Discovery could aid in detecting nuclear threats

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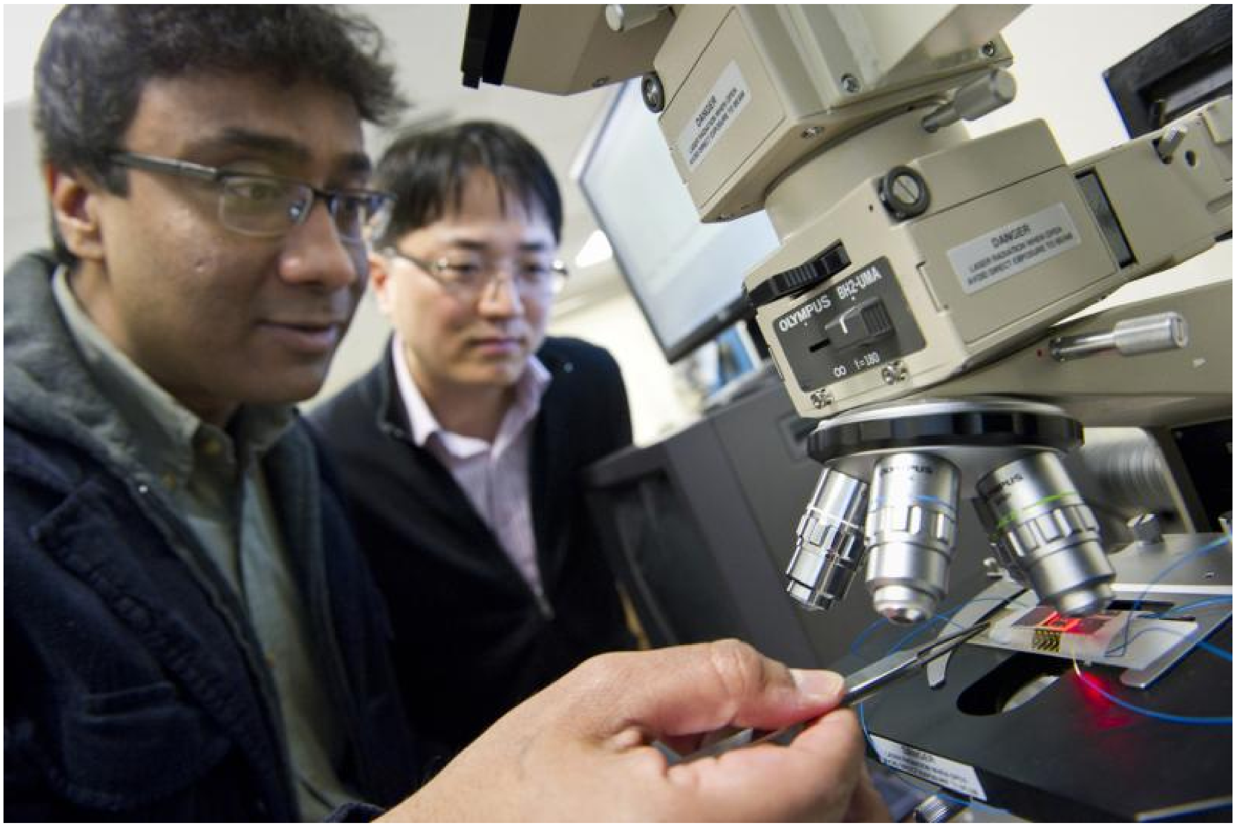

Associate professors Swastik Kar, left, and Yung Joon Jung, right, have been collaborating on research related to carbon nanotubes for more than 10 years. Credit: Mary Knox Merrill/Northeastern University

National security: The phrase resonates like a drumbeat these days.

Just one example: In its 2017 Budget-in-Brief, the U.S. Department of Homeland Security lists among its priorities allocating $103.9 million for radiological and nuclear detection equipment "to keep U.S. ports of entry safe and secure by detecting and interdicting illicit radioactive or nuclear materials."

