COMPACT X-RAY LITHOGRAPHY MACHINES GENERATE HOPE FOR SEMICONDUCTORS

Since last February, the Central Intelligence Agency, Defense Science Board and National Research Council have lamented in separate reports that the US semiconductor industry is in crisis. They agree that US companies still hold the edge in three advanced processing technologies—molecular-beam epitaxy, ion implantation and chemical vapor deposition. But the firms have already lost out to Japan's chip makers in a fourth—optical lithography. Worse still, US companies appear to be falling rapidly behind in the newest field—x-ray lithography, a technology that is being pursued at many Japanese and European centers. Thus, the warning lights are clear: US manufacturing techniques for semiconductors, which are widely regarded as the centerpiece of a series of industrial and military revolutions over the last 20 years, are in decline.

The reports read like jeremiads. The Research Council's latest, *The Semiconductor Industry and the National Laboratories*, for instance, argues that the nation's semiconductor industry, once the envy of the the world for its inventiveness and dynamism, has lost its technological leadership, with profound consequences for several other important fields—among them computers, telecommunications, transportation and medical equipment. The council panel, headed by Larry W. Sumney, president of the industry's own Semiconductor Research Corp, observes that "dependence on foreign sources for low-cost, high-quality chips can have pervasive downstream economic effects in terms of lost jobs, lost opportunities and a worsening quality of life for Americans."

What's more, the nation's national security may be adversely affected. Though the Defense Department accounts for less than 10% of total purchases of US semiconductors, it requires some of the most advanced and specialized chips. To rely on foreign manufacturers for custom-made semiconductors or to accept second-rate devices from US companies, says the Research Council's report, is "unacceptable." In transmitting the report of the Defense Science Board Task Force on Semiconductor Dependency, its chairman, Norman R. Augustine, chief executive officer of Martin Marietta Corp, concludes that semiconductors are "the most ubiquitous element for assuring the technological superiority of US military forces."

So what's to be done? The Research Council panelists support two ideas. The first is the Semiconductor Manufacturing Technology Institute, which the Defense Science Board's task force proposed in its report last February. The institute would be organized by a consortium of chip producers and require roughly $250 million per year, with about $200 million coming from Pentagon contracts for special devices used by the armed services.

The second is an organization known as SEMATECH (a foreshortening of Semiconductor Manufacturing Technology), an alliance of 14 major US companies, including IBM, Digital Equipment, Motorola, Texas Instruments and Intel, to try to advance chip making, not chip research or design. Its projected cost is about $1.5 billion over six years—to be shared about equally between member firms and the US government, with a few local governments also chipping in. The Pentagon's budget request for fiscal 1988 included $50 million for SEMATECH, though Defense Secretary Caspar W. Weinberger, who resigned from the Cabinet post in November, informed senators last summer he thought it right to spend twice that amount.

A funding shortcut

Both houses of Congress agreed with Weinberger. The omnibus appropriations bill, which Congress agonized over for nearly three months after fiscal 1988 actually began last 1 October, contains $100 million in DOD's R&D budget for SEMATECH. Until Congress passed the huge catch-all budget bill on 22 December, SEMATECH had been given $3 million by DOD through the Semiconductor Research Corp. The start-up funding had taken a curious route. In a letter dated 7 October, Ronald L. Kerber, deputy under secretary of Defense for research and advanced technology, formally requested that the National Science Foundation act as DOD's agent to transfer funds for SEMATECH to the Semiconductor Research Corp, thereby detouring well-marked military procurement byways, as well as sole-source avenues. The Pentagon's explanation was that DOD would have taken six to nine months to do the paperwork and make the award, whereas NSF could complete the transaction in weeks.

SEMATECH is now seeking a permanent site for its R&D facility to develop and demonstrate better chip production techniques. To that end, SEMATECH invited 13 states last summer to submit proposals to locate the center—applying the same strategy the Energy Department had used for the Superconducting Super Collider. This holds that as more states enter the site selection sweepstakes, more members of Congress have a stake in the outcome and so are likely to back the project.

