Research Themes

The following twelve sections of the report present Research Abstracts of many of the projects associated with the Microsystems Technology Laboratories. The research summarized in these Abstracts is being carried out by graduate students and/or research staff under the supervision of MTL faculty and senior research scientists. The Abstracts are divided into the following research categories:

Integrated Circuits and Systems, Microelectromechanical Devices, Electronic Devices, Quantum-Effect Devices, Submicron and Nanometer Structures, Modeling and Simulation, Fabrication Technology, Manufacturing, Materials, Optoelectronics, Educational Activities, and MTL Research Centers.

A total of 176 Abstracts are included here. Although the Abstracts are separated here by research categories, they could also be grouped into three major interdisciplinary, interactive research themes (Figure 1):

- **Microsystems**
- **Nanoscale Technology and Devices, and**
- **Manufacturing**

which provide a focus for MTL's research program. These three themes are described here.

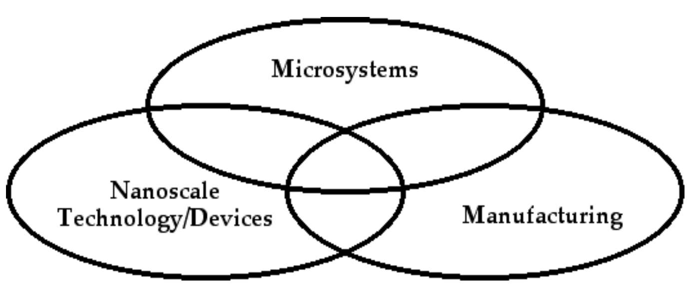

Fig. 1: MTL Research Themes

Microsystems

Projects within this theme are technology intensive, and explore the relationship of fabrication technology, device physics, and integrated circuit design, all driven by the requirements of a specific microsystem. Figure 2 shows MTL's microsystems research model, and identifies five individual system/function components of this model: sensors, analog signal processing, digital signal processing, actuators, and communication. At the input of the microsystem are physical signals which are converted to electronic signals via sensors. These electronic signals undergo analog signal processing, are converted to the digital domain, and enter the digital signal processor. After digital processing, the signals are converted back to the analog domain and prepared to interface with the outside world through actuators. Each microsystem may communicate with other microsystems either in the digital or analog domain, electronically or optically. A significant research challenge is in the system/function partitioning to ensure that the technology developed to carry out each of these five functions is the most cost effective power efficient solution to meet the performance requirement of the entire system. For example, as nanoscale technology continues to advance, an increasing fraction of the microsystem may be integrated on one or a few digital chips. The question then is how much of the other microsystem functions (i.e. sensing, actuation, analog signal processing, communication) should be merged monolithically with the digital part of the system. Most microsystem applications may benefit from the merging of analog signal processing with the sensor or actuator, leaving all communications between microsystems to be performed digitally. Several microsystems with this system partition are being investigated in MTL, and their Abstracts are included in the Integrated Circuits and Microelectromechanical Devices sections of this Report.

