

The newsletter covering the frontiers of MEMS, optronics and nanotechnology

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Taking the Pulse of the MEMS Industry

WTC has recently taken the pulse of the MEMS industry to answer the question: just how healthy is the industry? Over the period of February to March 2007 wtc carried out a global bottom-up survey of the top 60 MEMS companies, examining for each company the current MEMS revenues, products, applications and views on the ma-

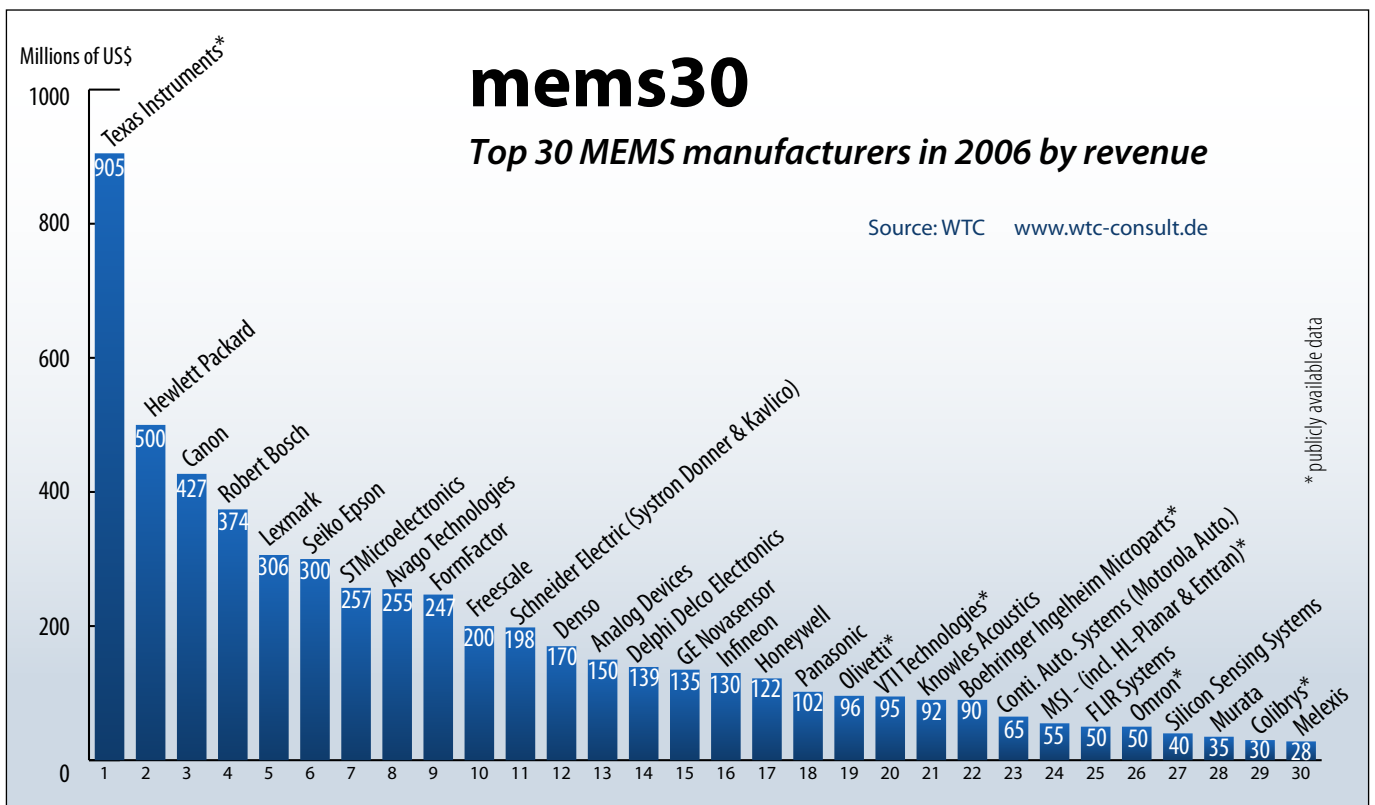
major changes taking place in the industry.

This article showcases the major findings from the survey. Key features are the two rankings, *mems30* and *mems10 foundries*, and the total 2006 market based on shipments.

Texas Instruments still leads the pack by a big margin with its DLP chips. TI established a new record in

2006 with turnover of \$905m. Following a 8% dip in revenues in 2005, its DLP revenue was up 15% last year. The company’s front projector business remains the main revenue driver. However, wtc expects that its tv business will continue to suffer from LCD and plasma competition.

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Microsystem News



Jérémie Bouchaud
Head of market
research

Pepsi or Coke? It's nice to have the choice and many people taste the difference. The same goes in MEMS market analysis, and we are happy to play the role of Pepsi. Only one MEMS ranking has been published in recent years, at the hands of our competitor. Revenue rankings are interesting tools to take the pulse of an industry, even if they don't report profitability. The available MEMS ranking was a good basis, but we did not agree with some of the results.

Worthy companies such as FLIR SYSTEMS, MSI and FormFactor were overlooked. In addition, MEMS revenue for some companies like Avago were largely underestimated, while in other cases, figures were inflated with non MEMS products like at Omron.

We now proudly present our own **mems30** and **mems10 foundries** rankings along with some keys for correctly interpreting them. We released our figures 10 days ago and have already received a lot of feedback, suggesting the industry currently enjoys Pepsi. Don't miss the FAQ page 10. Also it seems that Coke has had to change its formula in response on Omron, and added MSI and FormFactor to its previous rankings, following the publishing of our mems30. Enjoy this issue of ThinkSmall and taste the difference!

Jérémie Bouchaud

Tronics expands its downstream offer

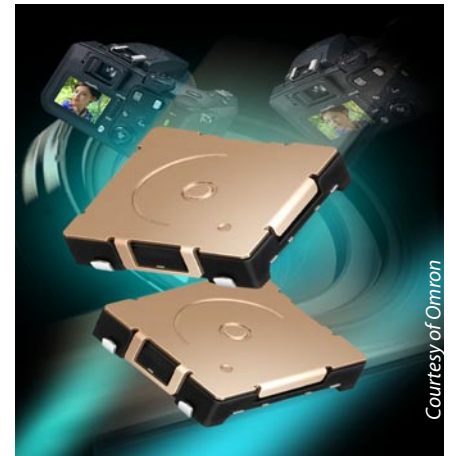
Tronics Microsystems has expanded characterization, assembly, packaging and testing capabilities at its Crolles headquarters in France, further supporting its design-to-manufacturing model and support for the entire supply chain. With additional space and new tools, this represents the second expansion inside a year. Last year saw Tronics add MEMS design and electronic interfacing of MEMS components, in addition to an upgrade to 150 mm wafer technology. Tronics will partner with subcontractors to provide all components required in medical, life sciences, instrumentation and aerospace.

WTC comment: Tronics has an original growth strategy. While Silex, Micralyne, Dalsa, APM, IMT, and others provide wafers and bet on growth in wafer shipments, Tronics is climbing the value chain to increase its revenues and customer loyalty. The company now takes responsibility for product development and production, and has developed competences in electronic interfacing to allow selection of ASIC subcontractors. While this is not a general MEMS foundry trend, we believe this strategy makes sense in the high value markets in which Tronics specializes.

