battery-powered, have similarly improved in performance and availability.



DLP-chip-mirror-technical-architecture (Courtesy of Texas Instruments)

"These live in-store demos or seeing a friend use the device will really help people see the value," argues Moizio.

Also helpful is the wide array of content now available on consumers' smart phones and tablets that can easily be projected directly, or easily ported to a separate projector with an HDMI cable connection, for more comfortable viewing and sharing of television, movies and games in any setting. One might think that the larger and sharper displays on all these handheld devcies would cut down demand for picoprojectors, but Moizio says, "Our experience is just the opposite. The 20-30 inch image is just much better, and the tablets make it easy to get content to the projected display."

"Demand for saving energy will drive adoption of low-cost, infrared noncontact thermal sensors," says Donna Sandfox, Omron Electronic Components LLC.

WiSpry says LTE should catalyze market pull for tunable RF

WiSpry argues that LTE will finally drive demand for RF MEMS devices. "It's become very clear over the last 3-6 months that the market has caught up with the solution we can provide," says Jeff Hilbert, president and founder. He notes that 3G phones had problems that antenna tuners could solve, but with the LTE generation tunability starts to become more essential—and LTE handset units will reach some 75-100 million units this year, 250-300 million next.

At the same time that even thinner phones mean less volume available for antennas, many more frequency bands and higher data rates make their job more demanding. Handset makers are also now looking to temporarily aggregate different channels to create one fatter channel for high-bandwidth on-demand data downloads, and this need for dynamic frequency flexibility brings much more interest in tunable components.

"In the last quarter I've had as many people ask about carrier aggregation as about antenna tuning in general," says Hilbert. "With LTE the technology is becoming essential. I'm bullish we'll finally get out of the full-production-soon stage. ...The sector is gearing up for the real deployment wave this time around."

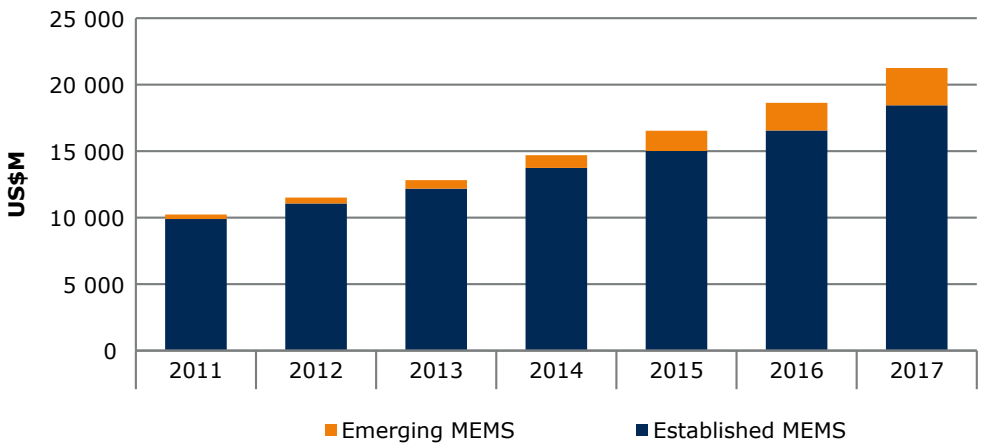
Though WiSpry has been shipping its RF MEMS devices in volume for multiple phones, customers have remained reluctant to add a new component and its cost, when network connection problems weren't of as much driving interest to consumers as things like display quality and applications. And customers needed more support to integrate an entirely new kind of device. "The number one lesson we have learned is the big gap between having a working MEMS and selling a working product," says Hilbert, noting the need for collateral, reference designs, development kits, applications support and the like.

In addition, competing semiconductor switch-based solutions made on GaAs or SOI didn't raise user concerns about MEMS manufacturability, and were somewhat easier to integrate, though Hilbert argues WiSpry's MEMS solution offers significantly better performance for more difficult applications.

The relatively larger size of a MEMS solution has also recently become more of a concern, but Hilbert argues that though the MEMS array is somewhat

2011-2017 MEMS markets

(Source: Status of the MEMS industry report, July 2012, Yole Développement)



larger than its semiconductor competitors, the actual area per amount of capacitance is about the same. WiSpry has also accelerated its roadmap to shrink its device, targeting products less than half the current size to come in the next two quarters, thanks to maximizing MEMS design re-use, a limited number of mask-level changes to create new floor plans and capacitor characteristics, and improvements in wafer-level encapsulation and packaging.

The company is also extending its tunable array platform to a wider portfolio of products, starting with on-demand filters and tunable antennas, and aiming next at tunable power amplifiers. It's sampling a tunable filter for LTE and CDMA low frequency bands which enables voice and data transmissison over the two networks at the same time. When not needed, the filter can be tuned out of the bands, essentially switching it off to eliminate over 75% of its insertion loss.

"The market has truly arrived that will need antenna tuners--that was not the case a year ago," Hilbert argues. "It's clear to customers now that they have to pay more attention to the RF front-end and the antennas, or the res t of the gee-whiz apps aren't going to matter because they won't work be fast enough and won't work reliably....LTE will drive significant revenue growth in this sector in 2013, with multiple design wins from multiple customers."

Omron counts on demand for energy savings to drive sales of thermal sensors

Omron expects demand for saving energy will drive adoption of low-cost, infrared non-contact thermal sensors--the latest new MEMS device to go into mass production. It's offering the devices in modules on boards with microcontrollers and connectors for easy integration into building automation systems, to sense the presence of people in a room—even if they're not moving-- to adjust lights and temperature accordingly to save energy. The system reportedly measures the heat of an area with sensitivity of 1.4°C, to detect people ~4-6 meters away, without the high resolution of an uncooled microbolometer, but at a much lower cost.

The thermopile-based technology is related to that used in some Omron flow sensors, but with improved resolution, based on the difference in temperature between the hot junctions on dielectric and cold junctions on silicon of the polysilicon/aluminum thermocouple stack.

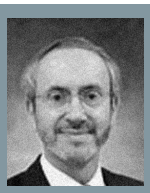
The array of 8 to 16 die is topped with a silicon lens to focus the radiation on the membrane.

Donna Sandfox, sensor and healthcare module product manager, says potential customers who've seen the demonstration device have been interested

D6T thermalIR
(Courtesy of Omron Electronic Components LLC)

in samples for a wider range of other applications as well, including turning off displays on computers and other appliances when no one is around. There's also interest in industrial monitoring applications, such as remotely watching for hot spots in equipment or checking the temperature of large containers of liquid.

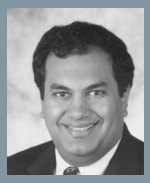
Paula Doe for Yole Développement



Jeff Hilbert, President & Founder, Wispry
Jeff Hilbert is founder of the company, bringing over 35 years of executive management and technical experience, in a number of leading semiconductor and MEMS companies including LSI Logic, Compass Design Automation, AMCC, Motorola, Harris and Coventor. Hilbert holds a bachelor of science in chemical engineering from the University of Florida and master of science in computer science from Florida Institute of Technology.

Frank Moizio, Business Manager DLP Pico Projection, Texas Instruments
Frank Moizio has contributed to the team at Texas Instruments in both management and technical capacities for more than 20 years. He holds a BSEE from WPI and a MSEE from SMU. He earned his MBA from SMU's Cox School of Business. Mr. Moizio holds six patents in the areas of Digital Control and Digital Signal Processing.

Donna Sandfox, Product Manager for sensors and MEMS products, Omron Electronic Components LLC.
Her primary area of expertise is in MEMS Mass Flow Sensors. She also supports Omron's pressure, thermal IR, tilt/vibration and optical (photomicrosensors) sensors, as well as their RF MEMS Switch products. Donna received her bachelor's degree in mechanical engineering from Southern Illinois University and an MBA from Roosevelt University.

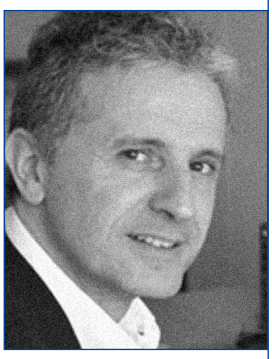


Piyush Sevalia, Executive Vice President, Marketing, SiTime
Piyush Sevalia has over 20 years of semiconductor industry experience. Prior to SiTime, Piyush was the Vice President of Marketing at Ikanos Communications (Nasdaq: IKAN). During his tenure at Ikanos, Piyush made significant contributions that drove the company's growth from a pre-revenue startup to a profitable, public company. Before Ikanos, Piyush spent over nine years at Cypress Semiconductor in positions of increasing responsibility. There, his key contributions included helping Cypress expand into wireless markets as well as defining and launching successful timing products that generated several hundred million dollars of revenue. Piyush earned Bachelor's and Master's degrees in Electrical Engineering from the University of Bombay and the University of Michigan respectively, and an MBA from the University of California, Berkeley.