In some ways SEMATECH reproduces a project that Japan pursued in 1976–80 to close the large lead that US manufacturers held in very-large-scale integrated circuits. Japan's electronics giants worked together, spending about $300 million and sharing patents. The effort is generally credited for accelerating Japan's great gains in the world chip market in subsequent years.

Cultural differences

Japan's vertically integrated electronics conglomerates, like Hitachi, Nippon Electric Co and Toshiba, never stop modernizing their equipment, even if there is no immediate return in sight. The US corporate culture, by contrast, stresses maximizing quarterly profits, particularly for firms that do little more than make chips. One recent study found that about 75% of US semiconductor production lines were using equipment of a type two generations old. In Japan the figure was 40%.

SEMATECH plans to set up a prototype assembly line with people from the member companies working elbow to elbow. The line is not intended to produce chips for sale, just to demonstrate equipment and processes that can be applied by members of the consortium. Member firms would have first rights to buy the results for use in their factories, and nonmembers would be next in line to get these under license.

When it was first unveiled, the SEMATECH concept encountered skepticism in Congress and the Reagan Administration. In its recent report, *The Benefits and Risks of Federal Funding for SEMATECH*, the Congressional Budget Office raised some indelicate questions: Wasn't this just another ailing industry seeking a Federal handout? What if SEMATECH's findings leaked out quickly, resulting in US taxpayers' underwriting new equipment for competitors in Japan? What if SEMATECH enabled its members to establish a chip cartel in restraint of free trade?

Some Washington observers, such as Jacques S. Gansler, a former deputy assistant secretary of Defense, wonder how many strings are apt to be attached to Defense Department involvement in the organization. The military often has special requirements for products built for it. Such requirements can make the products inapplicable to or too expensive for civilian uses. A bigger issue is SEMATECH's financing. In the light of the government's fiscal contraints over the next few years, the industry may have to put up much of the money itself, which some financially strapped semiconductor companies would find hard to do.

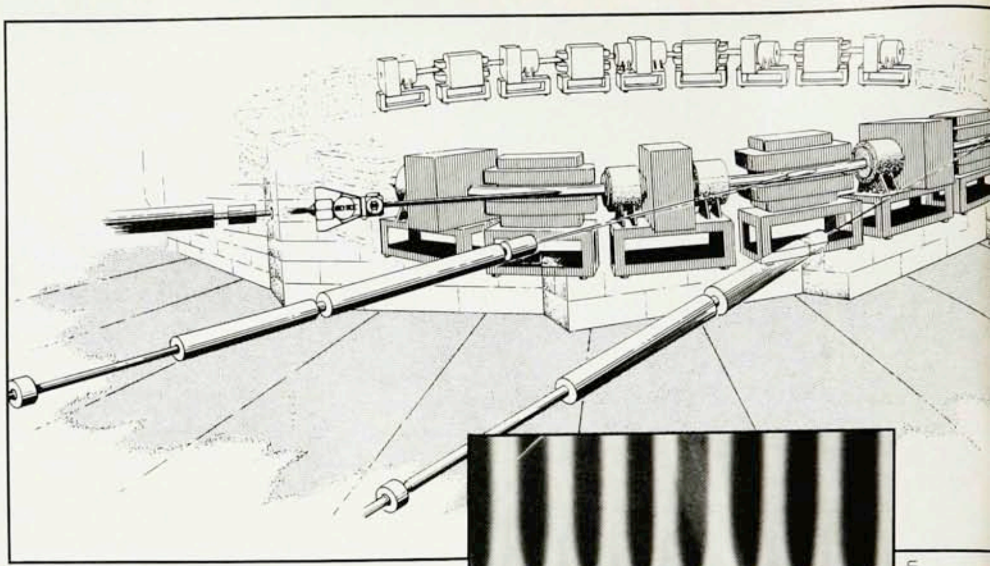
The Congressional Budget Office had another worry: DOD, which is to be SEMATECH's patron, has a bad track record in promoting technology that has immediate commercial application and is cost effective. Despite its qualms and questions, the Budget Office favors SEMATECH because it seems to be the only game in town. So, clearly, does Congress.

