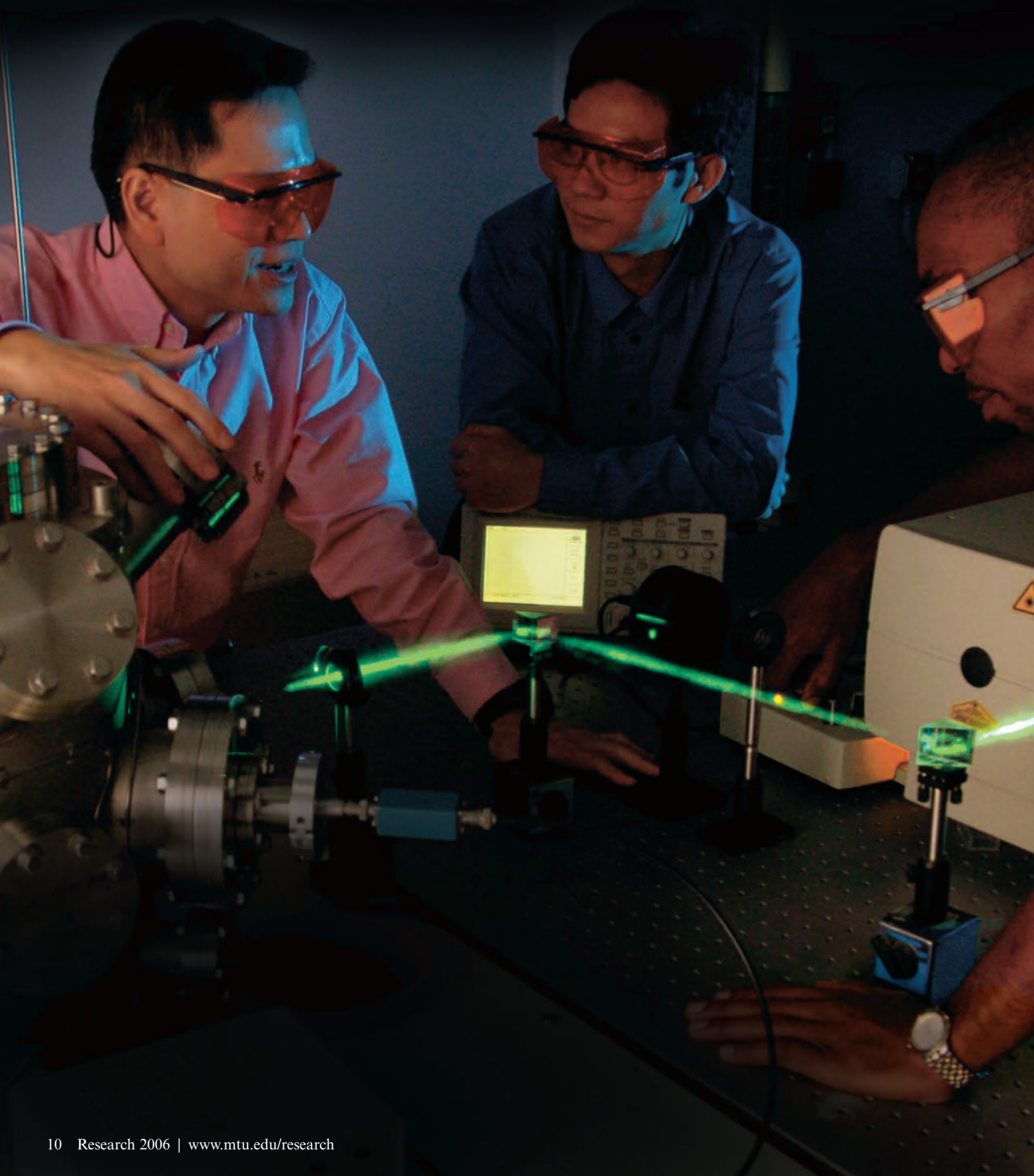


NANOTUBES: TUBULAR TECHNOLOGY!





