by Jørn Hvam

Collaborative R&D succeeds in Denmark

Manufacturing a tiny chemical laboratory, complete with filters, mixers, and pumps, all on a semiconductor chip, is one of the many innovative projects that have emerged from collaboration of research

The development of specific deposition and etching processes is at the heart of MIC's collaborative R&D

teams at the Mikroelektronik Centret (MIC) in Lyngby, Denmark, a northwestern suburb of Copenhagen. The MIC serves as a national R&D facility that provides Danish industry with advanced microtechnologies, which are created largely from semiconductor materials. Most of the MIC's projects combine its own investigators with colleagues from Danish industry and universities.

In 1990, Denmark's Ministries of Education and Industry provided a five-year start-up grant that established the MIC. Despite its original government funding and designation as a national laboratory, the MIC operates independently—under the advice of its board, which consists of five representatives from Danish industry, two from the Technical University of Denmark (with which the MIC is affiliated), and two members of the MIC staff. The first five years of operation at the MIC proved very successful and the Ministry of Education has provided a continuation grant through 1998. Moreover, the MIC now generates nearly 40% of its funding from public and private research sources, such as the companies that participate in the collaborative projects.

The R&D program at the MIC revolves largely around the process laboratory, which produces state-of-the-art components from semiconductor materials. The process laboratory's clean room includes facilities for photolithographic processes, dry and wet etching, ion implantation, dielectric and metallic thin-film deposition, and equipment to measure and characterize any materials or components that are produced. The MIC also provides many novel technologies, including micromachining silicon with lasers, photolithography on highly nonplanar surfaces, and thick photoresists that can be used to create metallic microstructures. The MIC shares these facilities and capabilities with a total of 11 industrial partners and 5 research partners.

Road map for research

The MIC focuses on three goals: (1) conducting R&D in semiconductor-process technology, (2) transferring technology to Danish industry, and (3) educating industrial engineers. Reaching the first goal revolves around research in three areas: microsystems, photonics (the physics and engineering of optics), and nanotechnology.

Although these research topics may appear rather distinct, many projects—especially ones directed toward applications—combine techniques from more than one research area. The work on microsystems combines silicon-based optical and mechanical devices as well as conventional microelectronics to produce sensors, transducers, and microliquid-handling systems. These devices may be used in a variety of applications such as accelerometers, microphones, and systems that provide total chemical analysis. Photonics research at the MIC explores integrated optical systems that can be applied to sensors and telecommunications systems. For example, integrated optics can be used to develop devices that detect specific chemicals or to create optical amplifiers that can be used in long-distance communications. The research on nanotechnology examines several areas: nanostructures, nanoelectronics, and nanooptics. Moreover, the small size of some nanoscale devices—particularly ones that incorporate dimensions below 50 nm—can exhibit quantum effects, which could produce entirely new forms of electronics.

Although the MIC is a relatively young operation, it has moved aggressively toward its second goal—transferring technology to Danish industry. It pursues this goal through interactive processes involving person-to-person contact, such as the collaborative projects with industrial partners. Moreover, private enterprise is encouraged to propose future research collaborations. So far, several collaborative projects have produced successful results; some details on two of them will illustrate the process.

Lab on a chip

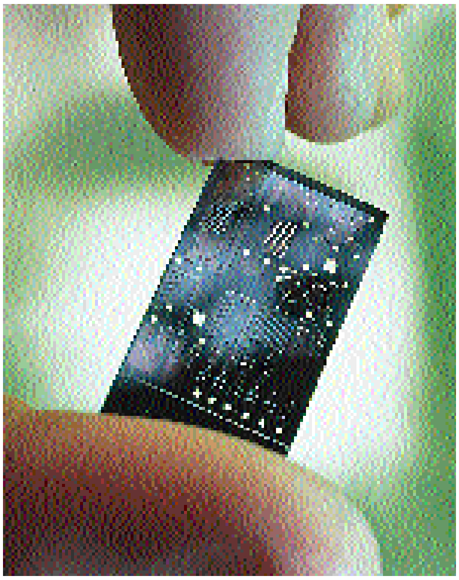
Microsystems technology can be used to fabricate robust and reliable on-line chemical sensors for industrial-process control. In fact, investigators at the MIC hope to develop a chemical laboratory on a chip. The combination of well-known technologies from the integrated-circuit industry and specific etching techniques makes it possible to fabricate microliquid-handling systems that consist of detection cells, filters, mixers, pumps, and valves, as well as channels that connect the various components.