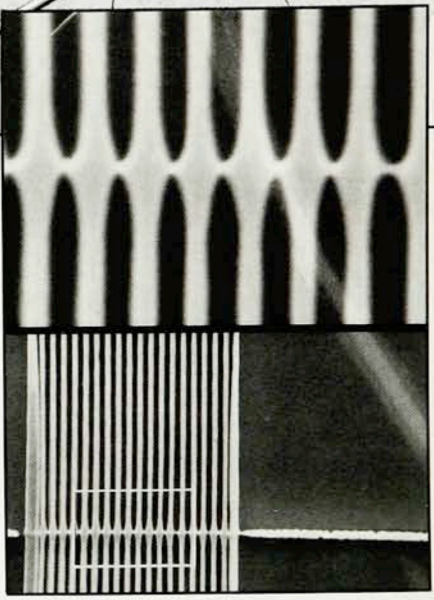
A few years before the DOD began fretting about the semiconductor industry, the Energy Department foresaw the need for advanced technology and even took some actions. DOE's fiscal 1986 budget included preconstruction R&D for the next two major synchrotron light sources—a 6-GeV machine providing hard x rays and a 2-GeV high-brilliance machine optimized for the vacuum ultraviolet and soft x-ray regions. The case for the new machines had been made by a committee of the National Research Council. (See PHYSICS TODAY, September 1984, page 57.) The panel had given the 6-GeV light source top priority, and to be sure of Congressional support, DOE assigned the machine to Argonne National Laboratory, which was casting about for new missions. DOE officials say they will attempt to include the machine, now designed for 7 GeV, in the department's fiscal 1989 budget request. The other priority, the 2-GeV machine, was approved by Congress last year and is under construction at the Lawrence Berkeley Lab's Center for Advanced Materials.

There are now five synchrotron radiation facilities running in the US. Two of them came on line within the past three years: the Aladdin machine at the University of Wisconsin's Synchrotron Radiation Center, and the National Synchrotron Light Source at Brookhaven. When the Research Council committee looked at synchrotron facilities, Aladdin was experiencing serious problems with beam stability and there was little certainty these could be solved. The troubles with Aladdin were cleared up a year later. Operating 60 hours a week, 45 weeks per year, with a reliability factor close to 98%, Aladdin now provides five beam lines to commercial users, including two in active use for x-ray lithography.

For chip makers especially, it is x rays that hold great promise for improving productivity. At the vacuum ultraviolet ring of the NSLS, for instance, IBM conducts x-ray lithography research on a dedicated beam line, with exactly the same goal pursued by the rest of the semiconductor industry: to develop an economical process for making submicron chips. Reducing the size of chip components makes new families of high-speed integrated circuits possible.

Many members of Congress are convinced that academic centers and national laboratories can help advance the work of the commercial chip makers. One persistent advocate is Representative George J. Hochbrueckner, a freshman Democrat whose Long Island district embraces Brookhaven National Lab and the Grumman Corp. On a Piedmont Airlines flight between Washington and Islip airports last January, Hochbrueckner found himself sitting next to Martin Blume, Brookhaven's depu-





To build better semiconductors several national laboratories and commercial companies are in various stages of developing compact synchrotrons for x-ray lithography. The sketch above of a machine proposed by Maxwell Laboratories shows beam lines that will be used to etch chips. Lower part of enlarged photo at right shows grating bar of 1.0-micron pitch with cross lines 0.2 micron wide, etched by x rays from the Aladdin light source. Upper detail is further enlargement of lower portion.

