An Information Technology Initiative on

High Aspect Ratio Microsystems Computer-Aided Engineering (HARMCAE)

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Introduction

Distributed fabrication of microsystems is a fact; the DARPA-sponsored MUMPS program has demonstrated the possibilities for remote microfabrication of microelectromechanical systems (MEMS) on a small scale. While this exemplary effort has enabled many designers without direct access to microfabrication tools to participate in the design of MEMS, additional developments will be required to broaden access to a full set of microfabrication processes to the entire design community.

The most important requirement is for the development of a new generation of computer-aided design/engineering (CAD/CAE) tools, which provide a clean separation between the designer and fabrication engineer without sacrificing the essential design freedoms. Lessons from the distributed fabrication of VLSI devices may provide guidance, but not necessarily a clear path to achieving a clean separation between the designer and the fabrication process for MEMS. Innovation in VLSI design is through the logical combination of basic components to obtain a desired function or level of performance; innovation in mechanical systems often relies on variation in the physical geometry or material composition in the realization of a fundamental physical law. It is essential that a full set of fabrication processes be available to a designer through CAD/CAE tools, so that innovation is not sacrificed for simplicity.

To date, most tools for MEMS CAE have focussed on the established wet bulk and surface micromachining processes for silicon-based MEMS. In order to realize innovative microscale designs requiring freedom in geometry or materials selection fabrication processes for producing high aspect ratio microsystems (HARM) are proliferating. Some of the processes available include: deep RIE; the LIGA process (a combination of x-ray lithography, electrodeposition, and molding); the UV-LIGA process based on new deep-UV photoresists, such as SU-8; and mechanical micromachining processes (MMP), which combine traditional material removal methods such as milling and drilling in the manufacture of microstructures. It is important that future developments in MEMS CAE tools and languages account for the broad needs of the diverse set of HARM fabrication processes at an early stage in order to give designers access to the widest possible selection or combination of manufacturing processes in the future.

NSF Workshops

The NSF held a series of workshops focussing on structured design/fabrication tools for rapid prototyping and MEMS. One workshop was dedicated to the future of distributed design and fabrication of MEMS. Some of the key points include (Antonsson, 1996) :

- A clean separation between design and fabrication is one ideal for MEMS manufacture, but may be difficult to achieve for true 3-D structures;
- Accurate simulations of fabrication processes are necessary for a reduction in the number of prototype cycles;
- NSF should support an infrastructure for MEMS processes in order to expand the community of designers;
- A digital data interchange format must be developed for conveying information for all analyses, not just shape;
- Improved mask layout generators should be developed.

The projected timeline for development of HARM, at the time primarily LIGA, CAE capabilities was ten years downstream. The rationale for the delay was that the number of HARM applications was limited and the commercial viability of the processes unproven. The subsequent rapid development and proliferation of deep-UV photoresists such as SU-8, molding of HARMS, and deep RIE silicon etching were not anticipated.

Proposed Initiative

Goals and Fundamental Issues

The initiative will be directed toward establishing the framework for a clean separation between the designer and fabrication engineer in the manufacture of high aspect ratio microsystems with the LIGA and UV-LIGA processes. This will include definition of the requirements, development or adaptation of necessary tools, and demonstration of distributed fabrication of HARMs across a clean separation.

Several questions must be answered in order to complete the proposed CAE tool development and testbed demonstration. The MEMS CAE community and NSF have expressed a strong interest in obtaining a clean separation between the designer and fabrication engineer, following the model of the VLSI community. This is understandably motivated by the cost of fabrication facilities in both VLSI and MEMS, but it is contrary to the trend in macroscale system design and manufacturing. One of the objectives of this work will be to determine whether the clean separation can be achieved for the LIGA and UV-LIGA processes through intelligent CAE tools.

The desired clean separation introduces a second question. The assumption in VLSI is that the designer is responsible for the planar mask set transmitted to the fabrication facility. This is consistent with the Manhattan geometry of a VLSI device. The design of HARMs starts with a 3-D realization of a microstructure or device. Reticulation of the object into mask patterns on the design side of the boundary is not as natural a step. If reticulation is shifted to the fabrication side of the clean separation, some process parameters must be defined on the design side. The CAE tools will have to enable this shift without requiring the designer to acquire detailed, process-specific knowledge.

Finally, once a parameterized design is passed to the fabrication facility, the degree of automation possible in parsing the design into a sequence of process commands must be established. Neither LIGA nor UV-LIGA are automated as processes, although some progress has been made with individual fabrication steps. The degree to which automation can be implemented will significantly affect the development and effectiveness of the CAE tools; operator intensive fabrication setup or operation would eliminate many of the gains in productivity obtained by automating the design process.

Principal Tasks

The principal tasks for the HARM CAE Initiative will be:

- Identify process parameter definitions required at the design stage to achieve the desired function and physical geometry of microsystems manufactured with the LIGA and UV-LIGA processes;
- Develop procedures for parsing designs passed across tbe design/fabrication boundary into a process sequence comprised of command sets for different fabrication steps (e.g. X-ray exposure, electrodeposition);
- Develop or adapt tools for reticulating parameterized 3-D designs into a set of 2-D mask patterns;
- Investigate knowledge-based approaches for selecting optimum HARM microfabrication processes for a given system;
- Develop or adapt simulation tools for process validation (e.g. electrodeposition, molding);
- Demonstrate remote design and fabrication of benchmark objects for evaluation of the CAE tools and the microfabrication processes. Transmit designs from remote sites across the network to fabrication facilities. Evaluate the process and results;

Completion of the proposed tasks will establish the potential of using intelligent CAE tools to permit remote design and fabrication of HARMs using diverse processes.

Rationale and Impact

LSU is becoming one of the recognized leaders in the development of HARMs fabrication processes and diverse applications of those processes in a variety of fields. The Governor's Vision 2020 Plan identified microsystems development as one of the areas for focused economic growth in Louisiana. The unique resources available at Center for Advanced Microstructures and Devices (CAMD), complemented by laboratories on campus, have allowed faculty members to draw over $14 million in competitive research grants since 1993. An effort is underway to establish a NSF Engineering Research Center for Modular Microsystems (CM^2) to carry developments into new applications and extend development of current research thrusts. The ERC will continue the effort to seek out industrial collaboration for HARMS research and development at LSU. Development of the proposed HARMCAE tools will enhance accessibility of the HARM fabrication resources to potential industrial partners and be a foundation for the center programs.

The project will be led at LSU, but active collaboration will be sought at other state universities, in particular the Institute for Micromanufacturing (I*f*M) at Louisiana Tech and the Advanced Materials Research Institute (AMRI) at UNO. In addition, partnerships will be established with commercial MEMS CAD software vendors, including IntelliSense (Wilmington, MA) and Microcosm (Cambridge, MA), to insure compatibility with existing software suites.

Requested Resources

There are significant ongoing activities at LSU in HARM design, fabrication, and education. The potential sustained growth of the program is apparent in the growth of funding and graduates. We are therefore requesting that our activities in this area be strengthened and enhanced by providing additional resources in the following areas:

(1) Additional faculty lines in Engineering in computer aided design, modeling and simulation (particularly of polymers in molding);

(2) Additional space, and resources to establish a state-of-the-art high performance computing facility in Engineering to support development;

(3) Additional students and postdoctoral research associates to carry the work forward.

References

Antonsson, E. K. (1996). Structured Design Methods for MEMS: An NSF Workshop November 12-15, 1995. National Science Foundation.