The Silicon Chip Race Advances into X-rays

A presidential advisory panel says the development of x-ray lithography for manufacturing integrated circuits is imperative, but many American companies are moving with caution

EIGHTEEN YEARS HAVE PASSED since Henry Smith and colleagues at the Massachusetts Institute of Technology showed that x-rays can be used to make ultra-small integrated circuits with conductors less than 1 micrometer (micron) wide. Their 1972 paper in *Electronics Letters* marked a milestone in the history of electronics because it held out the promise that x-rays could be substituted for visible light in the mass production of silicon chips, shrinking circuits to dimensions that once seemed impossible. Nearly two decades later x-ray lithography is poised to leave the research laboratory for the factory.

Today, Japan and several European governments are pouring more than a billion dollars into x-ray lithography R&D to make faster and more powerful chips for industrial and consumer applications. But neither the U.S. government nor the majority of American chip companies seem ready to invest in the research needed to develop the manufacturing know-how. With x-ray lithography production options still unfolding, and with continued debate on when the technology will actually be needed, profit-minded U.S. chip makers are approaching the technology with caution.

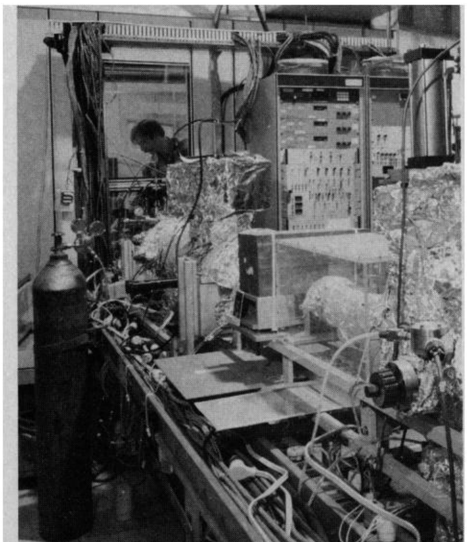
Smith, the father of x-ray lithography, says that the U.S. development program, because of its early start, may still be ahead of its competitors. He fears, however, that Japan will be the first to cash in on x-ray lithography unless U.S. companies accelerate their pace. So far manufacturers have finessed the issue by extending the range of the old optics technology. At some point in the not-too-distant future, these methods will become too costly to compete with x-ray lithography.

Fabian Pease, a professor of electrical engineering at Stanford University and a former Bell Laboratories researcher, agrees. X-ray lithography, he says, may be the best hope that the United States' crumbling semiconductor-related industries have to regain ground lost in the 1980s to Japanese competitors who now dominate the $50-billion semiconductor market. Says Pease, "If we want to survive and win this race, we better start investing."

Japan clearly sees a potential advantage in the technology. Its electronics industry and government are thought to have spent $700 million so far on x-ray lithography, and the Congressional Research Service says they are committed to spending more than $1 billion to devise manufacturing systems. Likewise, West Germany, a member of the Joint European Submicron Silicon project (JESSI), is building a $210-million institute to develop x-ray technology to make chips with features of 0.5 micron and smaller.

The U.S. government's commitment to developing x-ray technology is far less vigorous. The Defense Advanced Research Project Agency (DARPA) is spending $30 million this year, but estimates that $300 million should be spent on related R&D by 1994. Its spartan x-ray program exists primarily because Congress thinks it is important. SEMATECH, a federally assisted consortium of 14 companies that aims to restore U.S. leadership in semiconductor technology, allocates only a tiny amount of its $200-million budget to x-ray lithography.

But there appears to be little support for boosting work at SEMATECH or DARPA



BNL

X-ray light is channeled *from a synchrotron ring at Brookhaven National Laboratory to one of two tiny IBM-built clean rooms where researchers are developing technology for making integrated circuits with line widths of 0.5 micron and smaller.*

in the Bush Administration. Although DARPA and Commerce Department officials favor a more active government role, aides to the President's science adviser, D. Allan Bromley, say the White House is not likely to budge on the issue until the semiconductor industry steps up its research.