UNIVERSITY OF WISCONSIN SYNCHROTRON RADIATION CENTER ty director, who told him about two workshops the lab had conducted during 1986 for chip producers and equipment makers most likely to benefit from the NSLS storage ring. Before the plane touched ground, Blume had convinced him, the Congressman remembers, that synchrotron lithography in the x-ray range of the spectrum will be the technology of choice in fabricating integrated circuits. Blume had also aroused Hochbrueckner's interest in compact x-ray lithography machines that could be installed alongside semiconductor assembly lines.

Such relatively small light sources are in various stages of development in other countries. Britain's Oxford Instruments Group is building a prototype electron storage ring for IBM to use by the 1990s at its semiconductor plant in East Fishkill, New York. When completed, the Oxford machine will measure only 6 by 15 feet and beam x rays through as many as 12 lines onto the surface of silicon wafers to produce computer chips smaller, faster and cheaper than those made in more conventional ways.

At BESSY, the synchrotron source at the Fraunhofer Institute in Berlin, work is much more advanced. There, a compact storage ring is being built to produce x-ray radiation at 630 MeV. COSY, as the machine is called, will be only 29 feet in circumference, will contain its beam with conventional iron and copper magnets, and will have eight sites for experimental end stations. Technicians at BESSY have already produced semiconductors of 0.25 microns. What's more, a new company, COSY MicroTec, was organized last year by Siemens, Valvo Gmbh, Telefunken Electric and Leybold–Heraeus to manufacture and market the machines at around $12 million each.

Following its customary practice, Japan's electrical industry has entered the field in a big way—as usual, amply supported by the government and replete with customary company rivalries. Japanese companies working in groups or on their own are at various stages on more than a dozen different machines. SORTEC, a consortium of seven electrical giants, is constructing two compact synchrotrons to deliver soft x rays. Because SORTEC has received funds and blessings from the Ministry of International Trade and Industry, it is getting scientific and engineering help from the government's four dedicated light sources, particularly at the 2.5-GeV Photon Factory in Tsukuba. The clearest indication of Japan's ambitions for x-ray lithography is MITI's attention—a parallel to its previous emphasis on such fields as automobiles, shipbuilding, electronics and computers.

Beyond the SORTEC concept, NTT is building two machines with Fujitsu for internal use at both companies; Sumitomo has indicated it is developing a miniaturized superconducting ring only 3 meters in outside diameter (and at 1 meter, even smaller in its orbital diameter), capable of accelerating electron beams to 650 MeV; and NTT, NEC, Mitsubishi, Hitachi and Toshiba have teamed up to produce additional compact synchrotrons.

Even before the latest developments in West Germany and Japan, progress reports from abroad alarmed Congressman Hochbrueckner, who serves on the House Armed Services subcommittee for research and development and the House Science, Space and Technology Committee. After his casual meeting with Blume, he called on the Pentagon's VHSIC office to get backing for the Brookhaven project.

Boosters in the House

The US approach received a boost from House Armed Services Committee Chairman Les Aspin, whom Hochbrueckner enlisted to help convince DOD officials that funds might also be found to support additional x-ray lithography in his district, which includes the University of Wisconsin's Synchrotron Research Center, where a sixth beam line could be added to the rehabilitated Aladdin. Last 19 March Hochbrueckner announced to the press that DOD was sending $1 million from its 1987 budget to the Brookhaven Lab to design a machine and prepare to start construction in 1988.

In fact Brookhaven received something short of $1 million—specifically $750 000. The money passed through DOE to speed up the payment, just as DOD had sent SEMATECH's through NSF. The rest went to Wisconsin's Aladdin machine. DOD's 1988 budget provides $15 million for semiconductor research, with unspecified amounts to go toward designing and building conventional and cryogenic light sources. The new budget also calls for DOE's Basic Energy Sciences program to spend $10 million on x-ray R&D for chip production—specifically allocating $7.5 million to Brookhaven; $1.5 million to Oak Ridge for surface science work in ion implantation, laser annealing and other aspects of semiconductor processing; and $1 million for additional beam lines for x radiation at Aladdin.

