Microelectronics in the "More than Moore" Era

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In the fifty years since integrated circuits made their debut, we have witnessed amazing progress in the ability to perform electronic functions. Progress in microprocessors, memory, and data conversion has revolutionized data processing, control, communications, and the way we live. The number of transistors/ chip has increased by a factor of a billion and performance has improved at least a million-fold, with corresponding decreases in cost. For forty years, this progress has been driven by scaling and "Moore's Law"; however, fabrication facility cost has now increased to the point where it now exceeds the GNP of many countries, forcing many companies to go fabless. It also appears that the scaling paradigm is coming to an end, at least using devices as we know them. As a result, intense efforts on chip-stacking, through-silicon vias (TSVs), and new materials such as graphene are underway [1].

As we move beyond scaling ("More Moore") to attack critical problems in health care, the environment, infrastructure, security, and energy, microsystems will be required that combine low-power micro-electronics with sensing, wireless interfaces, advanced packaging, and energy scavenging. They will create major new markets, ushering in what has been called the "More than Moore" era.

Fig. 1 shows a generic architecture for microsystems that allows the major VLSI components to be shared over many applications. The microcomputer contains a wireless interface and a data-compensation engine that enables sensor calibration in software. It interfaces with an energy scavenging system and an open-architecture sensor bus that can accommodate a variety of sensors using a standardized bus interface. Thus, the microsystem can be configured for a given application based on the sensors selected and software loaded into the processor. Fig. 2 shows a microsystem [2] that integrates a microcomputer, flash memory, and sensors for pressure, temperature, and humidity into a silicon platform with TSVs.

A number of representative microsystems are now in development. The block diagram of an integrated gas analyzer based on gas chromatography is shown in Fig. 3. A preconcentrator adsorbs the analytes present in a sample of air and then thermally desorbs them into a column, from which they emerge separated in time to allow identification. They are converted into electronic form using an array of chemiresistive detectors based on gold-thiol nanoparticle films. Fig. 3 also shows the chromatogram from a cell-phone-size device, identifying the biomarkers for tuberculosis in breath [3]. Although the scaling limits for such devices are not yet known, Fig. 4 shows a 10cm-long microcolumn and a single-bed preconcentrator loaded with carbon nanotubes on a U.S. dime. Such devices could have a revolutionary impact on food processing, security, and health care.

Fig. 5 shows an intraocular pressure sensor being developed for treating glaucoma. The device, implant-ed in the iris, will take pressure readings every 15 minutes and transfer the stored data on demand once a day to the external world. It uses a glass-in-silicon wafer process [4] with a capacitive pressure sensor, an embedded processor, a rechargeable power source, and a wireless interface. The Phoenix processor [5] holds data at 30pW and operates at the nanowatt level. Finally, Fig. 6 shows an implantable neural interface with recording sites on 200µm centers [6]. Such devices, joined with implanted processors and wireless interfaces are emerging to launch a revolution in understanding the brain and treating its disorders.

This work was supported by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9986866, by a gift from Ms. Polly Anderson, and by the U.S. Army Research Laboratory (MAST Technology Alliance) under Contract W911NF.

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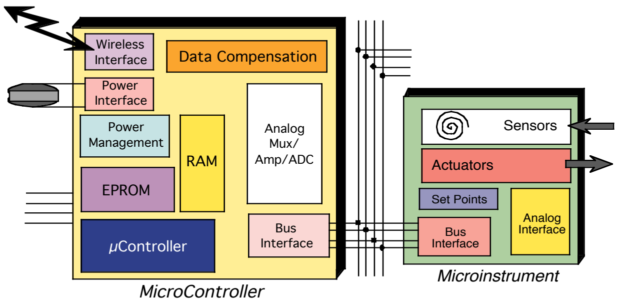

Fig. 1: A generic microsystem architecture.

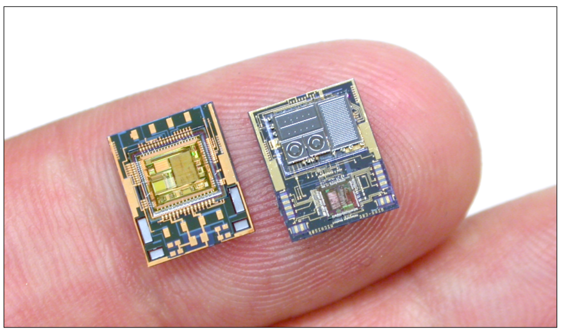

Fig. 2: An integrated microsystem integrated into a silicon platform, back- and front-side up [2].