Smith, however, calls the level of federal funding for x-ray lithography "very scanty" and often ill used because of poor coordination between the Department of Defense, the Department of Energy, and industry, for example. Indeed, Robert W. Hill, manager of Advanced Lithography Systems for International Business Machines (IBM), says one of the United States' "biggest barriers to success is the difficulty and inefficiency of harnessing the resources in this country. . .So getting it to be anything other than a loose confederation of warring tribes is a tough job." He adds that "the government is part of that problem" through its lack of leadership.

Just as troubling for MIT's Smith is the "myopia" afflicting industry leaders whom he says should see that the x-ray manufacturing technology will take time to perfect. IBM has committed upwards of $130 million to x-ray lithography and is considered the leader. But other companies like American Telephone and Telegraph (AT&T), Intel, and Texas Instruments have deferred investments because the timing is not right, the technology is immature, or for lack of financial resources.

Even with its massive R&D investment, IBM is not ready to decide to produce integrated circuits using x-rays. But Alan Wilson, director of IBM's x-ray lithography effort, says companies need to begin experimenting with x-rays now to gain the experience to apply it on the production line in the mid- to late 1990s.

Because IBM wants to keep the domestic industry healthy and avoid becoming dependent on foreign suppliers, it is offering to (i) transfer its x-ray research results for a modest fee to other U.S. chip makers, (ii) share its East Fishkill, New York, x-ray lithography research facility when it opens in 1992, and (iii) license its manufacturing technology if necessary. So far, only Motorola has taken advantage of IBM's offer.

Not everyone, however, is convinced that x-ray lithography will be the technology of choice for the late 1990s. "We think that optical lithography will definitely extend below half a micron," asserts Bob Doering, deputy director of Texas Instruments' microelectronics manufacturing science and technology program. Indeed, Robert N. Noyce, the president of Intel and chairman of SEMATECH, contends that by the mid-1990s the United States will be capable of producing integrated circuits with 0.35-micron line features using optical methods.

"It is way too early to know where to go," says Daniel Seligson, head of SEMATECH's two-man x-ray lithography group. While it is necessary to begin working on the technology now, he says it may not be needed until 2000, when manufacturers will be selling chips with circuit lines of 0.25 micron or smaller. But even at this level, he says, there may be room for improving the resolution of ultraviolet optics.

MIT's Smith, however, argues that "pushing optics to the limit" is not a good strategy "because it makes manufacturing very tedious and expensive." At submicron levels, he says it becomes increasingly important to align circuit patterns correctly in multilayer chips. Ultraviolet wavelength light can be reflected off the wafer substrate, distorting neighboring circuit features. With x-rays there are virtually no reflections.

Karl J. Johnson, manager of Motorola's advanced lithography research program, agrees with Smith's technical assessment. Although it is not absolutely clear that x-ray lithography will be economically competitive with advanced optical methods, Motorola sees strong production advantages. At submicron levels, x-ray technology provides sharper circuit features, greater latitude in circuit design and manufacturing, larger production volumes, and higher yields of defect-free chips. IBM researchers, in fact, report that the yield from making complex eight- and ten-level integrated circuits with x-ray lithography is much higher than they had anticipated.

Although IBM is praised for its achievements, companies such as Texas Instruments are reluctant to follow its R&D path because it is based on the use of a compact, helium-cooled, superconducting synchrotron ring that generates soft x-rays. At $16 to $20 million each, plus even costlier outlays for an oversized dust-free "clean room" and other equipment, the setup may be suitable only for companies producing high-volume chips such as DRAMS.

