Group Position Paper: Fundamental of MEMS Fabrication

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Overview: It is the consensus opinion of this group that MEMS fabrication technologies, in certain selected areas, have matured beyond the research and development stage and have enabled several high-volume products. Currently, the largest market segments for the MEMS industry include silicon-based pressure sensors, air-bag crash sensors, print heads for ink-jet printers, and digital light processors (DLP) for video projectors. The fabrication technologies that enable these high-volume products fall under two broad categories: bulk micromachining (pressure sensors and ink-jet print heads) and surface micromachining (air-bag accelerometers and DLP).

Bulk micromachining has a relatively long history of research and development. It is based on a combination of isotropic and anisotropic etchings of single-crystalline silicon to form micro mechanical structures from the bulk of the silicon wafer. Heated strong alkaline solutions were used to remove silicon material preferentially except the exposed [111] planes. Later, deep reactive-ion etching (DRIE) was developed to enable a greater degree of 2-D design freedom in creating microstructures with high aspect ratios.

Surface micromachining, on the other hand, is based on sequential deposition and etching of thin films on the surface of a carrier substrate. One or more intermediate thin films (the sacrificial layers) are removed in the final steps, leaving the subsequently deposited thin film structures hanging or released from the substrate. These hanging structures form the proof mass and the spring suspensions for accelerometers, or the micro mirrors in DLPs.

A unique characteristic of both of these MEMS techniques is their roots in microelectronics technology. The basic lithography, patterning, and batch fabrication approaches and equipments are adopted from the IC industry and customized to create micromechanical devices. At the same time, MEMS fabrication is progressing rapidly beyond the tool sets available in IC manufacturing. Other key techniques include wafer bonding that allows stacking of wafers with microstructures, deep X-ray lithography combined with plating and molding (LIGA) to create high-precision, high-aspect-ratio microstructures, laser micromachining, electro-discharge micromachining (EDM), thin-film or monolayer self assembly, etc. There are also other techniques customized to create microstructures based on materials other than silicon, such as SiC, polymers, ceramics, diamond thin films, metals, alloys, etc.

Challenges: It is the consensus of this group that there remain significant challenges in MEMS fabrications that are worth investigating. There is little dispute that MEMS fabrication research requires a multi-disciplined approach. In contrast to the IC industry, there are virtually no standardized MEMS fabrication techniques equivalent to the CMOS technology that will satisfy a majority of MEMS device fabrication needs. The materials used in MEMS fabrication are also far more varied than in electronics. Furthermore, compared with the IC industry, the volumes in MEMS are inherently lower due to the specialized nature of the specific devices. Finally, it is also obvious to this group that MEMS fabrication is coupled with the specific application as well as packaging and reliability, which are the subject matters of the other two groups.

Due to the vast diversity in MEMS fabrication methods and the intended applications, there was no *a priori* consensus on a single, prioritized list for research investment and technology roadmap. This group will engage in in-depth discussions on this issue. Several potential criteria for developing the fabrication roadmap, or at least a list of prioritized research topics, may include technology-push vs. application-pull, high-value vs. high-volume, incremental vs. disruptive approaches, commercial vs. scientific values, etc.

Research Topics: The individual members of this group proposed the following research topics:

LIGA and Ultra-Deep LIGA (M. Chyu, K. Kelly)

The goals are to establish a LIGA process that is manufacturable and to enable precision microstructures as thick as several mm. Research issues include wet developing process, thermal stress control, numerical simulation of wet processes, materials issues, plating high-strength alloys, etc. The potential benefit is the low-cost manufacturing of microstructures with virtually unlimited choices of structural materials, excellent heat transfer characteristics in the final devices, molds for polymer medical devices, etc.

Further Miniaturization and Nanofabrication (S. Evoy, G. Fedder, A. Tseng)

The goal is to establish processes to create sub-micron-scale devices. Research issues include internal dissipation and materials characteristics, transduction mechanisms, integration techniques with micromechanical devices and electronics, ever-higher aspect ratios, dimensional uniformity, repeatability, combining both small (microns and sub-microns) and large (> cm) dimensions in the same process flow, laser/FIB/FEB maskless fabrication, CAE/CAD/CAM tools for process flows, etc. The potential benefits are higher operating frequencies, potentially greater durability, ultra-sensitive force detection, deployment of novel experimental toolbox for nanostructural studies of materials, etc.

New Materials (G. Fedder, R. Horning, CJ Kim, T. Saif)

The goal is to establish processes that incorporate new materials beyond silicon, such as “active” materials, optical coatings, polymers, plastic, biodegradable materials, etc. Research issues include process compatibility, diversity in processing techniques and properties of polymers, scaling polymer processes to MEMS level, processing of quartz and glass, integration with electronics and mechanics, etc. The potential benefits include better performance or new functionality, low-cost production even at low volume, disposable products, biocompatibility, self-packaged devices, true 3-D shapes, leveraging the vast infrastructure of the polymer industry, etc.

Manufacturing Technology and Infrastructure (M. Chyu, G. Fedder, M. Huff, CJ Kim, N. Najafi, S. Pang, T. Saif, B. Sulouff)

The goals are to establish the technology to ensure manufacturability and to establish a resource for flexible manufacturing to support different process sequences while maintaining high quality, reproducibility, and relative low cost. Research issues include MEMS process control monitors, surface properties, contamination causes and effects, process modularization, process analyses, modeling and prediction, etc. Low temperature processing is gaining further importance to prevent the temperature bottleneck, especially with the increasing use of polymers. The benefits include efficient and cost-effective prototyping of research designs, stable manufacturing process for small to large volume production, short product development cycles, etc. Development of infrastructure for non-silicon processes is worth considering.