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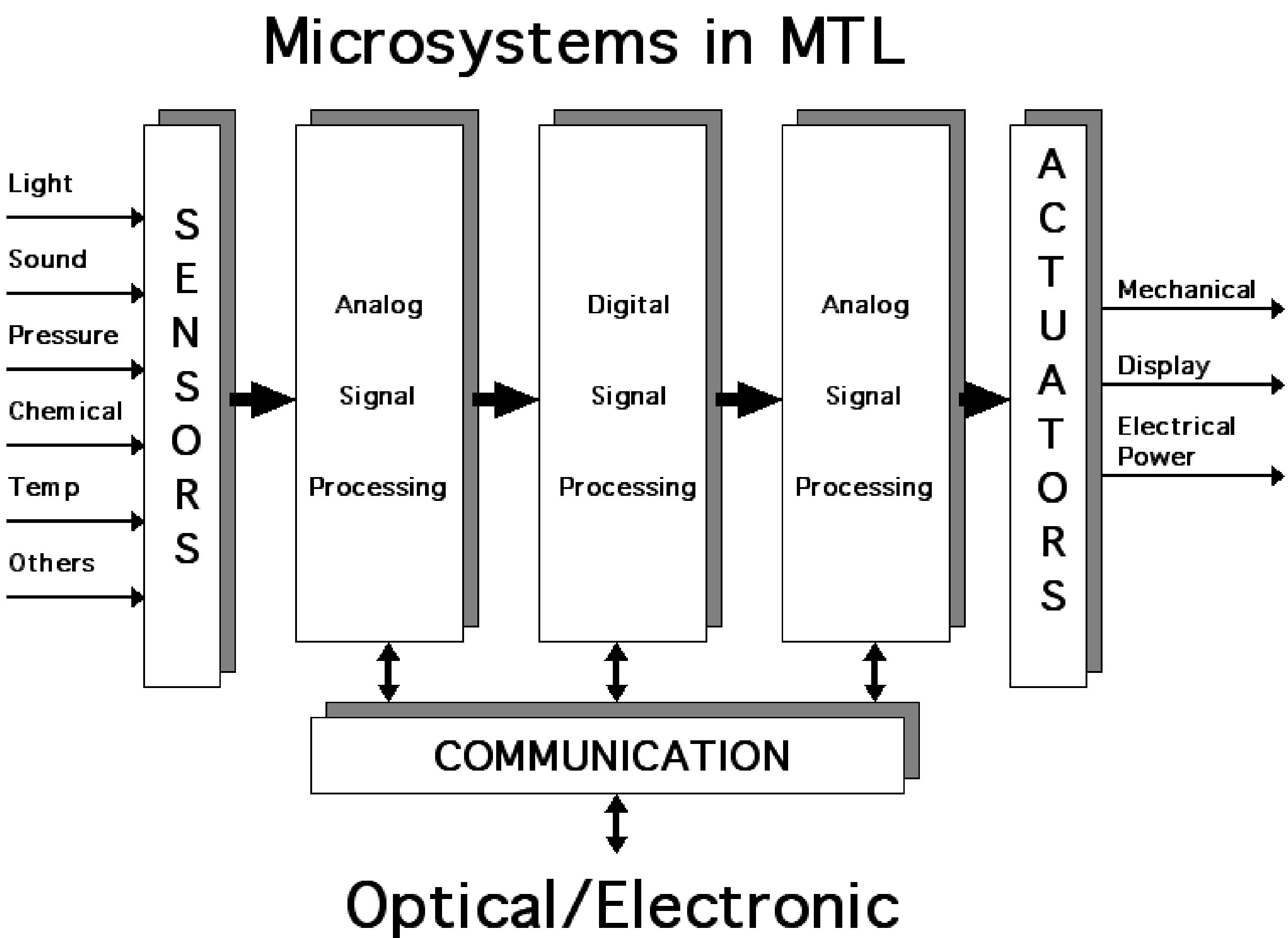
Microsystems work in MTL also includes MicroElectro-Mechanical Systems (MEMS), which encompasses four major research areas: materials, Computer-Aided Design (CAD), fabrication technologies, and applications. Research in materials and fabrication technologies is aimed at studying, understanding and measuring material properties and processes which are important in MEMS design and fabrication. The CAD effort is focused on creating a design environment for MEMS which includes a structure simulator for solid model construction, and research on computationally-efficient algorithms for important MEMS simulation tasks such as coupled electro-mechanical problems. A number of applications in microsensors and microactuators are explored which utilize the work in materials, CAD and fabrication technology. Abstracts of MEMS research projects appear in different sections of this Report.



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Nanoscale Technology and Devices

MTL research in nanoscale technology focuses on the development, modeling and understanding of enabling technologies. Examples of these are nanolithography; growth of dielectric, semiconductor and conductor films, sub-100 nm metrology , nanoscale etching, and novel surface cleaning methods. These enabling technologies are being investigated for silicon, compound semiconductors and other materials. A good example of work that fits within this theme is our nanolithography effort, which is driven by our research in nanoscale devices. Specific foci of this work include:

- Development of X-ray nanolithography and compatible alignment technniques, with the goal of a sub-100 nm manufacturing capability,
- Development of spatial-phase-locked electron-beam lithography, with the goal of sub-1 nm pattern-placement accuracy
- Interferometric lithography at 100 nm and 50 nm feature sizes, with plans of extending it to 25 nm features,
- Reactive-ion etching compatible with sub-100 nm features, and
- Low damage etching of III-V semiconductors.

