Dow, DuPont, and Northwestern Gain Access to Advanced Photon Source Research

Dow Chemical Company, DuPont, and Northwestern University have received approval to jointly build and operate research facilities at the Advanced Photon Source (APS), now being built at the U.S. Department of Energy's Argonne National Laboratory. (See article in the July 1990 *MRS Bulletin*, p. 12–15.)

The DuPont-Northwestern-Dow team is the first research team to be granted access for APS research. The team will involve about 40 principal researchers and about 60 other scientists, engineers, and postdoctoral fellows. Fourteen other research teams from industrial, university, and government laboratories are in various stages of development.

The $467 million APS accelerator is two-thirds of a mile in circumference. It is designed to produce x-ray beams one trillion times more brilliant than conventional x-ray machines when experiments begin in 1996. The DuPont-Northwestern-Dow sector will have two x-ray beamlines and six experimental stations capable of supporting four experiments at a time. Construction and installation of their instruments and facilities is set to begin this year.

The higher speed and definition provided by APS will allow researchers to evaluate materials at atomic levels and analyze chemical reactions at real-time speed. Researchers expect to improve properties and performance of materials like polyurethane foam, where chemical reactions in the first few thousandths of a second are critical.

Other areas of collaborative research will include studies of:

- High-speed fiber spinning to understand the development of fiber structure during spinning;
- Catalysts to improve chemical processes and make them more environmentally sound;
- Cracking and breakage in materials that could lead to stronger, more impact-resistant applications such as auto windshields;
- Bonded and blended materials that could lead to better end products such as adhesive tapes, audio tapes, and video tapes; and
- Ultrasmall crystals and grains that should point the way to making stronger, lighter composites, alloys, and other materials.

U.S./Japan Collaboration Targets Quantum Structures

The University of California, Santa Barbara and the Japanese Research Development Corporation (JRDC) recently announced a research exchange agreement to investigate electronic transitions in quantum structures. The agreement involves an exchange of scientists from the University of Tokyo and UC-Santa Barbara plus a sharing of views, expertise, and facilities. UC-Santa Barbara researchers will have access to the best of Japan's research in this field, while scientists from Japan will benefit from the unique combination of research facilities at UC-Santa Barbara, including a free electron laser and a scanning tunneling microscope. Both parties have spoken highly of the international, interdisciplinary nature of the collaboration.

Projects will involve fundamental and pre-competitive investigations of quantum-effect structures, said James Merz UC Santa Barbara professor and also director of QUEST (the Center for Quantized Electronic Structures), a national research center established at the University in 1989.

Work in Japan will be at the forefront, based on the results of a recently completed five-year ERATO project headed by Hiroyuki Sakaki under the JRDC. (See "Quantum Wave Structures Fabricated and Tested" in this section.) Researchers will study crystal growth mechanisms and surface science phenomena using advanced techniques such as STM imaging and spectroscopy in an ultrahigh vacuum environment while actual growth is in progress.

The agreement protects UC-Santa Barbara's rights to technology it develops under the agreement, including the right to market that technology to U.S. firms. The University will have control over licensing and patenting of any jointly owned (or co-invented) technology developed in the United States. JRDC will control technology developed solely by JRDC or jointly owned technology developed in Japan.

The five-year agreement will be funded by parallel support of approximately $600,000 a year by JRDC and the U.S. National Science Foundation.

Lighter-Than-Water Mg-Li Alloys Developed

A research group in the Department of Mechanical Engineering at Nagaoka University of Technology (Nagaoka, Niigata prefecture) recently announced the development of metal alloys with specific gravities as low as 0.95. A previous light metal alloy (also mainly magnesium) developed in the 1960s by the U.S. National Aeronautics and Space Administration had a specific gravity of 1.3. A specific gravity below 1 allows a material to float on water.

The new alloys are composed mainly of magnesium but have a high lithium content. One alloy is 57.4% magnesium, 37.6% lithium, and 5% aluminum. Another is 56.5% magnesium, 38.5% lithium, and 5% zinc. Lithium, the lightest metal (specific gravity 0.534), evaporates quickly when liquefied and so is difficult to use in producing metallic alloys. But researchers Yo Kojima and Shigeharu Kamado used a vacuum high-frequency induction furnace to increase the lithium content of the alloys from about 14% to as much as 38%.