COMPANY INSIGHT

poLight readies production of optical MEMS autofocus

Norwegian startup lines up production partners and camera module customers for piezoelectrically controlled gel lens



François Vieillard, Vice President Marketing & Sales, poLight

poLight says it is qualifying production of its optical MEMS autofocus devices, and expects to see phones with the units to be on the market by the end of next year.

The fabless Norwegian company is aiming to start volume production in Q1 next year, fabbing the MEMS actuator at Texas Instruments and assembling the lens unit at a major electronics assembly house in Asia. Multiple camera module customers in Japan, Korea and Taiwan will then need several months to qualify their modules with the unit, and then phone makers will need another few months to qualify the modules in their phones, reports poLight VP of marketing and sales Francois Vieillard.

It's been more than a ten year effort to develop the technology, which adjusts the focus by changing the curvature of a polymer gel lens using a piezoelectric ring embedded in a thin glass membrane. Two Norwegian companies who'd been working on the approach for years spun off the project into poLight in 2009. The company then raised $18.5M in 2011 in a round led by the Norwegian government's investment fund.

The key technology is the tunable inorganic polymer gel material, which needs to be highly transparent, and remain reliably clear and flexible through years of exposure to heat, cold, light and UV. Once the company chemists figured out the molecular design of the polymer, the material can be made fairly simply at the company's lab in Norway, where it will keep production in house. The lab has capacity to make up to 50 liters a week, and with only a drop for each lens, each liter can make about a million lenses. Adding this lens in front of the lens stack and sensor could potentially degrade image quality, but poLight says the polymer/glass transmission is better than 95%.

Uniform production of the optical MEMS actuator to flex the lens was also a challenge, requiring reliable fusing of the PZT piezoelectric ring into a thin sheet of glass on silicon. The MEMS cavity is etched through the silicon to leave the thin glass membrane without deforming it, then a drop of polymer is put on a glass support, and the glass and polymer is fit into the MEMS cavity during assembly. After a first foundry had difficulty producing reliable high yielding parts, poLight turned to SVTC late last year, who successfully developed a new solution, and production then moved to the Texas Instruments fab. TI is now qualifying the specialty Ulvac equipment to diffuse the piezo PZT film into the wafer. "TI is extremely good," says Vieillard. "The product has now passed all the reliability tests."

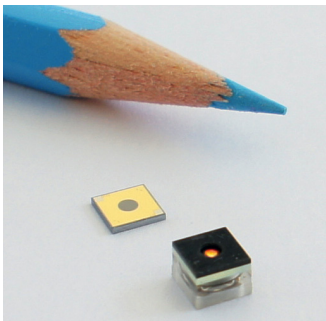
PoLight targets camera modules for mid to high end cell phones, where Vieillard says its product is competitive in price with current voice coil motors of the accuracy needed for ¼ or 1/3 inch sensors for 8 to 12 megapixel cameras. But the optical MEMS autofocus system reportedly offers up to 20X faster speed and up to 40X lower power consumption, as it doesn't have to mechanically move the lens stack back and forth in front of the sensor. The higher speed allows continuous focus for video, and also much longer run time on the battery-or probably more appealing to phone makers, the option of using a smaller battery. The high speed also allows multiple ultraquick takes at different focuses for a single photo shot, which can then be combined in post processing to select the desired sharpness for different areas of the image.

A secondary market may be for bar code readers, where the technology would also have advantages, but the 24-person company so far does not have the resources to address any other applications yet.

The company has also made progress on developing the necessary supporting infrastructure. It's developed processing applications on the TI OMAP processor, and Semtech Corp. is offering a high voltage, high speed driver optimized for the device. While customers will want a second source, TI's large capacity will be a good start, and the company plans to use two assembly houses, one in Taiwan and one elsewhere in Asia.

PoLight faces plenty of competition from a crowd of alternative autofocus technologies vying to replace the voice coil motor, which still commands more than 95% of the market for consumer camera modules. Piezoelectric motors and shape memory alloys have taken a percent or two share of this growing market, as has a liquid crystal-based approach from LensVector. Tessera Digital Optics Corp. says it plans to ship its MEMS autofocus solution in Q4, with its spring-shaped silicon actuators that move the lens. The new startup WaveLens out of CEA LETI is also developing a device using MEMS actuation of membrane curvature over a liquid-filled cavity.

www.polight.no



TLens pencil (Courtesy of poLight)

François Vieillard has 25 years' experience in the semiconductor industry, including 8 years in the mobile industry at NS, Cirrus Logic, Toshiba and ARC. He held various marketing and sales responsibilities and was Sales Director at Digital Imaging Systems (DIS). François holds a Master's degree in Electronics from Paris Ecole Centrale d'Electronique.

COMPANY INSIGHT

Audiopixels MEMS speakers expected for Christmas 2013

Israeli-Australian firm says surprising physics of small geometries enable digital recreation of big sound from small movements of MEMS membranes.

Audiopixels executives say they anticipate having a MEMS speaker product in the market for the Christmas season in 2013. "We're now in the latter stages of optimizing the structure," says Daniel Lewin, founder and CEO, who figures they're roughly six months away from the end of the seven-year effort to get big sound from small MEMS membranes. The company has started work on the production technology with joint development partner Sony and two of the other leading specialty MEMS foundries on 8-inch equipment, figuring development may initially be slower, but the manufacturing ramp should then be faster. The foundries may not like the unusual non-exclusive arrangement, he notes, "but the potential volumes are so huge there's enough room for everyone."

Target market is quality audio, in all applications from cell phones to stereo equipment. "Audio is so firmly embedded into all aspects of life that we've been able to attract the interest of some of the leaders across industries," says Lewin. "We're in conversations with many of the upper crust." He asserts that one of the company's 10x10mm chips provides better sound quality than current mobile phone speakers, while grouping more of the units together adds range and volume for more demanding applications. Multiple chips on a drink-coaster-sized substrate can reportedly match the performance of a high-end audio sub woofer.

Creating this entirely new application of MEMS technology has not been easy. Key to the technology is the ability to convert a very small amount of electrical power to a very large amount of acoustic power, in order to recreate sound waves digitally from a train of small pulses generated by an array of MEMS membranes. The proprietary design enables very short strokes of membranes driven by electrostatics to create sound pressure having many times the pressure per surface area when compared to conventional speakers. "The way acoustics is conventionally taught suggests this is impossible," says Shay Kaplan, founder and chief scientist. "But in very small dimensions, the physics turns out to be a bit different."

"The acoustical efficiency is orders of magnitude greater than one would expect," adds Yuval Cohen, founder and CTO. "All the rest is clever engineering." Some of this non-trivial clever engineering includes packaging with an acoustic window that protects the die but allows the sound to get out. Another example is the use of algorithms that can play a significant role to better shape the sound waves by shifting noise or distortion or reverberation into the ultrasonic range, out of human hearing.

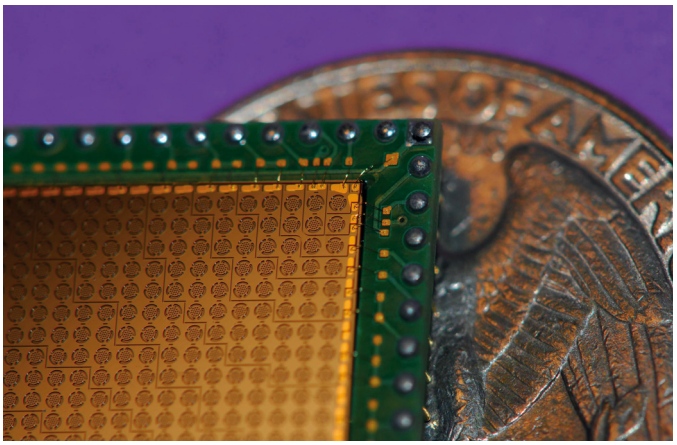
Moving selected elements in a large array of identical MEMS membrane units creates small, quick pulses of sound pressure that combine into a pulse train to construct the desired sound wave. Clever software filtering can create trade offs on the fly, as for example increasing loudness (for, say, a ring tone) or increasing frequency range (for voice) as needed. Increasing the active surface area by adding additional identical 10 x 10mm chip arrays would add more octaves of lower frequencies or additional decibels of volume.

The Israeli company started its quest to get better sound from smaller speakers back in 2006, when cell phone ringtones were a hot topic. It raised venture capital in 2006-07, and succeeded in first playing music from silicon in 2009. Differences of opinion arose among the stakeholders as the challenge moved to perfecting and commercializing the product, ultimately creating an opportunity for one of the private investors to buy out the VCs and take control, then reverse merge the company into an existing public company. Audiopixels Ltd. is now 100% owned by its Australian parent, AudioPixels Holding Limited and listed on the Australian stock exchange (ASX:AKP and OTCQX:ADPXY).

The development has taken some years, as the only way to figure out how the audio devices were going to work was to build them and test them. "MEMS simulation is pretty good for mechanical and electrostatic performance, but you can't conduct accurate MEMS scale airflow or damping simulations," notes Kaplan. "You have to build 100s of variants and measure them. The physics is unclear. Then we feed the data back into our own simulator. It's a long and expensive road a MEMS startup has to go down. There are no short cuts. It's a big financial undertaking to support a 10-year project."

