Position Paper: MEMS Fabrication

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Overview: Major advances in MEMS fabrication in the last 15 years include polysilicon surface micro-machining, the Bosch deep Si RIE process, and the creation of Si-Si wafer bonding processes. Modern equipment for the latter two processes has accelerated research and commercialization of bulk micromachined structures. Other highlighted advances include TMAH as a wet Si etch, LIGA (and LIGA-like) plating and molding processes, and the recent emergence of silicone (PDMS) molding and transfer to make structures for microfluidics.

Perhaps the most prolific research theme in MEMS fabrication is the incorporation of new materials. Slightly tensile polysilicon and low-stress silicon nitride are innovations from the early 90 's. Recent work on thin-film polycrystalline SiGe microstructures is motivated by the low temperature deposition and post-CMOS compatibility. Thin-film SiC structures deposited in molds and planarized with CMP are promising for applications at high temperatures and in harsh environments. ZnO and PZT continue to be explored as MEMS -compatible piezoelectric thin films for actuation and sensing. Most microfluidic structures incorporate SU8, parylene, PDMS, laminated plastics or injection molded plastics. In particular, with its ease in making high-aspect –ratio channels,SU8 resist has become increasingly popular in combination with glass or silicon bonding. Electroplating and sputter deposition of magnetic materials, including NiFe (permalloy), NdFeB and CoP , are of current interest for use in magnetic field sensing, actuation, and miniature probe-based data storage.

The number of MEMS fabrication techniques and process flows is far too large to discuss comprehensively in two pages. Most of these processes can be grouped into several broad areas. Much work is still ongoing on “standard ”surface and bulk micromachining.The U.Michigan dissolved wafer process successfully integrates surface and bulk micromachining techniques. Molding processes, as mentioned earlier in discussing LIGA, SiC and PDMS structures, are widely used in MEMS. Polysilicon (and silicon nitride)molding techniques, such as the HEXSIL process, have advantages in making high-aspect structures and microtubing. CMOS micromachining forms structures directly from the CMOS interconnect layers from which complex heterogeneous structures are made from multiple aluminum, polysilicon, and oxide dielectric layers. Deep Si RIE structures are now in widespread use, and several techniques have been offered to provide structural release and electrical isolation. Si structures are undercut with an isotropic etch in Cornell 's SCREAM process and interconnect is provided with sputtered metallization on the sidewalls. SOI MEMS processes have a built-in oxide sacrificial layer, which also functions as electrical isolation. Alternatively, Si bonding processes can first provide a pre-etched pit underneath the microstructures and oxide trench-fill isolation can provide electrical isolation. Carnegie Mellon 's CMOS-MEMS process has been recently extended to incorporate DRIE Si, where interconnect is provided through thin films on top of the Si structures. Certain kinds of 3-D microstructures can be made through multi-stacked wafer bonding, laser-assisted Si etching and microstereolithography. Another approach to 3-D structures is assembly of hinged 2-D structures. Polysilicon hinge technology with electrostatic

assembly is fairly advanced, and is primarily used in micro-optics applications. Bendable metal hinges with electromagnetic assembly have also been demonstrated.

Research Priorities: The advantages of MEMS are batch fabrication at low unit cost, miniaturization of function, and integration of sensing, actuation and information processing. Research in manufacturing continues to be driven by these factors. Most past, current, and future research thrusts can be grouped into three areas: technology scaling, materials and process integration, and manufacturability.

Scaling is important to almost all applications. Smaller (dimensions <10 microns) is better for applications such as high-density imaging pixels, high-frequency mechanical resonators, biomolecular measurements, and probes for microscopy and data storage. Bigger (dimensions >10 microns) is better for proof mass in inertial sensors and in most microfluidic channels. An ongoing challenge is in combining both small and large dimensions in the same process flow. A good example is in large-area sensor and actuator arrays for aerodynamic control. The sensors and actuators are micron sized, however it is desirable o have the array span over more than 100 sq. cm. Another example is the general challenge of making truly 3-D microstructures while maintaining the economics of batch fabrication. At the nano end of the scale, manufacturing research is driven by the national thrust on nanotechnology. This research must address problems with ever-higher aspect ratios, dimensional uniformity and repeatability.

Introduction of new materials within process flows often leads o process compatibility problems, such as excessive processing temperature, inadequate adhesion, high residual stress, and undesired chemical reactions. The potential better performance from new materials justifies his research. Several process flows that already integrate micromechanics and electronics benefit greatly from further integration of new materials. Some priorities include micromechanical process integration of “active ”materials (e.g.,PZT),of thin-film magnetic materials, of optical coatings, and of polymers. In the latter category, engineered polymers appropriate for biochemical applications are needed for structures, detectors and actuators in microfluidic systems. A growing area is biocompatible microsystems, for example, biodegradable MEMS materials.

A final area of importance is manufacturability, which includes process control, reliability and packaging. Research on MEMS fabrication and packaging is coupled, since the best solutions will probably integrate aspects of packaging directly with the microsystem. Process integration and reliability are also linked. Two examples are long-term mechanical reliability of composite microstructures in CMOS microsystems and reliability of interconnects on deep Si RIE structures.

The Role of NSF: **NSF** plays an important role in funding projects that have intellectual merit and make an impact on society. The recent successes a commercializing microoptics and microfluidics demonstrates the continued impact MEMS is having on society. However, future success requires a significant investment from NSF in research on innovative MEMS materials, processes and characterization with an emphasis on application-specific needs. Nanotechnology is an emerging and fertile research area, and MEMS fabrication will probably play a crucial role in interfacing nanosystems to the external world. An extremely important role of NSF is in the continued support for educational programs in MEMS, particularly programs that provide

education across traditional disciplinary boundaries. Fabrication of MEMS is best taught “hands on,” so continued investment in equipment infrastructure for dual use in research and education is essential.