The microfabrication boom

The worldwide demand for faster, cheaper processors is driving an explosive increase in production capacity on the part of silicon chip manufacturers. New challenges are emerging along with this expansion, offering a broad range of employment opportunities for Ph.D. physicists in materials research, circuit design, the development of alternative lithography techniques, and equipment design and development.

Manufacturing the latest semiconductor devices requires extremely clean surroundings, as well as high-precision equipment capable of imaging and fabricating several million electronic components in a half-inch-square piece of silicon.

Semiconductor Equipment and Materials International, a Mountain View, California-based organization that monitors the semiconductor industry, estimates that as many as 150 new microfabrication plants are planned in the United States, Japan, Europe, and Asia-Pacific over the next two years, at a cost of up to $1 billion each. "Everyone in the industry, from the raw material suppliers to test equipment manufacturers to actual chip manufacturers, is stretched to capacity," said Matthew Richter, a materials physicist employed with Intelligent Sensor Technology, Inc., also in Mountain View, California. "But even this explosive increase in capacity will barely keep pace with demand," he added.

According to Howard High, a spokesman for Intel Corporation, Santa Clara, California, the semiconductor chip market grew more than 40% in 1995 and is expected to grow about 15%-20% this year. Equipment sales grew about 40% in 1994 and 1995, and are expected to continue rising at about a 26% rate in 1996. Although this is largely perceived as a downturn, given the huge increases of the last few years, the industry is still growing much faster than the gross national product.

Most industry insiders agree that the primary driving factor behind this phenomenal growth is the continuing huge demand for personal computers, followed by telecommunications applications such as cellular telephones. Currently, the hottest selling item is memory chips, boosted by the boom in multimedia applications and the advent of Windows 95, which requires a minimum of 8 megabytes of memory to operate. "Software is a gas; it expands to fill available space," said Abbas Ourmazd, director of Germany's Institute for Semiconductor Physics in Frankfurt, of the public's seemingly insatiable demand for these products. Such industrial applications as automation and energy management systems are burgeoning, and as silicon becomes cheaper and more cost-effective, it is finding its way into new applications, including washing machines, wristwatches, and automobiles.

"All of the major innovations in the transportation sector over the last decade can be related back to the semiconductor chip," said High. For example, many large aerospace and automobile manufacturers are using computer simulation testing to design models, as a cost-effective alternative to physical modeling. In fact, 30-40% of the value of an automobile now resides in the electronical and electronic components, including all sorts of microcontrollers and microprocessors.

The demand for silicon technology has created a niche for workers who understand materials, materials modeling, and design. Some 12,000 job openings are expected in Silicon Valley in 1996, with only an estimated 10,000 qualified applicants available to fill them. With some extra training, physicists would be well suited to chip fabrication, circuit design, and developing predictive physically based simulation models for silicon devices. "I think what physicists primarily have to offer the semiconductor industry is problem-solving abilities," said Ourmazd, who suggests that physicists seeking to move into the field present themselves to potential employers as generalists, rather than specialists in a particular area.

Smaller, faster, cheaper

The semiconductor industry continues to demand smaller, faster, and cheaper devices, and depends on innovations from industrial physicists to reach new technological goals. Today, 0.50 and 0.35 μm lithography is cutting-edge technology, with 0.25 feature sizes expected to be reached by 1998. As devices get smaller, the need for higher accuracy and precision is even greater. According to Richter, the shrinkage in dimensional size, combined with an increase in wafer diameter, requires an order-of-magnitude increase in positional accuracy for every critical piece of equipment in the fabrication process, some of which has yet to be designed. Surface geometry and contamination also have a much greater effect on electronics performance as sizes decrease.

The never-ending search for cost savings is prompting a planned move from 200-mm (8-in.) to 300-mm (12-in.) wafers, which would double the wafer's surface area, and hence the number of devices per wafer. However, the increase in production efficiency is offset by the large capital investment required to upgrade existing facilities to meet the new specifications. Motorola and Samsung are leading the industry in the transition from 8-in. to 12-in. wafers; each plans to have 300-mm fabs on line by 1998, and Motorola plans to move simultaneously to deep UV 0.25 technology.