Inertial sensor news

Omron has unveiled a PCB mounting tilt sensor based on a Hall-effect IC. The assymetric output allows determination of tilt direction and also left and right orientation. The D6BN-1 has an activation angle of between 40° and 80° in either direction, and operates with a power consumption of 10 μ A. The

realization of the design in as a single Hall effect IC replaces two devices in previous tilt sensors and lowers the cost.



Hall IC tilt sensor knows its left from right

DoCoMo, Japan's biggest wireless operator with 54% of Japan's mobile phone users, unveiled a new mobile phone equipped with a motion sensor, that lets users play games like in the popular Nintendo Wii console. With DoCoMo's D904i, made by Mitsubishi Electric, users can swing the handset like a tennis racket or wield it like a sword to control game play, instead of punching on the keypad.

WTC comment: Worth noticing, on the same day it unveiled the motion sensing phone, DoCoMo also released two other phones that use a camera to detect motion. This is an alternative approach to MEMS, which avoids having to add additional hardware in the phone. Nokia is also investigating use of cameras for additional functionalities, such as augmented reality in the MARA project.

Also, Omron's sensor uses a hall effect IC and not a MEMS accelerometer as tilt sensor. These pieces of news show that MEMS manufacturers should keep an eye on competing technologies for motion sensing in consumer products.

Microsystem News

MEMS microphones from Yamaha and MEMSTech

Yamaha recently entered the microphone fray with sample shipments of analog MEMS microphones designed for consumer applications. The YAM551 and YAM552 measure 4.3 mm × 3.4 mm × 1.28 mm thick. The devices deliver sensitivity of 42 dBV/Pa and S/N ratio of 55 dB measured at 1 kHz. The YAM552 features an amplifier and offers a gain of 20 dB. Samples are priced at \$1.80.

MEMSTech has won a contract to supply 10 million digital silicon microphones per month to a large US multinational for mobile phones and two-way radios. Starting this year, the deal is expected to be worth \$40 million in annual revenues. The microphones will be designed and developed by the group's SensFab subsidiary in Singapore, and packaged by Senzpak. A \$7.2 million MEMS innovation centre will be set up in Bayan Lepas, Penang to conduct development work, which includes other mobile telecommunication products.

WTC comment: New players are hoping to join Knowles, Infineon et al in supplying this fast growing market. We estimate the market was \$100 million in 2006 and will hit \$350 million by 2010, largely driven by mobile phones, automotive applications and laptops—a market focus of Akustica. The latter has teamed with Microsoft and its new Vista operating system to provide digital microphones for improved voice quality and directionality. Early adopters include the likes of Fujitsu and TabletKiosk.

More information is available in WTC custom market workshop #2 on MEMS microphones (see page 4 or www.wtc-consult.de/workshops for details).

Discera MEMS oscillators displace quartz for telemetry

M/A-COM has qualified **Discera's** MEMS oscillator for use in telemetry transmitters, replacing quartz crystals as the timing components. The MOS1 series passed military grade muster, including being shot from an air gun. The reliability and high shock resistance (up to 100,000 g) indicate that MEMS resonators are ready for the rigors of consumer electronics products, says Discera. Also to report: a CTO voted by EE times as Innovator of the Year, a cash injection of \$17.5 million and a savvy alliance with frequency control supplier Abracon.

WTC comment: Last year, consumer markets were addressed by MEMS oscillator's start-ups, betting on the competitiveness of small components with relaxed specifications. Defence markets are also interesting for MEMS oscillators, where advantage is lent by higher reliability in harsh environments compared to quartz. Discera took the initial step with Vectron last November, covering telecom infrastructure, aerospace and defence, and automotive sectors. Meanwhile European aerospace company EADS is similarly involved in the European project NanoTimer, investigating potential military applications of MEMS oscillators.

Silicon Clocks is another company exiting stealth mode. It recently signed sales and distribution agreements with six partners worldwide. It also strengthens its team by hiring new staff with strong industry backgrounds, e.g. a new VP of engineering from TI and VP of marketing from Pericom. There has been progress on the technical side, too. Silicon Clocks recently demonstrated a multiple-MEMS resonator in a single die. The path is always long from demonstrator to serial product, especially multiple

resonators on a single die. Achieving sufficient yield will be the issue. But this breakthrough is worth mentioning; we believe that the capacity for integrating multi-frequency operation on the same chip is one of the greatest advantages of MEMS over quartz oscillators.

RF MEMS news

EPCOS has unveiled first prototypes of an FBAR-SAW hybrid duplexer targeting W-CDMA Band II applications in mobile communications. The LSO6 has the advantage of a single component with high power and low insertion loss combined with the miniaturization and simple impedance and signal conversion of SAW technology.

WTC Comment: The SAW filter has not completely lost the battle against FBAR for duplexers. Major



The hybrid FBAR-SAW duplexer is 3 mm × 2.5 mm and is 1.1 mm thick (courtesy EPCOS)

breakthroughs in temperature compensation and power handling took place last year at Murata and Fujitsu. This again reinforces this technology as a tough competitor for FBAR even in the PCS band (above 1850 MHz).

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Today, only EPCOS can combine the best of both technologies, since its two existing competitors Avago (#1) and

Microsystem News

Infineon (#2) originate from the silicon side and do not have SAW experience. By contrast, **FBAR** new comers **Fujitsu**, **Triquint**, **Skyworks** and probably **Murata** are all grounded in SAW technology and will likely be able to follow suit with similar hybrid approaches (more details in custom workshop 3).

Delphi just spun-out a new antenna company called Monarch Antenna, which will commercialize innovative Self-Structuring Antenna (SSA) technology developed by Delphi and Michigan State University. Monarch develops an integrated two-way communication antenna solution for a multitude of services such as Cellular, Bluetooth, Wi-Fi, and WiMax for a wide range of applications including laptops, home entertainment systems, computers, routers, military networks,

cell phones, consumer products, and automotive. The company announced that its antenna technology could make use of *RF MEMS* switches in applications beyond 24 GHz.

WTC comments: The architecture proposed by Monarch is very interesting, because it allows antenna parameters to adapt (e.g. gain, bandwidth and directivity), according to signal conditions by means of changing the state of several switches. This potentially offers more degrees of freedom than conventional phased array antennas. WTC believes the Delphi's spin-off can make best use of RF MEMS switches in applications such as automotive radar at 77 GHz, 60 GHz WLAN, and military networks.

Drug delivery news

Debiotech and **STMicroelectronics** will cooperate on microfluidic-based insulin delivery pumps integrated into a disposable skin patch. Existing insulin pumps are about the size of a pager, but the patches, which are about one quarter in size, promise continuous insulin therapy as an attractive alternative to insulin injections administered several times a day. A product is expected to hit selected markets in 2008.

MicroCHIPS has received a \$13.4 million financial injection from a group of investors led by Novartis Venture Fund to continue development of implantable biosensing and drug delivery devices targeting therapeutic control for those suffering from diabetes, osteoporosis and cardiovascular diseases.

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WTC launches custom market workshops on emerging MEMS

Identify opportunities for your company, whatever its position in the supply chain

Workshops:

1. Inertial & magnetic MEMS sensors for consumer electronics
2. MEMS microphones and micro-speakers
3. RF MEMS
4. MEMS oscillators
5. MEMS-based displays
6. Micro autofocus and zoom
7. Micro energy sources and micro energy scavengers
- 8. MEMS industry 2007 - 2011: Status, trends and strategies**



More information at www.wtc-consult.de/workshops or contact jeremie.bouchaud@wtc-consult.de



What's in it for you?

