Can Synchrotron Light Save the Chip Industry?

With U.S. integrated circuit companies reeling under Japanese competition, a new x-ray patterning technology may help, but to make it happen a cooperative plan is needed

EARLY in March, a group of about 50 engineers and scientists met at Brookhaven National Laboratory to consider one possible response to the Japanese threat to the American integrated circuit industry.* Open for discussion was the idea that industry and U.S. national laboratory researchers could jointly develop an advanced x-ray lithography system for the production of future generations of integrated circuits to be introduced in the early 1990's.

At the center of it all would be a synchrotron light source tailored expressly for the production of high fluxes of x-rays. By the end of the workshop, preliminary specifications were in hand for a push-button operation machine that would be inexpensive enough for individual companies to buy and incorporate into future chip production lines. Those attending also agreed to set up a steering committee to pursue the matter as urgently as possible at the appropriate levels in industry and government.

The rush is due to x-ray lithography efforts already mounted overseas. In Japan, groundbreaking took place last October at Nippon Telegraph and Telephone Corporation in Atsugi near Tokyo for an x-ray lithography facility to be centered around a compact synchrotron source with an electron beam orbit having a circumference of only 10 meters that was jointly developed by NTT, Hitachi, Ltd, and Toshiba Corporation. Cost of the facility is said to be $80 million. A second project under way is coordinated by the Ministry of International Trade and Industry's Electrotechnical Laboratory, which is contracting to Japanese industry to develop and build synchrotorn x-ray sources.

A further advanced cooperative program that is jointly financed by German industry and government and involves some 80 researchers has been under way for 4 years at the Fraunhofer Institute for Microstructure Technology in West Berlin. A prototype compact synchrotron x-ray source is due later this year, and a company has already been formed to market it.

Dynamic random access memory (DRAM) chips illustrate the nature of the Japanese threat, as they incorporate leading-edge semiconductor technology and represent one of the highest volume segments of the worldwide integrated circuit industry. There is no question about the high quality of Japanese chips. But the Japanese conglomerates are so huge that they can absorb the losses when specific products are targeted for sale outside Japan for what the much smaller American firms consider unrealistically low prices, while the home Japanese market appears to American eyes to be protected from competition.

"If the synchrotron source is necessary for our survival, who cares how big it is?"

Some combination of high quality, low price due to the targeting strategy, the until recently overvalued U.S. dollar, and a slumping market has allowed the Japanese to capture 90 percent of the business in the now-mature generation of DRAM chips that store something over 256,000 binary bits of information. Only a few American manufacturers remain in the advanced DRAM competition. Everyone expects the Japanese to maintain the same level of domination in the newest state-of-the-art DRAM's that store over 1 million (1M) bits and in the succeeding generation of 4M chips that may be ready in the next 2 or 3 years.

If the threat were confined to DRAM's, it would be possible for American chip makers to thrive without being a major player in the DRAM business. But from the American point of view, the game does not stop there. Next comes domination achieved by the same targeting strategy in other types of memory chips; then logic chips, microprocessors, and so on. Preliminary rulings by the U.S. International Trade Commission and the Department of Commerce that could lead to penalties being levied against several Japanese integrated circuit manufacturers found these companies guilty of selling DRAM's and electrically programmable read-only memories (EPROM's) at unfairly low prices, a practice termed dumping.

Loss of markets means that a manufacturer cannot accumulate the capital needed to develop the technology for the next generation of products. In the worst case, the United States could be left without a viable integrated circuit industry. This puts at risk all the electronics companies whose products rely on chips of these sorts. A particularly sensitive case in point is supercomputers.

Norman Kreisman, who manages a technology transfer program at the Department of Energy, explained to those attending the Brookhaven workshop that no American manufacturers now supply the special high-performance DRAM's needed for supercomputers. These chips come from Japanese companies, who are themselves computer manufacturers. Total reliance on Japanese suppliers is not a healthy situation when the availability of supercomputers is widely considered to be essential for the maintenance of America's economic vitality and national security.

