Position Paper: MEMS Manufacturing Fabrication: Going Back to Basics

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Fabrication is the heart and soul of any MEMS -based product. There are many other aspects of a MEMS-based product that would affect the product, including readout electronics and package. However, if the MEMS part is not reliable the entire product is rendered inoperable. Moreover, the best MEMS-based products can achieve is the performance of the MEMS components. Currently MEMS manufacturing technology is the most underdeveloped segment of the entire MEMS field. MEMS manufacturing problems demand a great deal of work, time and money while providing a small amount of glory in the sense of technical papers, SEM pictures, and lofty promises.

There were two major points mentioned in the invitation of NSF-2000 workshop on manufacturing of MEMS, MEMS fabrication section. The author agrees with the second point: "… however, the mechanical interfacing of these systems to the non-silicon world has been a problem. …Therefore, innovative techniques are needed for all fabrication processes to achieve the goal of making complex and reliable MEMS devices inexpensively."

The author, however, disagrees with the amount of emphasis placed on the first point: "with the increasing demand in MEMS applications, technical challenges lie in new processes capable of fabricating a variety of materials for MEMS as well as high aspect ratio microstructures. Broader micro fabrication technologies need to be explored and established."

As the founder of a startup company facing the challenges of MEMS fabrication manufacturing for the last 6 years, the author believes that there is a great need to refocus on the basics, rather than exploring new fabrication technologies and materials. There is no doubt that the emphasis on new fabrication technologies and materials is both exciting and attractive, with a great potential for publishing papers and cute SEM pictures. The author strongly believes, however, that there is a great danger rapidly approaching the MEMS manufacturers (or future manufacturers) due to (1) such an emphasis on new fabrication technologies and materials and to (2) lack of focus on the needs of MEMS manufacturing technologies that are currently at a fragile state of evolution. The existing MEMS manufacturing fabrication technologies are facing major manufacturing problems that have put their successful commercialization in great jeopardy. In other words, it is not a wise approach to try to directly go from crawling to 100-meter dash.

As much enthusiasm as there is for the future of MEMS technologies, there is real danger that MEMS technologies may never see fruition at a meaningful scale. MEMS can go either as far as silicon-based microelectronics has gone – present in every aspect of our lives -- or as low as GaAs-based microelectronics – only present in limited specialized applications. MEMS industry is currently at a much more vulnerable position than it appears, regardless of how wonderful its future may look like.

In the author's opinion, the magnitude of the difficulty of fabricating MEMS devices at the manufacturing level is highly underestimated by both the current and emerging MEMS communities. There is a great need to go back to the basics of MEMS manufacturing fabrication. Below are a few facts worth mentioning.

A Limited Number of MEMS Manufacturers and Products Exist: There are very few companies with real MEMS fabrication facilities at the manufacturing level. Up to now, only a handful of MEMS products have been manufactured, in areas such as automotive industry, ink jets, and disposables pressure sensors for blood bag applications. Most of other MEMS products are currently on the bubble: to be or not to be. The high-priced MEMS companies that were acquired in the recent months by the optical communication companies have neither real products nor real manufacturing capabilities. For example, JDS Uniphase is spending several hundreds of millions of dollars in establishing an MEMS manufacturing facility after acquiring coronus for $750M! According to the CEO's of these communication companies, the MEMS - based companies were acquired based on their perceived potentials (intangibles), and not based on their current states (tangibles). Therefore, one cannot look at these acquisitions as a sign of MEMS manufacturing success, rather more like betting on the future of MEMS. Similarly, there is no manufacturing success story in the creation of many recent MEMS startups; most of the startup companies have money but no real fabrication processes, manufacturing facilities or production expertise. Before emphasizing exotic new fabrication processes, we need to ask why there are only few MEMS manufacturers, and why the four basic MEMS processes (surface, bulk, LIGA, and dissolved wafer process) are only manufactured at a limited capacity. An important consideration is that although the success of these four basic MEMS processes has been limited, they nevertheless offer a great potential for the mass manufacturing of a variety of products. In other words, the current fabrication technologies and materials are advanced enough to satisfy the needs of the market; they are, however, are not developed enough (manufacturing-wise) to do so.

MEMS and Microelectronics Processes Are Not the Same: Although MEMS fabrication technologies are evolved from microelectronics fabrication technology, they are not the same. Indeed, MEMS and microelectronics fabrication processes are far from being the same. This fact is evident by the long development time and extreme cost of the MEMS technology development phase by large companies such as Delphi-Delco, Motorola, Ford Microelectronics Inc., and Analog Devices. The benefits that MEMS leverages from the microelectronics industry usually stop at the facility and equipment level, and in most cases, cannot be expanded to the fabrication manufacturing. Microelectronics fabrication is 2D while MEMS is a 3D process. The mechanical properties that are not important to microelectronics are vital to MEMS fabrication. A CMOS fabrication process is independent of the circuit under manufacturing (product); while a MEMS process must be custom designed for a specific product. At this time, establishing an ASIC paradigm equivalent for MEMS more and more looks like a mirage.