In its Energy and Water Authorization Act, passed a month earlier, the House had directed $15 million to Brookhaven for construction of a 1.08-GeV compact synchrotron using conventional magnets of 1.6 tesla and producing specific soft x rays. The lab's plan, developed by its accelerator specialists and a steering committee consisting of experts from IBM, Bell Labs and Perkin–Elmer, calls for a machine that would be 98 feet in circumference, a scaled-down version of the lab's present vuv ring, which is 167 feet around. A parallel effort would be R&D on an even smaller superconducting ring about 32 feet in circumference, somewhat larger than the COSY machine. It would have cold magnets of 3.5 tesla and a beam energy of 600 MeV. Once the technology is proven, the smaller synchrotron is expected to become the prototype for others built by commercial companies. But in the end, the Senate–House budget conference decided that Brookhaven would get only half the funding authorized by the House energy group.

The Senate Appropriations Committee had submitted its version of DOE's 1988 budget bill with another $12 million for Louisiana State University to set up a Lithography Research and Training Center. This item was inserted by Senator J. Bennett Johnston, a Louisiana Democrat who commands both power and respect on the Energy and Natural Resources, Budget and Appropriations committees. It is not certain how LSU will put this money to work, but with that sum it is not hard to imagine how it might be used to advance semiconductor science.

Meantime, several major commercial companies are putting their talents into light sources—among these are Grumman, General Dynamics, GA Technologies, McDonnell Douglas, Varian Associates and Westinghouse. At least one consortium is working on a compact x-ray source. Made up of Maxwell Laboratories of San Diego, Brobeck Corp and Princeton Scientific Consultants, the group has already spent more than $100 000 in designing and testing components of a room-temperature ring with a maximum energy of 1 GeV and a current of 400 mA. The Maxwell group's machine would be 30 meters in circumference, double the size of the Oxford Instruments x-ray source. It would have 12 beam lines.

"It's moot whether the compact machine needs to be warm or cold," says Robert A. Jacobsen, who heads Maxwell's R&D work. "The point is that it be asolutely reliable in producing line features of 0.25 microns or less while maintaining throughputs similar to those of today's optical systems. Using x-ray lithography is far simpler than the lithographic alternatives such as electron beam direct writing or optical projection step-and-repeat printing in exposing a photoresist through a mask."

Jacobsen claims the Maxwell group could deliver such a compact x-ray source to a semiconductor company in about 30 months once the order for it was placed. The cost for such a machine would be around $25 million. "If you survey the use for such facilities worldwide," says Jacobsen, "there would seem to be a market for as many as 180 machines over the next ten years, with about 40% in the US. The first kid on the block might pick up 60% of the business."

—IRWIN GOODWIN

UNESCO ELECTS A SCIENTIST TO LEAD IT, BUT US AWAITS REFORMS BEFORE REJOINING

The election of Federico Mayor Zaragosa, a biochemist from Spain, as the new director-general of UNESCO has changed few minds in Washington. The US has no illusions about returning soon to the United Nations Educational, Scientific and Cultural Organization, which it left with no regrets at the end of 1984. (See PHYSICS TODAY, February 1985, page 53.) Sources at the State Department and White House admit to adopting a wait-and-see attitude about the reforms in the organization's structure, management and programs that Mayor promised when he took office on 16 November, after being elected overwhelmingly on 7 November by 142 of UNESCO's 158 member states.

"It's premature to even think about returning to UNESCO until the next general conference," says Richard T. Miller, a US foreign service professional who has been the official observer at the organization since the departure of Jean Gerard, the last American ambassador. The big biennial conference will take place in Paris in 1989. By then a new US Administration may reach a different position on UNESCO from the one held during the Reagan Presidency. "Expectations that UNESCO can be restored to its basic principles in a few weeks or in a year or two are just unrealistic," Miller told us.