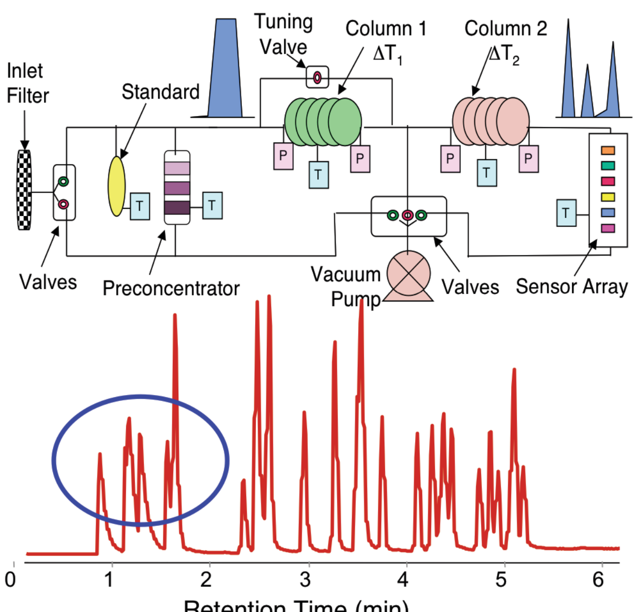

Fig. 3: Block diagram of a chromatography-based gas analyzer (above), with a chromatogram separating breath biomarkers for tuberculosis from interferences [3].

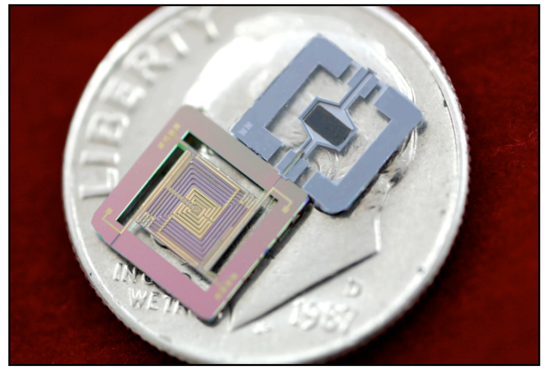

Fig. 4: A CNT-loaded preconcentrator and 25cm separation column on a U.S. dime.

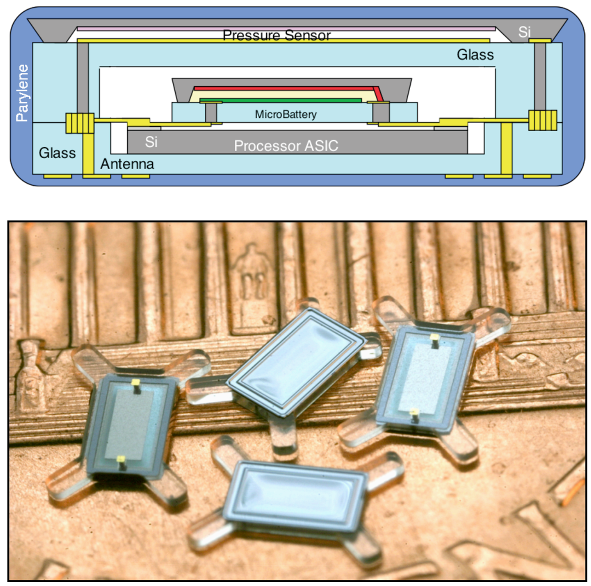

Fig. 5: Block diagram of an intraocular pressure sensor containing a processor, sensor, power source, and wireless interface in a parylene-coated glass package (above, along with several pressure sensors on a U.S. penny [4].

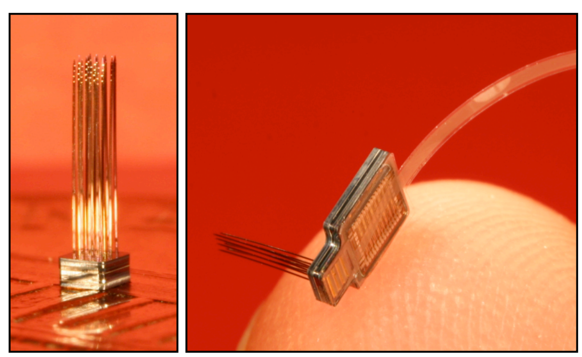

Fig. 6: A 3D microelectrode array for neural recording with 64 sites on 200μm centers (left) and a complete recording front-end with embedded signal processing on a fingertip [6].