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Nanotube X-Rays

Radiology readies for the nanotube revolution

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“We are on the forefront of the nano revolution,” says materials scientist Srikanth Raghunathan, PhD, referring to the recent sub-microscopic technology that has grabbed the attention of the science world. **“Nanomaterials and nanotechnologies will touch all areas of our lives. We will use them to solve problems related to aerospace, automotive, biomedical, microelectrical and other fields. And we will do it one atom at a time.”**

Carbon nanotubes are a new form of carbon discovered a little more than a decade ago. The cylindrical structures measure just one billionth of a meter in diameter. Despite their tiny size, however, nanotubes outperform conventional materials because of their superior chemical, physical and mechanical properties. They're thinner than hair, yet stronger than steel. “It's the strongest stuff that will ever be made,” says David Luzzi, PhD, a professor at the University of Pennsylvania in Philadelphia.

Excited by the virtually limitless applications of nanotubes, researchers have been dreaming up possible uses of the material. Some scientists envision microchips consisting of only a few atoms. NASA researchers have imagined using a nanotube cable to tether satellites orbiting the Earth; they've even thought of making an elevator that could stretch into outer space, eventually stopping at a space station.

The ideas are wild and possibilities are endless, but some scientists have managed to keep their aspirations grounded. A research team led by Otto Zhou, PhD, a materials scientist at University of North Carolina, Chapel Hill, has used carbon nanotubes to create a smaller, faster and more precise X-ray machine. Using nanotube-coated filaments, the UNC research team has revamped traditional X-ray tubes, which have remained essentially unchanged for more than 100 years. The new X-ray tube could significantly impact diagnostic and therapeutic radiology in the next few years.

“We believe we have made a major breakthrough in X-ray technology,” says Zhou. “If this research works, we can make machines a lot smaller, a lot cooler and we will be able to turn them on and off much faster.”

A report on the UNC research appeared in a recent issue of *Applied Physics Letters*.

Building a Better Tube

There are several components to X-ray tubes, says Zhou. Perhaps the most important component is the electron source. Current X-ray tubes, like common light bulbs, use metal filaments. However, the tungsten filaments in an X-ray tube need to be heated to temperatures as high as 2,000 degrees C. Once heated, an electric current is applied to the filament to “boil off” electrons. These electrons are then bounced off a metal target to create X-rays.

Although the process has remained essentially unchanged, it's far from perfect, says Zhou. Because the tubes consume inordinate amounts of energy, the filaments have a short lifetime. Furthermore, replacing the tubes can cost as much as \$10,000, not to mention the significant cost involved in heating the filament.

Zhou knows the frustration of working with X-ray tubes. The hassle of constantly changing the X-ray tube in his lab prompted him to develop a better tube more than two years ago. "I was at lunch with a colleague complaining about the X-ray tube in my lab," he recalls. "I told him I had to replace the X-ray tube again, and we began to discuss what we could do to create a new tube."

source, says Zhou. "These electrons travel from one point to another with very little divergence and produce a highly accurate X-ray beam. It's an improvement because conventional X-ray tubes require a lot of work to focus them on a target. Conventional tubes emit electrons randomly because of the high temperatures."

Armed with a new material, Zhou and his research team set out to test their tube, and it didn't take long for them to create their first X-ray image using carbon nanotubes. "It took us about two months," says Zhou. "From then it has been a two-year process of fine tuning."

To help refine the system, Zhou recruited Sha Chang, PhD, a colleague in UNC's radiation oncology department. The two researchers collaborated to develop appli-

cation 3-dimensional image-guided computerized radiation treatment planning tools to design radiation dose distribution with high accuracy. However, the X-rays good for treatment are not good for imaging. We lack technologies to verify the high accuracy in the actual patient treatment. The treatment may be far off from what we designed in the computer," she explains.

The nanotube-based X-ray tube may be able to solve this important problem in radiotherapy. Because of its smaller size, Chang believes that future linear accelerators could incorporate a diagnostic X-ray tube inside the head of the linac. "It's not a new concept. We have been discussing that for quite some time, but we never had an X-ray tube small enough to fit inside the treatment head before," she says.

With a diagnostic X-ray tube positioned inside the treatment head, radiation therapists will be able to switch back and forth between the treatment mode to deliver radiotherapy and the diagnostic mode to image the patient anatomy under the treatment field.

The tube's small size could also make diagnostic X-ray machines more portable. Zhou imagines handy diagnostic X-ray units that can be carried to trauma scenes.

But the biggest impact of the smaller tube is its precision. "The nanotube creates an X-ray that is already collimated. It has a focal point of about 2 centimeters," says Zhou. The tube's small size combined with its ability to be rapidly turned off and on could create the linear accelerator of the future. "You could use many tubes in one machine, which would be like having 1,000 laser pointers with the ability to turn each one off and on rapidly." Such a machine would provide revolutionary control in radiation therapy, adds Zhou.

Long Lasting

Another benefit of a nanotube X-ray source is that it may never need to be replaced. Although research is still in preliminary stages, nanotube electron sources could, in theory, last forever. Chang compares the nanotube coating to a bunch of tiny hairs. "Only the longest hair produces electrons. Over time when that hair burns



X-ray image of hand created by carbon nanotube electron source.