Melting to form these alloys was conducted in an argon atmosphere using magnesium, lithium, aluminum, and zinc of 99.9% purity. Magnesium and aluminum or zinc was first melted at 700 – 800°C in a crucible made of mild steel.

Then, lithium was added to the melt at that temperature; the melt was stirred by repeatedly turning an electric source on and off. Finally, the melt was poured at 700°C into a steel cavity mold with a 50 mm X 150 mm base and a height of 100 mm. The inner side of the steel mold, which contacts the metal, was sprayed with boron nitride. Up to 10% of the lithium was lost during the process.

Kojima says that these light alloys have excellent workability and should have many applications in the space and aircraft industries, and in industries for office automation. Some problems remain to be solved, such as how to make the alloys more corrosion resistant and how to improve their mechanical properties, particularly strength.

A paper will be published in *Keikinoku (Journal of Japan Institute of Light Metals).*

F.S. MYERS

Study Ranks Science and Technology in Germany

A study of international scientific literature, registered patents, and trade balances revealed the following results about the standard of German science and technology: Recent years have seen a worldwide surge in demand for the work of German scientists. Compared with other European countries, German research ranks second behind Great Britain in the number of publications per researcher, but German scientific literature is cited more frequently than its British counter-

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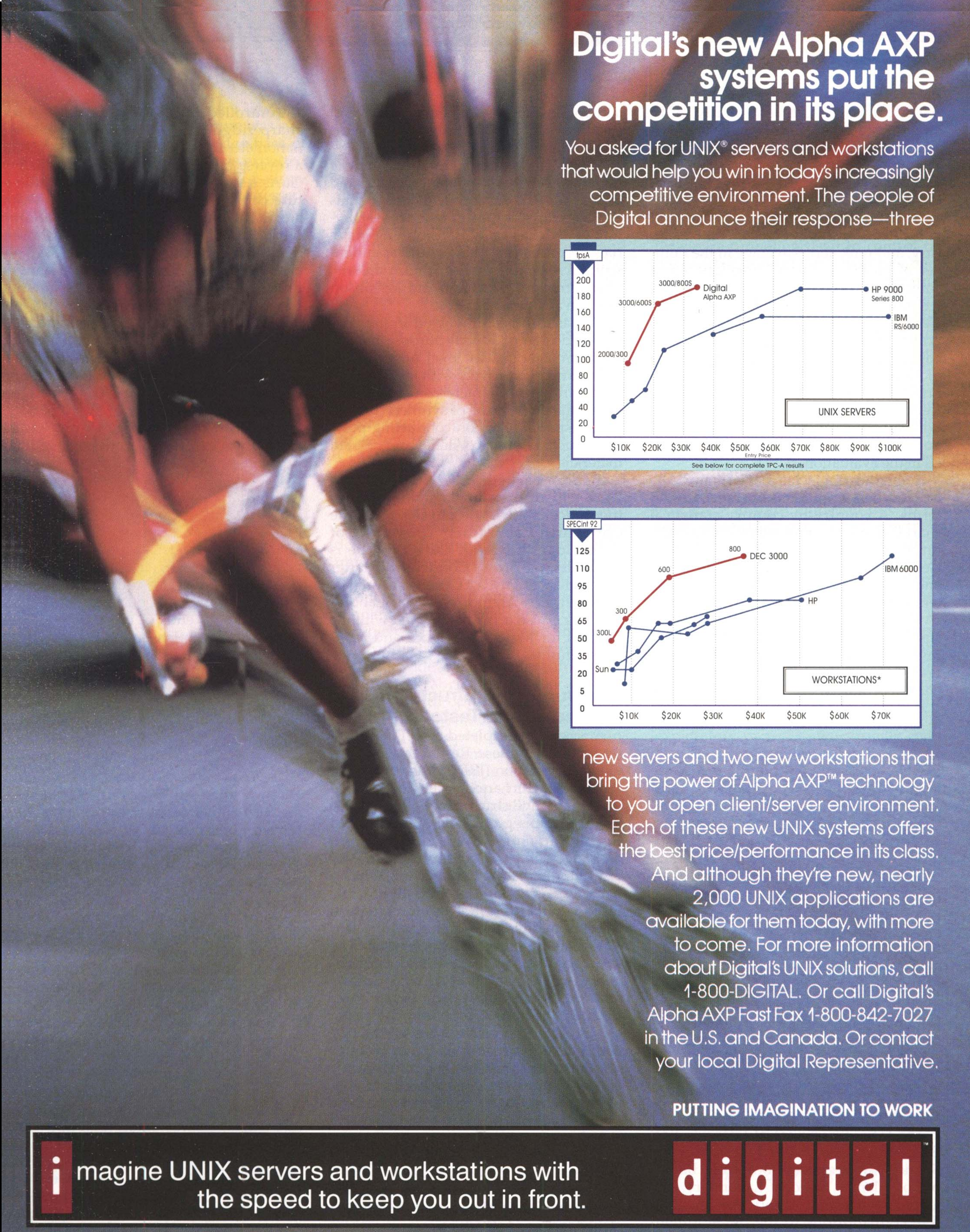
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part. Compared internationally, only Japan has a higher number of research-based patents than Germany; and together with the United States, Germany is the world's second largest exporter of leading-edge technology.