But the MEMS sector's maturing process technology now makes the development possible.

"We're using the experience that people gained from making all those accelerometers and gyros in high volumes for cell phones for the processes to make our speakers," notes Kaplan. "Plus MEMS has became a money maker, so big players have gotten involved," adds Lewin. "It used to be that MEMS was just something you did with older equipment, but now it's beginning to use the latest and greatest from the semiconductor industry. We had a lot of luck, but also good timing. Even five years earlier we probably would have failed."



Chip in IR (Courtesy of Audiopixels)

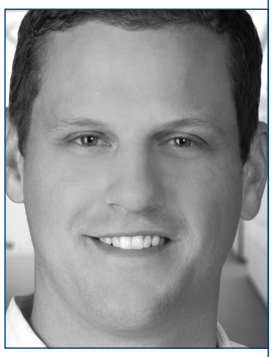
The company counts on high volumes to drive down costs. The MEMS die and controllers will be the same for all applications, just more devices modularly combined for more demanding applications. The array of membranes needs the relatively large surface area, which pushes the manufacturing a bit for yields, and there's limited potential for shrinking the die to reduce costs. But learnings from the potential large volumes should facilitate tight process control and allow eventual loosening of tolerances to drive down costs.

www.audiopixels.com.au

COMPANY INSIGHT

Georgia Tech startup NextInput aims at force-sensitive touch pads

Company counts on systems partners and relatively simple manufacturing technology ease time to market.



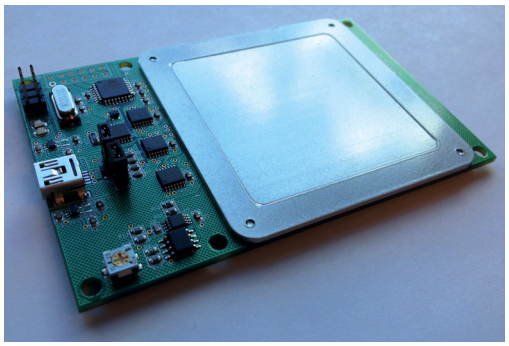
Ian Campbell, COO, NextInput

"We're talking about detection of surface deflection at scales of microns or nanometers that are undetectable to the human touch," says Ian Campbell.

Georgia Tech startup NextInput counts on joint development agreements with major potential OEM users, and relatively non-revolutionary technology to get its force-sensitive MEMS touch sensor solution to market.

The company reports it has formed joint development agreements with a tier-one automotive supplier to work on touch sensitive controls on the steering wheel, and with several other big potential users in the consumer mobile device space to work on touch pads. Two years out of the gate, NextInput has evaluation kits out to customers with the force sensors, hardware, embedded firmware, and Windows 7 software for the touch pad, the first target product.

This initial touch pad technology puts a force sensor in each corner under a flexible input surface like a laptop touchpad. Founder and COO Ian Campbell says the sensors respond sensitively to how much force is applied, allowing more efficient control by adding this third dimension, so the user can, for example, select and scroll in a single motion by touching and then pressing harder. The system reportedly would work more dependably under a wider range of conditions than capacitive touch devices, responding to a stylus or a finger or a finger in a glove, or not responding unless a specific amount of force was applied, like a mechanical switch but without moving parts. It would also reportedly use less power, and be competitive on cost.



EVK-1s-Top (Courtesy of NextInput)

NextInput aims eventually at the much larger touch screen market, where it plans to put its ultrasensitive touch sensors underneath the rigid displays. Campbell says the company has demonstrated its force touch sensors working for multi-touch input underneath an OLED display under 200µm glass. "We're talking about detection of surface deflection at scales of microns or nanometers that are undetectable to the human touch," says Campbell, noting that even rigid objects deform enough for touch to be detected. But that will take some further development to make the device more sensitive, and thinner and smaller.

One key enabler for the high sensitivity at low cost is replacing conventional packaging with a flexible but protective encapsulation that still allows re-flow soldering of the unpackaged MEMS die, while saving significantly on manufacturing cost. The device is much like a conventional pressure sensor with a diaphragm with piezo resisters that change as the membrane bends, but this membrane is mechanically coupled to the touch surface. Engineering the reliability of this connection was also key, to assure a secure coupling and to devise a system for overload protection to prevent the delicate tens-of-microns-thin membrane from shattering. Campbell argues the device shouldn't present unusual manufacturing issues, as it uses only a five-mask process, with working prototypes for the development kits sent to customers currently being made by hand in Georgia Tech's four-inch R&D MEMS fab. "We're not doing anything revolutionary," he says. "It's kind of an old school approach to a new problem. It's a simple design. We've just optimized some of the latest micromachining techniques coming out of university research labs." He says they've vetted the process technology with several of the top specialty MEMS foundries who helped them estimate costs and concurred that very little is out of the box so porting to manufacturing should be fairly direct. The company aims to select its foundry later this year.

With venture capital funding for MEMS companies in very scarce supply when the company started in 2010, NextInput managed to raise a small seed round of more than $1 million to grow its team, but now plans to fund development with joint development agreements with partners in key applications and verticals, who will get market exclusivity for a period. The tier-one automotive partner will fund development for a steering wheel switch which the two companies will take to market together. Campbell also credits the facilities and support of the Georgia Institute of Technology's Advanced Technology Development Center and its affordable world class research center, and the company's strong board of MEMS expert advisors.

www.nextinput.com

Ian Campbell is an experienced technology developer who has brought dozens of successful products to market. Ian began his career designing automated manufacturing lines for consumer electronics companies like Nokia. Later, Ian worked as an embedded systems engineer at the Georgia Tech Aerospace Systems Design Laboratory. After receiving his MBA from Georgia Tech, Ian worked as a consultant for Booz Allen Hamilton and Value Prism Consulting, where Ian consulted with Fortune 100 companies in strategy, operations, sales, and product development.

TELEDYNE DALSA
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Teledyne DALSA puts C2MI center's new 8-inch MEMS R&D line to work on multi-use platform technologies

Company will focus on copper TSV, high vacuum WLP, and piezoelectric MEMS platforms for both in-house sensor business and foundry customers.

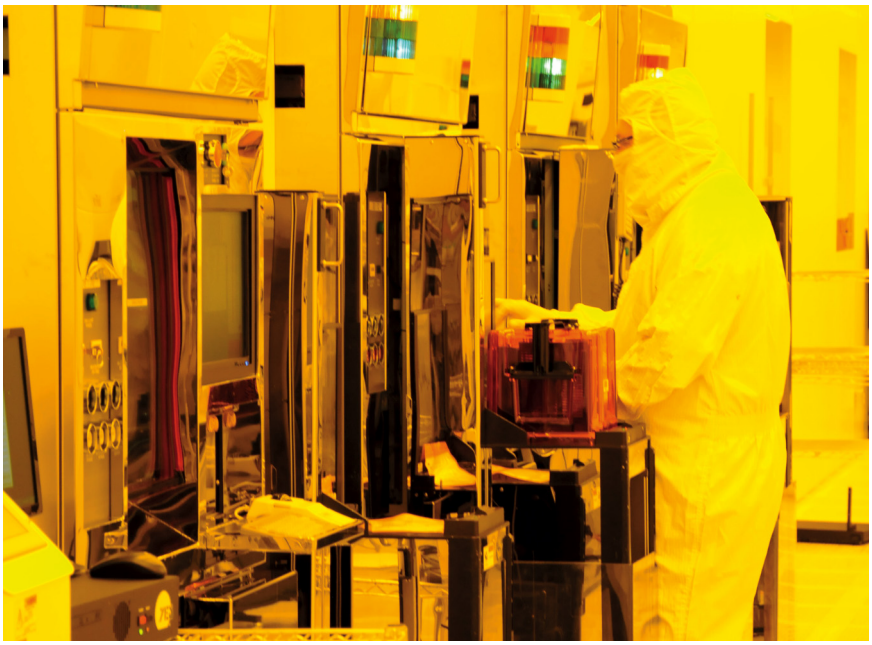
Donald Robert, Vice President Sales and Marketing, Teledyne Dalsa

The MiQro Innovation Collaborative Center (C2MI) in Bromont, Quebec, is completing the installation of its 8-inch production equipment for MEMS development, and starting first silicon runs. Founding partner Teledyne DALSA is beginning work there on platforms for low cost copper through-silicon vias, and on high-vacuum wafer-level packaging, aimed first at IR sensors, both for the company's own internal products and for use by its foundry customers. Next on the agenda is development of a piezoelectric MEMS platform.

