muon imager searches for smuggled nuclear material

Only a few percent of the cargo containers and trucks that pass through national borders are thoroughly inspected for potential weapons of mass destruction. X-ray transmission imaging systems can identify lead shielding, false walls, and other smuggling methods, but these systems are unable to directly identify biochemical or nuclear agents. For that purpose, experts suggest additional sensors such as gamma ray detectors to catch smuggled nuclear material.

A new muon imaging system developed at Los Alamos National Laboratory (Los Alamos, NM) could allow border guards to both image structures inside containers and positively identify hidden high-atomic-number materials such as uranium and plutonium while alleviating many of the cost and health concerns that accompany high-power x-ray imaging systems. The group reported on the work at the SPIE Annual Meeting (San Diego, CA; 3–8 August; paper #5199A-39).

Muons are created when charged protons strike the Earth's atmosphere, creating pions. Pions quickly decay into muons that remain relatively stable through the atmosphere before striking the planet's surface. High-energy x-ray imaging systems for cargo inspection generate 9 MeV x-ray radiation capable of penetrating up to 12 inches of steel. However, naturally occurring, high-momentum muons with giga-electron-volt energies can easily pass through several feet of dense material. Muon absorption was used to find hidden chambers in the second pyramid at Giza, for example.

A group at Los Alamos led by Christopher Morris and William Priedhorsky has harnessed this naturally occurring radiation to reveal high-atomic-number materials by detecting the path of individual muons and analyzing the multiple Coulomb scattering caused by dense materials (see figure).
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A phosphosilicate core of 24-µm diameter and 0.21 NA, surrounded by a pure silica D-shaped inner cladding of 400-µm diameter and 0.49 NA. The outer cladding is a low-refractive-index polymer. Fresnel reflections of 3.6% from the angle-polished fiber define one end of the cavity and a Littrow prism defines the other. This external cavity configuration allows the wavelength of the laser to be tuned across the broad emission spectrum typical of glass-host lasers by changing the prism angle. The group pumped the 18-meter-long fiber from both ends by beam-shaped diode stacks at 940 nm using dichroic mirrors that reflected 83% of the launched pump power into the fiber’s inner cladding.

One of the primary design objectives for this fiber laser is for use as a pump source in Er-doped yttrium aluminum garnet (Er:YAG) lasers operating at 1064 nm for lidar applications. The pulse energies in the solid-state laser can be higher since these lasers store energy longer and more efficiently than fiber lasers, and this higher power improves the performance of lidar and remote-sensing systems.

**Koheras (Birkerød, Denmark) is also developing new fiber lasers in the eye-safe regime. Its designs are based on Bragg grating distributed-feedback fiber laser technology.**

“LIDAR and remote monitoring are active application areas, and laser power is important for improving system performance,” says Jens Pedersen, COO of Koheras. “Also critical to many precision remote sensing applications are stability and low noise, which are achieved with narrow linewidths and robust designs.” Koheras has been developing very stable, narrow-linewidth fiber lasers for several years with applications from undersea oil exploration to atmospheric sensing and lidar.

Laser 2003 displayed many new fiber laser technologies such as the 300-W ytterbium fiber laser shown by IPG Photonics Corp. (Oxford, MA). For all these applications, cost of ownership and reliability are fundamental, so one legacy of the telecom boom seems to be the seeding of other applications such as lidar with these important elements.

—Michael Brownell

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The group’s first demonstration system uses four horizontal 60 × 60 cm² muon drift detectors placed 27 cm apart: two above the object under test and two below. The first pair of detectors determines the initial path of individual particles as they pass through two detectors. The muons penetrate the object under test and pass through a second pair of drift detectors that measure the outgoing path of each particle after its interaction with the test object. A scintillator plate placed below the imaging system acts as a counter/trigger for the system, recording approximately 850 counts/min.

Analog signals from the detectors are amplified and separated by standard nuclear instrumentation module electronics, digitized by a fast encoding and readout analog/digital converter and fed to a standard PC using an acquisition software for analysis. The Los Alamos group has developed its own reconstruction algorithms based on the single-scattering approximation of multiple scattering interactions, resulting in successful detection of high-atomic-number materials in 3-D experimental image simulations.