Nanotube X-ray Advantages

- Faster response time
- Programmable electron distribution
- Ultra-fine focal spot
- Rapid pulse capability
- Longer lifetime
- Smaller tube size
- Lower maintenance cost

Zhou, who leads the N.C. Center for Nanoscale Materials, has been working with nanotubes in a variety of applications for more than four years. When he and his colleague were lamenting the limitations of the current X-ray tube, he knew nanotubes were the answer. "We have been trying to replace the hot tungsten filament for many years," says Zhou. "Until recently, we never had a material that could produce enough electrons to create the X-rays needed to create an image."

The nanotube is an effective electron

source that would be particularly useful to the field of medical imaging.

Radiology Benefits

The tiny tube can have huge implications for medical imaging, says Chang. "One of the major benefits is the potential small size of the tube. A big challenge in radiation therapy is delivering the radiation precisely to cover the tumor volume and at the same time spare the nearby critical structures. Right now we are able to

Flat-screen Displays and Radiation Detectors

Thinner screens that use less power may soon be available as a result of an emerging technology involving doped nanoparticles, particles peppered with light-emitting atoms. This technology could make possible flat-panel displays that are sharper than laptop computer screens. It should also lead to higher-resolution detectors of gamma rays, X-rays and other ionizing radiation.

Researchers are developing a new class of nanosensors and nanodevices using caged atoms in doped nanoparticles. Each particle is doped with a few atoms of a rare-earth element that emits light of a specific color when excited by an electric field, ultraviolet light or mechanical action. The dopants are europium (emitter of red light), thulium (blue light) and terbium (green light).

"The dopant atoms caged inside the nanoparticles show interesting properties as a result of quantum confinement," says Thomas Thundat, PhD, a senior research scientist at Oak Ridge National Laboratory (ORNL) in Tenn. "Because of the overlap of the electron shells of the dopant and host atoms, the nanoparticles are more efficient photon sources."

The researchers are building a flat-panel display that uses low voltage for operation. "When the device is under an electrical potential, the electrons excite the doped nanoparticles sandwiched between the silicon base and a conducting glass electrode on the top. The light from these doped particles should be sufficiently intense for a flat-panel display because they have a much higher quantum efficiency than undoped nanoparticles," says Thundat.

Some scientists are trying to find ways to control the sizes of nanoparticles because size determines the color of the light they emit. Doping the nanoparticles with rare-earth atoms to get the desired color removes the need for stringent control of the size of conventional nanoparticles.

In a television set, each tiny square, or pixel, on the screen contains emitters of the different colors — red, blue and green — behind which are sources of electrons that stimulate the emission.

If the pixel for the image being shown must be red, then only the voltage source for the red emitter will be turned on for that pixel. In the device developed at ORNL, each microchannel represents one pixel. The nanoparticles are arranged so that only one type of doped particle is electrically activated if light of only one color is desired.

Because of the smaller sizes of the nanoparticle light emitters, very little power will be used and less space required for the power sources. Thus, the doped nanoparticle approach could enable the development of thinner flat-panel displays and could extend the lifetime of laptop computer batteries.

In a radiation detector made from the ORNL nanodevice, the gamma rays excite the caged atoms in the nanoparticles. The radiation detector consists of hundreds of vertical channels 10 microns in diameter and 300 microns deep. Packed inside each channel are thousands of 2nm to 3nm particles of gadolinium oxide. The emitted light from the doped nanoparticles travels through the channels and reaches a photodetector at the base.

"Today, it takes more than five incoming photons to produce an outgoing photon that can be detected in a photodetector," says Adosh Mehta, a post-doctoral scientist at ORNL. "Our device will have a much higher quantum efficiency because it will produce a photon for every photon coming in, providing a much sharper image or giving a more precise reading."

— Oak Ridge National Laboratory

out, it does not need to be replaced. It only gets shorter making, one of the surrounding hairs longer. The process could continue forever," says Chang.

The potential benefits of carbon nanotubes are staggering. But there is one benefit that patients and RTs will easily warm up to. Because the nanotube electron source does not require extremely high temperatures to produce electrons, the radiology department will no longer have to feel like winter at the North Pole. "Electrons can be generated at room temperature," says Zhou, "so there is no need to cool the X-ray machine."

As a result, the radiology department would no longer have to maintain at uncomfortably low room temperatures. Bad news for patients who love the cold X-ray table.

New Directions

The first images from nanotubes may not be impressive — they were produced just to prove that the concept worked, says Zhou. "Now we need to work with manufacturers to design a prototype."

He expects a prototype in two years with a commercial release soon after, but

it's hard to determine where this research will go. After all, we are on the forefront of a new technology, says Chang. "It's high risk research. With cutting-edge technology, you're never sure what will materialize. You just have to keep pushing in new directions."

— Jeremy Kuhar is an associate editor at RT Image magazine. Questions and comments are encouraged and can be directed to jkuhar@valleyforgepress.com.

