U.S. government provides 16% of the ATCC's $18 million budget, with the remainder coming largely from sales of cultures and diagnostics. But unlike some lab cultures, such as human cancer cells, plant viruses, with their relatively low sales, generate little income, and their maintenance costs, especially for greenhouses, are high. Plant-virus collections "can't be run just on sales," agrees Stephan Winter, who operates a smaller service at the University of Braunschweig in Germany. This collection, Winter adds, receives most of its support from German federal and regional governments.

To cut costs while trying to maintain this valuable resource, Cypess says the ATCC has made arrangements to share a greenhouse at neighboring George Mason University after it occupies its new building in March 1998. The organization has also reassigned several biologists to oversee the collection in the absence of the outgoing collection curator, who departs this month.

But plant scientists fear that these measures won't be adequate. "It's not doable to have a generic plant biologist curate a specialized plant-virus collection," says Rutgers University plant biologist Peter Day. Contributions of new and important cultures are unlikely to be made to a collection that is not actively curated, says de Zoeten. He adds that there are also concerns that the agreed-upon greenhouse space might not be sufficient nor available on a timely basis. Many plant viruses have to be transferred to a new batch of plants every few months to survive, which puts heavy demands on greenhouse space.

Cypess responds that the ATCC wants to address these concerns. Among others, the organization is studying the possibility of shifting the plant-sciences program to a land-grant university that supports a lot of plant biology, although no plans have been made yet. But even he concedes that the plant-virus collection might be in jeopardy. "It's never going to develop adequately at the ATCC," he says, "unless additional resources to support it are identified."

In the meantime, the ATCC and plant biologists, together and independently, are exploring various strategies for strengthening the plant-virus collection. One possibility, Cypess says, is for the plant-science community to find new funding to support an endowment for the collection. Where that funding might come from is unclear, however. The National Science Foundation rarely makes the type of long-term commitment needed to maintain a collection. And the obvious agency for long-term support of the plant-virus collection—the U.S. Department of Agriculture—has given nothing. As Vidaver points out, "There is no long-term national policy for supporting the maintenance of culture collections of microorganisms, including viruses."

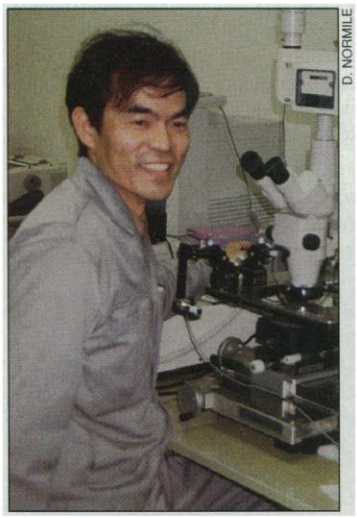
–Anne Simon Moffat

JAPANESE INDUSTRY

Staying Off Beaten Track Puts LED Researcher a Step Ahead

ANAN, JAPAN—Nichia Chemical Industries Ltd. is an hour's drive from Tokushima airport. But jump in any airport taxi, say "Nichia Chemical," and the driver will speed down Tokushima Prefecture's narrow roads, through miles of rice paddies and sweet-potato fields, past racks of drying seaweed, to your destination in the tiny town of Anan. "Probably every taxi driver in this prefecture knows the way to Nichia," says one cab driver about the prefecture's third-largest employer. "It's famous."

Materials scientists around the world would agree. For them, however, the company's fame rests on the research of one man: Shuji Nakamura, a researcher who is a far cry from the traditional image of a corporate scientist. Holding only a master's degree and working with just one assistant, Nakamura developed the world's first bright blue light-emitting diode (LED). And he is leading the race toward an even bigger prize: the commercialization of a blue laser. He pulled off these feats while working at this small company, far off the beaten high-technology track on Shikoku, the smallest of Japan's four major islands. Even his competitors are generous with their praise: "It's a truly remarkable achievement," says Shigeru Sato, the head of research for Fujitsu Ltd., the giant Japanese electronics firm, about Nakamura's work.