- ▶ Get focused, up-to-the minute market information relevant to your business
- ▶ Obtain answers to the marketing and technical questions you have
- ▶ Gain insights in emerging market for your company
- ▶ Save time and money in evaluation new opportunities

Microsystem News

Apogee Technology has signed a license agreement with Georgia Tech Research Corporation for exclusive know-how on micro-needle drug delivery systems. Georgia Tech's technology will increase the drug dose of Apogee's current PyraDerm™ platform, says the company.

New inkjet arrays

Australian company **Silverbrook Research** has spent the last 10 years developing Memjet, a printer that uses an array of ink jet nozzles that span the width of the paper. This allows print speeds up to 60 pages a minute. Company plans

include shipping an 8 × 10 colour inkjet for under \$200 by the end of 2008.

Silverbrook's Memjet technology uses a series of individual MEMS inkjet nozzles; each chip measures 20 mm across and contains 6,400 nozzles. To protect itself in the highly aggressive market, Silverbrook itself has filed 1,500 patents.

HP also revealed product plans for page-wide printheads. Contrary to Memjet, HP is targeting professional and industrial printing and not the SOHO (Small Office Home Office) mass market. The heads are already used in HP Photosmart Express retail photo kiosks, that deliver fast prints of

digital photos, and the HP Photosmart pm1000 Microlab printer (\$11,990).

WTC comment: Things are moving in the inkjet area. Following the recent move by Kodak into the SOHO market (see previous issue), the Memjet from Silverbrook is also going after SOHO. This is another threat to the big four HP, Seiko, Lexmark and Canon. Also worth clearing up is an article on the internet which reported that TSMC will manufacture the Memjet printheads. We believe it is a misunderstanding. According to our insider source, another Taiwanese MEMS foundry will manufacture the Memjet printhead, whereas TSMC will provide the CMOS wafers. ■

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Photovoltaic News

Applied Materials exploits Gen 8.5 FPD technology for solar

Within the last two months, **Applied Materials** has sold three production lines for large area, thin-film silicon cells. The lines of Applied Materials run with 5.7 m² (2.2×2.6 m²) glass panels, which correspond to the Gen 8.5 factories in flat-panel displays.

T-Solar Global S.A. is building a 40 MW plant for a-Si cells in Ourense, Spain. Production is slated to start mid 2008. The investment is €75m.

Moser Baer, headquartered in New Delhi, India, has also acquired a line with a 40MW capacity for a-Si cells, to be delivered in the second half of 2007. The total investment in the facility is \$200m over three years. Moser Baer has a plan to scale to 200 MW by 2009. Moser Baer, a leading manufacturer of optical media, recently entered the solar energy business by getting a 40 MW wafer-based cell factory.

Sunfilm AG in Großröhrsdorf (about 40 km from Dresden, Germany) has announced a plant with a capacity of 60 MW for tandem cells (amorphous and microcrystalline silicon). The company was founded in April 2007 as a joint-venture between the American-Dutch-Swiss solar investment company, Good Energies, and the Norwegian producer of monocrystalline wafers Norsun. The line is being designed and built with financial support from several local institutions including the Land of Saxony. Sunfilm plans to start manufacturing in 2008 or 2009.

WTC comment: the emergence of Moser Baer as a cell supplier should not be a surprise since large-scale CD/DVD manufacturing shares some striking similarities with cell manufacturing.

SolarWorld plans 500 MW cell factory in the US

SolarWorld has bought for €30m a silicon wafer production plant in Hillsboro, Oregon, USA. The plant was previously owned by Komatsu. With the support of the state of Oregon, SolarWorld will invest €300m in the facility to make it an integrated cell manufacturing plant.



SolarWorld facility in Hillsboro

WTC comment: the Komatsu wafer factory, located close to its intended main customer Intel, actually failed to find its market. Now it is poised to become the largest solar cell factory in the US, right next to the largest Intel factory in the US.

Silpro to start polysilicon production in France by end 2008

The newly-founded Silicium de Provence (**SILPRO**) SAS, located in Saint Auban, France, is dedicated to the production of high-purity solar-grade polysilicon. Production should start by the end of 2008 with an initial capacity of 3000 t per year. The plant could be extended to 7500 t.

As Silpro will exploit the Siemens process, which uses chlorosilane, the proximity of a chemical plant from the Arkema group was a major factor in choosing the location. The Arkema plant will provide purified hydrogen

chloride (HCl) and hydrogen. **SILPRO's** project also includes the construction of a chlorosilane plant by Degussa.

Silicium de Provence is a joint venture between the French **Photon Power Technologies (PPT)** created for this project, **SOL Holding** and the Norwegian producer of monocrystalline wafer **Norsun**. SOL Holding itself is a joint venture between the Dutch company **Ecoconcern** and the German module manufacturer **SOLON**. The total investment in Silicium de Provence will be about €300m.

Kyocera invests €175m to double capacity by 2011

Kyocera has unveiled its plans for expanding its production capacity in solar cell and module. The company will invest ¥20bn (about €125m) in its Yohkaichi plant in Japan, which produces cells for the other facilities in the group. The plant is expected to increase capacity to 500 MW by 2011. Regarding modules, Kyocera will invest in all its existing plants:

- ¥4bn (about €25m) in Mexico to increase the capacity from 35MW to 150 MW by 2008
- ¥4bn (about €25m) in the Czech Republic to increase the capacity to 150 MW by 2011
- ¥1bn (about €6m) in China to increase the capacity to 90 MW by 2011
- ¥1bn (about €6m) in Japan (Ise) to get the capacity to 110 MW by 2011

WTC comment: Kyocera's plan looks ambitious, but given the expected rise of several multi-100 MW facilities by 2010, it may actually be barely enough to keep them in the top three cell manufacturers of 2011.

Photovoltaic News

Massey University develops new organic dyes for DSSC

Dr. Campbell and his team from the Nanomaterials Research Centre of Massey University in Wellington, New Zealand, have developed a range of organic dyes for use in dye-sensitised solar cells (DSSC). The dyes are derived from natural compounds: e.g. synthetic chlorophyll for the green dye, haemoglobin for the red, porphyrin for the purple. The two main advantages of DSSC are the production cost (estimated by the university at one tenth of a silicon cell) and the fact that the cells do not need direct exposure to work well. Currently only a proof-of-concept cell has been made but Dr. Campbell estimates that the first prototype could be ready in 2–3 years.

WTC comment: According to the university, the dyes mark a breakthrough in DSSC efficiency but no hard numbers were given. The lifetime of the cells is likely to remain problematic, but at this stage of the development is obviously not a major concern. DSSC uses titanium dioxide nanoparticles coated with dyes. Titanium dioxide could be produced from ilmenite which is abundant in New Zealand, hence the interest of the country for these type of cells.

New PV research centre in Halle, Germany

The two Fraunhofer institutes IWM (Institute for Material Mechanics) and ISE (Institute for Solar Energy Systems) are establishing in Halle the Center for Silicon Photovoltaics. The CSP will be a R&D centre focused on:

- material analysis and crystallisation of silicon for photovoltaics
- integration of solar modules
- later on thin-film.

