MEMS-Based Systems Solutions: Analytical Instruments for Gas Analysis

Analytical instruments offer a great opportunity for MEMS- based systems solutions, as introduced in the Sensor Magazin 2-2011[1]. The inherent benefit of MEMS being small, robust, low power and low cost along with surprisingly high performance make them ideally suited to hand-held and portable/field useable instruments. These instruments find their way into a broad assortment of applications for solid, liquid and gas analysis including environmental monitoring, process control quality assurance, homeland security and defense.

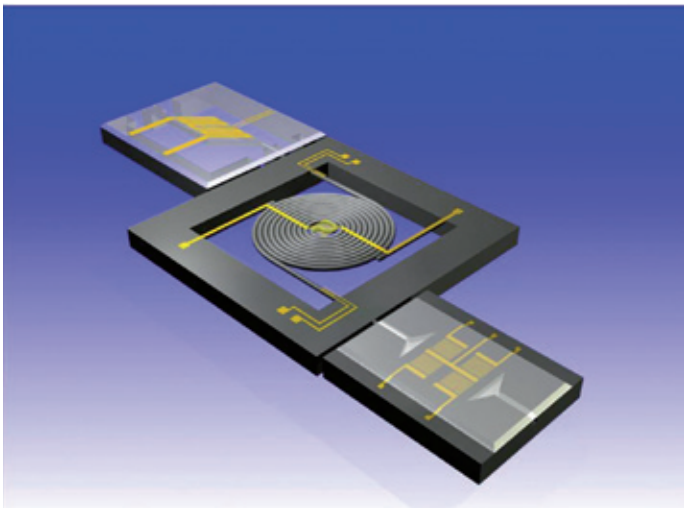
Strategic Directions International (SDI) has estimated that the total worldwide and analytical and life sciences market to be approximately $35 billion (US) in 2008 with a compounded annual growth rate of 5-6 %. The majority of this market is for 'benchtop' laboratory instruments. However, SDI reports that the portable and handheld market is expected to grow at double digit rates over the next five years.

Needless to say that this opportunity needs to be addressed by companies that can provide cost effective solutions to the myriad of application opportunities. Therefore we will provide some examples of MEMS based system solutions (MBSS) for analytical instruments and specifically for gas analysis that are either in production or are in the product development cycle. This MBSS concept comprise the integration of MEMS front ends including sensors, actuators and or structures with signal processing vis-à-vis ASIC, embedded software in the microprocessor-based ASIC, energy management/storage and network connectivity either wired or wireless. All of this is interconnected and housed in a package.

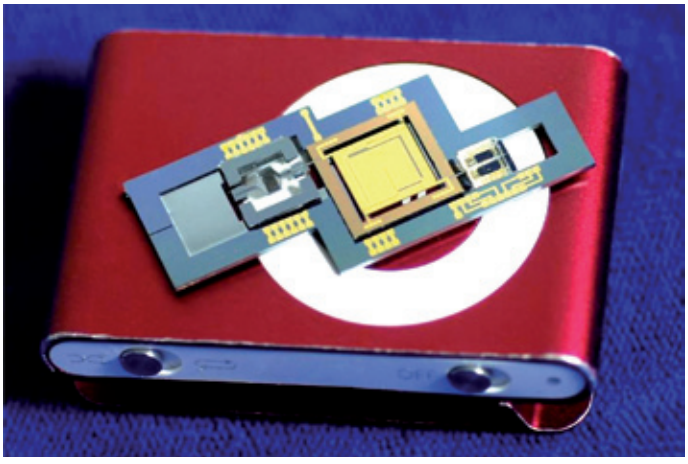
The concept is based on systems engineering, co-design principles and design for manufacturing and test. The concept is driven by the need to vertically integrate the recently commoditized MEMS front end devices and to provide a total solution to the end user while simultaneously providing product differentiation and higher gross margins to the supplier.

