Exploring the world at nanoscale

At UC Riverside, a group of young researchers is gaining recognition for its pioneering work in nanotechnology.

At the meeting of the Materials Research Society last April, two presentations stood out among several from top-ten U. S. universities. These award-winning presentations were given by two UC Riverside colleagues – post-doctoral researcher Olga Lazarenkova, and Ph.D. student Jie Zou. Both researchers work with electrical engineering professor Alexander Balandin, himself a recent recipient of a National Science Foundation Young Investigator award. “I’m pleased our group did so well, especially against such stiff competition,” says Balandin.

Balandin and his colleagues study the electrical and thermal properties of nanostructures and nanoscale semiconductor devices. These devices are so small that they are measured in nanometers, or billionths of a meter. In a computer chip, silicon atoms are spaced just a few to the nanometer, so nanoscale devices involve interactions between a handful of atoms. In the diagram above, the 200 nanometer line spans only about 700 silicon atoms.

The realm of nanotechnology exists on a scale in between the subatomic realm of elemental particles and the macroscopic world of electronic devices and circuits. “To understand nanotechnology,” says Balandin, “you have to realize that as you reduce the scale, at some point quantitative changes become qualitative changes.” This is an Alice-in-wonderland world that plays by its own rules – rules researchers have yet to understand fully.

Imagine a transportation planner flying over a busy freeway. She can make very good predictions about traffic flow rates and about how many cars leave each freeway exit every hour. But this same traffic planner knows very little about how to predict the movements of one car in particular – where it entered the freeway and where it will exit, or how it will interact with the cars around it.

Nanotechnologists have a similar problem. They must understand not how millions of electrons move through a copper wire thousands of atoms thick, but how far fewer electrons move through a nanowire just dozens of atoms thick. At nanoscale, quantum effects – due to the wave nature of the electrons at this scale – begin to influence the characteristics of electronic devices.

Balandin oversees the Nanoelectronic Materials and Device Laboratory (NOMAD) in conjunction with professors Roger Lake and Alexander Korotkov, also of the UC Riverside electrical engineering department. At NOMAD, Balandin’s group focuses both on deriving theoretical models for the behavior of nanomaterials and on testing them.
Early radios and computers used vacuum tubes to control and amplify electrons. By the 1950s, a standard five-tube radio was small enough to sit on a bedside table, although crude computers occupied whole labs. By the 1960s, transistor radios were small enough to sit in the palm of a hand, and mainframe computers began to shrink in size and grow in power.

With the development of the integrated circuit, at first thousands, and then millions, of semiconductor transistors could be embedded in a substrate of silicon. Over the last four decades this progression has been described by Moore’s Law, named after Gordon E. Moore, a co-founder of Intel and UC Berkeley alumnus. Moore predicted the number of transistors that could be placed on a silicon chip would double every 18 months.

Engineers now can put 100 million transistors on a silicon wafer only a few square centimeters wide. Some features of these computer chips measure only 180 nanometers. Within a few decades, this size may be reduced to close to 100 nanometers, a tricky descent into the nanoscale world where the rules begin to change.

The award-winning paper that Zou presented at the materials conference addresses one of the problems of nanoscale circuits—heat conduction in nanowires and ultra-thin films. The phonon, the smallest unit or quantum of heat energy, is confined in nanoscale devices in a way that may make it difficult to cool future generations of computer chips.

“Part of what we are trying to accomplish is to keep Moore’s Law alive by better understanding the problems of nanoscale devices,” says Balandin. “But ultimately, the more useful approach will be to learn enough about the characteristics of the nanoworld so that we can take advantage of its special properties to design new types of devices.”

Strong contenders for these new devices already exist in quantum dot crystals, three-dimensional regimented arrays of small blocks of semiconductor materials embedded in silicon or other host materials. The electrical conductivity of these quantum dot crystals manifests a variety of intriguing properties that can be used in the design of novel devices. Lazarenkova’s award-winning presentation for the materials conference describes just such a quantum dot crystal.

Nanoscale devices not only will allow the creation of smaller and more powerful computers, they also will aid in creating a new generation of photodetectors that can help bring fiber-optic communications to households. They may dramatically increase the efficiency of photovoltaic cells, making solar power a more viable alternative to burning fossil fuels.

“Nanotechnology has tremendous potential,” says Balandin, “and we are grateful for NSF’s support of our work and for the leading role it has taken in funding nanotechnology research.”

Nanotechnology is the ability to work at the molecular level to create new molecules and structures. At the level of molecular building blocks, the traditional boundaries between the scientific disciplines dissolve. Nanotechnology embraces physics, chemistry and biology and may lead to breakthroughs in all of these areas. Possibilities include high-strength materials, miniature electronics systems and new drugs and biomedical devices.

In February 2000, the Clinton administration announced the $495 million National Nanotechnology Initiative (NNI) to coordinate federal efforts to stimulate nanotechnology research. Since then, more than 30 universities have announced plans for nanotechnology research centers.

The Bush administration has requested another $485 million for nanotechnology research in FY2002. Just as nanotechnology spans several academic disciplines, at the federal level, nanotechnology research will span several different agencies. The federal government’s efforts will be coordinated by the National Science Foundation.

At UC Riverside, chemist Robert Haddon will direct the new Center for Nanoscale Science and Engineering, an interdepartmental effort combining the talents of UC Riverside faculty in several departments.

Haddon’s specialty is the formation and application of carbon nanotubes and other nanoscale structures. Nanotubes have several unique properties, including the ability to act like a semiconductor, or to act as the matrix for growing new human neural tissue.

UC also will sponsor the California Nanosystems Institute, a joint project of the Los Angeles and Santa Barbara campuses. With the field still in its infancy, it is too early to tell how the UC centers will specialize. Until then, the campus centers “will both compete and collaborate with each other,” says Haddon. “No one has a monopoly on good ideas.”