Richard R. Freeman, head of electromagnetic phenomena research at AT&T Bell Laboratories, says betting on synchrotron technology is "shortsighted" because "there are only a handful of people today who are capable of doing anything useful with a synchrotron." Companies such as his, which do not produce DRAMS, are looking for a so-called "point source," a laser-pumped plasma device that generates x-rays and is much smaller than a synchrotron. Hampshire Instruments, a Rochester, New York, start-up company, is trying to develop such a tool, which could sell for about $4 million.

Another difficult technical question is whether x-ray lithography can be pushed below 0.25-micron circuit sizes in a factory setting. IBM is relying on a "proximity" system. With this approach, circuit dimensions on the mask used in making a chip are the same scale as the final circuit, and the masks must be positioned within 20 microns of the face of the silicon wafer to be etched. But at scales below 0.25 micron, the task of writing patterns on masks and aligning the masks becomes much more difficult and time consuming.

Projection imaging, in which mask patterns are reduced to size with optical lenses, is an attractive alternative routinely used in optical lithography. Its use in x-ray lithography, however, hinges on the development of special focusing lenses and multilayer mirrors that efficiently reflect penetrating x-rays.

With these kinds of technical concerns about x-ray lithography, says Texas Instrument's Doering, it is easy to see why many U.S. companies are biding their time. Firms like his own are conducting limited research in the area, hoping that an equipment vendor will develop a working system. SEMATECH and DARPA, he adds, are working with companies to develop masks and to attack other questions.

But IBM's Wilson is concerned that these efforts may be "too little, too late." The pace of commercialization may be too slow unless industry and government collaborate to develop mass production quality masks, inspection tools, pattern alignment and imaging machines known as "steppers," and related lithographic materials.

Motorola's Johnson is more emphatic. He says that neither the government nor industry can afford to continue the current "laissez faire" attitude in what he sees as nothing less than economic war.

■ MARK CRAWFORD

Japan's Big Gamble on Synchrotrons

Since the mid-1980s the Japanese, Europeans, and Americans have been working feverishly to optimize designs of electron storage rings—synchrotrons—that can supply x-rays for manufacturing the next generations of integrated circuits. The pace ought to be feverish if one accepts the estimate made about a year ago by Arnold Yanof at AT&T Bell Laboratories that the world's semiconductor makers might need as many as 175 of these machines in the next few decades. Forecasts have the competitive juices flowing most particularly in Japan, where the government and industry are building no less than seven synchrotrons devoted to x-ray lithography. Indeed, Hitachi is currently struggling to get that country's first compact superconducting synchrotron ring to work, but even as it struggles, many researchers and industry executives in the United States view the technology as a production tool of last resort.

Says Daniel Seligson, head of SEMATECH's x-ray lithography program, "The longer the Japanese work on synchrotron-based radiation lithography the better." What concerns Seligson and companies such as Texas Instruments, Intel, and Motorola is that storage rings may be a bad bet. The machines are expensive in terms of space requirements, capital outlays, and operating costs.

Industry objections to the bulky contraptions became pronounced at a mid-November meeting on synchrotron-based x-ray lithography held at Brookhaven National Laboratory (BNL). Participants in the meeting recommended against a Department of Energy plan to have private industry build two more compact rings with superconducting magnets. Robert O. Hunter, Jr., the former director of the Office of Energy Research, in fact, received the same negative advice in September from a group of Stanford University researchers.

Both the Stanford and BNL groups suggested that the $15 million would be better spent on other x-ray lithography research. One candidate is x-ray "point source" machines—truly compact, laser-driven x-ray sources like the one being developed by Hampshire Instruments of Rochester, New York. While it looks promising and affordable, more R&D is needed to boost the power of the neodymium laser that produces an x-ray–emitting plasma. Special, highly reflective lenses to "collimate" or force the x-rays to travel in a focused beam also are needed to make submicron circuits efficiently.

Until these problems are resolved in the laser device, the U.S. x-ray synchrotron R&D program is likely to be kept alive as an alternative production technology. Although the compact rings being built by IBM and BNL could serve as manufacturing prototypes for lithography, they have yet to be tested. ■ M.C.