Among Teledyne DALSA's first projects now starting at the new facility is a low cost wet-plated copper TSV platform, aimed at wafer –level MEMS to ASIC connections and other 3D packaging. It's using technology licensed from Alchimer that integrates via isolation and filling in the same process modules, reducing the equipment and material costs. Researchers are also working with an equipment supplier on optimizing the process for volume production. Though the development is apparently in large part motivated by the need to reduce MEMS packaging costs, and the technology will be offered as a standard TSV platform for the MEMS foundry, it can also be used for image sensors for $1.9 billion parent Teledyne Technologies' ~$340 million digital imaging business. "We've optimized the design rules to minimize the total etching and via filling costs, and we will offer that as a standard technology platform that all our customers will share," says Donald Robert, Teledyne DALSA VP of sales and marketing.

The company's other research focus for the next twelve months will be development of a microbolometer using wafer-level packaging, particularly targeting new materials for IR sensing, for bonding and for use inside the cavity for reliable high-vacuum WLP devices, targeted at lower cost uncooled microbolometers for Teledyne's internal use, and as a platform technology for the foundry. "Packaging of IR sensors today is mainly done at die level and requires special materials like getters and antireflective coatings," notes Robert. "The ability to perform these steps at wafer level will reduce significantly the cost and will enable IR sensors to penetrate new markets.''

Next project on the roadmap will be to add equipment to develop piezoelectric materials, particularly lead-free ones, as a platform for its foundry customers. Robert suggests that the piezo materials could be less sensitive to vacuum conditions and therefore less costly for a wide range of MEMS devices, not just for actuators like inkjet heads, but to compete with Si/SOI micromachining technology for resonators and inertial sensors as well. "We see this as mainly for the consumer market," he notes. "The very small devices could be quite cheap."



C2MI MEMS Fab : the class 10 FAB with automated equipment (Courtesy of Teledyne Dalsa)

$80M 8-inch MEMS development line for speeding ramp to volume production

Teledyne DALSA has specified some $80 million worth of production equipment over the last couple of years for the C2MI MEMS fab. "The idea is an 8-inch state-of-the-art MEMS development line with the same equipment as that for mass production at the major foundries, where proof of concept work already done in university labs on smaller diameter, lower volume equipment can move for its final year or so of commercial development and prototyping, to then be ready to move more quickly and smoothly to mass

production," says Robert. "We spent a lot of time visiting labs around the world, and we believe that C2MI is unique in the MEMS industry with its focus only on MEMS development, and its large technology portfolio using state of the art equipment, including a wide range of characterization equipment. We spent a lot of time looking at equipment capabilities, and have worked with suppliers to meet aggressive specifications and add automation to the line." He notes particular progress recently in new metrology tools, especially those with IR to inspect the bonding through the silicon cap, a technology likely driven by the larger IC industry's interest in 3D IC packaging, but now also optimized for the MEMS industry.

"The ability to perform these [packaging] steps at wafer level will reduce significantly the cost and will enable IR sensors to penetrate new markets," says Donald Robert.

The fab is open to any company to rent time to do its own development, or it can work with Teledyne DALSA engineers there. The University of Sherbrooke owns and manages the center, which was funded by some $395 million from the Canadian and Quebec governments, and is supported by $14 million for operations for the first five years. Founding partners Teledyne DALSA and IBM and equipment suppliers contributed another $40 million. Other members to date include Cogiscan, Varitron Technologies and Akrion Systems, plus six Canadian universities. The facility also includes separate facilities where IBM is working on development of advanced die level packaging.

Multi-use platforms for Teledyne imaging products, and foundry customers

The new high-vacuum WLP process under development is a key component in a new MEMS infrared sensor, aimed at expanding parent Teledyne's high-end IR sensor business to a wider market. The big defense systems company currently is strong in high-performance cooled IR sensors for advanced military night vision applications, and it made its largest-ever acquisition of DALSA in large part to expand its digital imaging offerings to visual and UV image sensors. Now the WLP MEMS uncooled microbolometer will give it an entry to lower- cost, lower-end military night vision applications. Teledyne will use the MEMS IR sensor in its own systems and cameras, as well as sell the device to third parties. First product introduction for a military application is slated for 12-18 months out, with a roadmap to then extend in the future to industrial and automotive night vision and thermal sensing markets. Developing the device outside the US at the Canadian lab allows access to world-wide markets without US technology export restrictions. "Teledyne acquired us partly because of this program," says Robert. Teledyne DALSA will also offer the IR sensor platform to its foundry customers.

"We've been talking to customers for some time about the possibility of licensing common technology to speed time to market, but I'd say less than 5%, maybe one or two in the last year, have been open to it. Most people still want to differentiate themselves by technology as well as design," notes Robert. But he expects that some customers will be interested in the InvenSense technology now available for licensing, and with X-fab now also promoting licensing of their optimized inertial sensor fabrication platform, the idea of re-using technology platforms may be on the verge of getting some traction, as some customers see opportunity to take advantage of established manufacturing technologies to differentiate themselves instead by design or system integration. "This is something that we were expecting in the future, but not so soon as this," adds Robert.

Growth from inertial sensor integration, telecomm optics, then bioMEMs

Teledyne DALSA's MEMS foundry business saw healthy 23% growth in 2011 to some to $37 million in revenues, according to Yole Développement, making it one of the largest of the crowd of pure-play specialty MEMS foundries. Growth has come from consumer inertial sensors, especially combo sensors integrated efficiently with ASICs, and the company expects that to continue, as it moves the integration technology along from WLP, to TSV and eventually to 3D packaging of the ASIC and the MEMS at the wafer level. DALSA has also seen healthy growth in optical MEMS, for optical switching in telecommunications applications. "That market is not growing much faster than the average of the rest of the industry, but we think we've been gaining market share for high end devices with complex micro mirror arrays on large die that push the manufacturing technology," says Robert. The company also supports the mirror arrays with specialty high-voltage electrostatic driver ASICs to enable more tilt of the mirrors, not readily available elsewhere.

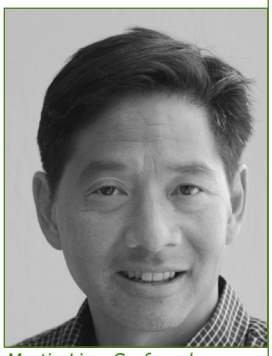
In the midterm, 3-5 years out, the company expects bio MEMS to be a major growth driver, such as lab-on-chip devices, especially those for point-of-use testing for environmental screening applications, which don't require the long medical approval cycles that human point-of-care diagnostic devices do. It's systems companies, not MEMS companies, developing most of these microfluidics testing devices. And indeed more and more of the foundry projects are now coming from systems companies who want to develop their own MEMS devices to differentiate their systems products, and cut their dependency on outside suppliers' development schedules and pricing. "Our business model, our DNA is highly engineered solutions. We don't want to play in commoditized applications, says Robert. "We bring value in developing new solutions with our customers."

www.teledynedalsa.com

Donald Robert, Vice President Sales and Marketing, Teledyne Dalsa
Mr. Robert has been involved in the Semiconductor industry for more than 30 years. He joined Teledyne DALSA Semiconductor's Bromont foundry in 1981. From 1987 to 1997 he held various management positions in Process and Manufacturing Engineering and at the Bromont foundry . In 1998 and 1999, he was head of Mitel Semiconductor waferfab operations in Jarfalla Sweden. He came back to the Bromont Foundry in late 1999 as Director of Sales and Marketing with the mandate of developing the Teledyne DALSA Bromont Foundry as a key MEMS Foundry supplier. He has been promoted Vice President Sales and Marketing in 2006. Mr. Robert has a degree in electronics from Sherbrooke College and a degree in Business Management from University of Sherbrooke.

InvenSense opens its proprietary Nasiri fabrication process to other potential MEMS users

The fast growing fabless company says other users could cut time to market by 60% and costs by 30% by using its proprietary fabrication platform. It looks for access to new ideas and new business deals, as well as licensing revenues.



Martin Lim, Co-founder and Senior Director Advanced Technology, InvenSense

Fari Assaderaghi, Ph.D. Vice President of Advanced Technology, InvenSense

Who would have thought that the first big push towards a standard MEMS process platform would come from a company whose innovative manufacturing technology has been key to its success? InvenSense has driven its 74% CAGR over the last few years to become the fourth largest consumer MEMS supplier at ~$150 million, according to Yole Développement, thanks in large part to its low cost gyroscopes enabled by its proprietary direct wafer-level eutectic bonding of the MEMS to CMOS die called the Nasiri Fabrication (NF) Platform. Now the company figures it will gain more by offering the technology to other users in the form of a shuttle than by keeping it 100% in house.