To be sure, until November 1989, Mayor will be carrying out the remainder of a three-year, mid-term program plan devised last year by his predecessor, Amadou-Mahtar M'Bow. That plan was possibly the primary reason the US pulled out of UNESCO. A former education minister in Senegal, M'Bow had been director-general since 1974, and as US officials noted in explaining America's withdrawal to Congress, he, more than any other person, bore responsibility for distorting and disrupting the principles and practices of the organization. During M'Bow's two terms, at least two deputy director-generals quit after accusing him of running UNESCO as a personal fiefdom and of neglecting important projects in science and education while adopting programs plainly hostile to Western developed countries. Under M'Bow, they lamented, the Paris bureaucracy waxed while UNESCO projects waned.

After studying UNESCO, such US government agencies as the National Science Foundation and Government Accounting Office concluded that its activities were largely mismanaged, frequently politicized and excessively trivialized. In the circumstances it was no wonder that the organization, which began in 1946 as an international crusade to upgrade education, uplift science and prop up ancient monuments, had fallen into disarray, its professional staff demoralized and 80% of its budget spent to operate its headquarters in Paris.

When Britain and Singapore followed the US out of UNESCO in 1986, thereby trimming the organization's budget by 30% to $187 million per year, M'Bow was forced to cut both staff and projects. Already bloodied by attacks from his critics, he then bowed to demands from Japan, West Germany and the Netherlands, which threatened to leave unless major reforms were introduced. But, in the event, the changes were more show than substance. After M'Bow's strong backer, the Soviet Union, openly complained that under his leadership UNESCO was no longer delivering its money's worth and then withdrew its support for a third term, he announced, in October 1986, that he would not stand for reelection.

One job, many candidates

Within weeks, campaigns were launched for M'Bow's job. Most candidates were old-guard one-time politicians. None of the early candidates had science backgrounds with the exception of Abdus Salam, who directs the UNESCO-supported International Centre for Theoretical Physics at Trieste. After Salam threw his turban into the political ring in December 1986, the British science journal *Nature* and a few newspapers in Italy, Britain and the Netherlands noted that as a Nobel Prize winner, a founder of the Trieste center and president of the Third World Academy of Sciences he was eminently qualified to restore the organization to its original objectives and to follow in the path of UNESCO's first director-general, Julian Huxley, a distinguished British chemist. But Salam's candidacy failed to receive the support of a single member state, a requirement for official nomination. His own country, Pakistan, nominated General Sahabzada Yaqoub Khan, a former Foreign Minister and ambassador who had the personal backing of President Mohammed Zia-ul-Haq. Salam had been a supporter and adviser to the Pakistani leader whom Zia deposed in a military coup and later hanged.

Then, last February, Mayor began lobbying for support. A year earlier he had described his plan to democratize and decentralize the organization in a speech entitled "Restructuring UNESCO," delivered at a conference sponsored by the University of California's Institute on Global Conflict and Cooperation and the Carnegie Foundation. In it he proposed that UNESCO should concentrate on only a few major global programs and cooperate with separate government or regional activities in the sciences, education, culture and communications.

Mayor earned a doctorate in pharmacology at the University of Madrid in 1958 and studied biochemistry with Nobel laureate Hans A. Krebs at Trinity College, Oxford, where he was a visiting professor and senior fellow in 1966–67. He turned away from research in 1974–75 to serve as Spain's under secretary for education and science, then became founding director of the Severo Ochoa Center of Molecular Biology at the Autonomous University of Madrid, where he spent the next three years. In 1977 he was elected to the Spanish Parliament and named chairman of the education and science commission of the Chamber of Deputies and adviser to the Prime Minister on such matters.

In 1978 he joined UNESCO as