Difficulty of MEMS Fabrication at Manufacturing Level: MEMS fabrication at the manufacturing level is a very difficult task; to some extend much more difficult than that of microelectronics. The following words will put a great deal of fear in the heart of anyone who has spent a few years in real MEMS manufacturing: yield, repeatability, reliability, cost of product, and ownership cost of the manufacturing line.

No Infrastructure for MEMS Manufacturing Fabrication Technology: microelectronics manufacturing fabrication is recognized as a stand-alone field and as such there is a great deal of effort in understanding its issues and overcoming its problems. MEMS manufacturing fabrication does not exist as a standalone field, rather, it is perceived as a branch of microelectronics fabrication technology. Therefore, there has been no organized, and more importantly no focused, effort towards its evolution. Although single companies have paid attention to this field out of necessity (usually after wasting a few years), this lack of recognition is more evident at the national level. For all practical purposes, there is no infrastructure for MEMS manufacturing fabrication. All the efforts are done at a company level, reinventing the wheel over and over again.

Real Life, Real Problems! The manufacturing problems are not about new technologies; they are about carrying out the current technologies in a manufactureable fashion. A manufactureable process can be defined as a process that has the following characteristics: high yield, high reproducibility, non-sensitive to any single manufacturing step, functional, capable of producing high performance devices, and low cost. For example, we spent more than a year to develop a manufactureable anodic bonding technology using a standard, expensive, bonder from EV. The anodic bonding technology has been around for more than 30 years in the research field. Developing new manufacturing technologies and materials is pushing the frontier without having a base to stand on. MEMS manufacturing fabrication field needs the base, not the frontier. A few MEMS companies went bankrupt not due to lack of new technologies and materials, but due to the long process of converting existing technologies into manufactureable technologies.

Recommendation:

1. The author highly suggests that we pay more attention to the well being of the young technologies that are currently blossoming than to the future technologies.
2. It is of paramount importance that MEMS Manufacturing Fabrication be recognized as a standalone field. This will shed lights on the mostly-hidden problems and will allow the future improvements to be made in a much easier fashion. For example, national committees can be organized to attack some of the major associated issues in a collective manner. A new field must be created that is solely dedicated to MEMS Manufacturing Fabrication and all of its taboo words such as yield, reliability, and quality control.
3. Furthermore, establishing a standalone field will allow the US government to play a more focused role in facing the current problems. More specifically, NSF and DARPA, for example, can diverge a portion of the financial resources dedicated to future manufacturing fabrication processes and materials to identify and overcome the current manufacturing hurdles.
4. The selection criteria that has been used for MEMS federally supported efforts is heavily biased towards “high risk-high reward” projects. This is justified for basic research activities; however, “high risk-high reward” is not the best selection criterion for the manufacturing-related projects. In business there is a common rule of thumb, referred to as “rule of 10,” which suggests that the cost of making a pre-manufacturing prototype (i.e., Technology Transfer Phase) is about 10 times the cost of making an R&D prototype (i.e., Basic Research phase). Also this rule states that the cost of producing the final products (i.e., Manufacturing Phase) is about 10 times the cost of the Technology

Transfer phase. In other words, the cost of manufacturing a MEMS product is about 100 times the cost of the development of the R&D prototypes (i.e., basic research). Our experience from carrying out our projects confirms this rule. An important consideration is that the factors that prevent investment (from companies or venture capitalists) are different for the MEMS basic research and MEMS manufacturing. While the high risk factor prevents an investment in the basic research, the high cost and long development cycles are the factors that prevent such investments in MEMS manufacturing. As a result, it is of paramount importance that US government assists the evolution of MEMS manufacturing fabrication based on a new set of criteria.

5. With all due respect, although most MEMS professors are excellent researchers and creative thinkers, they usually have both little knowledge and no experience pertaining to MEMS manufacturing issues. Worse, in many cases, they have a distorted version of the manufacturing reality, which in turn may adversely affect the field. The same way that MEMS basic research should be directed by MEMS academia, manufacturing efforts should be governed by the people who are in the frontline of the battle: manufacturers. In the author's opinion, the heavy involvement of MEMS academics in MEMS manufacturing efforts would result in more MEMS technologies that are not ready for manufacturing. Therefore, a suggestion is to have only a few percentiles of the people involved in a MEMS manufacturing effort be from MEMS academia, and none in a leading role. The author, however, highly recommends the involvement of academic experts in the following fields: manufacturing sciences and industrial operations.