Industry and Academia Join Hands in Search for Post-CMOS Logic

The end of Moore's law—the halving in size of electronic components every 18 months or so—is approaching. But the law could get a reprieve and lead to a technological and economic gold rush if non-charge-based information manipulation is attained.

Six US semiconductor companies have teamed up to pursue long-term research with academic scientists and engineers. At two new university-based nanoelectronics institutes—and a third one in the works—the research varies, but the mission is the same: Find a technology to succeed CMOS.

The international semiconductor industry predicts that the lower size limit for CMOS, complementary metal oxide semiconductor technology, the basis of today's electronics, will be reached in about 15 years. The current generation of CMOS is at the 65-nm scale, and calculations suggest that below around 10 nm, excessive leakage, scattering, and power dissipation will make CMOS impractical.

The semiconductor industry has "become more and more interested in exotic physics. They can see that we are going to run out of capability with the technology we are using," says Jeff Bokor, who specializes in nanofabrication and nanoelectronics at the University of California, Berkeley, and is a member of the new Western Institute of Nanoelectronics (WIN). "So industry is coming to university folks and saying, 'We need a new way to represent information and processing. Help us figure it out.'" For university researchers, Bokor adds, "that is a pretty exciting proposal. It's a way to have impact."

"We are trying to come up with a revolution," says IBM's Hans Coufal, director of the NanoElectronics Research Corp (NERC), which represents the six participating companies—Advanced Micro Devices, Freescale Semiconductor, IBM, Intel, MICRON Technology, and Texas Instruments (TI). "For decades progress in the semiconductor industry has been the engine driving increased productivity and the increased standard of living in the US and globally. If we don't come up with a solution to the problem in the next 15 years, progress will stop." The NERC companies are committing roughly $40 million in cash and equipment over four years, but with matching funds and facilities provided by the host states and universities, says Coufal, assets for the three institutes will total some $750 million.

WIN and the Institute for Nanoelectronics Discovery and Exploration (INDEX), headquartered in New York, are just getting started. The South West Academy for Nanoelectronics (SWAN), led by the University of Texas at Austin, is to be launched later this year.

The idea, says WIN spintronics researcher David Awschalom of the University of California, Santa Barbara, "is to develop a new paradigm for faculty and students interacting with industrial scientists. It's an attempt to deal with the demise of basic research within industrial labs around the country."

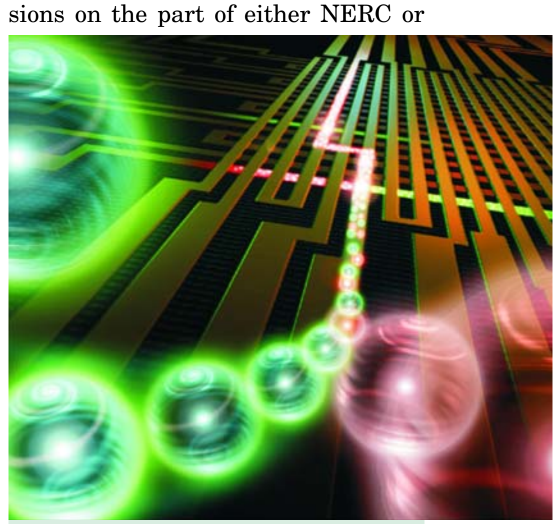
High risk, high payoff

The nanoelectronics institutes will be governed by executive bodies made up of equal numbers of industrial and academic researchers. Those bodies will guide the flow of money, decide on research directions, and determine when to move a project to industry for development and marketing. Says Bokor, "There has to be consensus. Neither side can outvote the other."

The industry partners will place scientists on site at the institutes for months or years. "Part of the plan for influencing university [research] directions is to have company assignees participating at these centers," says Hans Stork, TI's chief technology officer and a member of the NERC governing council. "They can help prioritize and interpret the value of certain activities, and they would be a conduit to bring information and knowledge back to the company." The close collaboration, says INDEX lead investigator Alain Kaloyeros of the State University of New York at Albany, "is an amazing opportunity for students. They will work on the most exciting, most enabling solutions for industry, and see what it's like to work in industry. I will be surprised if a lot of employment opportunities don't come out of these interactions."

