Position Paper: Critical Role of Materials Research for Packaging and Reliability of Micro-Electro-Mechanical Systems (MEMS)

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Overview: Packaging and integration of micro-electro-mechanical systems (MEMS) is a critical enabling technology that involves the design and interconnection or interfacing for optical, electrical, electromagnetic, mechanical and thermal functions of individual micro devices, components, and functional units for high-performance and reliable operation of a macro system and its low-cost manufacturing. Researchers and engineers in MEMS packaging and integration ought to be jacks-of-all-trades. On one hand, they have to understand physics of the devices/components/units to be integrated and their operation requirements; while on the other, they have to work closely with application engineers to know the system-level requirements, operating environment of the system, user preferences or aesthetics of the system. These interactions are necessary to design the package architecture for the system. As they engage in the interfacing and protection of system fabrication, they have to demonstrate their core competence in physics and chemistry of materials and processing as well as the interactions between different materials and processes that may contribute to failure mechanisms. Furthermore, they also have to constantly monitor market directions and develop new materials and processing technologies to allow low-cost manufacturing of the systems.

It is clear that MEMS packaging and integration falls in the multidisciplinary field of science and engineering and requires the efforts of a team of researchers and engineers who are willing to cross over the traditional disciplinary boundaries. Georgia tech's packaging research center (prc), funded by the national science foundation (nsf) as an engineering research center (erc), is advancing the packaging and integration technologies for the microelectronics industry by successfully pooling together a team of experts in disciplines like electrical, materials, mechanical, industrial systems. Virginia tech-based center for power electronics systems (cpes), also an erc funded by NSF, has a multidisciplinary research team addressing challenges in the packaging and integration of power electronics systems. Both prc and cpes mainly deal with the integration of electrical devices and components. Researchers in MEMS packaging and integration face more difficult challenges because they have to deal with the integration of electrical and mechanical devices and components in a package and have to pay additional considerations to dynamics of motion and its interactions with thermal (thermodynamics) and surroundings (fluid dynamics and friction).

Although one may see the performance and cost advantages of MEMS based on the successes of the integrated-circuits industry, moving parts in an MEMS package pose a unique challenge to address the concern for its reliability. In addition to all the failure mechanisms experienced in an electronic package, such as thermo-mechanical stress caused fatigue, due to its required electro-mechanical-thermal couplings, an MEMS package may encounter yet to be discovered failure mechanisms within its constituents and at materials interfaces. Traditionally, reliability part of packaging and integration research is done near the end after a considerable effort has been devoted into materials and processing developments. This may lead to the danger of wasting

valuable resources on some intrinsically unreliable concepts and approaches that never succeed in the marketplace. Therefore, given the more processing and integration complexity of an MEMS package, it is important to adopt the concept of design for reliability in the early stage of every development effort for MEMS. Assessments of intrinsic reliability based on physical principles have to be done when selecting a combination of materials for interfacing and protection, processing conditions (temperature, pressure, time), and application conditions (voltage or current levels, extent of motion, speed, environment, etc.).

Research Priorities: There should be no doubt that packaging and integration of MEMS is critical to the success of the MEMS industry. It should also be clear that to make significant advancements in MEMS packaging and integration, multidisciplinary research efforts should be focused on solving fundamental issues related to materials and process developments and understanding of the behavior of different materials and interactions between them under the influence of electromagnetic, electro-mechanical, and thermo-mechanical driving forces. Therefore, the following areas should be included in future research priorities:

- Processing of interfacing and protection materials for an MEMS package aiming at improving system performance, reliability, and manufacturability;
- Interface engineering for reliable and high-density integration of different types of materials in a high-performance MEMS package;
- Study of degradation of materials and materials interfaces under electromagnetic, electro-mechanical, and thermo-mechanical loads;
- Development of integrated analytical tools for performance and reliability prediction at the component and system level.

Role of NSF: Since research efforts for MEMS packaging and integration are highly multidisciplinary and are likely considered to be high risk by the MEMS industry, the National Science Foundation should foster a collaborative environment that promotes close working relationships between academia and industry. NSF ought to increase the funding level to programs that address the fundamental barriers blocking the technological advancements of the MEMS industry. NSF should continue to fund high-risk single-investigator projects that address the specific areas of MEMS packaging and integration to plant seeds for future breakthroughs. Multidisciplinary multi-investigators programs that have a significant support from the private sector have to be encouraged and awarded by NSF. However, the approach of funding a few large research centers at the expense of single-investigator projects ought to be avoided.

Recommendations: The format of vertically integrated workshop such as this one that brings together researchers in device/component, packaging and integration, and manufacturing is excellent for promoting idea exchanges amongst the participants and ought to be continued. To better inform and define future research challenges and opportunities, it is suggestive that a coherent roadmap for MEMS technology development should be worked out at this workshop or at the next one in the near future.