Synchrotron Light for X-ray Lithography

Researchers in West Berlin are building a miniature electron storage ring to test this new microcircuit fabrication technology

West Berlin. The focus in the integrated circuit industry is on the march toward production in commercial quantities of random access computer memory chips that hold a little over 1 million binary bits of information—the 1-megabit RAM. However, Anton Heuberger spends his time pondering the 16-megabit RAM, which is two chip generations farther into the future. Heuberger, who is director of the Fraunhofer Institute for Microstructure Technology here in West Berlin, thinks that x-rays will be the key to making such densely packed memory chips, some of whose components will have dimensions of the order of 0.2 micrometer.

Lithography is far from the only step in integrated circuit fabrication that must be refined if the dimensions of circuit features are to continue to shrink with each successive generation, but as the basic process that defines circuit patterns it is clearly crucial. Because of continuing progress in optics, the current procedure based on near ultraviolet light is likely to be useful even for 4-megabit RAM's, which may have circuit features with characteristic dimensions as small as 0.7 micrometer. But after that something else will have to take its place.

The use of shorter wavelength radiation, namely, soft (long-wavelength) x-rays, is one of the alternatives. However, most x-ray lithography research is on a laboratory scale. To convince integrated circuit manufacturers to invest large sums of money in a new technology, argues Heuberger, it will be necessary to demonstrate that the x-ray process can do at least as well as the present optical one in a realistic environment. His goal is to demonstrate up to the pilot line stage a complete production process for a 4-megabit RAM by about 1988, in time for comparison with commercial chips.

Heuberger is getting a chance to put his convictions to the test. The Fraunhofer Institute, which was formed in 1983 as an independent organization under the auspices of the Fraunhofer Society, a West German applied research organization, is putting the finishing touches on a new building that is connected by an underground passageway to the institute's existing laboratory at the Berlin Electron Storage Ring for Synchrotron Radiation, also known as BESSY (*Science*, 15 March, p. 1323). When finished, it will house all the equipment needed for integrated circuit production. At the hub of it all will be the world's first electron storage ring built for the sole purpose of generating long-wavelength x-rays for the photolithographic process by which patterns are transferred from masks to silicon chips.

The virtues of synchrotron radiation are its high intensity, which makes for short exposure times—a necessity if future chips are not to cost much more than present ones because of slow production processes—and collimation. Collimation is more subtle. Because there will always be a short distance (50 micrometers in the research so far undertaken at BESSY) between the mask and the silicon surface, using x-rays from a blurred image will occur whenever light rays from different points on a source of finite size pass by a given spot on the mask. If the light is highly collimated, light from only a small part of the source contributes to each point in the image, thus minimizing the blurring effect.

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Unfortunately, synchrotron light facilities are large and expensive, and hence unsuitable for a company considering incorporating one into a production process. The new ring, dubbed COSY, will use high field strength (5-tesla) superconducting magnets to guide and focus the electron beam in a racetrack-shaped orbit. The high field means that the orbit can be small without a significantly lower beam energy than in larger machines, so that the miniaturized storage ring continues to produce x-rays. The circumference of COSY will be 9 meters, as compared to 62.4 meters for BESSY, but COSY will actually generate shorter wavelengths than its big sister. The smaller size is reflected in the cost, which at 5 million deutsche marks for COSY is 1/4 that of BESSY.

BESSY's accelerator division is developing the new storage ring under contract to the Fraunhofer Institute. Gottfried Mülhaupt, who is directing this effort, estimates an end of 1986 completion date for the COSY project. The major uncertainty at the moment is the means of injecting high-energy electrons into the storage ring. High-energy injectors tend to be large and expensive themselves, thereby negating any benefits of a small storage ring. Mülhaupt says that two schemes for injecting electrons at low energy and accelerating them in COSY are scheduled for testing.

It is not only Heuberger's enthusiasm but also some solid progress that has motivated the West German government and four German electronics companies to jointly cough up funding for the project that will total about 100 million deutsche marks, including the present laboratory, the new one, COSY, and a host of the most advanced equipment (scanning electron beam pattern generators, plasma etching machines, and so on). Experiments began when BESSY opened up for business in mid-1982. The Fraunhofer Society's Institute for Solid-State Technology was the initial coordinator for a five-way research program involving itself and the four companies: Siemens, Telefunken, Valvo, and Eurosil. The Institute for Microstructure Technology grew out of this effort.

The cooperative research focuses entirely on developing technology up to but not beyond the stage where proprietary interests would exert themselves. Thus, while each of the partners can undertake its own projects, the results are shared fully. Development of a mask technology is one example. The mask comprises a thin but structurally strong membrane that is transparent to x-rays, and an x-ray absorbing material that is deposited on the membrane with the requisite pattern. X-rays passing through the mask thereby transmit the pattern to a polymer material that covers the silicon surface and is sensitive to the x-rays.

