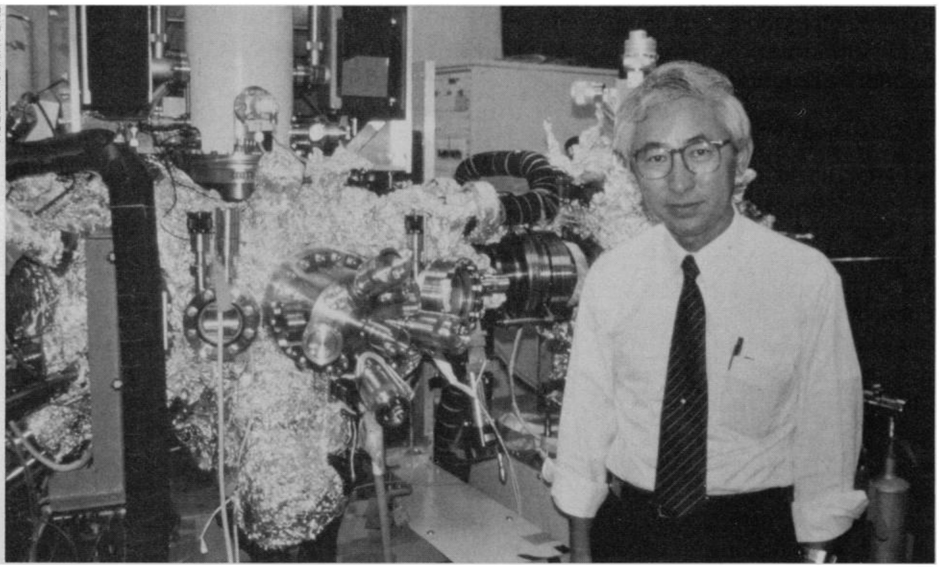


ROBERT CRAWFORD

**Desperately seeking nanostructure.** *Yoshifumi Katayama of the Optoelectronics Technology Research Laboratory.*

# Japan Starts a Big Push Toward the Small Scale

## *Japanese industry is watching doubtfully as MITI embarks on an ambitious program of nanotechnology research*

*Tokyo*—IN 1990, ABOUT THE TIME researchers in the United States spelled "IBM" by lifting and depositing individual, supercooled xenon atoms onto a nickel substrate with a scanning tunneling microscope (STM), some boisterous competition in the new field of nanotechnology was getting started across the Pacific. Less than a year later, Shigeyuki Hosoki, an electronics researcher at the Hitachi Central Research Laboratory (HCRL) in Tokyo, carved "PEACE '91 HCRL" into a sulfur medium using an STM—but, unlike the IBM team, he did it at room temperature, without the need for a massive cooling system. Soon afterward, several other Japanese electronic equipment manufacturers moved in with further improvements on the U.S. technique, reducing from hours to seconds the time needed to etch lines just a few atoms wide in silicon.

That Japan is once again demonstrating its extraordinary capacity to borrow, improve, and excel will come as no surprise to the West's battered electronics industries. As the STM advances show, Japanese companies are already refining the instruments vital to nanotechnology research—so much so that many U.S. laboratories may soon be relying on Japan for their STMs. But in the coming race to dominate the nanometer scale, Japanese researchers are determined that this trans-Pacific competition will be different from those of the past: In building nanoscale devices—atomic memories, quantum wells, and single-electron transistors—Japanese researchers say they want to draw on their own basic research.

The big question now is how that research will be organized. Big corporations are already flocking to nanotechnology research, bringing with them variations on research strategies that they have used in the past. But they know that government support will be necessary for the long-term effort needed in nanotechnology. And that large-scale government support is beginning to be put together, with the Ministry of International Trade and Industry (MITI), pledging as much as $225 million over the next 10 years. The only problem: Nanotechnology researchers in Japan worry that MITI doesn't understand what it takes to do basic research. MITI officials, they suggest, may say they are eager to foster creativity, but in practice they are inept managers.