Application Examples

Block Engineering (www.blockeng.com) of Marlborough Massachusetts USA is currently developing its Chem-Pen TM Fourier Transform Infrared (FTIR) Michelson miniature spectrometer which uses a very sophisticated MEMS SUMMiT IV process from Sandia National Laboratories (SNL) to create its MEMS-based optical engine. This technology is currently being funded by the US Department of Defense who has invested over $8 million (US) to date. It is expected to be commercialized by the beginning of 2013 targeting a sell price of $1000 each in large volumes. The Chem Pen technology is expected to revolutionize the field of high-performance portable instrument technology much the same way that laptops did for computing and mobile phones did for communications. It could be adapted to



▲ Artist drawing of a three chip µGC with preconcentrator, column and detector (K. Wise, Univ. Michigan)



▲ A 25 cm separation column of a palm-size µGC with embedded thermal sensing and closed-loop microprocessor-based control on a 2nd. Generation Apple iPod Shuffle (K. Wise, Univ. Michigan)

provide a possible mobile phone solution to breath analysis and toxic poison monitoring of gases such as Sarin. Target applications include chemical warfare agents, homeland security, life safety/first responder and toxic industrial chemical detection under field conditions[2].

Thermo-Fisher Scientific (www.thermofisher.com) Andover Massachusetts (US) a world leader in portable analytical instruments recently acquired Polychromix who has developed a unique Near Infrared (NIR) optical spectrometer 'engine' again using the SNL SUMMiT IV process. This device has been fully commercialized by Polychromix by creating a hand held instrument (micro Phasir TM) capable of measuring measure liquids and solids selling for approximately $17,000 (US).

Applications for this system include hazardous materials analysis, asbestos analysis, counterfeit materials analysis, narcotics analysis and process quality control. A most interesting gas analysis application of this NIR technology by was the NASA Lunar Crater Observation and Sensing Satellite (LCROSS) who mission was to undeniably determine the presence of water at the south pole of the moon. Measuring less than 2 liters in volume, consuming less than 3 watts of power and weighing less than 1.5 kg. it cover s the 1200-2400 nm. spectral range.

On October 9, 2009, after travelling 9.3 million kilometers in 113 days, mission used two such NIR spectrometers carried by the trailing LCROSS instrument module to look at the impact plume of the impact plume of a Centaur rocket impacting the surface of the moon.

A NASA spokesperson announced during the NIR-2009 Conference that the Polychromix spectrometer found 'buckets of water' on the Moon based on the measured spectra. ThermoFisher is currently assessing this as well as other technical approaches to making gas measurements using portable/hand held approaches[3].

Defiant Technologies (www.defiant-tech.com) of Albuquerque New Mexico has also produced and made available to the market a hand-held micro gas chromatograph using a number of their internally developed MEMS components including a chemically selective pre-concentrator (collector), micro GC column and SAWE micro balance detector.

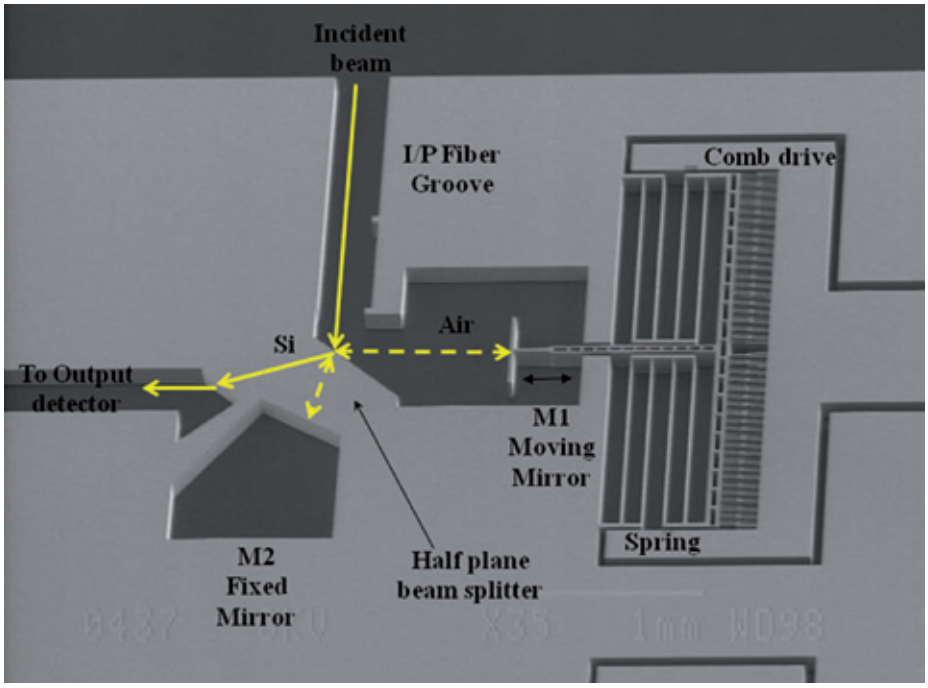
Their Canary TM weighs 13.8 kg and measures 19 cm x 13.3 cm x 5.7 cm, operated from a 9v/2A battery, has a RS-232 interface and a LCD display. This system has applications in environmental monitoring and chemical warfare agents.

