Position Paper: Manufacturing Issues in Integrated Systems of Small Size

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Introduction: Microfabrication has played the key role in the fast development and commercialization of Micro-Electro-Mechanical Systems (MEMS). With the proliferation of integrated microsystems in the automotive, aerospace, health-care, telecommunication, and other industries, the quest for newer micro-manufacturing technologies is likely to grow at the same pace, if not faster. Manufacturing is inextricably tied to the materials used to build systems of any size. A report by a committee appointed by the National Research Council in 1997 [1] classified the evolution of micro-manufacturing technologies of the past, present, and future into four phases*:

- Phase 1: Old processing techniques for old materials
- Phase 2: New processing techniques for old materials
- Phase 3: Old processing techniques for new materials
- Phase 4: New processing techniques for new materials

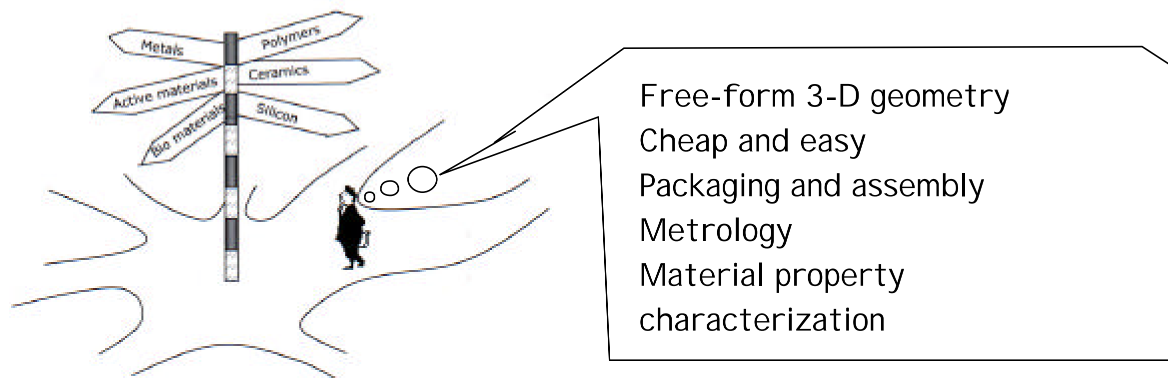

Figure 1 material crossroads for the engineers of the microsystems

Until now silicon, the *old* material, has been the choice material for microsystems, but recent trends in the field suggest that the interest in *new* materials is growing. As shown in figure 1, we are at the crossroads facing multiple material choices that include ceramics, polymers, active materials, bio-materials, and metals. While silicon has been a great semiconducting and mechanical material, it has its own shortcomings that include: expensive equipment, lack of the third dimension and freeform 3-d geometry, packaging, and the difficulties associated with making microsystems that can act upon macro environment. The new materials are shown to overcome some or all of the limitations. For example, integrated fluidic systems made using low

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* "Old" here refers to materials used in microelectronics and integrated chip (IC) processing techniques. By this definition, polymers and ferroelectrics are "new" materials, and sacrificial layer technique used to get released micro-mechanical structures, and deep reactive ion etching (DRIE) and LIGA used to obtain deep etching with vertical sidewalls are "new" processing techniques.

temperature co-fired (LTCC) ceramic tapes greatly alleviate the packaging problem [2]. The processing technology for polydimethylsiloxane (PDMS) is shown to be very inexpensive and fast [3]. Very large displacements and forces are shown to be possible with ferroelectrics [4]. Processing techniques for silicon carbide have been developed for high temperature applications [5]. Thus, the research is already underway in phase 3, and to some extent in phase 4. Micro-manufacturing techniques in the future should be directed in this direction to enhance the capabilities of building things at small sizes.

The Needs: In spite of impressive developments in micro-manufacturing techniques, the designers of microsystems today are still constrained in many ways. Accessibility and affordability and the choice of materials are the main reasons for this. The MEMS foundries (e.g., MCNC/Cronos MUMPs) have helped a great deal, but their fixed processes hamper widespread usage as newer materials in newer applications begin to emerge. Therefore, it is beneficial to develop inexpensive micro-manufacturing techniques for a wide range of materials. Furthermore, the ability to obtain freeform 3-d shapes, multi-material "hybrid" microsystems, and easing the packaging problems also necessitate further developments in micro-manufacturing. Other related issues include metrology, material property characterization, standardization, and CAD/cam. Although batch-processing without much assembly is preferred at micro scale perhaps assembly cannot be avoided as the range of materials and processing used grows. Therefore, improved micro-assembly technique will be useful. Finally, the "micro"-manufacturing techniques should extend their capabilities to the meso (100 μm to a cm) and nano (10^{-9} m) scales in order to encompass wider range of applications.

Current phase 3 and phase 4 techniques: Each design has its own unique features and may warrant a new processing technique even if silicon is chosen [6]. So, further developments (in phase 2) for silicon and related material processing will continue to be important. In this subsection, a few techniques that fall under phases 3 and 4 will be mentioned. The ceramic tape technology being developed at the University of Pennsylvania [2, 7] and other places is a good example of applying old processing techniques (CNC milling, punching, chemical etching, screen-printing, and co-firing) to a new MEMS material (the alumina-based green tape and Kapton). The soft lithography techniques [8] (near-field phase-shift lithography, micromolding in capillaries, microcontact printing, etc.) Being developed at Harvard university for polydimethylsiloxane (PDMS) are good examples that come under phase 4. Gray-tone lithography [9], laser micromachining [10], pulsed laser deposition [11], adaptation of macro manufacturing techniques to micro domain, etc. Will help enhance the capabilities of micro-manufacturing.

CAM for MEMS: In the last six years, the interest in computer aided design (CAD) of microsystems has grown significantly with several MEMS CAD companies in existence today. However, the efforts toward the computer aided machining (cam) are scarce. For example, when a designer creates and optimizes a solid model of a MEMS device, it will be necessary to automatically generate the masks for a lithography-based process. Some efforts in this direction are underway [12, 13], but more work that encompasses wider variety of processes is necessary.

Closure: Micro-manufacturing techniques for materials in addition to silicon will be helpful in faster growth of the microsystem technology. These techniques should address the critical needs of 3-D geometry, larger sizes than just a few hundred microns, hybrid structures, packaging,

assembly, metrology, material characterization, and CAD/CAM. These techniques should be widely accessible and easily affordable because the "microfabrictaion facilities" of today are likely to be the "machine shops" of the future. Finally, the development of micro-manufacturing techniques should pay attention to the emerging nanotechnology [14] as it will be mutually beneficial to both.

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