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Emerging MEMS Technologies to Watch

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The bi-annual Transducers conference in Barcelona, Spain featured top-notch research from around the world, and in this brief report, I highlight several themes and papers with important implications for the MEMS industry. The papers cited below come from two topical areas where the sheer variety of different variations on a common material or device suggests an area likely to spawn commercial opportunities. The particular papers were chosen for their commercial relevance and readiness to move into development.

The emerging MEMS technologies to watch are:

- Resonant devices
    - Detection
    - Actuation
    - Switching
- Gas Sensors (metal-oxide-nanowire + polymer)

In addition, two papers from Japan with innovative design and processing approaches that caught my eye are also discussed below.

Resonant Devices

The possibilities for the use of resonant devices continues to expand with more than 250 papers (talks and posters) ranging in application from detection to actuation to switching. In each case, either a shift in resonant frequency in response to an external stimulus or the signal amplification that occurs at resonance was used to create a significantly improved device.

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On the detection side, there were multiple papers looking at Lorentz magnetic field sensing, IR sensing, local temperature, gas detection, and acceleration. One paper that stood out was from researchers at Politecnico di Milano and STMicroelectronics[1], who compared a variety of capacitance topologies (parallel plates, comb fingers, and fringe-field) and showed that the higher Q devices (less damping) but lower capacitance-signal devices (e.g. fringe-field) could give better performance when using a resonant frequency shift read-out approach. This points in a promising direction for improved sensitivity of MEMS magnetometers for navigation.

For detecting IR light, two different papers used the temperature rise from IR light absorption, coupled with the temperature dependence of Young's Modulus, to sense a change in the resonant frequency. Of particular note was work by researchers from Northeastern University[2] which demonstrated an uncooled pixel with a 250nm thick AlN resonator and SiN absorber that had a high sensitivity and a fast response time of 1.4 ms. The processes used for this device are compatible with silicon and miniaturize concepts explored at much larger scales with quartz or GaN. This approach provides an interesting path to creating a much higher-performance uncooled IR detector in silicon. This could reduce the cost of cooled-IR applications in health care imaging or enable high resolution IR imagery for consumer products.

A series of resonant-actuation papers focused on scanning mirrors for applications like pico-projectors. Many of the papers showed the use of piezoelectric materials plus resonance to achieve scan angles greater than 75 degrees at 25-50kHz frequencies with voltages below 25V. Of particular interest was a paper from a team at Tohoku University and Fujifilm[3] that demonstrated a 1mm x 1mm mirror with a 144 degree tilt at 55kHz with only a 5V driving voltage and used a metallic glass for the torsional hinge to improve reliability.

On the switching side ("resoswitches"), there were two interesting papers from UC Berkeley that used a micromechanical resonator as an oscillating switch by creating a contact point at one extreme of its motion. In one paper they used a comb-drive oscillator to create a low-voltage, low-off-current switch with no diode drop to enable a charge pump to reach 100V versus the normal ~15V limits in CMOS[4]. By building the charge pump in the same layers as the MEMS device, this approach can enable cost reductions or larger design spaces for such devices as timing references, which require high voltages for operation. The second paper using the resoswitch concept demonstrated an RF filter and power-amplifier based on a modified wine-glass disk resonator[5]. Such a device shows a path to much higher efficiency RF transmission and ultra-low-quiescent-power receiver filter-amplifiers. Beyond these two specific applications, the resoswitch holds promise for repetitive switching applications with its fast switching speed, low activation voltage, and the potential for higher reliability.

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Gas Sensors

The more than 30 papers on MEMS-based gas sensors (either polymer or metal-oxide-nanowire based) showed that these devices are moving out of the research phase and into the development phase. These sensors could have broad applicability from disposable CO_2 sensors in meat or vegetable packaging, to indoor air quality (CO, ozone) monitoring for building systems, to car exhaust monitoring (CO, NO_x).

Although commercial thick-film (multi-crystalline) metal-oxide-based devices are commercially available (e.g. Applied Sensor's SnO_2 devices), papers from both South Korea's KAIST and China's Academy of Sciences demonstrate that the selective growth of single-crystal metal-oxide nanowires can achieve higher sensitivity (100x) devices[6] at lower power (1/10th), and easier integration of multiple metal-oxide materials onto the same device[7] as a last step post CMOS processing. Although the metal oxide devices all operate at elevated temperatures (250-550 °C) using integrated micro-heaters, a second paper from KAIST demonstrated material improvements that keep driving that temperature down by increasing the sensitivity[8].

On the polymer side, a paper from NXP and three Dutch universities showed the successful integration of multiple polymers required to remove the cross sensitivity (CO_2 and humidity, in this case) that is common. They demonstrated the addition of the polymer layers on top of a capacitance sensor and read-out electronics, all fabricated on commercial CMOS electronics – thus enabling a way to tailor the sensor at the final fabrication step[9].

Innovative Design and Process Techniques

System architecture that mimics biological approaches can open up new possibilities for creating efficient sensor networks. For touch sensors, researchers at Tohoku University and Toyota put an A-to-D converter ASIC below each sensor, connected the sensors onto a digital bus, and followed the human-nervous-system approach of transmitting data when there was a change in the force applied to the touch sensor[10]. This enabled them to integrate hundreds of sensors with only a 4-wire strip, rather than wiring each sensor individually. They showed that the reduced data transmission enabled them to have a very high number of sensors on the network and still avoid packet collisions.

While Stealth dicing is already a key part of the success of many MEMS products, researchers at the University of Tokyo have optimized backside Stealth dicing half-way through a wafer before the final frontside DRIE and oxide release step to enable position dependent cleaving below a released structure[11]. Rather than etching away the wafer bulk under the cantilevers, that bulk

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material preferentially cleaves across the existing Stealth dicing modification, and can be removed mechanically during the tape-stretching.

For more in-depth analysis of the technologies discussed here and their commercial applications, please contact Keith Jackson at kmj@amfitzgerald.com or +1 650 347 6367 x106.

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