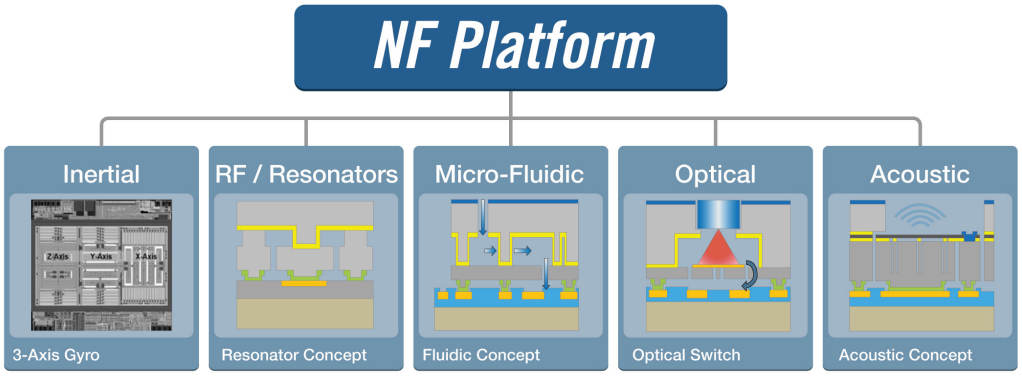
"We still see our manufacturing technology as a huge competitive advantage for us, but we're humble enough to know that we can't generate all the new ideas. By providing access to our NF Platform, we get a first look at more new ideas which we can either license or acquire," says Fari Assaderaghi, InvenSense VP of advanced technology development. He notes that InvenSense is especially interested in opportunities in consumer markets and mobile applications, but is more inclined to license its fabrication technology for applications in other markets outside its established business.

The immediate appeal for potential users is jumpstarting time to development of volume-manufacturable MEMS devices, by using shared-cost shuttle runs of the established InvenSense Nasiri Fabrication process at tier-one CMOS foundries. The company estimates users could cut a typical twenty-month development cycle to proof of concept with a new process platform down to just eight months with the well-established NF Platform. And after proof of concept, the transition should be seamless to volume production on the proven process already qualified at tier-one foundries. InvenSense supplies a PDK for the MEMS, and a PDK for the ASIC from its foundry partners. The MEMS process uses well-characterized single-crystal silicon for the mechanical structures. The shuttle includes an InvenSense reference design for monitoring process results. And having the CMOS bonded directly to the MEMS allows wafer-level extraction of key mechanical and electrical parameters of the MEMS.

Initial users have primarily been university researchers. The company worked with select local MEMS and IC professors at institutions like U.C. Berkeley and Stanford on the first shuttle run, where resultant devices included an integrated MEMS resonator and a symmetrical-drive gyroscope for a DARPA program that worked on first silicon. Early interest has now expanded to a wider range of universities in the U.S. and abroad and to some small companies, both traditional MEMS players and some in entirely different areas. "Larger companies, some with their own captive fabs, are also showing more interest," says Assaderaghi. The next two shuttle runs are in process, but openings remain on a fourth run slated for the first half of next year.

But the ultimate advantage, InvenSense argues, will be the smaller size, lower cost, and better performance enabled by connecting the MEMS and ASIC electrically and mechanically in a single step, with the company's proprietary aluminum-germanium eutectic bonding. Biggest beneficiaries of the NF Platform may be those applications that need the most intelligence, for significant calibration, or any close coupling and integration of the signals between the MEMS and the CMOS, as for example multiple sensor integration, says Martin Lim, co-founder and senior director of MEMS R&D, noting how the short interconnects speed transmission and reduce parasitics.

The more demanding automotive and industrial applications could also see direct benefit. "These tend to be $10, 5mm x 5mm devices, where we can dramatically reduce the size and cost," suggests Lim. InvenSense says the low-cost bonding of the MEMS to the ASIC creates both high quality vacuum encapsulation and sturdy die that can be tested at the wafer level by conventional wafer probing, singulated by conventional sawing, and then packaged as a single die in conventional IC packaging, cutting the expense of MEMS custom packaging and test from the typical 50% of total cost down to 15% to 20%. While InvenSense uses very low cost plastic packages for its consumer devices, higher-performance packaging can of course be used where needed in automotive and industrial applications.



Diverse applications supported by the NF Platform - extending beyond inertial sensors (courtesy of InvenSense)

The company suggests there are few limitations to the kinds of MEMS structures that can be etched in its silicon-over-cavity platform. "The process is our own internal sandbox for new products as well," says Assaderaghi. "And we think the platform is very versatile, analogous to a general-purpose CMOS process supporting a broad range of applications." Some applications may need further processing of the bonded wafers, such as opening a port to the environment, for example, for chemical sensing, optics, microfluidics, or pressure sensors. "We believe that the separate MEMS and CMOS model is obsolete, and that MEMS developers and CMOS foundries will both benefit greatly from this new model," he adds. "Our additional MEMS steps are few and simple and can be viewed as a value-add-on to the standard CMOS process, similar to high-voltage or embedded non-volatile memory modules. The lack of CMOS-MEMS integration is a business challenge for both the small MEMS-specific foundries and the IDMs, as it erodes their initial advantage with their captive MEMS-only fabs. Attempting to compete with standard CMOS foundries in manufacturing and standard semiconductor backend processes may ultimately challenge even the most established IDM players.

www.invensense.com

Martin Lim joined InvenSense in 2004 as a founder and the Director of MEMS Fabrication. He has been responsible for the development activities and technology transfer of the Nasiri-Fabrication to foundries. Mr. Lim has over 20 years of experience in fabrication and process development for various MEMS devices.

Fari Assaderaghi has more than 18 years of experience in high-performance, mixed-signal design and development. His areas of expertise span semiconductor device physics, process integration, mixed-signal design and MEMS.

ANALYST CORNER

Energy harvesting market will approach $250M in five years, with fastest growth from thin film thermal technologies

The energy harvesting market is poised for significant growth, but demand for MEMS solutions will take longer to develop.

Antoine Bonnabel, Technology & Market Analyst, MEMS Devices & Technologies, Yole Développement

Yann de Charentenay, Senior Analyst, Yole Développement

The energy harvesting market has potential to approach the $250 million mark in the next five years, thanks to growing demand for wireless networks for the building and industrial sectors. Progress in low power electronics and communication protocols are enabling sensor networks to run of energy harvesters in conditions where it's not practical to replace batteries.

Wireless building networks will largely use pulse, solar and thermal harvesting technologies, while industrial equipment monitoring will look to vibrational and thermal energy. Tire pressure monitoring systems now look likely to stick with batteries for some time, but will eventually turn to MEMS vibrational harvesters to supplement the batteries to make them last longer.

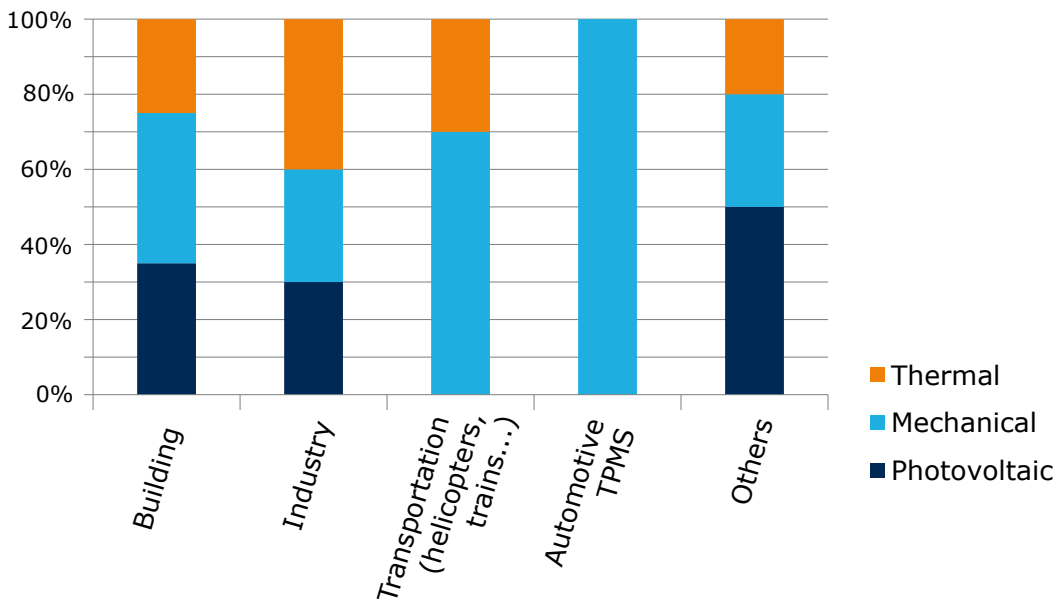
We've been looking closely at the markets for converting mechanical or thermal energy to electrical energy in the range from tens of microwatts up to tens of milliwatts for our soon-to-be-released report on energy harvesting. That's the range where most of the recent technological innovation is taking place, and where most demand for wireless sensor networks will likely center.

First real market: Energy harvesting for wireless sensor networks in buildings

The big cost savings from eliminating copper wiring in new construction and especially in remodeling of commercial buildings is starting to create a real market for energy harvesting devices in the building industry. The savings in both installation time and materials costs can be huge. Batteries are being used now for some of these applications, but the impracticality of changing them by the hundreds or even thousands in large commercial buildings will enable strong penetration of energy harvesting. And the necessary infrastructure of ultra low power electronics, standard low power communications protocol, suitable trickle-charged rechargeable thin film batteries and improved super-capacitors, and wide range of available components from multiple suppliers are

2017 energy harvesting transducer principle breakdown

(Source: Energy Harvesting report, Yole Développement, to be released in November 2012)



already in place, largely due to successful efforts of driving supplier EnOcean to develop the low power technology and promote the standard.