The Fraunhofer Gesellschaft and the Land of Saxony-Anhalt have committed €60m over three years for the foundation of the centre.

PV manufacturing in China

WTC had the opportunity to interview with Frank Haugwitz, Technical Adviser for Renewable Energies of the German Technical Cooperation (GTZ), who was in post in China. Here are some excerpts from the interview.

WTC: Are there any solar valleys in China? Where are they?

Frank Haugwitz (FH): The PV production is concentrated mostly in the Shanghai and Jiangsu areas, with also some activities in Beijing (Yn-

gli) and Hebei. Silicon production is in West Henan and Sichuan.

WTC: What are the advantages of setting up the manufacturing of PV products in China?

FH: Buildings can be made extremely cheap. Electricity prices are very low. Depending on the province and zone, there are possible tax breaks.

WTC: And what are the drawbacks?

FH: Chinese managers have understood that quality is the key to successful development. They are having their companies undergo certifications. However the culture of quality has not propagated to the workers yet. The land can only be rented and remains the property of the state (this rules applies to all, private and corporate). ■

Solar Cells Manufacturers Database

Facts and figures

For each manufacturer in the database, you get its:

- Cell technology, partners and investors
- Production capacity in 2006, 2007, 2008
- Production status
- Investment flow
- Address of manufacturing site and contact person
- Reach over the value chain

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For example if you are thinking of:

- Studying the profile and distribution of cell manufacturers
- Evaluating the potential for an equipment, material or service
- Getting a wide-angle view of the industry players

You will appreciate the time and effort our database can save in getting you started.

The database including one year subscription to the updates (three quarterly updates) is available for 1100 € excluding taxes.

For inquiries, please contact Katja Brodmann at: katja.brodmann@wtc-consult.de
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Nanotechnology News

Merger fosters commercialization of products that use carbon nanotubes

Carbon nanotubes producers, **Carbon Nanotechnologies, Inc.** (CNI) and **Unidym, Inc.**, that are developing carbon-based materials, processes, and devices for the electronics industry, announced that they have entered into a definitive agreement to merge the two companies. The combined company will operate under the name Unidym, and be headquartered in Menlo Park, California. It is planned to integrate CNI's carbon nanotube manufacturing capabilities into Unidym's ongoing development of transparent, conductive films.

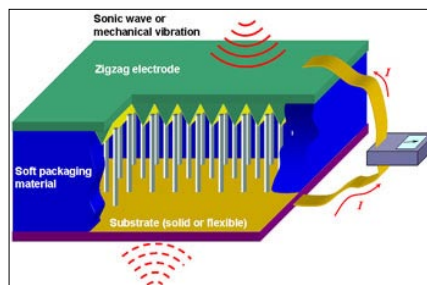
WTC comment: Bringing together complementary partners — a start-up with extraordinary intellectual properties, and a device manufacturer who is launching first nanotube-enabled products — this kind of vertical integration can push the commercialization of nanotechnology.

Nano energy news

Researchers at the **Georgia Institute of Technology** have demonstrated a prototype nanometer-scale generator that produces continuous direct-current electricity by harvesting mechanical energy from such environmental sources as ultrasonic waves, mechanical vibration or blood flow. The device consists of an array of vertically-aligned zinc oxide nanowires, sandwiched in between a solid or flexible substrate (e.g. gallium arsenide, sapphire, polymer) and a silicon "zig-zag" electrode.

Due to their unique coupled piezoelectric and semiconducting properties, zinc oxide nanostructures produce small electrical potentials when they

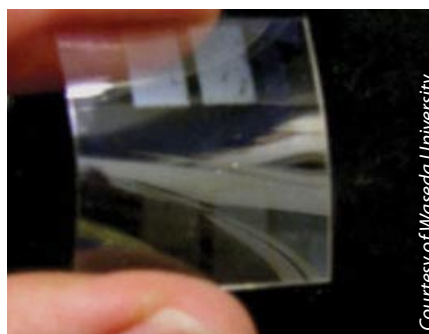
are flexed. Being exposed to external vibrations, the nanowires periodically make contact with the electrode, and transfer the charges accumulated due to flex, thereby transforming mechani-



Nano energy converter (vibration/waves to DC)

cal energy into an electric current. The current prototype produces an output in the nano-Ampere range. Further optimisation could enable outputs of up to 4 W/cm^3 , opening up potential defense, environmental and biomedical applications.

Japanese scientists at **Waseda University** have developed a flexible, rechargeable battery. The organic-based, paper-like device has an electrode made from a redox-active, organic polymer film about 200 nm thick.



Flexible organic battery

Nitroxide radical groups in the polymer film act as charge carriers. High charge/discharge capacity, high power rate performance and long cycle life are the main advantages the 'organic radical' battery has over other organic-based materials. In the future, these bat-

teries may be used in applications that require high-power capability rather than high-energy density, such as motor drive assistance in electric vehicles.

Researchers at **Delft University of Technology** can now predict the performance of nano-based Li-ion batteries. Shortening the distance ions have to travel within the electrode material, and thereby enhancing charge and discharge speeds, the nanostructuring of battery materials is likely to be common practice in the future. However, until now the battery performance of materials nanostructured in this way has failed to meet expectations. Using neutron diffraction techniques, the Delft researchers could show that due to significant material structure changes, occurring when electrode particles are scaled down, nanostructuring is not always performance-enhancing. Effects strongly depend on the exact material composition and particle size.

Finland hot for nanotech

The Finnish nanotechnology sector shows impressive growth, as indicated in a current investigation by Tekes, the Finnish Funding Agency for Technology and Innovation. According to the study, the number of Finnish companies, active in nanotechnology, has more than doubled from 61 to 134 in just two years. Over 40 of these companies already have commercial products based on nanotechnology. Development is seen in all of the key sectors of the Finnish economy, from electronics to forest products. The main factor behind the increase in activity is Finland's National Nanoscience and Nanotechnology Programme, FinNano.

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Nanotechnology News

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Finland is the first EU country to announce a national program level partnership with China, focusing on nanotechnology research and development. The cooperation was agreed upon in Beijing early this year, and followed by an official Chinese delegation visit to Helsinki during Nanotech Northern Europe 2007 in March. The cooperation continues, with a Finnish delegation next attending the international China Nano 2007 event in June.

Nokia and the **University of Cambridge** (UK) have agreed to collaborate in several areas of long-term research, beginning with nanotechnology. Nokia stated that it will establish a research facility, initially with a team of 10 scientists at the university's West Cambridge campus. The scientists will focus initially on the design of nanoelectronic devices and circuits.

National Semiconductor adopts NEMS memory

Cavendish Kinetics, a fabless semiconductor IP company, announced today that **National Semiconductor** Corporation is working with them to qualify its Nanomech embedded, non-volatile memory technology for National's key analog and mixed signal processes. Nanomech harnesses arrays of nano-electromechanical switches for information storage, and is aiming to replace conventional non-volatile memory, namely embedded flash. "The excellent operating characteristics of Cavendish Kinetics' novel embedded non-volatile memory makes it a key addition to our technology portfolio. It can be easily combined with our current process technology options to enable higher performance signal

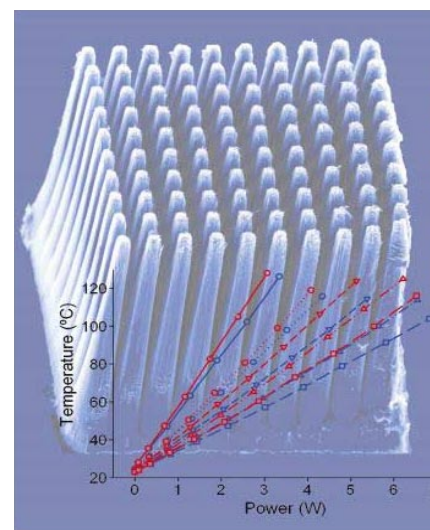
path and power products" said Mohan Yegnashankaran, senior vice president of worldwide technology development for National Semiconductor.