A similar situation also seems to hold across a broad range of military electronics systems, and the Pentagon's Defense Science Board is looking at the increasing problem of a U.S. semiconductor dependency. A National Academy of Sciences report due out in this month will also address this issue.

By itself, a new technology such as x-ray lithography can solve none of these problems, but the feeling at the workshop was that the upcoming switchover from an old to a new way of making integrated circuits could provide an opportunity for American manufacturers to recapture some momentum. And, in any case, the timely availability of the new technology in the United States is a sine qua non to avoid further dependency on overseas suppliers.

Franco Cerrino of the University of Wisconsin, for example, showed projections developed by him and William Johnson of AT&T Bell Laboratories that had upcoming DRAM generations, each with four times the storage capacity of its predecessor, arriving at an accelerated rate of one every 2 years. The 16M DRAM would be here in 1990 and would require a patterning process with a resolution of 0.6 micrometer, as compared to the 1 micrometer in 1M chips.

Advanced versions of the traditional optical lithography probably will be able to achieve this level of detail, but succeeding generations will require something better.

*Workshop on Compact Storage Ring Technology, Brookhaven National Laboratory, 4 to 5 March 1986.

X-ray lithography is a leading candidate, although not the only one. A concerted effort on the part of American manufacturers is needed for them to be ready when the changeover takes place.

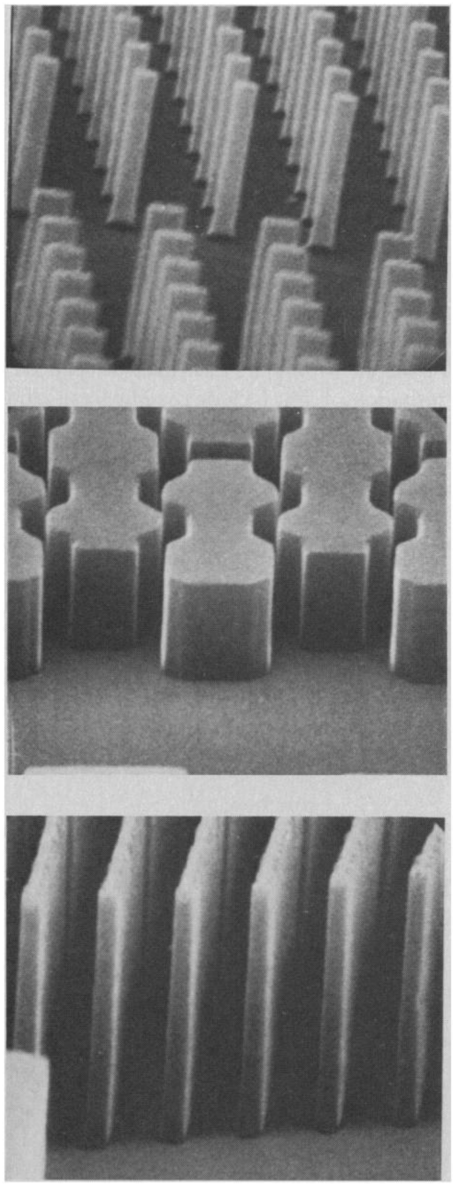
As the cooperative efforts in Japan and Germany testify, the days seem to be numbered when individual companies can themselves develop all the increasingly complex and expensive technology called for by future high tech products. One purpose of the workshop was to explore how the U.S. national laboratories and Brookhaven in particular could help facilitate a pooling of national resources in a cooperative x-ray lithography project. If it materialized, such a project might also serve as a model for similar efforts in other areas of technology

Brookhaven's entree comes by way of its National Synchrotron Light Source. "We at the NSLS would be embarrassed if x-ray lithography with synchrotron sources took off and the United States was left behind," said NSLS chairman Michael Knotek. Already at the NSLS, a group from the IBM Yorktown Heights Laboratory headed by Alan Wilson has been exploring the benefits of x-rays from synchrotron light sources as compared to conventional x-ray tubes. More recently, Wisconsin has set up the Center for X-ray Lithography at its Synchrotron Radiation Center in Stoughton with operating funds to come from a consortium of industrial users.