D. NORMILE

"If I get 10 ideas, I try all 10. I just need a target."
—Shuji Nakamura

The challenge of creating more efficient solid-state devices that would emit blue light without burning up in seconds has long stumped legions of scientists at the world's largest electronics companies and leading universities. Nakamura solved the problem in 1993 by taming gallium nitride, one of the few semiconductor materials capable of emitting light at the desired blue wavelength but notoriously difficult to fabricate into working devices.

The commercial stakes are high. With their shorter wavelength, blue lasers promise to quadruple the amount of information stored on music CDs and CD-ROMs. As the last of the primary colors—red, green, and blue—to be available as an LED, the blue LED has also paved the way for the use of these long-lasting, highly efficient light emitters in giant outdoor displays and other high-demand sources, among other applications. What's more, combining red, blue, and green structures in one device produces white light, something that may eventually make the light bulb obsolete. Ramu Ramaswamy, an electrical engineer at the University of Florida who works on optoelectronics, predicts that the developments stemming from Nichia's breakthroughs "will change the world as we know it."

A lighter side. The 42-year-old Nakamura does not have the air of someone who is changing the world. An easygoing, self-described country boy, he laughs easily and often as he tells of his research travails. His first scientific paper, he recalls, was sent back three times. "The English was incomprehensible," he confesses before breaking up. Even more mystifying to those familiar with the buttoned-down norms of industrial research in Japan is the fact that Nakamura never sought nor received corporate permission to publish his results. Indeed, when a company salesperson, contacted by a customer who had read about Nakamura's work, asked what was up, "I told him I didn't know anything about it," Nakamura says, laughing even harder.

But the real punch line of the story is how Nakamura got his research under way. In 1988, after 10 years at Nichia, Nakamura was fed up with working with "near-zero" budgets on themes picked by others. He wanted to choose his own target, and he knew that the first blue LED would be a big prize. He guessed that the founder and chair of the company, Nobuo Ogawa, might be a kindred spirit, so Nakamura bypassed his immediate boss and went straight to Ogawa to request $5 million in equipment. "And," Nakamura says, his eyes and grin widening, "he said, 'OK'!"

Ogawa, now a feisty octogenarian who spends his vacations trekking the world's mountains, founded Nichia in 1956 in his hometown of Anan. A major supplier of phosphors used in cathode-ray tubes and fluorescent lights, Nichia has a work force of 900, annual sales of about $250 million, and holds about 25% of the world market. Luckily for Nakamura, the family-controlled company likes to do things differently. For starters, Ogawa disdains graduates of the nation's elite universities. "Their heads are too full of book learning," he says. And Ogawa eschews many standard business practices, including annual R&D budgets. "You just spend what's needed to do the job," he says.

Nakamura was already familiar with LEDs when Ogawa gave him permission to plug away. An LED is essentially a sandwich of conductive materials with electrodes attached top and bottom. Passing a current through the sandwich forces electrons and positive-charge carriers called holes to combine in the middle of the sandwich and emit photons of light, the color of which depends on the characteristics of the materials.

At Nichia, Nakamura had worked on three development projects, each involving basic materials used in semiconductor and LED manufacturing. Although the sales force had picked the target products, they fizzled in competition against similar products from bigger companies with established reputations in semiconductor materials. That experience taught Nakamura the importance of finding an original solution to a problem. And so, for his blue LEDs, he chose gallium nitride, a material the rest of the world had given up on. While theory predicted gallium nitride would produce blue light, it had proven extremely difficult to form the material into thin layers and to entrain the impurities needed for it to carry the positive-charge–carrying holes effectively.

The glow of success. Nakamura had doubts about whether he could succeed where others had failed. Before beginning his research, Nakamura spent a year in the United States studying a semiconductor fabrication technique, called metal-organic chemical vapor deposition (MOCVD), that he anticipated would be a key to the successful use of gallium nitride. He worked with Shiro Sakai, who preceded him at Tokushima University and was then developing MOCVD equipment as a visiting professor at the University of Florida, Gainesville.