WTC comment: Various memory concepts are currently being investigated as potential alternatives to the established technologies such as hard-disk, DRAM, SRAM, or flash. There are the well known approaches already being commercialized by some semiconductor giants, like Samsung and Freescale, which are often referred to as "emerging memories", for example ferroelectric RAM (FeRAM), magnetic RAM (MRAM), and phase-change RAM (PRAM). However, there are also some small innovative companies driving several "nano-memories" towards maturity. Concepts relying on nanomechanical switches, as followed by the companies Cavendish Kinetics and Nantero, enable low power and fast embedded non-volatile memory. Since the manufacturing processes are CMOS compatible and fully scalable, these nano-memories can have a significant impact in this mass market.

Cool electronics with carbon nanotubes

Researchers from **Rensselaer Polytechnic Institute** and the **University of Oulu**, in Finland, have proven that carbon nanotubes can dissipate chip heat as effectively as copper — the best known, but costly, material for thermal management applications in the electronics industry. Using an innovative processing and transfer technique, the researchers have integrated structures made of aligned multiwalled, carbon nanotube arrays on silicon chips. Mounted to the back of a chip, the nanotube-based heat sink dissipates heat as effectively as the best thermal conduc-

tors. At the same time, it is more flexible, resilient, and 10 times lighter than any other available cooling material, offering the possibility of a lightweight, solid-state, add-on structure for an on-chip thermal management scheme.



Heat sink with carbon nanotubes

WTC comment: Due to continuously shrinking devices, resulting in increased power dissipation, thermal management is currently one of the biggest problems in the electronics industry. For further miniaturization, manufacturers are challenged to find new ways to combat this issue. In particular, there is a growing need for miniature on-chip solutions. Because of their unique combination of thermal and mechanical properties, carbon nanotubes probably constitute the most promising materials system in this context. Unlike in several other applications of carbon nanotubes in electronics (e.g. as channel material in field effect transistors), for heat sinks low-cost multiwall material can be used. The demonstrated manufacturing method is scalable and integrable with conventional processes — the most important prerequisites for the commercialization of carbon nanotube technology. ■

Feature Article

Taking the Pulse of the MEMS Industry

Continued from page 1

Inkjet print heads still contribute greatly to overall MEMS revenues. Five companies in the top ten: **HP** (#2), **Canon** (#3), **Lexmark** (#5) and **Seiko Epson** (#6) with their own print head production, and **STMicroelectronics** (#7) as a major foundry partner for **HP**.

The automotive sector is the next major revenue source. **Bosch** (#4) clearly heads the pack with estimated MEMS revenues of \$374m. It is trailed by nine further companies jostling for position between **Freescale** (#10) with estimated \$200m and **Panasonic** (#19) with estimated \$102m. Both gyroscopes and accelerometers for Electronic Stabilisation Programmes (ESP) and pressure sensors for Tire Pressure Monitoring Systems (TPMS) were major stimulants for the growth of the automotive MEMS markets in 2006.

Newcomers to the top 30

- ▶ **FormFactor** (#9), a manufacturer of MEMS-based wafer probes cards, exploded onto the market just four years ago. Its revenues have grown 55% in 2006 to reach estimated \$247m.
- ▶ **FLIR systems** (#25) with estimated \$50m is the leader of the fast growing market for microbolometers typically used in industrial, security and emerging automotive applications.
- ▶ **Melexis** (#30) sold in 2006 estimated \$28m worth of MEMS sensors such as pressure sensors for automotive applications. Its product palette is expanding fast and includes infrared sensors for luxury cars and more recently gyroscopes.

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Frequently Asked Questions about the mems30

Why are some of the well-known pressure sensor companies absent from the ranking?

Concerning the large pressure sensor manufacturers that supply industrial and medical applications, most of them (Danfoss, All sensors, Emerson etc) buy the MEMS die and package it, which is why WTC did not count them. Other large pressure sensor suppliers, such as Wika and Huba, produce capacitive ceramic sensors, not MEMS sensors. WTC also checked Sensata (formerly part of TI), and the vast majority of their pressure sensor revenue was with ceramic capacitive sensors, only few of their products are MEMS-based. WTC also investigated Endevco and Grundfos but they did not make it into the mems30 in 2006. WTC believes to have all the other significant ones in mems30: Honeywell, Bosch, Infineon, Freescale, Denso, Delphi, Melexis, Kavlico (part of Schneider), and GE.

Why are some revenues so different than in the ranking from other analysts?

We saw the rankings from others. Especially for HP, Avago and FormFactor there are strong divergences.

▶ **HP** is outsourcing more than half of its printhead production, mostly to STMicroelectronics. WTC counted only the printheads which HP does manufacture in its own two fabs in the US and in Singapore. In other rankings, either there is some double counting or the outsourced part is underestimated.

▶ WTC validated with **Avago** and its competitors its figure for shipments and price in units by type of FBAR products (Duplexer for the PCS band, Quintplexers and CDMA filters). It is easy to get

misled by the different ways Avago and Infineon communicate their shipments. Infineon counts FBAR dies, whereas Avago counts FBAR products: a filter has one die only, but a duplexer consists of two FBAR dies and a Quintplexer of five. This can lead to major misunderstandings.

▶ Concerning **FormFactor**, WTC's first estimate was already higher than the one of other analysts, yet one can notice that WTC has even increased its original estimate. FormFactor publishes its total revenue (\$369m), but the MEMS value of their probe cards was unclear. WTC discussed in more detail with FormFactor. The main share of their costs/revenues lies in the MEMS, in which a typical MEMS probe card for DRAM testing contains 26,000 micromachined contacts. WTC revised and validated its estimate with FormFactor, and is now very confident with its figure.

Adding the revenues of the mems30 comes way short of the market numbers in the Nexus report. Where are all the billions of dollars?

There are two main reasons for the discrepancy:

1. The mems30 does not include read-write heads manufacturers. RW heads were traditionally counted as microsystem in the NEXUS report and accounted for half of the total market.
2. When we estimate the total market size, we consider the value of 1st level packaged components for all products. In the mems30 ranking, if a company ships only wafers or dies, which is often the case for pressure sensors for example, we count only their revenue with wafers or dies which is of course a fraction of the value of 1st level packaged components. ■

Feature Article

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Two additional companies must be highlighted as a result of impressive growth. **Avago Technologies** (#8) consolidates its clear leadership in the FBAR duplexers and filter business for cell phones. After selling 100 million FBAR products in 2005, it shipped 220 million duplexers in 2006 and doubled revenues to reach rank 8 with \$255m. In a similar fashion, **Knowles Acoustics** (#21) shipped 200 million MEMS microphones and confirmed its clear leadership in this sector, doubling its estimated revenues to \$92m.