The energy harvesting used in buildings remains based on fairly conventional electromagnetic induction or photovoltaic. For light switches, the push of a finger snaps a spring that produces a millisecond pulse of voltage by electromagnetic induction with a wire coil, but that's enough to send an RF switching signal some meters to the light. Other sensors or controls are powered by conventional solar cells or by low cost thermo-electric converters on pipes or windows. There is little vibrational energy to be harvested and little demand for the ultra small size of MEMS devices.

This building market currently accounts for almost all of the commercial energy harvesting business, with some two million energy harvesting units sold in 2011. We project it will see tenfold growth over the next five years, to still make up more than half the energy harvesting market in 2017. EnOcean sees a consumer market developing as well for wireless home networks powered by energy harvesting in 2-3 years– after consumers have first purchased battery-powered systems and had to change their batteries.

TPMS market will stick with batteries for a while longer

Not so long ago, tire pressure monitoring systems looked like the best opportunity for MEMS energy harvesting, as automakers thought they would reduce costs, but at this point we do not see wide adoption for at least five years, and then the role of the energy harvester will likely be to supplement the battery to make it last longer. First to make the transition to supplemental energy harvesting will be the trucking industry, which is less cost sensitive. In the future TPMS will likely move from the rim to inside the tire, so the industry will need to change from selling to automakers to selling to the tire makers. This could provide an opportunity to add more sensors for smart tires, especially for the trucking industry, for sensing temperature, tracking leased installation, or even monitoring driving.

We expect MEMS energy harvesting to make inroads in TPMS in the 2015-2020 timeframe. MEMS harvesters could also be used to power sensors to monitor engine fuel consumption, where the environment is too hot for batteries to work well. The other potential market for the MEMS devices with most promise is medical implants, particularly pacemakers, though the long qualification time could delay commercialization past 2020.

Opportunities for thin-film thermal energy harvesters and MEMS sensors in industrial sensor networks

The next major energy harvesting market to develop will be industrial wireless sensor networks for monitoring industrial processes and equipment condition. We expect to see growth start to pick up sharply from about 2015, as low power electronics and low power communication protocols come down in cost and become more widely accepted.

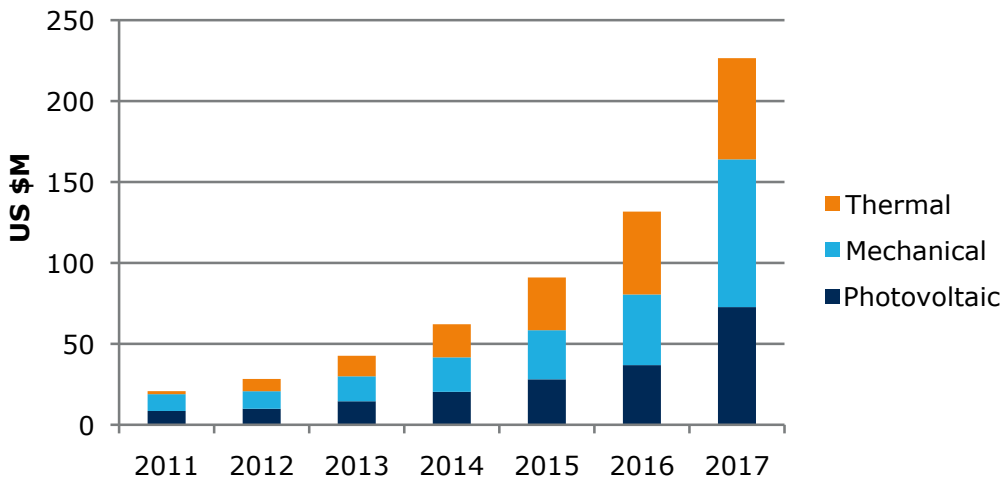
These applications will mainly use vibration or thermal gradients to power accelerometers and other sensors to monitor equipment condition in extreme environments, from high temperature industrial equipment to oil pipelines, where it's difficult to change batteries.

Here first installations are using relatively large and costly electromagnetic vibration harvesting devices from companies like Perpetuum for high

"The big cost savings from eliminating copper wiring in new construction and especially in remodeling of commercial buildings is starting to create a real market for energy harvesting devices in the building industry," reports Antoine Bonnabel.

Market for modules

(Source: Energy Harvesting report, Yole Développement, to be released in November 2012)



benefit applications, largely in the oil and gas industry. But as cost and size come down, we expect volumes will start to grow significantly, though of course the price decreases will keep revenue growth more limited. Most of these applications do not demand ultra-small size or ultra-low power communication however, so electromagnetic and thermal technologies will likely dominate.

Indeed micromachined thermal energy harvesters will likely find their market here in the industrial space, where there are ample sources of temperature differentials. Suppliers Nextreme and Micropelt have advanced prototypes of their thin film thermal harvesters and should enter the market soon. Micropelt has developed a module for monitoring the condition of busbars for power transmission, as well as for powering valves to control steam heating for building automation. It's building a new fab to mass produce the products. These micro technologies will face competition from more standard thermal electrical technology, from suppliers such as Marlow Industries, which is adding energy harvesting to its line of larger generators.

We expect thermal energy harvesting to be the fastest growth opportunity over the next five years as the industrial market develops, to jumping from a few percent now to some 25% of the total energy harvesting market by 2017. Mechanical technologies will continue to dominate with about 39% share, with solar about 36%.

Transportation applications for energy harvesting (other than TPMS) will also reach more than $25 million by 2017. Here electromagnetic vibration harvesters are in use in pilot projects to power sensors to monitor the location of freight trains without electricity aboard, and to monitor the load on rotating helicopter blades that can't be otherwise tracked for preventive maintenance savings.

The much hyped Internet of Things will need smaller-scale energy harvesting solutions to power its wireless networks of sensor nodes, but so far the technology remains too expensive and too unreliable for practical application. We project that the first real IoT applications are likely to be the same applications where energy harvesting is now starting to make economic sense—building automation and industrial or environmental monitoring.

www.yole.fr

Antoine Bonnabel, works as market analyst for MEMS devices and technologies at Yole Développement. He holds a M.Sc. in microelectronics and microsystems from Grenoble Institute of Technologies and a M.Sc. in marketing and business management from Grenoble Graduate School of Business.

Yann de Charentenay was granted a master degree in physics in INPG in Grenoble and also in Innovation management from Compiegne University. Since 2003, he has worked for Yole Development in the field of MEMS, materials and compound semiconductors. He has contributed to more than 60 marketing and technological analysis.

WHAT'S INSIDE

FLIR microbolometer ISC0601B and the i7 thermal imaging camera

FLIR, the world leader in thermal imaging cameras, continues to reduce the price of its low-end camera and microbolometer.

Sylvain Hallereau,
Project Manager,
System Plus Consulting

With new environmental standards placed on the thermal insulation of buildings, the sale of thermal cameras for diagnostics has risen sharply. The increase in production volumes and the development of low-cost solutions has enabled the market arrival of low-end cameras costing less than 1,000€. Compared to a cost of over $10,000 several years ago, thermal cameras are becoming more and more affordable, and the desire to reduce cost for the adoption of thermal cameras in large-volume applications such as security and automotive is at the heart of every manufacturer's strategy.

i7 Camera teardown
(Courtesy of System Plus Consulting)

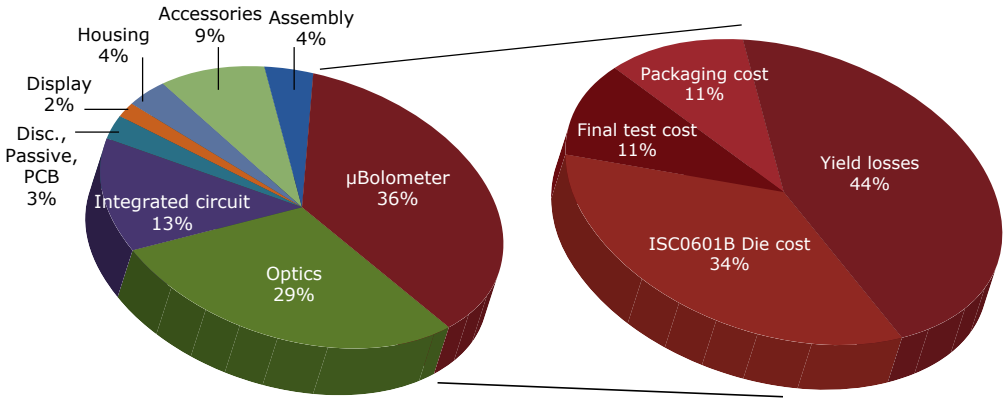
The camera family i3, i5 and i7 from FLIR is emblematic of effective cost reduction. The three cameras are nearly identical, which makes cost reduction easier. Mechanical parts, electronic boards and even the microbolometer sensors are similar; only the optic in GASIR changes. The electronic is designed around a PXA270 processor, an FPGA, and 512Mbit of SDRAM and 256Mbit of flash memory. The presence of an FPGA suggests that there is still room for integration of the electronics. The decision to describe one camera under three different names implies that the cost of a low-end camera is still impacted by technologic choices made for high-end cameras.

