Position Paper: CAD Enabled Innovation of MEMS Applications

N. R. Aluru
Beckman Institute for Advanced Science and Technology
University of Illinois, Urbana, Illinois 61801

Introduction: The current approach to developing innovative microsystem applications is a long layout, build and verify process. This approach is very expensive and time consuming with little or no design optimization built into it. Development of commercial successes like micromachined accelerometers, pressure sensors and optical displays took at least a decades time of hundreds of designers and engineers. Rapid prototyping of innovative MEMS technology can only be enabled by breakthrough advances in a number of areas: advances in non-traditional fabrication approaches, new design methodologies with a clear separation between design and manufacturing, efficient and accurate computer-aided design (CAD) tools for mixed-technology systems, and robust control and design optimization strategies. Such advances will provide aggressive designers with a host of weapons to explore radically new applications at microscopic scales.

Since our research expertise is in the area of CAD for microsystems, in this position statement, we summarize how advances in CAD can enable new developments in MEMS applications. Specifically, we discuss research issues in 3 areas - process design, device design and integrated system design.

Process Design: Process simulation typically involves the conversion of a two-dimensional layout geometry and process information into a three-dimensional geometry. The shape of the resulting three-dimensional geometry is very important as it serves as the starting point for functional or device design and the device performance could depend significantly on the device shape. Some of the existing process simulation tools (e.g. Simulation of oxidation, diffusion, etching, deposition and ion implantation processes) for VLSI technology could be applicable to MEMS fabrication processes. However, they have not been fully integrated into existing MEMS CAD systems. In addition, some of the fabrication processes for MEMS are very different from those of VLSI technology. In such cases, very little or no CAD tools exist for manufacturing processes. Design of innovative MEMS applications can be accelerated by utilizing existing process simulation tools and by developing CAD tools for new fabrication processes.

Mixed-Domain Device Design: A fundamental challenge to micro sensor and actuator development is to be able to predict the functional behavior of the micro device. Development of CAD tools for many existing as well new applications in MEMS has been very complicated due to the following reasons:

1. The presence of several energy domains (mechanical, electrical, fluidic, chemical, biological, optical etc.) or analysis functions complicates the development of device CAD tools. For example, in most macroscopic devices the interaction of two or at most 3 energy domains is the most complicated scenario. However, in microsystem designs the presence of two or 3 energy domains is a very common problem.

2. Macroscopic theories at microscopic scales are not valid for some energy domains e.g. fluidics. The breakdown of continuum theories at small scales necessitates the use of molecular approaches such as Monte Carlo and molecular dynamics techniques. Incorporation of molecular approaches into CAD tools significantly increases the design cycle time.
3. For many new and emerging application areas in microsystems, mathematical theories that can accurately describe the device behavior are missing. For example, mathematical theories for biomaterials (such as hydrogels) are missing. Existing theories do not describe the experimental observations. In addition, accurate constitutive relationships for the material behavior are also missing.
4. Lack of data on material properties has been a big issue. This can be expected to be more of an issue for MEMS applications based on new materials.

Breakthrough developments in the above research topics could lead to advanced CAD tools for accelerated microsystem design.

Integrated System Design: Integration of electrical, mechanical, optical and fluidic components on a chip enables design of revolutionary integrated systems. Analogous to very large scale integration of electronic components on a chip, system-level design tools for integrated microsystem technology can enable revolutionary advances in rapid system level design. Critical research issues that need to be addressed are:

1. Development of structured design methodologies for integrated micro system design
2. Development of compact or reduced-order models for micromechanical, microfluidic, optical, electronic and other components
3. Development of spice-like simulation tools for integrated microsystems

Summary: While a number of applications have already been prototyped using MEMS technology, there is abundant scope for development of new applications, especially in microfluidics, optics, and biomedical areas. Development of efficient and accurate CAD will not only enable design optimization of existing applications, but will also lead to rapid computational prototyping of several innovative applications.