German scientists publish a great deal in the fields of energy research and chemistry, and rank above average in the number of publications on information and communications science, physics, biotechnology and medicine. Surprisingly, Germany underperforms in one area generally regarded as its domain, that of engineering science. The Federal Ministry of Research and Technology, (BMFT) attributes this to the fact that many German engineering publications are seldom stored on international, English-language databases and so were not included in the evaluation.

In engineering science, Germany performed below average in international terms. A country-by-country statistical chart showing the number of newly registered patents per worker, ranked Germany in second place behind Japan and above the U.S., but Germany registers many patents in less research-intensive areas and less specialized fields. A study of the "scientific content" of patents revealed that German industry is traditionally less geared towards strongly "scientific" products.

Enjoying an 18% share of world trade in specialized "research and development intensive goods," Germany shares second place with the U.S. However, as recently as the late 1980s Germany was the world's leading exporter in this market, ahead of Japan and the U.S.

The study found that Germany lags in rapidly expanding leading-edge technologies such as data processing and microelectronics, and German industry has suffered considerable export losses in these fields. According to the BMFT, German industry is currently living off the rewards of earlier research achievements. One of the most important tasks for Germany in the next few years is to identify areas of research with high technological and economic potential and convert them into commercial products, said the BMFT.

E.O. Lawrence Award Goes to Alan Bishop

The U.S. Department of Energy's 1993 E.O. Lawrence Award in Materials Science was presented to Alan R. Bishop of Los Alamos National Laboratory. The award recognizes Bishop "for imaginative contributions to the development and application of nonlinear concepts and techniques to a broad range of problems in materials science."

Bishop is known for his application of nonlinear concepts (coherence, chaos, and complexity) to practical fields in materials and condensed matter science—structurally and elastically transforming materials, ferroelectrics, charge- and spin-density wave materials, synthetic metals, charge-transfer materials, and Josephson junction and array devices.

He has also been involved in the controlled design of special-purpose materials from a molecular level upward. He has worked extensively with interdisciplinary synthesis/characterization/modeling teams in the areas of synthetic metals, with a special focus on conducting polymers such as polyacetylene, and related materials.

Bishop earned his BSc from the University of East Anglia and his PhD in theoretical solid state physics from the Cavendish Laboratory, University of Cambridge, England. Currently, he is group leader of the Condensed Matter and Statistical Physics Group, Theoretical Division, Los Alamos National Laboratory. He is also actively involved with the Centers for Materials Science and Nonlinear Studies.

Quantum-Wave Structures Fabricated and Tested

A recently completed ERATO project under the Japanese Research Development Corporation (JRDC) has resulted in the fabrication and testing of several quantum-wave structures. Following the success of this project, JRDC announced the signing of a five-year research exchange agreement with the University of California, Santa Barbara to conduct a Quantum Transition project. (See "U.S./Japan Collaboration Targets Quantum Effect Structures" in this section.)