The institutes, says Kaloyeros, "are a one hundred percent NERC-driven project. NERC's position was to put in seed funding, and New York is very interested in being at the leading edge in this field. These two things happening concurrently helped us set up INDEX with the right level of resources." INDEX gets off the ground with $175 million from New York and $100 million from Georgia for new laboratory space in those states. (In addition to SUNY Albany and the Georgia Institute of Technology, INDEX's 40 or so researchers are at Harvard University, MIT, Purdue University, Rensselaer Polytechnic Institute, and Yale University.) The WIN partners—Stanford University and the Berkeley, Los Angeles, and Santa Barbara campuses of UC—will have access to the UCLA–UCSB California NanoSystems Institute (see PHYSICS TODAY, February 2001, page 24), nanofabrication centers at Berkeley and Stanford, and other local infrastructure. Membership in SWAN hasn't been finalized.

The challenge for these institutes, says SWAN principal investigator Sanjay Banerjee, is "to come up with devices that operate at room temperature, are small, consume less power, and are faster than CMOS. It's very high risk, with a potentially high payoff. I don't think there are any delusions on the part of either NERC or



Will circuits relying on spin be the future of electronics? (Artist's rendering courtesy of Slim Films, http://www.slimfilms.com.)

the centers that it's a sure bet. But clearly it's time to start looking."

"Trial balloons"

One area all three institutes are looking into is spintronics. "All electronic devices, even back to vacuum tubes, have always relied on movement of charge and causing a current to flow," says WIN electrical engineer Jim Harris of Stanford. Now, scientists aim to create, manipulate, transport, store, and read out information using the spin of electrons instead of charge. Says Awschalom, "We've performed a variety of physics experiments, but the spin property of electrons in semiconductors has never been fully exploited for information processing and devices." Different approaches, taking advantage of various spintronics phenomena, adds Bokor, can be taken "to make something that looks very similar to a logic gate that we use today in digital electronics."

Research at WIN includes manipulating spins with electric fields, storing information in nuclear spins, and exploring how to use spin to communicate from device to device. "You would probably have to have spin-to-electrical conversions and communicate that by electronic processes," says Harris. WIN also includes a small effort in plasmonics—information transmission using collective oscillations of electrons.

INDEX is doing some spintronics, but the focus is more on magnetic devices, molecular switching, and understanding the leap to manufacturing, in terms of yields and costs. "This assessment will be done hand in hand with industry," Coufal says.

The scope of research at SWAN has not been firmed up, says TI's Bob Doering, a member of the NERC technical program group, to which the individual executive bodies report and which guides research across the institutes. "But there will be some form of spintronics there as well. There is also a suggestion of exploring phasetronics—encoding information on electron wavefunctions." Spintronics, he adds, "is a big bite in each of the institutes. The research community has built a consensus that it's a promising direction. Each institute is looking at a different aspect, a different implementation of spintronics."

"A lot of these ideas are trial balloons," says Stork. "What we expect is to get a better fundamental understanding. Nobody is looking for an industrial return any time soon."

Toni Feder

Science Board Warns of Global S&T Competition as US K–12 Education Lags

The US remains the world leader in science and technology, but China, with total R&D spending that reached $84.6 billion in 2003, is rapidly moving toward the front of the line. And while China's S&T development is rushing forward, many other countries, particularly those in East Asia, are steadily increasing their investments in science, engineering, and mathematics and are becoming serious competitors in the S&T race. Those are the basic findings of the National Science Board's *2006 Science and Education Indicators,* a biannual report that assesses the state of science worldwide.

China and other East Asian nations are "recasting the international S&T scene" through heavy investments in science, engineering, and mathematics.

The extent of investment by China and other East Asian countries, particularly South Korea and Taiwan, has turned what the NSB's 2004 report called the "potential" S&T competition with the US into "reality," the new report says. The emerging East Asian countries are Singapore, Malaysia, and Thailand, which have "boosted their market strength and showed potential for further increases in competitiveness."

But China is the elephant in the room. According to the report, "China is growing at the most rapid pace, and its government has declared education and S&T to be the strategic engines of sustainable economic development." Data from the Organization for Economic Cooperation and Development indicates that China's R&D spending reached $84.6 billion in 2003, up from $12.4 billion in 1991. The NSB notes that it is difficult to draw precise comparisons with R&D spending and investment data from different countries, but if the numbers are accurate, they "put China in third place, behind only the United States and Japan, and ahead of Germany."

While R&D investment in the US, Japan, and the European Union increased between 4% and 5% annually from 1991 to 2003, China raised its R&D spending by an annual average of 17%, the report says. For the past