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Challenges and Opportunities in Multi-Sensing Microsystems – A Case Study

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Microsensor arrays deployed in distributed networks are expected to revolutionize fields ranging from medical instrumentation[1] for neural interfaces to environmental monitoring[2] for industrial effluents, weather, and homeland security. This paper reports on an effort to develop a generic multi-sensor environmental monitoring platform which has stimulated substantial research at all levels, ranging from materials, fabrication methods, and packaging, to sensor, actuator, circuit, and system design.

A prototype multi-sensor node will consist of a cube[3] assembled from a micromachined wafer (of silicon or other material) around a stack of micromachined sensors and circuits (Fig. 1). Electrical and fluidic interconnects will be embedded into the walls of cube and interleaved between the devices in the stack. The system-level architecture[4] (Fig. 2) bears similarity to the IEEE 1451 transducer network standard; it is intended to be modular, and to support local signal conditioning and data conversion. A low-power wireless interface based on the IEEE 802.15.4 Zigbee™ standard is being developed. The long-term performance goals for the network nodes are ambitious, partly to force paradigm changes: they include accuracy to 16 bits, size of 1-2 cm^3, wireless range of upto 1 km, and lifetime of 6-12 months. Of course, battery performance turns power consumption into a limiting constraint on each of the other specifications. The target for average power consumption is <1 mW, which will be achieved by the appropriate use of low power circuits and components, power-gated modules, and power-saving modes. Reduction to 100 μW would permit energy scavenging to be an option[5].

A wide variety of microsensors are being explored for this application, including pressure, temperature, humidity, acceleration, air quality (gas analysis), nuclear radiation (Geiger-Muller counter), and others. The use of capacitive transduction methods for the first four of these variables facilitates extremely low energy operation (down to a few nJ per measurement), and the concomitant availability of electrostatic actuation provides self-test capability[6,7]. With interface circuits that can read 0.1 fF, the resolution achieved for pressure, temperature, and humidity sensors ranges from 10-100 ppm of the dynamic range, whereas the accelerometers are able to resolve <1 μg. Gas analysis is being performed by a micromachined gas chromatograph[8] (Fig. 3). Gas is pumped through a particle filter and into a pre-concentrator, from which the target molecules are thermally desorbed and driven through one or two micromachined columns (upto 3 m in length), in which they become separated due to varying temporal characteristics of interaction with the walls. The emerging concentration peaks are detected by a chemi-resistor array which provides an additional level of differentiation. An early version of this uses boron-doped bulk Si dry-etched channels anodically bonded to a glass substrate, whereas a newer version provides better thermal isolation, achieving 100°C at 10 mW. The chemi-resistor arrays are also being improved with the use of gold-thiolate nanoclusters with varying terminal groups for specific selectivities. A micromachined gas pump is being developed for this instrument[9]. Other pumping mechanisms have also been explored, leading, for example, to the first fully micromachined Knudsen pump[10]. Associated projects in vapor sensing and gas delivery have focused on high-speed spectral measurements of arc discharges[11]. The Geiger-Muller counter[12]

(Fig. 4) is fabricated from a glass-Si-glass stack of wafers that enclose an electrically biased cavity with trapped He or Ne gas. As a beta particle passes through, the bias field generates electron cascades, resulting in a current pulse or “count”. A prototype die of 2 cm^2 houses 6 independent chambers ranging in size from 8x8 mm^2 to 1x3 mm^2. The device has been successfully been tested with Uranium-238, ^{90}Sr, ^{60}Co, and ^{204}Tl, all beta emitting isotopes. A micromachined high-voltage generator is also being explored to bias this device[13].

Despite the progress made by this and other research teams in recent years, many challenges remain in processing materials for sensing for wafer-scale packaging; in developing sensitive and selective sensors; in developing power-efficient fluidic actuators; in the design of low power circuits for data acquisition and signal conditioning, and wireless communications.

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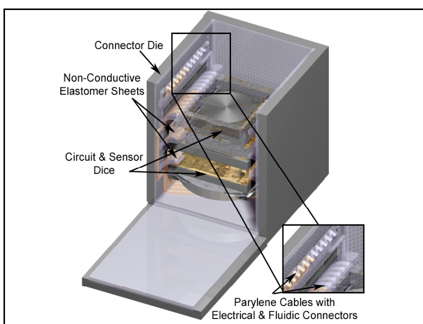

Fig. 1 (left): The WIMS cube has fluidic and electrical interconnect embedded in its walls.

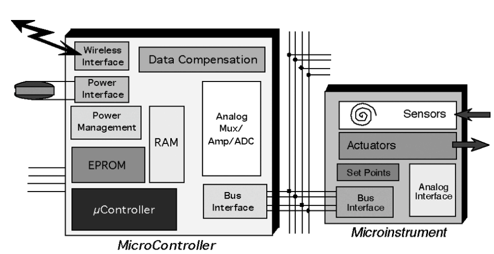

Fig. 2 (right): The system architecture for the distributed nodes.

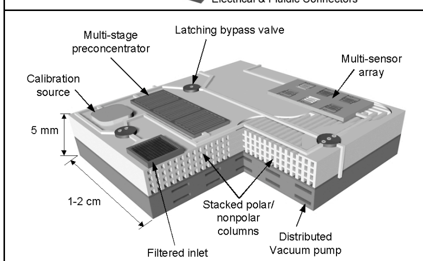

Fig. 3 (left): The long-term vision for the micro GC.

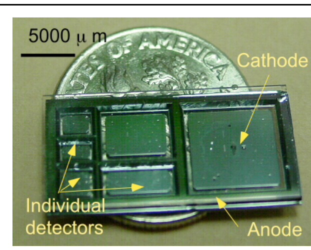

Fig. 4 (right): The micromachined Geiger-Muller counter.