Other companies are more cautious, such as Intel, which took the lead in the transition to the 6-in. wafer. “It’s very expensive, and it’s not clear that there’s a competitive advantage to do so,” said High. Intel and several other companies have formed an international consortium to agree on a set of specifications and move forward together, rather than any one company shouldering the financial burden alone. A similar Japanese consortium is also working on the issue.

New technologies

Physicists continue to play a vital role in the development of alternative etching technologies. Optical lithographic techniques still dominate the industry, but shorter and shorter wavelengths are needed as sizes decrease. Some manufacturers are moving toward deep UV lithography, but John Poate, head of silicon processing research at AT&T Bell Laboratories, Murray Hill, N.J., estimates that the industry will be printing at the wavelength limit of optical lithography in about 10 years.

More revolutionary alternatives include X-ray lithography, ion beam projection lithography, and electron beam projection lithography. Of these, the most widely touted as a potential replacement is X-ray lithography, although the equipment is more expensive. Joseph Mogab, manager of advanced process development at Motorola’s Austin, Texas, facility, said the company is exploring the extendability of X-ray lithography to the regime of 0.09 μm or below to determine whether the technological benefits to be gained outweigh the initial cost.

Another alternative technique is plasma processing, in which a partially ionized gas is used to initiate the chemical etching reactions. Plasma-based etch tools use an electrical charge to attract the plasma ions, drawing them straight downward to cut straighter etch walls and finer features on silicon wafers, resulting in chips that are more tightly packed with memory and logic circuits, at a lower cost to the manufacturer. However, collisions with neutral atoms can deflect the plasma ions while they are being accelerated, and researchers are still refining the technique to minimize such effects.

Ourmazd believes that the most promising work still lies in the evolution of current technology, rather than revolutionary replacements. Intel’s High agrees. “We see optical extensions lasting at least another two generations, down to about the 0.18 or 0.13 level, and we’ll stay with that technology as long as we can, because it’s a more cost-effective solution than the beam technologies,” he said, pointing out that in the past there were just as many skeptics who believed that optical technology could never go below one micron.

Poate identified the doping and defect problem associated with ion implantation as another critical issue facing the semiconductor industry where the expertise of physicists could find useful applications. “All integrated circuits are doped using ion implantation, and there is now the realization that the interaction between the dopants and silicon point defects can create roadblocks for the next generation of devices,” he said. “If implantation runs out of steam, alternative doping technologies such as low-temperature silicon epitaxy will have to be developed. These problems are bringing about a renaissance of defect physics in silicon.”

Instrumentation

The emphasis on smaller semiconductor features is also fueling the development of analytical surface science instruments for such applications as monitoring fabrication processes and performing on-site failure analyses. One important advance is IBM Zurich’s invention of scanning tunneling and atomic force microscopes, which is having a profound impact on the semiconductor industry in terms of surface topology measurements and atomic-level metrology.

Many smaller companies have found successful niches in the instrumentation sector of the market. Physical Electronics in Eden Prairie, Minnesota, has introduced a semiconductor microanalysis tool for 200-mm wafers that provides submicron defect location, morphology, and elemental identification. Specs USA (Pittsburgh) offers a secondary ion mass spectrometer with high sensitivity for trace analysis and excellent dynamic range, and a few companies have begun placing scanning probe microscopes in semiconductor process-support applications. Intelligent Sensor Technology manufactures optoelectric process monitors for the semiconductor industry.

Time-of-flight (TOF) secondary ion mass spectrometry (SIMS) surface analysis techniques, favored for their high spatial resolution and static operational mode, are currently the fastest growing market niche for instrumentation. However, because data from TOF instruments are more complicated than those derived from conventional instruments, improvements to data-interpretation software are needed. For this, processors are looking to companies such as Intellisense, Inc. (Louisville, Kentucky), which specializes in the development of microfabrication software, the manufacturing of silicon micromachined devices, and consulting services.

In short, the silicon industry still offers opportunities for cutting-edge physics research. “The physics culture does not easily embrace the applied or industrial end of things, but the scientific challenges at the atomic and macroscopic levels of basic silicon research are as tough and as fundamental as any I know,” said Poate. “The physics community should be reveling in this problem-rich environment.”