Should a program aimed at developing a full-scale x-ray lithography processing line come into being, Brookhaven would offer its accelerator and synchrotron radiation expertise and possibly also house the prototype facility. No American companies manufacture synchrotron light sources, although Micronix Corporation offers an x-ray lithography system with a conventional x-ray tube.

At the workshop, John Warlaumont of IBM reviewed the advantageous properties of x-rays. The principal benefit, resolution, stems from the shorter wavelength of x-rays as compared to the near-ultraviolet radiation now used in optical lithography. Radiation passes through the openings in an opaque mask on a transparent substrate and exposes a polymer material called a resist that coats the semiconductor surface. When the resist is developed, it contains the mask pattern. Subsequent processing steps transfer the pattern to the semiconductor. For x-ray lithography, the mask resides 40 micrometers or so above the semiconductor. Diffraction of the x-rays and scattering of photoelectrons generated by x-rays in the resist combine to give an optimum resolution in the neighborhood of 1000 angstroms.

The main advantage of synchrotron x-ray sources over conventional ones is the dramatically higher intensity—1000 times that of a rotating anode tube, for example. An exposure time of 1 second, which is considered the maximum allowable for a manufacturing process to be economically competitive with the existing optical technology, demands such high intensities. Also important, the small source size (0.1 millimeter at the NSLS), highly collimated radiation, and source-to-mask distance of several meters mean that for practical purposes the radiation from a synchrotron source is perfectly parallel and that the kinds of blurring effects due to a large source that radiates in all directions, which plague x-ray tubes, are much reduced.



IBM

X-ray lithography

Test patterns in a poly(methyl methacrylate) (PMMA) resist exhibit the submicron resolution and high aspect (height to width) ratio made possible by x-rays from the National Synchrotron Light Source.

At the close of the workshop, Brookhaven's Benjamin Craft summed up the findings concerning a synchrotron source. The ideal source, small enough to be transportable on a truck, would require superconducting magnets, since only these generate magnetic fields powerful enough to confine a high-energy electron beam to a small orbit. Both the German and Japanese projects aim at superconducting magnets. While workshop attendees from the electronics industry set a goal of 1991 for a commercially available lithography system capable of 0.25-micrometer resolution, the accelerator experts demurred. The demanding nature of superconducting magnet technology means that, even with a crash development program, it would take until late 1990 to have a working prototype. The consensus was that a larger source with conventional magnets was the best bet for the first cut. "If the synchrotron source is necessary for our survival, who cares how big it is," was one comment from the floor.

James Clemens, who manages the advanced lithography programs at Bell Labs, emphasized that the x-ray source was only one part of the total lithography system. An electron beam exposure machine with at least the same high resolution is required to generate the mask pattern. The mask must be rapidly inspected and, if necessary, repaired, for which no means now exist at the resolution of an x-ray mask. To build up an integrated circuit, several exposures with different masks are required, and an alignment machine to line up succeeding patterns with an accuracy of about one-quarter the pattern resolution must be devised. Finally, a resist with high contrast—that is, it is sufficiently sensitive to high fluxes of x-rays to allow short exposure times, while insensitive to the low fluxes that may penetrate the opaque portions of the mask—is necessary. All these activities must go on in parallel if the goal of having a complete system by 1991 is to be met.

In sum, at the close of the workshop, the sentiment for proceeding was strong. But the important task remained of identifying the key individuals in industry and government who could make the project go. The Semiconductor Research Corporation in North Carolina, which is funded by American electronics firms, could be one important player. ■ ARTHUR L. ROBINSON

ADDITIONAL READING

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