

## **Position Paper: Opportunities for Research Collaboration in the Manufacturing of MEMS**

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**Introduction and Overview:** Many opportunities exist to improve the fundamental understanding of MEMS manufacturing processes. Analog Devices manufactures for shipment over 2 million surface micromachined accelerometers per month for applications in a wide range of inertial sensing, with the largest being the air bag. Research into the manufacturing of Micro-Electro-Mechanical Systems (MEMS) requires a multi-disciplined approach to a very complex subject. As much as researchers would like to believe that science precedes production, much the opposite seems to occur. Simple cause and effect relationships are used to initiate a MEMS process using equipment and materials in common use. The manufacturing capability and limits are soon discovered and design of experiments is applied to reveal the hidden variables and ultimately the theoretical basis. Economics dictate that yield with control and consistency is the best indicator of success. Experience at Analog Devices has shown that success in yield results in a reliable product with the appropriate disclaimers for application and environment.

**Research Priorities:** There is such diversity in MEMS fabrication methods and applications that a prioritized list would be impossible to develop. However many common requirements and a strong trend to more complexity and smaller sizes does exist. Methods to simulate, measure, characterize, and correlation techniques can be applied to many manufacturing environments. The tools and techniques available to understand the physics of materials and surfaces as MEMS devices go through the substrate fabrication, packaging, testing and application life are required. Many times the MEMS device in production is the most appropriate means of measuring manufacturing process issues but due to the competitive environment of industry no information is disclosed. Process control monitors are a commonly used method in IC fabrication and are also valuable for MEMS production. These process control monitors also make correlation across industry possible. MEMS devices do have some common attributes that often have a large impact. The role of surfaces, contaminants and large surface to mass structures make the monitoring and definition of “clean” a challenge. Like wise identification of the surface condition in a cost effective manner in production requires new methods and tools that can be used by production personnel.

Directed research of these analysis methods and tools to the real world of MEMS manufacturing would be most productive and interesting if applied to the “hot applications”. Optical MEMS is currently creating billions of dollars of valuation and receiving high levels of attention and easily qualifies as a hot application. BioMEMS is another hot application that has been identified as promising new levels of impact both socially and economically. Unfortunately there is a reverse correlation between hot applications and manufacturing experience. Optical MEMS and BioMEMS are emerging and dramatically changing which equates to a lack of manufacturing experience base or even a well defined trend. Predicting the appropriate manufacturing research before there is manufacturing leads me to believe that common tools and techniques applicable to current production should be applied and extended.

**Role of NSF:** Manufacturing is performed by industry and is specific to a product and manufacturing process. NSF has the opportunity to address common issues in MEMS manufacturing if there is industrial manufacturing, industrial research and academic/technical institute research in collaborative roles. Funding that encourages this type of collaboration should be pursued by NSF. Matching funds with significant industrial contributions are a means of encouraging collaboration. NSF funding in support of centers of expertise which provide for a critical mass of personnel and equipment would be productive assuming that there is sufficient industry participation.

**Recommendations:** MEMS manufacturing research is cross functional and would benefit from interaction from the Fundamental MEMS fabrication, application and packaging/reliability groups. The after lunch times would benefit from some type of interaction.