The main component of the camera, the microbolometer ISC0601A, has never been used before for this range of camera. The cameras i3, i5 and i7 have, respectively, a definition of 60 x 60 pixels, 80 x 80 pixels and 140 x 140 pixels. But the sensor itself has a definition of 320 x 240 pixels. The sensor used in the i3 has 20 times more pixels than necessary, and four times more pixels than the i7. Incidentally, the same sensor can be used in more expensive cameras. The extremely high cost of developing a microbolometer explains FLIR's decision to develop a limited number of sensors, and use downgraded sensors in low-cost cameras.

As shown in the i7's cost breakdown, the microbolometer is the most expensive element of the camera, representing 36% of the manufacturing cost.

ISC0601A microbolometer

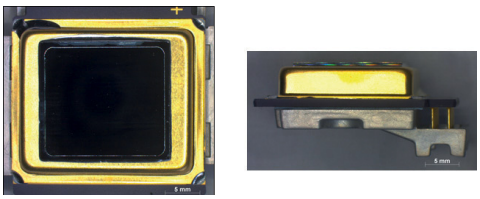
The microbolometer is encapsulated in a hermetic housing consisting of a ceramic substrate HTCC, a metal box and an IR window in silicon. The microbolometers operate under a high vacuum, 10-4mbar, 100 times lower than for a MEMS gyroscope. The final test integrates an expensive four-day leak test to guarantee package tightness.



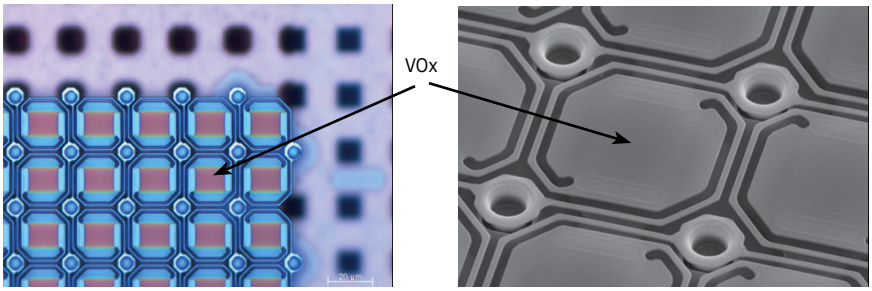
i7 Camera cost breakdown (Courtesy of System Plus Consulting)

Each pixel is composed of a thin resistance in vanadium oxide (VOx) covered with an absorber in silicon oxide which absorbs the infrared ray. The temperature of the SiO2 layer is proportional to the temperature of the IR radiation, and the value of the resistance VOx is proportional to the temperature of the absorber. A measurement of the resistance provides the temperature. For maximum operating frequency, the thermal mass must be minimized. This is achieved by suspending the VOx resistors and the absorber on a micro-bridge. The read-out electronic is manufactured on the silicon substrate before the micro-bridges; therefore, it is under the micro-bridges.

It is the production of these micro-bridges with very thin layers deposited on a sacrificial organic material that makes manufacturing microbolometers extremely complex and expensive. The deposition steps are very slow because of the low temperature used.



Microbolometer ISC0601A package (Courtesy of System Plus Consulting)



Pictures of the micro-bridge with the VOx resistor - Optic and SEM views (Courtesy of System Plus Consulting)

Supply chain and cost structure

Initially manufactured internally on 150mm wafers, FLIR microbolometers have since 2006 been manufactured by ON Semiconductor on 200mm wafers. The transition to 200mm and the outsourcing of production to a large-capacity foundry has reduced manufacturing costs.

Today, the manufacturing cost is still high, due to a low yield and a low production volume: 100,000 units for Thermography in 2011 (source : Yole Développement)..

www.systemplus.fr

Sylvain Hallereau,
Project Manager,
System Plus Consulting
Sylvain is in charge of costing analysis of Integrated Circuits, Power Semiconductors and Packaging. He has significant experience in the modeling of the manufacturing costs of electronics components. Sylvain has a master's degree in Microelectronics from the University of Nantes, France.

NF-Shuttle: Standardizing the fabless MEMS Industry

The standard process aims to bring turnkey CMOS manufacturing benefits to MEMS designers. The highly recognized success of the fabless semiconductor industry has stemmed from the standardization of CMOS processes. Rapid development times based on well-developed design infrastructure and tools are further supported by low-cost manufacturing and virtually inexhaustible capacity. In addition, the standardization of semiconductors has triggered economies of scale for both packaging and test, which translate into a lower cost of finished products.

In order for the MEMS industry to replicate the success of the CMOS fabless model, there is a need for a similar standardized process technology. This paper will describe the challenges for MEMS standardization, and introduce the patented Nasiri-Fabrication (NF) Platform as the most effective way to overcome them. Attributes of the NF Platform and its benefits are also highlighted.

Challenges to MEMS standardization

MEMS commercialization has largely stayed with a one product, one process paradigm. Most MEMS devices require unique fabrication development and product-specific parameters that are not transferable to other MEMS products. To become a viable MEMS fabrication platform, processes must meet the fabrication requirements for a very wide array of MEMS products and applications. The MEMS platform should effectively address the widely-accepted difficulties for MEMS developers including long and costly custom process development, complicated and sub-optimum electronic integration, custom packaging processes and test procedures whose combined costs can exceed 50% of the total cost.

Nasiri Fabrication Platform – A solution for MEMS standardization

InvenSense's proprietary NF Platform is based on integrated CMOS-MEMS as shown in Figure 1. The innovative NF Platform, with years of optimization, has proven to be a highly-reliable, manufacturable, and low-cost process, and is currently in production at the top two leading tier-one semiconductor foundries.

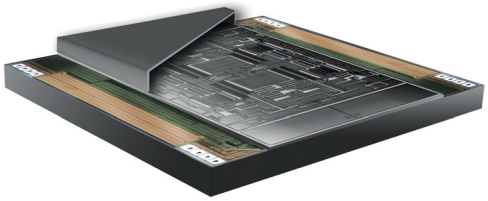


Fig 2: NF Platform integrated CMOS-MEMS device. (Courtesy of InvenSense)

The NF Platform provides on-chip MEMS integration with CMOS circuits. The CMOS area for the device can be used for signal conditioning, analog to digital conversion, filtering, or other sophisticated functionsincluding microprocessors, FIFOs, memories and others. MEMS devices built on the NF Platform tend to be highly integrated System On Chip (SOC), or "smart sensors."

The NF Platform is the first MEMS fabrication process that allows for the integration of MEMS and CMOS with no interdependency on either the CMOS technology or MEMS technology. Each wafer is fabricated separately using the appropriate optimized process. The MEMS and CMOS wafers are bonded together using a patented, low-

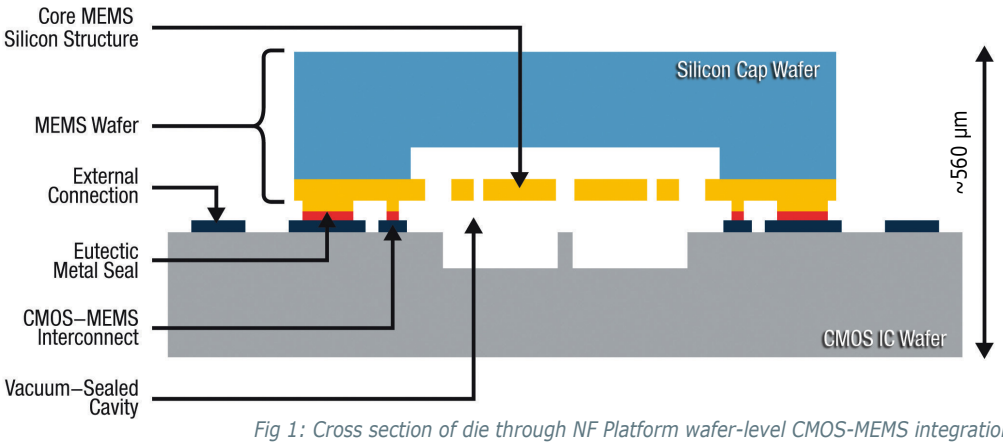


Fig 1: Cross section of die through NF Platform wafer-level CMOS-MEMS integration. (Courtesy of InvenSense)

temperature eutectic bonding process. This bond produces wafers with hermetically sealed and electrically interconnected self-contained die that may be treated, processed, and packaged like standard CMOS wafers (Figure 2).