Each of the partners initially investigated a different combination of support and absorber materials. The Fraunhofer Institute and Telefunken, for example, looked at a silicon support with a gold absorber, while Eurosil experimented with a silicon nitride/gold combination and Valvo tried silicon/tungsten. As it happens, the first two turned out to be good choices, but others have not worked out. Now the entire project is concentrating on these materials. One recent accomplishment is finding a way to minimize distortions in the mask due to the different physical properties of the membrane and the absorber.

Some tasks are contracted to German industry. For example, a critical part of any photolithography process is alignment. Several masks with different patterns are needed in building up a complete circuit pattern, and each mask has to be aligned with the pattern left by its predecessor to an accuracy much better than the minimum feature size in the pattern. The Karl Süss Company near Munich together with a group from Siemens took on the job of constructing a mask alignment system. In tests at BESSY, the apparatus successfully achieved an accuracy (3 standard deviations) of 0.1 micrometer. Unfortunately, the time taken to do the alignment is excessive; it will be shortened.

Development of polymers, also called resists, that combine a high sensitivity to x-rays for rapid exposures and a good contrast, so that low intensities of x-rays leaking through the absorber do not expose the resist, is another example of a project contracted out to the chemical company Hoechst and to other research institutes in this case. Such resists are sensitive subjects as well as sensitive objects and tend to be proprietary, so Heuberger would only say that promising materials are being looked at.

All in all, with about 80 researchers and administrative staff on site, the x-ray lithography project in West Berlin is the largest and most ambitious of any at the moment. In the United States, IBM, which carried out some of the first synchrotron x-ray lithography experiments, has a more modest project under way at the National Synchrotron Light Source at Brookhaven National Laboratory. German electronics companies would no doubt love to be the first to succeed in a frontier area of integrated circuit technology, which is almost totally dominated by American and Japanese firms. If Heuberger is right, they will.

—ARTHUR L. ROBINSON

Forecasting the Weather a Bit Better

A new computer model provides a distinct improvement in short-range forecasting, but you may not notice much of a difference by looking out the window

If you don't take your umbrella to the office tomorrow, will it rain on you despite the weather forecaster's reassurances? Will the weekend's picnic be rained out? Sometimes it seems that a look out the window and crossing your fingers is as reliable a guide as the official weather forecast in such situations. Forecasters share your frustration—predicting whether it will rain and how much it will rain has been their most frequent downfall. But now they have a brand new computer model that spins out a sharper and apparently more accurate picture of future weather, especially future precipitation.

Despite their enthusiasm for the new system, forecasters caution that their field is a tough one in which even the greatest efforts yield only modest improvements. An incremental, although significant, improvement such as this one will likely be heralded by meteorologists but go unnoticed by the public, they say.

The new forecasting model is an improvement in many ways, but perhaps the most important difference is its sharper, more detailed view of the atmosphere. A leading forecasting model used during the past 10 years at the National Weather Service's National Meteorological Center (NMC) outside Washington, D.C., is the Limited-area Fine-mesh Model (LFM). Like many computer forecasting models, the LFM can make a forecast using only atmospheric properties at points defined by the intersections of a three-dimensional grid system. All the weather between grid points must be summed up as well as possible at the nearest grid point, so the closer together the grid points the more realistic the model's view of the weather. In its most recent form, the LFM divides the atmosphere horizontally into grid squares about 190 kilometers on a side and vertically into seven layers.

The new system, the Regional Analysis and Forecast System (RAFS), has a grid spacing or horizontal resolution of about 80 kilometers and 16 vertical layers. It was created from scratch in NMC's Development Division, which is headed by John Brown, with particular contributions by Norman Phillips, James Hoke, Geoffrey DiMego, and Joseph Sela. With the improved resolution, weather that occurs on smaller scales, such as the narrow band of rain along a front, is more likely to be clearly defined in the model's initial picture. When the model applies its set of built-in physical laws to compute future weather patterns, the size, shape, and intensity of the forecast rain band should be more realistic as well.

A less fuzzy picture of the atmosphere may be desirable, but it extracts a heavy penalty. Halving the space between grid points over a given area requires increasing the number of calculations by a factor of 8. The burden of the new model's closer grid spacing is carried by the NMC's new CYBER 205 supercomputer, which is up to 50 times faster than the old computer. But even the CYBER could not handle an additional intended improvement—the expansion of the area covered by the model from a box over North America and adjacent oceans to the entire Northern Hemisphere—without special adjustments.

From its beginnings, the old LFM had the problem of determining what weather should be moving across its boundary into its grid from the rest of the hemisphere. A 12-hour-old forecast from another model was the best solution available. But the RAFS extends so far—as far as the equator—that no weather from outside its domain is likely to have much effect over North America during the 48 hours of a forecast period.

In order to handle the increased computational burden of hemispheric coverage, Phillips and Hoke focused the high horizontal resolution on North America where it is most needed. Within a hemispheric grid having 320 kilometers between grid points, they embedded a square having 160 kilometer resolution, and inside that they placed the highest resolution grid (80 kilometers) centered on North America. Weather is free to move back and forth across these grid