And that's a serious concern, Japanese researchers say, because conventional silicon technology—the mainstay of existing microelectronics—cannot be driven much further. "If DRAM chips continue to quadruple their density every 4 years, by 2010 we will probably produce the gigabit chip, and this will push silicon chips to their ultimate limit," explains Masakazu Aono, laboratory head at Japan's Institute for Physical and Chemical Research (RIKEN) and director of the "Atomcraft" nanotechnology project of the Exploratory Research for Advanced Technology (ERATO) program, a government effort to fund promising researchers. "Once conventional transistors reach abut 0.1 micron, about the wavelength of an electron, silicon technology will break down—electrons will tunnel through their switchgates."

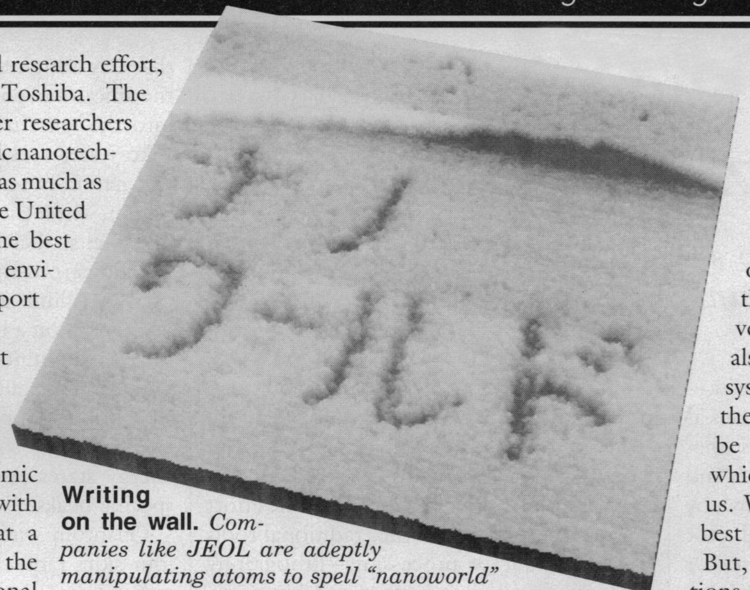
To go any further, says Yoshifumi Katayama, a research director in the MITI-funded Optoelectronics Technology Research Laboratory, "we need to change the basic operating principles of circuits by introducing nanostructures." Shojiro Asai of Hitachi, for example, envisions replacing the electric charges of conventional semiconductor memories with single atoms to make an "atomic memory" device. "If you remove an atom with an STM probe tip," he says, "the atomic hole could be used to encode one bit of digital information. It would be an extremely compact information storage device." In theory, a 1-square-centimeter surface, containing 1 quadrillion atoms, could store all recorded human knowledge.

Another way around the 0.1 micron barrier, advocated by Jaw-Shen Tsai, a Research Manager of NEC's Advanced Device Research Laboratory, is the single-electron tunneling (SET) transistor, which exploits the very quantum effects that confound conventional circuitry. "By making the tunneling junction smaller and smaller," he says, "eventually you can squeeze the current down to a regime where you start to influence individual electrons.... You just can't make a smaller circuit than that."

Both Tsai and Asai know that the practical problems of such devices are legion. In atomic memory devices, for example, thermal expansion of the substrate material could shift the position of encoded information, making it difficult, if not impossible, to retrieve. "And even if you construct an SET circuit," says Tsai, "you still have to assemble nanostructures around them and wire them into electronic devices."

Transforming these concepts into working devices will take a sustained research effort, says Akinobu Kasami of Toshiba. The United States, he and other researchers acknowledge, is ahead in basic nanotechnology research, perhaps by as much as a year. "To compete with the United States, we need to unite the best researchers in a competitive environment. Government support is crucial," Kasami says.

That large-scale support will take the form of two 10-year nanotechnology projects announced by MITI this year: the Atomic Technology Project (ATP), with funding virtually assured at a total of $185 million, and the smaller Quantum Functional Devices Project, with a total budget of $40 million. Both projects have formidable goals that, if fulfilled, would give Japan a stronger grounding in homegrown research in nanotechnology than it has in any other field.