The five-year project which resulted in such positive implications for quantum-wave devices was headed by Hiroyuki Sakaki. The ERATO project aimed at breaking the barrier imposed by a lack of crystal fabrication techniques on the 50 - 200 Å level. The project's goals were to develop an understanding of microscopic crystal growth, develop methods to control the wave state, and to prepare wire and dot structures with good size and cleanliness control.

Researchers worked on methods to make such quantum structures as a sharp ridge-type wire, an edge-type wire, a self-organized island-type structure, and an etched v-shaped structure.

Controlled MBE was used to grow a sharp ridge-type quantum wire at the nanometer scale. MBE growth of GaAs on a reverse mesa stripe structure on a (001) GaAs substrate produced a ridge structure consisting of two (111)B planes. Ga atoms deposited on the top (001) surface were readily incorporated, but those deposited on the neighboring (111)B (B = arsenic-rich) surface migrated efficiently to the top (001) plane. Thus, as growth progressed, the width of the top (001) surface was reduced until a ridge structure was formed. The substrate temperature was found to affect the narrowness of the ridge; at 580°C, the ridge was 10–15 nm, but at greater than 600°C the ridge exceeded 20 nm.

Based on this finding, 15 nm wide quantum wires were formed on the top portion of the ridge by depositing a AlAs/GaAs/AlAs sandwich structure. Photoluminescence and cathodoluminescence measurements showed a clear and intense peak of luminescence from the quantum-wire state. Though laser action was not observed, Sakaki said he expects lasing when a light confinement layer is additionally grown and a set of mirrors is made on both ends of the cleavage. For laser operation, plans are to make a double-wire structure: one wire for electron confinement and another larger wire for light confinement.

In the edge-type quantum wire, electrons in quantum-well structures were pulled to their edge regions by an electrostatic potential to form a wire. A 100 nm wide N-AlGaAs/GaAs edge quantum wire was successfully fabricated by growing a layered faceted structure on a patterned substrate and then depositing another overlay on its edge. The one-dimensional nature of electron motion was clearly observed by measuring the magnetic depopulation effect, indicating the presence of quantum-wire confinement. In addition, a gate electrode was formed on the edge-type quantum wire to modulate the density of such one-dimensional electrons, leading to successful transistor action in the wire.

The group also showed that a novel microscopic process of crystal growth can lead to the formation of dot structures when a small amount of InP is deposited on GaAs. Coagulation automatically gave an InP island structure. The effective size of the islands was small (≤70 nm) and uniform, but their location was random. Modification of the substrate with a focused ion beam, however, was found to effectively define preferred sites for island formation, probably because the ion beam creates local step structures,

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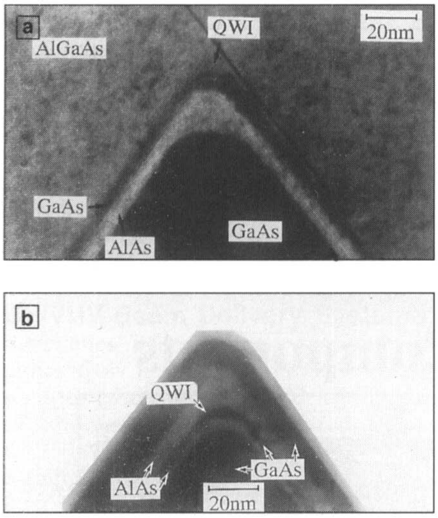
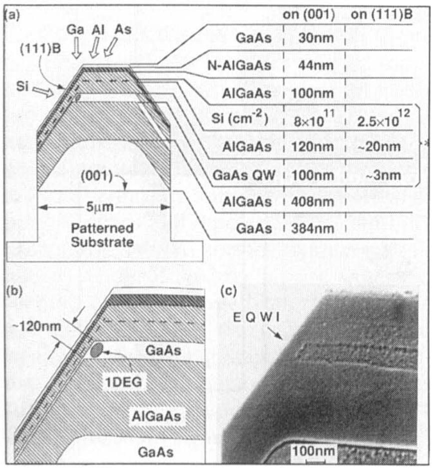
suggests Sakaki. By drawing a line pattern, a pyramidal ridge structure was successfully prepared with a ridge base of about 100 nm; its top portion is expected to function as a quantum wire. This structure, however, still needs to be assessed. In their efforts to control crystal structure, the researchers sought to develop an ultraclean selective etching technology for GaAs and related materials because the overgrowth of other materials onto the edge surfaces of quantum wells exposed by etching would allow the formation of edge quantum wires and other nanostructures.