NF Platform benefits

The NF Platform has three major benefits leading to successful commercialization; faster development time, low cost, and fast production ramp up.

1. Faster development time

The versatility and simplicity of the NF Platform enables designers to focus on disruptive designs and applications vs. laboring on costly process development. Developers can readily design using predictable properties of single crystal silicon and interface with necessary electronics to build a complete MEMS system. Historically, it has taken twenty-five years or more for a MEMS device to mature from initial proof of concept to high-volume production for the consumer market. The NF Platform not only eliminates lengthy process development, but its single-chip solution circumvents any packaging development. In contrast, MEMS to electronics integration traditionally has been done with a two-chip solution.

2. Low cost product

The NF Platform and its inherent wafer-level integration of electronics and hermetic sealing address two major cost components, namely packaging and testing. Since the MEMS structures are hermetically sealed, and therefore protected, with contact pads exposed (Figure 3), the wafer may be treated as a normal CMOS wafer, without the need for special handling during further processing (e.g. dicing or grinding).

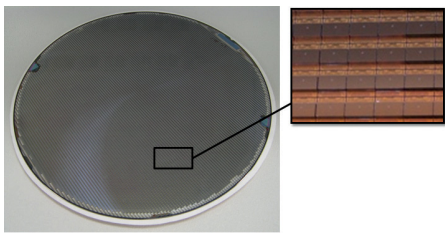


Fig 3: Completed 8" CMOS-MEMS wafer using the NF Platform. The inset shows a close-up of the die with exposed wire-bond pads. (Courtesy of InvenSense)

The wafer-level encapsulation protects each MEMS component and enables standard backend processes including lowest cost Quad Flat No-lead, QFN, plastic molded packages. Further cost improvement is achieved through wafer-level testing. The CMOS-MEMS wafer-level integration transforms a traditional MEMS die and supporting CMOS electronics die into an integrated system.

3. Fast production ramp and high volume capacity

The entire NF process is CMOS compatible and is sufficiently simple for CMOS manufacturers to embrace. For this reason, it is very attractive to Tier 1 CMOS foundries as they can leverage their existing infrastructure and modify it to accommodate a wide range of MEMS designs. The same benefits that these foundries provide to their CMOS users, including great process control, high yield, high-volume capability, predictable and reliable delivery, are now provided to their MEMS customers.

Access to NF Platform expansion through NF Shuttle Program

The availability of the NF platform to outside users was initially announced with the NF-Shuttle service in May 2012. The NF-Shuttle apportions costs amongst multiple users as they can purchase "seats" on the same mask set. This approach reduces upfront development costs for participants to a fraction of the total, providing a greater opportunity to verify advanced designs and prototypes in silicon. The designs are run on multi-user wafers using the NF Platform at the same foundries used for InvenSense production, thereby assuring users that their designs will run on a stable and reliable process every time. The program is open to qualified MEMS device developers from commercial companies as well as from the research community. For the MEMS industry, the NF-Shuttle opens the opportunity for bringing additional MEMS innovations to the market at increased speed due to shorter development cycles and lower development costs.

Interested companies and research institutions are encouraged to contact InvenSense as soon as possible. There are no open seats on the December 2012 shuttle run. The next available shuttle has a tape-out scheduled for May 2013.

For the complete whitepaper or for more information, please visit the NF-Shuttle website at www.invensense.com/nfshuttle, or contact InvenSense by e-mail at nfshuttle@invensense.com

Martin Lim joined InvenSense in 2004 as a founder and the Director of MEMS Fabrication. He has been responsible for the development activities and technology transfer of the Nasiri-Fabrication to foundries. Mr. Lim has over 20 years of experience in fabrication and process development for various MEMS devices. Prior to InvenSense, he was the Director of Engineering at SiTek, developing silicon MEMS gyros. He also served as Chief Technical Officer of OpticNet, an Optical MEMS startup, where he patented, manufactured, and licensed a bi-stable optical switch for telecommunications. He held a research staff position at Xerox Palo Alto Research Center, where he was the project leader for the fabrication of a novel acoustic inkjet print head. Mr. Lim earned MS and BS degrees in Mechanical Engineering from the University of California at Berkeley and has been awarded 14 U.S. Patents.

Fari Assaderaghi has more than 18 years of experience in high-performance, mixed-signal design and development. His areas of expertise span semiconductor device physics, process integration, mixed-signal design and MEMS. Prior to joining InvenSense, he served as Sr. VP of Engineering and Operations at SiTime. Prior to that, he worked at Rambus as Sr. Director of Engineering, developing high-speed communication circuits for Sony's PlayStation3 and TI's digital light processing. He has also held senior management positions at IBM research and Siliconwave, a company that developed Bluetooth solutions for wireless communications. Assaderaghi received his B.S. in electrical engineering from SDSU, graduating summa cum laude and university valedictorian. He earned his MS and Ph.D. degrees in electrical engineering from UC Berkeley. He holds over 50 patents and has had articles and papers appear in approximately 100 publications.

Mike Daneman, Manager of MEMS Fabrication, InvenSense Advanced Technology group.
Mike was one of the early employees at Silicon Light Machines working on MEMS grating light valves and then went on to co-found Onix Microsystems in 1999 developing MEMS optical switches for the Telecommunications Industry. Mike joined InvenSense in 2007 and has since worked in Product Development, Fabrication, and Advanced Development groups. He has also been managing the InvenSense NF Shuttle program since its inception in early 2011.

EVENTS REVIEW

Bretzel, beer and MEMS technology at Semicon Europa 2012!

Held in Dresden, Semicon Europa is known as the major European semiconductor trade show. MEMS is a topic of increasing interest, and each year a MEMS forum is part of the conference program. This year the forum once again attracted many industry leaders…

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

As the MEMS industry is currently driven by mobile applications, it was only natural to have the leading consumer MEMS manufacturers share their views on the industry's evolution. Greg Galvin, CEO of Kionix, highlighted the big drivers that are shaping MEMS: mobility, interconnected devices and self-aware devices. In a keynote given by Leopold Beer, Bosch Sensortec highlighted the major trends for each motion sensor.

Outside of the well-known mobile devices & gaming applications, other promising markets such as white goods and logistics were discussed. However, these large, unrealized markets require close collaboration between different players in order to be enabled; it's different than the smartphone area, where application developers can easily benefit from sensors. Bosch even proposed development of a "network and service framework" that could be supported by European players (which are actually MEMS leaders).

ST, now producing more than four Million MEMS sensors per day, gave a visionary presentation focused mostly on audio MEMS developments. We learned that outside of microphone developments, ST has smart solutions on the roadmap, such as a bionic ear which combines microphones and speakers. We also learned that ST is evaluating microspeaker technology, such as Audiopixel one.

New types of MEMS products were also spotlighted. Indeed, Jeffrey Hillbert unveiled Wispry's next tuner products; the company now numbers 45 employees. SiTime is another leader in the Silicon MEMS timing area, and it was impressive to hear that zero MEMS failure occurred in the 120M units already shipped to the market. Sand 9, another MEMS timing start-up, unveiled for the first time its foundry partners, and disclosed more details on the resonator technology, which is based on piezo-electric thin-film. Knowles talked about a new MEMS product as well – namely, the MEMS joystick -- and shared details on the technology, including the front-end manufacturing and assembly sides.

But the focus was not solely on consumer applications; both Freescale and Continental reminded us that automotive is still a key application for MEMS technology. Megatrends were developed: Mobility, Cleaner, Safety, Connected, and Intelligent driving. It is clear that significant changes can be expected in this area as well. In particular, the supply chain can be modified, as Continental is now integrating MEMS bare die on its own platform to build modular systems and gain flexibility. Data fusion will also be critical for future solutions.

There were many visionary presentations discussing MEMS' future, but insights on technology challenges were also part of this extensive program. In particular, System Plus Consulting gave an interesting analysis on the different generations of accelerometer and gyroscope technology at STMicroelectronics to reduce sensor size both at the sensing frame level and at the sealing area level. Other presentations focused on various manufacturing evolutions, such as the development of CMOS-MEMS technology at Baolab. A market review closed this latest MEMS forum, and included a market-oriented presentation from Yole Développement.

After such a successful conference, the 2013 edition promises to be even bigger and better!

Laurent Robin during his presentation at SEMICON Europa (Courtesy of SEMICON Europa)

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Come and visit the leading European exposition for microelectronics manufacturing with an expanding focus on growing markets including MEMS, printed/flexible electronics, solid state lighting and related technologies. Participate in the high-class conferences at SEMICON Europa 2013 from 8-10 October, 2013 in Dresden/Germany.

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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- Technology analysis
- Reverse engineering and reverse costing
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- Corporate Finance Advisory (M&A and fund raising)

TECHNOLOGY & MARKET REPORTS

- Collection of reports
- 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
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CONTACTS

For more information about:

- Services: Jean-Christophe Eloy (eloy@yole.fr)
- Reports: David Jourdan (jourdan@yole.fr)
- Media: Sandrine Leroy (leroy@yole.fr)

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