Returning to Anan in 1989, Nakamura started his gallium nitride work by first tackling the problem of formation. In the MOCVD process, reactant gases under carefully controlled temperatures and pressures are blown into a reactor, where the target material forms and is deposited on a substrate as a thin film. Producing gallium nitride requires high temperatures that heat the substrate above 1000°C, much higher than processes using other materials. The high temperature triggers convection currents that interfere with deposition.

Nakamura's solution was to counter the effect by adding a second jet to the reactor that directed a stream of gas perpendicular to the face of the substrate. This technique allowed him to grow gallium nitride layers with minimal defects. His report on this process—the one that was returned three times for its poor English—appeared in *Applied Physics Letters* in 1991. It was Nakamura's first published paper. He was 37.

Nakamura continued to make steady progress, and in January 1993 he hooked up his latest test fabrication and got a glow. It was dull, but pure blue, with a wavelength of 450 nanometer. Half afraid it might burn out, he left it on overnight. When he peeked into his lab the next morning, however, it was just as blue as when he'd left it. Fiddling with the structure increased the brightness, and in November, Nichia announced that it had a blue LED that put out 1 candela of light.


D. NORMILE

"You just spend what's needed to do the job."
—Nobuo Ogawa

The level was more than 100 times brighter than previously available blue LEDs and bright enough to be used alongside red LEDs. In April 1994, Nakamura switched on a panel of sample LEDs during a presentation at the spring meeting of the Materials Research Society in San Francisco, and the standing-room-only crowd of scientists "oohed" and "aahed" like children watching fireworks. One year later, Nichia's blue LEDs were showing up in outdoor displays throughout Japan.

Competitors have only recently brought their own blue LEDs to market. And none matches Nichia's brightness, an indication of how far ahead of the field Nakamura was. His lead reflects his talent for working with gallium nitride, says Sakai, now a professor at Tokushima University, who adds that the material's "unique growth properties" mean that theories and experiences gained from other materials don't apply.

Family time. Nakamura's decision to stick with gallium nitride, despite the formidable technical hurdles, is typical of his approach to science. "If I get 10 ideas, I try all 10," he says. "If I get 20, I try 20." And his laid-back manner is deceptive. "He's an extremely hard worker," says Florida's Ramaswamy. "He just plugs away." With few interests outside work, he wastes little time pondering how his discoveries are put to use. "The sales and applications are up to somebody else. I just need a [research] target to work on," says Nakamura, who finally received his engineering Ph.D. in 1994.

His target these days is the blue laser, and his team, which now numbers 15 researchers and technicians, is leading the pack past several significant milestones. They have found ways to form the laser mirror cavity in the gallium nitride efficiently and have simplified the structure of the device to lower the lasing threshold current and voltage. In December 1995, they announced the first room-temperature electrically pumped blue laser diode, and 1 year later they had extended the life to 36 hours.

"At the moment, Nichia is clearly ahead of everyone else," admits Minoru Morio, chief technology officer for Sony, which has its own blue-laser program. Nakamura predicts that his team, by continuing to fine-tune laser materials and structure, will extend the laser's lifetime to 1000 hours by the end of this year. By the end of 1998, he hopes to reach 10,000 hours, the life-span needed for commercial applications.

By then, it will be time to move on to something else. And he says the work will be done right here at Nichia. Since gaining prominence, Nakamura has rebuffed any number of offers of employment from larger, wealthier companies. "The calls come in," he says, "but I turn them all down. This is like family here; I couldn't say good-bye."

Nakamura's work seems likely to boost sales and increase the work force at Nichia Chemical. That means more business for Tokushima cab drivers. It may also mean greater scientific recognition for a company that's off the beaten track but the star of the LED universe.

–Dennis Normile