A team led by Northeastern's Swastik Kar and Yung Joon Jung has developed a technology that could go a long way toward achieving that goal. "Our detector could dramatically change the manner and accuracy with which we are able to detect nuclear threats at home or abroad," says Kar, associate professor in the Department of Physics.

It could also help streamline radio-medicine, including radiation therapies and scanning diagnostics, boost the effectiveness of unmanned radiation monitoring vehicles in mapping and monitoring contaminated areas following disasters, and revolutionize radiometric imaging in space exploration.

Made of graphene and carbon nanotubes, the researchers' detector far outpaces any existing one in its ultrasensitivity to charged particles, minuscule size, low-power requirements, and low cost.

Enabling safety and security

All radiation, of course, is not harmful, and even the type that may be depends on dosage and length of exposure. The word "radiation" refers simply to the emission and propagation of energy in the form of waves or particles. It has many sources, including the sun, electronic devices such as microwaves and cellphones, visible light, X-rays, gamma waves, cosmic waves, and nuclear fission, which is what produces power in nuclear reactors.

Most of the harmful radiations are "ionizing radiations"—they have sufficient energy to remove electrons from the orbits of surrounding atoms, causing them to become charged, or "ionized."

It is those charged particles, or ions, that the detectors pick up and quantify, revealing the intensity of the radiation. Most current detectors, however, are not only bulky, power hungry, and expensive, they also cannot pick up very low levels of ions. Kar and Yung Joon's detector, on the other hand, is so sensitive it can pick up just a single charged particle.

"Our detectors are many orders of magnitude more sensitive in terms of how small a signal they can detect," says Yung Joon, associate professor in the Department of Mechanical and Industrial Engineering. "Ours can detect one ion, the fundamental limit. If you can detect a single ion, then you can detect everything larger than that."

Consider a border guard at U.S. Customs, says Kar. He or she is using a Geiger counter to scan for nuclear material in a ship's cargo. Such material could be hidden inside a lead container, making the radiation levels leaking out too low for the Geiger counter to detect, or the guard might be 100 meters away from the source, allowing the intensity of the radiation to dissipate before it reaches the detector. "That means the guard not only fails to detect the leak but also is being exposed to radiation at unknown levels," says Kar. "Using our technology, the guard could detect hidden sources from a safe distance, or even with a drone."

Interdisciplinary breakthrough

The ultrasensitive detector developed out of a unique interdisciplinary partnership between Kar and Yung Joon, who have been collaborating for more than 10 years. "We would not have made this discovery without contributions from each of us," says Yung Joon.

Yung Joon's expertise is in carbon nano-manufacturing. He works with graphene, a stronger-than-steel infinitesimally thin lattice of tightly packed carbon atoms, and carbon nanotubes—sheets of graphene rolled into hollow tubes with walls that are just one atom thick.

Kar specializes in the underlying physics of carbon nanotubes and other materials, including the quantum mechanical properties that describe their electrical conductance.

"When a charged particle sits on the surface of a material, the material undergoes a small change in its electrical property," says Kar. On a bulky material, the particle affects the surface but the rest of the material remains unchanged. On carbon nanotubes, which are essentially only surface materials because of their exceptionally thin walls, the particle significantly changes the material's total electrical conductance. "So the effect of the particle becomes much more measurable," says Kar.

Ji Hao, PhD'17, a mechanical engineering student in Yung Joon's lab, discovered carbon nanotubes' sensitivity to charged particles by accident while testing the nanotubes inside a vacuum gauge. He was puzzled by the changes in the nanotubes' electrical resistance when he turned the gauge on and off. "He thought he had a dysfunctional circuit that was giving rise to the changes," says Kar. "He didn't know at the time that the small amount of ions released from the gauge could measurably affect the electrical properties of carbon nanotubes. Believe it or not, initially he tried very hard to get rid of the changes."

Having developed the detector technology, the pair are now focused on building prototype detectors for the various types of radiation relevant to particular disciplines, including X-rays and beta particles. In the process, they are exploring the commercialization of their invention with an award from the National Science Foundation. "This will enable us to identify potential customers for any products we may build," says Kar.

Adds Yung Joon: "Our aim is to learn what kind of measurements each specific arena needs."

Provided by Northeastern University

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