One team studying how GaAs and InAs are etched by chlorine gas with and



Sharp ridge-type quantum wire fabricated by scientists in Japan.



Edge quantum wire formed by MBE.

without an electron beam initially found that GaAs can be easily etched as it reacts with Cl_2 and becomes volatile. In contrast, an InAs layer formed on GaAs was rather stable and etched at a very low rate, about 1/1000 that of GaAs, and so it could act as a protective layer. Supplying an electron beam and Cl_2 at the same time onto the InAs film, however, was found to enhance etching of the InAs. Scanning the electron beam to locally remove the InAs layer allowed mask patterns to be engraved into the InAs layer. A further supply of chlorine gas allowed selective etching of the GaAs not covered by the InAs layer. This led to the formation of the v-shaped groove structure as the chemical process exposed a particular crystallographic plane. Because the entire procedure is a very clean process done in a UHV environment, further overgrowth of N-AlGaAs layers on v-grooves is expected to result in edge quantum wires.

The ERATO project researchers also studied quantum wave phenomena and devices, including a resonant scattering transistor, a turnstile device, and electron relaxation in a quantum dot structure. A resonant scattering transistor is almost as simple as the usual field effect transistor in which the flow of electrons through a thin conducting channel is controlled by a gate electrode. What is interesting about the device fabricated by Sakaki's researchers with optimized design is that the channel consists of two stacked layers, one slightly doped and the other undoped to ensure smooth conduction. In this case, the current is carried mainly by electrons in the undoped channel because they have a higher mobility here than in the doped channel. In this structure, electrons are usually confined in each channel independently, as a standing wave state. However, when an appropriate voltage was applied to the gate, the energies of frequencies of these states became identical, and they resonated. The electron waves were no longer confined in each channel, but instead moved from one to the other very frequently. On reaching this resonance state, all the electrons became affected by the doping impurity, which led to a substantial drop by a factor of 3 in conductivity. Thus it was found that an increase of the gate voltage or electron concentration does not always increase the current but decreases it at the point of resonance. This feature was recently used to triple the action of a particular fundamental frequency.

The word "turnstile" is often used to describe devices with two gates controlling the flow of particles. When gate one is open, electrons pop into a central island (the GaAs channel), and the gate is closed; in the next step, gate two is opened, which lets the electrons out. If the middle island becomes very small, the number of electrons that pop into the island can be reduced to one because of the coulomb repulsions. The failure rate for single tunneling used to control the passage of a single electron has been rather high. However, in cooperation with the Technical University of Delft, Sakaki's group developed a turnstile structure to control the transfer of one electron per one cycle of the gate modulation with a failure rate as small as 10^{-4}.

Quantum dot lasers are expected to have a number of desirable properties, and so a decade of efforts has gone toward the realization of quantum dot structures. Recently, however, it has been argued that quantum dots injected with high-energy carriers may not show a high efficiency in light emission due to the slow relaxation process of electrons between the discrete energy states. In calculating the relaxation rate in a GaAs dot up to the second order in electron-phonon interactions, Sakaki's researchers found that a two-phonon (LO+LA, LO–LA) process can give rise to rapid (subnanosecond) relaxation for suitable values of level separation. Based on this finding, prescriptions for highly efficient quantum dot lasers have been achieved.

Sakaki credits the success of this exploratory project to the strongly cooperative approach used by many researchers around the world. He believes that progress in this field depends on cross fertilization and mutual stimulation among different groups. It is in this spirit that the Quantum Transition project is being jointly pursued with UC-Santa Barbara.

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