**Writing on the wall.** *Companies like JEOL are adeptly manipulating atoms to spell "nanoworld"* (above)*, but researchers like Genya Chiba* (left) *and Jaw-Shen Tsai worry about the government's ability to seize a lead in basic science.*

CRAWFORD (BOTTOM); JEOL (TOP)

"We plan to lay the groundwork for the age of terabit chip technology," says Takeo Hoshino, the MITI official who manages ATP, "and that requires us to observe and eventually manipulate individual atoms to build nanostructures. We need to develop a wide array of basic supporting technologies, like ultra-high vacuum chambers, supercomputer simulations of surface physics and chemistry, and a femto-second pulse laser." The Quantum Functional Devices Project has narrower goals; it will develop the technology needed to build ultrafine semiconductor structures that take advantage of the quantum features of individual electrons.

Sounds great, but this is where many researchers start to worry. Existing national laboratories, such as MITI's famous Electrotechnical Laboratory in Tsukuba Science City, provide good reason to be skeptical, many private sector officials and researchers interviewed by *Science* say. Kazunobu Tanaka, director of materials science at the Electrotechnical Laboratory, explains: "The problem in the national labs is management—there isn't any. Young researchers enjoy enormous freedom at the beginning. However, they can't get support from the top—if they discover anything interesting, they can't get extra funding or become team leaders. Everything is determined by seniority, so they just have to wait."

Reformers in Japan's policy elite hope that a different culture will permeate MITI's new nanotechnology push. According to one top research manager, who declined to be named, "We want to build an organization for nanotechnology that runs like the Natonal Science Foundation, with a peer-review granting mechanism and competition by research quality....To attract the best people, we have to make it challenging and rewarding."

But the would-be reformers are facing considerable opposition. Genya Chiba, who heads ERATO, explains: "You have to be very patient because you're going against hundreds of years of history"—traditions that hinder organizational flexibility by discouraging merit-based promotions and firings. "The problem is, there are limits to what anyone can do: The scientists and bureaucrats are already hired, and we can't just get rid of them. We have to see which ones are willing to change, find new places for those who don't perform well, and select new scientists."

For now, all eyes are on the new nanotechnology lab that MITI wants to build in Tsukuba Science City as part of the Atomic Technology project. Its success will determine the willingness of companies—already short of science and technology manpower—to loan their researchers to the government's nanotechnology effort. One research team leader in a corporate lab, who spoke on condition of anonymity, expresses the reluctance MITI is facing: "It is very hard to hire top level professionals in Japan because the educational system just isn't producing enough of them. Unfortunately, we are forced to be involved in many MITI projects, which are often just a waste of time for us. We usually can't afford to send our best people."

But, practical as ever, Japanese corporations aren't waiting for the outcome of MITI's basic-research push to try and make money from nanotechnology. They are focusing their sales plans on the instrumentation needed for nanotechnology research. Part of the market for these devices, designed for examining and manipulating matter on the atomic scale, will come from industry and government labs. But as conventional microcircuits go on shrinking, a demand for similar equipment will also develop in the microelectronics industry. Take STMs: As circuit makers abandon lower-resolution techniques in favor of electron-beam lithography—capable of etching circuits just hundreds of angstroms wide—STMs could be the only instruments capable of inspecting the resulting devices.

One instrument maker—Japan Electron Optics Laboratory (JEOL)—typifies this dual strategy. "We will manufacture a low-level [STM] for surface inspection of chips and of extremely fine chemical films," says research manager Masashi Iwatsuki, "and a higher-resolution device for scientists."

For now, U.S. researchers may have a lead in basic research—and, given the organizational difficulties besetting the Japanese research effort, they may end up keeping it. But when it comes to equipping their labs, they may still end up buying Japanese. Here is Iwatsuki's description of his company's strategy: "We start by producing for customers in Japan, and eventually improve quality enough to enter the international market. By selling on a large scale, we will reduce production costs, and thus our prices." The orders are already coming in "from Bell, Kodak, and U.S. government labs," he says. Sound familiar? ■ ROBERT CRAWFORD

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