Nanoscale device research in MTL includes Si MOSFETs (bulk Si and SOI) at the limits of scaling, heterostructure FETs, heterojunction bipolar transistors, quantum-effect devices, single-electron transistors, optoelectronic devices and photonic-badgap structures.

Manufacturing

MTL's manufacturing program addresses the understanding and control of variation, flexibility, rapid turnaround and high yields, as well as increased concurrence and decreased design-to-production times for highly integrated microsystems. Research projects within this theme, as shown in Figure 3, focus on unit processes, process modules, and distributed process design and optimization. Projects closely related to unit processes include:

- Development of *in-situ* and in-line process sensors, communication, and monitoring methods which provide information on the wafer and process state during and after each unit process,
- Modeling of unit processes to enable a faster and superior design of equipment as well as provide the physical insight for process control,
- Development of methods for run-by-run and real-time feedback control of unit processes.

Projects which examine short-flow methods for process module characterization and optimization include:

- Development of statistical metrology approaches incorporating test structures, TCAD tools, and analytic methods to identify systematic variation in critical device and interconnect modules,
- Application to modeling of spatial variation of dielectric and copper line thickness variation (in CMP) and line width variation (poly and metal),
- Development of CAD tools to understand the impact of device and interconnect variation on circuit performance.

continued

Finally, projects which enable the design and operation of full process flows and fabrication facilities include:

- Development of Technology CAD (TCAD) tools that evaluate reliability in devices (e.g. hot carrier reliability) and interconnects (e.g. electromigration, signal integrity),
- Development of a Semiconductor Process Representation (SPR) to support the integration of process/device design and manufacture, and enable the synthesis of new or modified process flows,
- Development of a web-based Labnet software system to support operation of university fabrication facilities,
- Creation of a national network infrastructure for distributed design and fabrication to enable remote experimentation, collaboration, and effective utilization of resources.

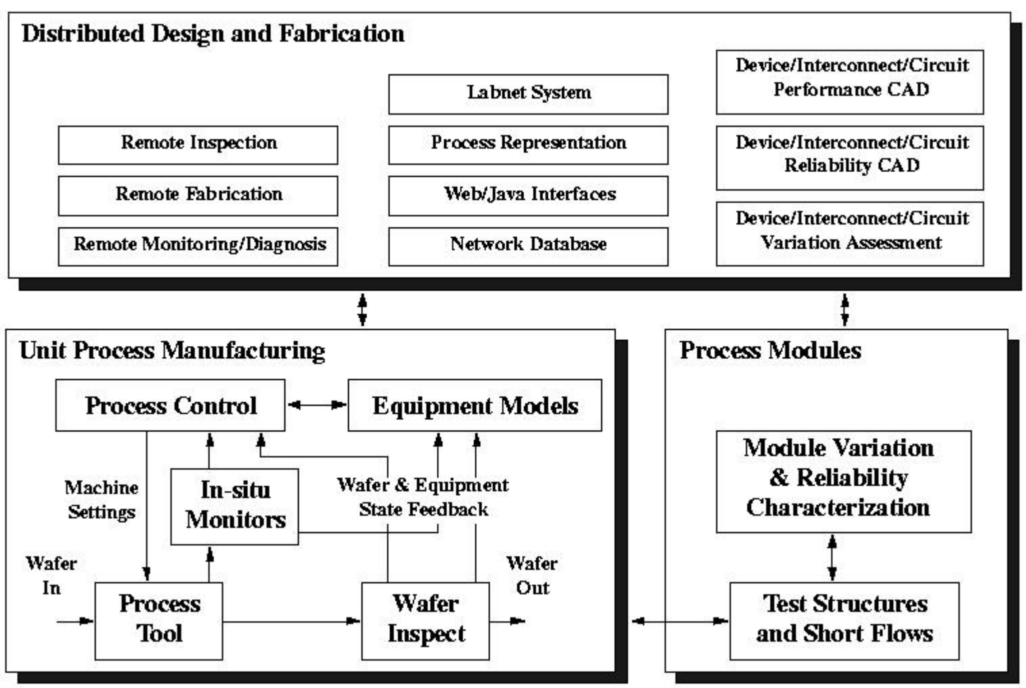

Fig. 3: Manufacturing research in MTL.