Yoke Khin Yap dreams of sensors that could detect any known toxin and fit in a soldier's shirt pocket. Of a supercomputer the size of your credit card. Of a cable that's long, strong, and light enough to lasso the moon.

To build them, he says, you have to start small. And in his lab, Yap, an assistant professor of physics at Michigan Tech, is doing just that.

Yap and his research team are constructing nanotubes as small as a billionth of a meter across and a few hundred micrometers long. It's not as easy as it sounds. Inside a small, airtight chamber, a special laser blasts the raw material (carbon and, more recently, a mix of boron and nitrogen) and blows it through a plasma cloud. It crystallizes on a silicon substrate, atom by atom, ring upon ring, forming impossibly tiny, infinitely perfect tubes.

What these tubes may be capable of is anybody's guess. As the carbon in a No. 2 pencil is not the same as the carbon in the Hope diamond, so the properties of carbon nanotubes are vastly different from those of naturally occurring forms of the element.

"The bonding in the tubes is as strong as the bond inside a diamond," Yap said. "With this, you could make a cable five times lighter and one hundred times stronger than steel.

"You could make super-light, super-strong plastic for use in your car, in aircraft, in rockets. You could form a cable and build an elevator to the moon."

Yap has received a \$506,000 National Science Foundation (NSF) Faculty Early Career Development grant, known commonly as a CAREER Award, to begin making designer nanotubes that might someday change the fabric of our lives. (In some respects, that's already happening: Yap himself has a pair of dirt-resistant pants, made possible by another type of nanomaterial.) The goal of the NSF project is to build nanotubes with various physical properties, depending on the elements used in their construction and how those elements fit together.

Yap is just the person to do it. He is the only researcher in the world to successfully build nanotubes on silicon chips from the elements nitrogen and boron, which, compared to carbon, have been notoriously difficult to manage. "They are promising, but so difficult to make," he says. "Carbon nanotubes will grow at 600 degrees Celsius, but boron nitride tubes typically need 1,200

degrees," about the temperature of molten lava. Yap has succeeded in growing them at the more-manageable 600 degrees, aligned in one direction and free of impurities.

The problem with nanotubes made with carbon is that they oxidize at high temperatures, which can limit their applications. "But the boron nitride nanotubes resist oxidation, so they wouldn't burn up as easily," Yap says.

With his CAREER Award, Yap wants to begin building nanotubes with all three elements, incorporating the benefits of each. "We want to mix them together precisely, atom by atom," he says. "That would be true nanotechnology."

Because nanotubes can behave like semiconductors, they have huge potential for use in electrical and photonic devices. With funding from the military, Yap has already been investigating the electrical properties of carbon nanotubes, which have the potential to make computers much smaller and faster, as well as displays that are thinner, lighter, and brighter, all at much lower power consumption.

However, he is particularly intrigued by the promise of nanotubes custom-built with boron, nitrogen, and carbon. "It is possible to tune the band gap of boron nitride nanotubes by substituting carbon to make boron carbon nitride nanotubes," he said. Thus, you could tailor nanotubes for high-powered electronic and photonic devices, such as lasers, that can't be made using nanotubes constructed of carbon alone.

You could also use this technology to build nanoscale sensors, each designed to detect a specific chemical or biological molecule, he adds. "The substance would bind onto a receptor molecule, which would send out a warning signal," Yap says. "It could be used on the battlefield, in airports, as a diagnostic tool. . . . There are so many possibilities."

Yap is also working on a \$1.6-million project funded by the Defense Advanced Research Projects Agency to make molecular electronics that could make even nanotubes seem big. The aim is to design switches that will be the size of a single molecule, on the order of one-tenth of a nanometer across.

"There's a whole, big family of materials just waiting to be explored," Yap says. "It's going to be a whole new world."

For more information on nanotechnology at Michigan Tech, visit <http://nano.mtu.edu/>

Physicist Yoke Khin Yap, left, and his graduate assistants use lasers to build impossibly tiny, infinitely perfect tubes from carbon, nitrogen, and boron. With such as these, Yap says, "you could form a cable and build an elevator to the moon."