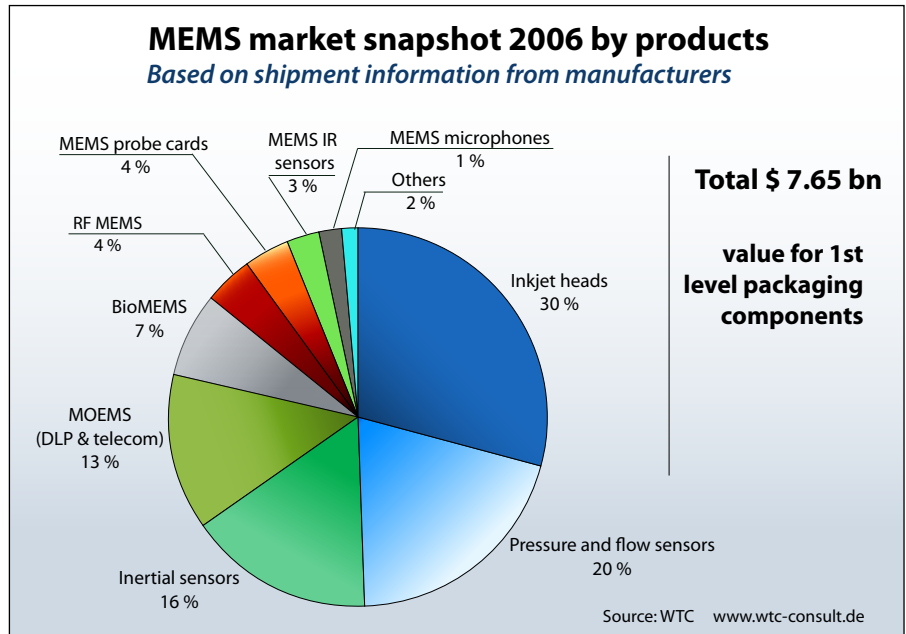
Inkjet heads amount to 30% of MEMS market

The inkjet market is still the largest with 30% share of the overall MEMS market. However, from the point of view of the MEMS component it is a stagnating market, with the industry moving away from disposable MEMS print heads and most new printers featuring a fixed print head. This is manifesting itself in slow growth in this sector.

Although the four biggies have been left alone for years in this very profitable market, things are changing with a series of new players trying to get their share of the pie (see MEMS news p. 5). **Kodak** will enter the market this year, leveraging its “photography” brand to establish itself on the high end segment of digital photo printing (see February issue of Think Small!).

Pressure and flow sensors

Pressure and flow sensors make up a fifth of the MEMS market. Industrial and automotive applications are neck and neck in revenue. The industrial share is big because of the high price of the package. **Honeywell** (#17) and **GE**



(#15) dominate this market together with other large companies such as **Danfoss**, that buy pressure sensor dies and package them. The automotive market for pressure and flow sensors is propelled by TPMS, which will be mandatory this year in the US.

Inertial sensors

Inertial sensors are neck and next with \$1220m. Consumer applications grow fast with use in cell phones and gaming, however automotive still clearly dominate with 70% of the revenue. Contrary to what we expected two years ago, the airbag market is not completely saturated and keeps growing thanks to new markets, e.g. India and China. Un-sophisticated sensors, like in the early 1990s, fit in cars costing typically \$3000. In developed countries, gyroscopes for ESP drive the market growth and will still do so in the next four years. Indeed, penetration will grow from 25% in the US today to nearly 100% in the US in 2010 due to a new ESP regulation.

MOEMS

MOEMS for displays and telecom applications are the fourth largest MEMS segment, mainly because of DLP. WTC expects TI's revenue in DLP to surpass the \$1bn mark in 2007 for the first time. MOEMS for telecom applications experienced healthy growth in 2006, as companies are benefiting from investment in fiber optical metropolitan networks e.g. from British Telecom and Verizon. As the price of copper cabling rises, it makes fiber optical networks more and more attractive. MEMS foundries such as **Memscap**, **Micralyne** and **Silex** and specialized start-ups like **Dicon** are also profiting from the recovery.

BioMEMS

WTC has divided bioMEMS into two separate categories, microfluidic chips in silicon, polymer and glass, and drug delivery systems. There is a nice niche market for MEMS foundries in drug discovery. However a mass market for microfluidic chips for point-of-care applications (continued next page)

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has not yet materialized because of barriers from health insurance systems and medical doctors. There are some notable exceptions such as I-Stat blood gas monitors, but a mass market is not expected for at least another three years.

On the other hand, things are moving rapidly in the drug delivery market (see the Microsystem news section on page 4). **Böhringer Microparts** (#22) has already reached a turnover of \$90m in 2006 with its nebuliser technology, although the product was only certified in Germany and for one medication. Revenue is expected to explode by 2010 for this product, as it will obtain certification for additional medications in more EU countries and in the USA.

RF MEMS

RF MEMS market earned \$ 330m last year with three companies shipping FBAR duplexers and filters in series: **Avago**, **Infineon** and **Epcos**. It should be noted that Infineon's share is under-represented in the mems30 ranking since it sold mainly FBAR wafers, while the \$330m corresponds to the value of first-level packaged duplexers and filters. MEMS oscillators just started at the end of 2006 with the first million shipments by **SiTime**. **Seiko Epson** also started to ship its QMEMS oscillators. RF MEMS switches were only in the sampling phase in 2006 (e.g. at **Teravicta** and **Panasonic**), but are now jolting the market with Teravicta shipping 10,000

units per month, and plans to reach the million mark by the end of 2007.

mems10 foundries

WTC's mems10 foundries ranking includes contract manufacturers specializing in MEMS or having MEMS as a majority business, including **Dalsa** where MEMS exceeded CMOS in their foundry revenue in 2006 for the first time, but excluding STMicroelectronics foundry activities for HP and Sony for Knowles. Several MEMS foundries including **Olympus**, **Semefab** and **Microfab Bremen** are chasing hard on the tail of **Touch Micro-system Technology** (TMT) with revenues estimated between \$5m and \$7m. *(continued next page)*

Exhibition

Micromachine/MEMS

Japan's leading exhibition focusing on Micro/MEMS & Nano Technologies

July 25_[Wed] – 27_[Fri], 2007

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NEW! MEMSdevice Zone

– Various Types of MEMS Devices to be Displayed!