Si-Ware Systems (www.siwaresystems.com) of Heliopolis Egypt has introduced what they consider to be the first commercially available high resolution monolithic fully integrated FTIR spectrometer fabricated using MEMS SOI technology[4].

The spectrometer is based on a Michelson interferometer integrating as Si beam splitter, a moving mirror and a fixed mirror all fabricated in a single deep reactive ion etching (DRIE) step and self aligned with a lithography technique.

This approach allows the spectrometer to have unique features like miniature size, low weight low power consumption and low cost due to batch processing. Having all the optical components integrated in one chip and self aligned through fabrication provides no need for realignment and calibration.

University of Michigan (www.wimserc.org) Wireless Integrated Microsystems Center (WIMS) of Ann Arbor Michigan has for well over 10 years undertaken major research efforts on micro GCs that integrate numerous other functions of an instrument into a total analytical instrument solution. Their approach is to meet the emerging needs of in-field measurements through the development of long-term, unattended operation in the field with drastically reduced cost, power, using no consumables and run-



▲ MEMS FTIR Spectrometer (Si-Ware-Systems)

ning on energy scavenged from the environment through a wireless-based system.

Their recent research is centered on their Orion program whose primarily goal is to reduce the power requirement of the system using a thermally engineered MEMS pre concentrator and column that can be manufactured with high yield and will be robust in its operation[5].

Using Carbon nanotubes to coat the pre-concentrator, high thermal conductivity with low mass can be achieved. Currently at the 200 mw level, their goal is to reach a power dissipation level of less than 100 mw.

From a packaging perspective, their goal is to put the entire microsystems fluid analysis path consisting of the pre-concentrator/injector, detector, pump and separation column into the volume of a mobile phone or wristwatch.

Summary/Conclusions

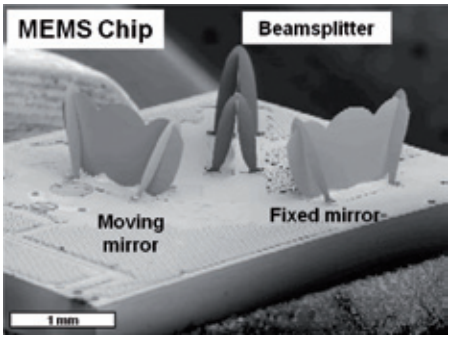
We have provided several good examples of MEMS being used as the 'engine' for portable/hand held analytical instruments using either chromatography or spectroscopy approaches. The offerings from Thermo-Fisher, Defiant Technologies and Si-Ware Systems are expected to be in production soon. Block Engineering is expecting to have prototypes in early 2013. MEMS by their inherent nature lend themselves favorably to these types of applications because of their robust nature, small size, low-cost and low-power consumption.

Much of the research that is being conducted today at leading research institutes worldwide including those given above will result in many new products that will increase the quality of life of the world's population.

Furthermore these systems become more mature, their costs will be significantly reduced to the point that they will find themselves in mobile phones and other low cost consumer applications making them and their diagnostic data affordable and accessible to a large sector of our population especially in under-developed nations... truly an exciting concept and something to look forward to.

Want to know more?

Roger Grace has organized and will chair the October 10, 2011 all-day 'MEMS-Enabled High Volume Commercialization Opportunities' session at the Sensors Tech Forum which will take place at the Sheraton Hotel in Boston Massachusetts. R. Grace will be one of 16 speakers who will address a broad spectrum of topics including MEMS-based analytical instruments. For more information please visit www.sensorstechforum.com.



▲ MEMS-chip with spectrometer parts (fixed and moving mirror, beam splitter) on a data processing chip (Block Chem Pen)

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[3] A. Coloprete et al, 'Detection of Water in the LCROSS Ejecta Plume', Science, October 22, 2010, pp.463-468.
[4] D. Khalil et al, 'Characterization of MEMS FTIR Spectrometer', Proceedings of SPIE Photonics West, San Francisco California, January 2011.
[5] K.T.M. Beach et al, 'A Low-Mass High Speed uGC Separation Column with Built-In Fluid Chip-to-Chip Interconnects', Proceedings of IEEE MEMS, Cancun Mexico, January, 2011, pp. 813-816

▶ INFO

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