As part of a national research program that involves several Danish companies, Danfoss A/S and the MIC have developed the technology platform needed to fabricate microliquid-handling systems. Furthermore, this program has demonstrated the feasibility of controlling mixing and chemical reactions in microliquids.

These microliquid laboratories composed of semiconductor components perform differently than macroscopic systems composed of rubber tubing and flasks. As it turns out, some fundamental aspects of physics must be reconsidered when scaling down chemical processes. For instance, liquid-solid interfaces become increasingly important in several phenomena, including adsorption, catalytic effects, and corrosion. Moreover, detecting a specific chemical species in a nanoliter volume proves challenging—so much so that it may require new methods of optical detection. Solving this microsystem problem will probably require advances from photonics as well.

A fundamental problem for a chemical laboratory on a semiconductor chip is that liquids mix entirely differently on macroscopic and microscopic scales. The turbulence that ensures efficient mixing of macroscopic liquids disappears in microscopic liquids, which experience only laminar flow. The Danfoss A/S-MIC collaboration produced a successful mixer concept, based on stacking liquids in a multilayered structure. In just milliseconds, this process efficiently mixes microliquids. In addition, this technique exceeds the requirements for on-line analysis applications in industry and it opens up new possibilities for microreactor applications and basic research on the kinetics of fast chemical reactions.

This project provides an example of how an interaction between industrial and academic research can produce spin-offs for industry as well as for basic research. The strength of the collaboration between Danfoss A/S and the MIC depends largely on the exchange of personnel. Danfoss stations some employees at the MIC, which allows them to contribute new ideas for future basic research and gives them full access to the technology involved in the project.



Chemical laboratory on a semiconductor chip developed at the MIC

In the early 1980s, the inventions of the scanning-tunneling microscope and the atomic-force microscope spawned a new era of high-resolution microscopy that culminated in scanning-probe microscopes. The family of scanning-probe microscopes includes one member called the scanning near-field optical microscope. In contrast to conventional optical microscopes, the imaging in a scanning near-field optical microscope depends on the nonpropagating, or evanescent, field mode, whereby the achievable lateral resolution can surpass the far-field diffraction limit.

A matter of scale

In August 1994, the MIC and Danish Micro Engineering A/S started a collaboration involving an industrial Ph.D. project on scanning near-field optical microscopy. Within one year, a reflection-scanning near-field optical microscope facility was set up at the MIC. Reflection-scanning near-field optical microscopy features simultaneous imaging of two features: (1) a sample's topography (with a lateral resolution of 10 nm) and (2) the optical contrast of its surface (with lateral resolutions of 25 nm). In this technique, force microscopy generates the topographic image, and near-field reflection microscopy produces the optical contrast of a sample's surface.

Besides ordinary imaging, the scanning near-field optical microscope was used recently to assess experiments on surface modifications that were produced with photochemistry. In the near future, the spatial resolution of the scanning near-field optical microscope will be applied to optical characterizations of quantum wells and quantum wires. Moreover, this R&D project with a scanning near-field optical microscope should meet other imaging challenges, including time-resolved microscopy and low-temperature measurements.

In its first year alone, this three-year industrial Ph.D. project produced an instrument that is now commercially available. This is the Danish Micro Engineering Rasterscope instrument family, which includes a scanning near-field optical microscope, which can be exchanged with conventional units for atomic-force microscopy and scanning-tunneling microscopy.

Educational edge

The MIC approaches the third goal—educating engineers in collaboration with the Technical University of Denmark—in several ways. First, we offer a complete set of theoretical and practical courses on all levels; more than 150 students attended these courses in 1994. Second, we train industrial Ph.D. students such as the ones involved in the project on scanning near-field optical microscopy. Third, we host members of private industry at MIC seminars and conferences. Finally, we operate a "semiconductor club," which relays the latest research information to its industrial members.

Again, most of the MIC's success comes from person-to-person interactions within a team framework. We approach all three of our goals—semiconductor-process technology R&D, technology transfer, and educating engineers—by creating groups of people from academia and industry, then exposing them to advanced equipment and technology. So far, most of these collaborations have involved Danish industry, but the MIC has been developing international collaborations as well. By involving other countries in this model of collaborative R&D, it is hoped to provide even more technological advances.

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