Optical MEMS, RF-MEMS, MEMS Physical Sensors, Micro Fluidics, MEMS Actuators, Bio/Chemical MEMS, Power MEMS, Others

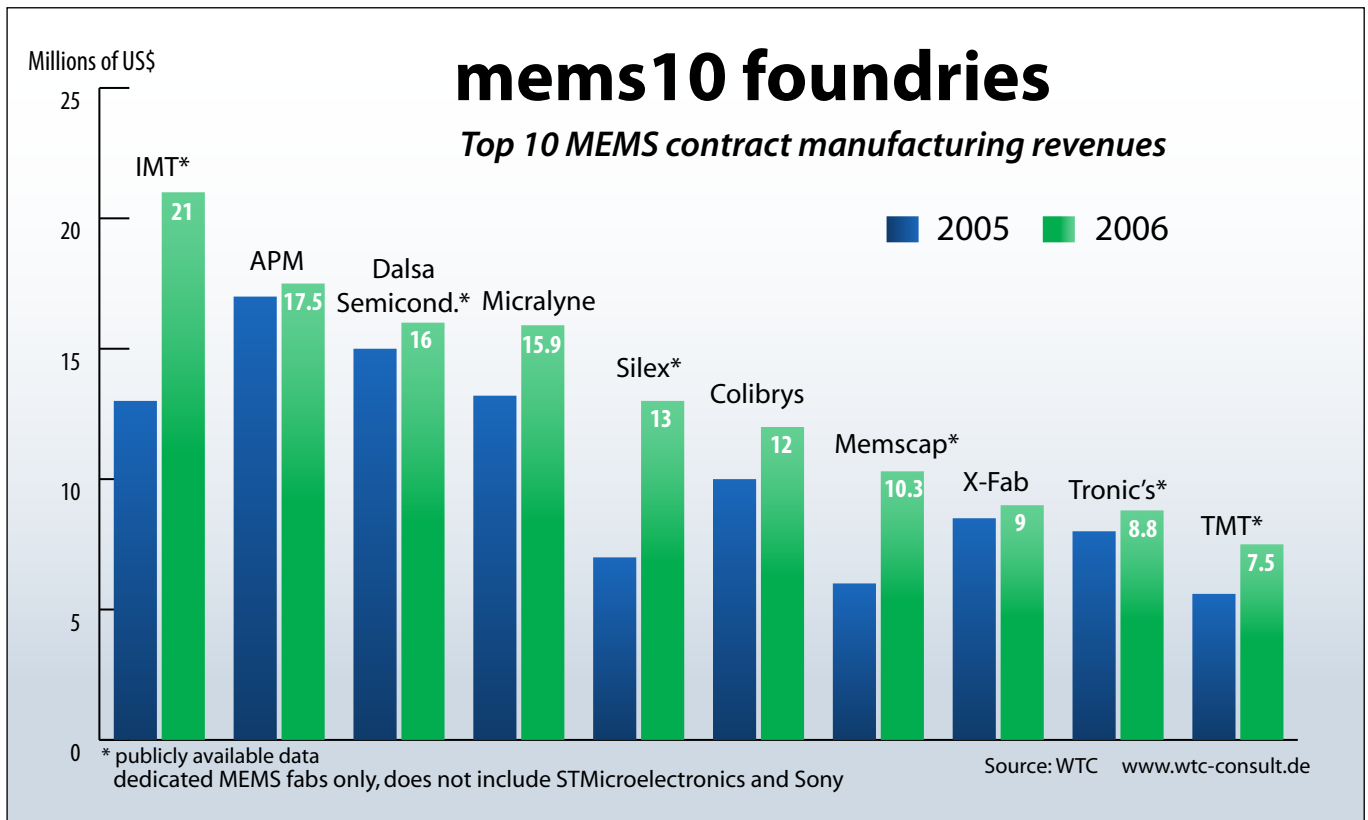
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messe frankfurt

Feature Article



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The group of top ten foundries reflects different realities. One can first distinguish the foundries specializing in high value products, such as telecom infrastructures, biomedical, aerospace and energy. These are typically **IMT, Micralyne, Silix, Colibrys, Memscap** and **Tronic's**. On the other hand some like **APM, Dalsa, TMT** and **X-Fab** focus on high volume applications in automotive, inkjet, or even consumer business. The border becomes blurred sometimes as Silix expands to 8", and Memscap grows in the microphone business.

One can also differentiate the companies shipping wafers (most foundries), and the ones which offer packaged products or full modules as a way to increase margins and lower customer volatility, such as Tronics, Colibrys and Memscap.

Finally, few of these foundries have a range of standard products in parallel to foundry services. This is the case for Colibrys and Memscap, and more recently Microfab with their own pressure sensor product line. This is a way to increase revenue, but also to become more independent from the customer. This is not, however, a general trend in the MEMS foundry business. Most prefer to remain a pure foundry player to avoid frightening their customers. APM, for example, spun out its standard product business in February.

Is contract manufacturing a profitable business?

The total revenue for MEMS contract manufacturing from the mems10 foundries list reached estimated \$131m in 2006, as the business swelled to a 30% increase last year. IMT overtook APM as the leading MEMS foundry with

an impressive leap from estimated \$13m to estimated \$21m based on contract manufacturing of infrared sensors, MOEMS and DC switch arrays for telecom applications.

Silix enjoyed the largest boost, doubling its revenues to estimated \$13m in 2006, largely from sales increases in life science and telecom applications

The foundry business is not only expanding but also profiting. In the past, Micralyne and Memscap were one of the few companies writing black numbers in the market, however, several companies started to reach profitability on a monthly or quarterly basis in 2005. Furthermore, companies such as Tronic's, Silix, TMT and others experienced profitability throughout 2006. The pipeline of the mems10 foundries is well nourished and should allow for a healthy growth in the next two years.

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While most foundries had typically three to five products in serial production in 2006, two to three additional products will emerge for each company in 2007 and another 15 to 60 additional customers are in the R&D phase.

Telecom and biomedical are driving growth of foundries

In terms of MEMS applications, automotive dominates today due to Dalsa's production of pressure sensors for Freescale, in addition to some activity at APM, tmt and X-Fab. The most significant growth last year was due to telecom infrastructures and bio-medical applications. In optical telecom, MOEMS products, that have been ready for 4–5 years now, are going into production as the demand materializes.

In a similar fashion, big pharma companies, that have been "playing" with microfluidics for two or three years now, are subcontracting production at MEMS foundries, especially for drug discovery.

In the future, what will be the major propellers for MEMS foundry business by 2010? Without surprise, the Taiwanese foundries APM, tmt and TSMC expect significant opportunities from Consumer Electronics. But also Silex, Memscap and X-Fab bet on consumer electronics e.g. for contract manufacturing of MEMS microphones. The other foundries, more specialized on high value markets, will consolidate their position in telecom, biomedical, energy, and aerospace and defence.

Limited outsourcing for automotive MEMS

What about automotive? Contrary to other analysts' opinions, WTC does not believe that subsystem and component manufacturers will systemati-

cally externalize the MEMS component manufacturing in the future. The investment of Bosch in a 8" fab is a clear sign. The partnership between Dalsa and Freescale only concerns some of the old pressure sensor technology. Freescale will keep the leading edge accelerometer and gyroscope technologies in-house. Most automotive MEMS manufacturers have investigated this "make or buy" concept and come to the conclusion that it is not more profitable to externalize fab activities.

Opportunities exist, however, for MEMS foundries in special cases. When considering to convert to 8" wafers some automotive MEMS suppliers will choose to use an external foundry already running 8" wafers, instead of building an expensive new fab. Also after buyouts and mergers, when a pure system company inherits a MEMS components production, this might also be externalised to a MEMS foundry.

Optimistic outlook for foundry business

To summarize, the outlook is now good for pure MEMS foundries. They all expect significant growth of their businesses in 2007 (at least 30%), as well as several are expanding capacities. TMT is currently the only 8" foundry in the mems10, but APM and Silex will soon join in the next two years.

One should also mention larger semiconductor companies like **STMicroelectronics** and **Sony Semiconductor Kyushu Corp** (sck). In contrast to the mems10 foundries which serve from 15 to 60 customers, these companies' MEMS foundry activity is usually focused on a key customer. STMicroelectronics has a strategic relationship with HP for the production

of print-head wafers, while sck is the prime MEMS wafer supplier for Knowles acoustics. Although MEMS is a very small part of the activity, these players actually dominate the MEMS foundry business in revenue terms. WTC estimates that the MEMS foundry revenues from STMicroelectronics and sck to be around \$240m and \$35m, respectively.

In conclusion, WTC says: The pulse of the MEMS industry is beating fast

The big players are alive and well, especially TI at #1, with DLP revenues recovering after a drop in 2005. The smaller players, such as the foundry companies, are starting to be profitable. Automotive application remains the major engine for growth and innovation in MEMS. RF and optical MEMS for telecom applications are taking off. Consumer electronics is still young, yet it already makes up for 10% of the MEMS market and contributed significantly to the revenues of seven of the top 30 players in 2006. Consumer applications are not only driving market growth, but also stimulating technological breakthroughs in the front and back end. These breakthroughs are essential for beating the extreme price pressures that go along with this new mass market. ■

Jérémie Bouchaud

The full results of the survey are available to you in the new Custom Market Workshop from WTC:

MEMS industry 2007–2011: status, trends and strategies

For more details and to book, see www.wtc-consult.de/workshops

Interview

Dr John Foster, CEO of Innovative Micro Technology

IMT is now the No 1 MEMS foundry in terms of revenue, with an impressive jump from \$13 million in 2005 to \$21 million in 2006. What propelled your leap from fourth to first place?

In 2006, we grew to over 20 customers, including adding two production customers: silicon planar lightwave circuits for Xponent Photonics and infrared devices for emission and gas sensing for Ion Optics. Dc switches for telecom infrastructures were another important contributor to our revenues last year. In term of expertise and offering, our strengths include hermetic devices, wafer level packaging and wafer bonding, getters for vacuum, experience with metals and magnetic materials, in addition to sub-micrometer lithography expertise (e.g. <math>< 0.1 \mu\text{m}</math> three-sigma etch tolerances) with products exceeding 20 mask layers, and with up to four wafers bonded together. Another factor is our capacity — with the largest and, we believe, best equipped independent mems fab in the world, our customers know that we have the additional capacity to support them as they grow. We expect to increase our output for our existing production customers and add a few more this year to their ranks.

What are your typical customers? Start-ups, large groups?

We serve and continue to see interest from all types of customers, everything from startups with a few people and an idea, all the way up to the large multi-nationals. In terms of quantity of inquiries, last year we did see a transition from mostly startups to more interest from larger companies.

Startup activity did slow toward the end of 2006 — and we've confirmed this in discussions with vcs — but we're seeing a recent pickup in interest from startups this year, including some of the more mature startups as they gain traction — so things are evening out again. One trend is toward outsourcing from some of the larger electronics companies — they want to have two sources, their own fab and IMT.

Some analysts have been announcing that automotive components and sub-systems suppliers would outsource their MEMS production to foundries. Do you see this happening?

This is happening in some circumstances, but perhaps not as much as foundries have hoped. We've had some contacts with automotive suppliers, and we have discussed everything from "make versus buy" to additional capacity to new product development leveraging some our unique capabilities. We see best opportunities for us with new product development, for example infrared imaging for night vision, cabin environmental sensing, telematics and other communication links.

What is the fuel for further growth of your business in the next three years?

We're just getting started, and I would like to state that this is a terribly exciting business! We do expect substantial growth going forward as demand appears to be robust for our existing production customers. And of course, we also expect to promote more of our development programs and shift them into volume production. New programs



Dr John Foster is CEO and chairman of the board of Innovative Micro Technology (IMT), which he co-founded in 2000. Before IMT, Mr. Foster held management positions with Applied Magnetics Corporation and IBM. He was also a former faculty member at Stanford University. He has 21 years of experience in both research and management. He also holds 22 U.S. patents with the most recent one in MEMS cell sorter technology. Dr. Foster received a B.A. in physics from the University of California, San Diego and his Ph.D. in applied physics from the Stanford University.

are coming into production this year, including RF MEMS, and a biomedical product — and of course our new getter services are generating a lot of interest as well. IMT is diversified by design so we are involved in many different applications and industries. We are particularly excited about strong growth in biomedical applications including cell therapy, switching applications including DC, microwave and millimeter wave, infrared applications including gas sensing and imaging, and finally optotelecommunications for fiber to the premises (FTTP) products, such as planar lightwave circuits (PLCs). ■

Events



SENSOR+TEST 2007
DIE MESSTECHNIK-MESSE

NEXUS workshop helps find partners for EU projects in MEMS

In parallel to the SENSOR+TEST exhibition in Nuremberg, WTC organizes the Nexus Workshop, "Finding partners for EU – Projects in MST/MEMS" on 23rd May, 2 p.m. This workshop presents the upcoming topics of R&D supported by the EU Commission in the Framework Program 7. Invited companies and research institutes will present their project ideas and request partners for the upcoming event, "EU call for Micro and Nanosystems".

The topics that will be addressed at the SENSOR+TEST exhibition are: structural monitoring, sensors for automotive and industrial applications, wireless sensor networks and energy scavengers.

There is still some space for additional presentations. If you want to present a project idea, please contact WTC, Ms. Marion Aschenbrenner, Communication Manager, at marion.aschenbrenner@wtc-consult.de.

Your attendance at the Workshop is free, however space is limited. Please register online at: www.nexus-mems.com/workshop2007

Meet WTC at the following events:

Event	Date	Location	Booth # / Presentation
Micromachine Summit	April 26–28	Venice	"Changes in the MEMS industry"
AMAA 2007	May 9–10	Berlin	"Prospects and strategic considerations for automotive MEMS"
SENSOR+TEST	May 22–24	Nürnberg	Hall 7, Booth 609 "MEMS in auto, industrial and consumer electronics"
ICNTE	May 24–25	Bologna	"Carbon nanotubes applications in electronics"
Nanotrends	June 4–6	Cologne	"Carbon nanotubes roadmap"
Transducers'07	June 10–14	Lyon	Booth 4
Sensors Expo & Conference	June 11–13	Rosemont (Illinois)	"Micro energy scavenger applications & markets"
Nano RF	June 15	Lausanne	"RF applications of carbon nanotubes"
Memswave 2007	June 26–29	Barcelona	"RF MEMS roadmap" and moderation of industrial panel on RF MEMS
Micromachine/ MEMS	July 25–27	Tokyo	Booth

WTC presents carbon nanotube roadmap

Stefan de Haan of WTC will present the first results from the European project ARCORC at ICNTE, NanoTrends and Nano RF. The carbon nanotube roadmap is based on interviews with over 80 interviews in the industry

and research community. The roadmap will be completed in October. ■

We welcome your comments and feedback about this newsletter and its contents. Please contact:
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WTC–Wicht Technologie Consulting is a consulting company specialised in microsystems and microelectronics. WTC offers customised market analysis, strategy planning, roadmapping, business development and search for technology partners. We also offer several off-the-shelf market reports (see www.wtc-consult.de for more information) and organise conferences on behalf of third-parties.

Our customers include small, medium-sized and large companies as well as research institutions and public organisations. WTC was founded in 2000 by Dr Henning Wicht and now employs 10 consultants.