“Several aspects of this work are very appealing,” noted Patrick Doty of Sandia National Labs Engineered Materials Department and chairman of the program on hard x-rays at SPIE’s 48th annual meeting. Using background radiation for security screening combines benefits of both active and passive techniques. As with active methods, materials that emit no radiation signature are detected, but like passive screening, the subject of interrogation receives no increased radiation dose. This “no-dose” radiography is good for public acceptance, as well as foiling smugglers’ attempts to shield from or even detect the interrogation.

“It also enables new long-term monitoring scenarios in which humans can freely roam the scene without adverse health effects,” Doty continues. For example, one can envision such systems installed in cargo holds, operating while freight is in transit. Integrating an image for the entire duration of a trip dramatically improves statistics relative to portal monitoring, reducing the minimum detectable mass, again with no penalty due to radiation dose.

Simulations on standard cargo containers have been done and corroborated by small-scale experiments. The next step will be to build a full-sized system of detectors capable of imaging a car, says Konstantin Borozdin of the Los Alamos team. In addition, the group continues to work on reconstruction algorithms and visualization to allow automatic detection of small quantities of nuclear materials. —Winn Hardin
metallic photonic crystal defies Planck's law

There have been no revolutionary changes to the light bulb’s design since Edison first invented it over 100 years ago, but that is all about to change. Using 3-D, micron-sized tungsten photonic crystals (PCs), researchers at Sandia National Laboratories (SNL; Albuquerque, NM) achieved emission in the IR and near-IR spectral regions in excess of that predicted by Planck’s law of blackbody cavity radiation. Indeed, the SNL group demonstrated that heated filaments fabricated of tungsten-lattices emit more energy than solid tungsten-filaments in certain near-IR bands. According to Sandia, photonic crystals create more complex energy/matter interactions than the solids Planck considered in developing his law; moreover, the crystals allow energy to escape only in certain, well-defined frequency bands.

The samples, with emission in the 1.5 to 2 µm range, exhibit minimum feature sizes of 0.5 µm on a 1.5 µm pitch. “The emission wavelength scales linearly with minimum feature size,” explains Jim Fleming of the research group. The key figures of merit of these PC structures are the narrowness of the peak in the emission spectrum and the energy density of the emission. The team’s fabrication approach borrows from standard IC fabrication processes. “Since our approach is based on IC processing, we have a good idea of its limitations; relatively small structures could be made cheaply, but large areas will be expensive,” notes Fleming. “There are other potentially cheaper ways of fabricating the structures, but at present they are much less developed,” he adds.

Future work will focus on better understanding the fundamental mechanisms involved and shrinking the dimensions of the lattice to access shorter wavelengths. The results of this work will potentially lead to more efficient IR sources for spectroscopy and scientific instruments, and include applications in thermophotovoltaics and lighting.

— Phillip Espinasse

quantum dots emit white light

Conventional lighting technologies suffer from low efficiencies, which provides a point of entry for solid-state lighting. Now, quantum-dot-based nanophosphors offer improved quality, lifetime, and better conversion efficiency than existing technologies.

By encapsulating 2-nm cadmium sulfide (CdS) quantum dots (QDs) and exciting them with near-UV LEDs, researchers at Sandia National Laboratories (SNL; Albuquerque, NM) achieved white-light emission with 60% conversion efficiency (see figure). “The QDs strongly absorb light in the near-UV range and re-emit visible light that has its color determined by both their size and surface chemistry,” explains Jess Wilcoxon of the research group. The group synthesized the QDs in a solvent containing surfactants acting as stabilizers. Their surfaces were subsequently stabilized by passivating surfactants, concentrated, and then redispersed in an epoxy used to form the dome of the LED.

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Tungsten-photonic lattice glows in a vacuum chamber. SNL researcher Shawn Lin holds in his hands an iridescent disk containing near 1000 of these lattices emitting in the NIR.

Photonics crystals

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MSTAR sensor gets absolutely accurate

Optical path-length control is of particular concern in ground and space-based interferometers, with some applications now demanding sub-micron absolute accuracy. By resolving the integer-wavelength ambiguity of standard laser interferometers, Serge Dubovitsky, Oliver Lay, and colleagues at the Jet Propulsion Laboratory (Pasadena, CA), in collaboration with William Steier and colleagues at the University of Southern California (Los Angeles, CA) and Pacific Wave Industries (Los Angeles, CA), have developed a new absolute distance measurement system potentially capable of nanometer-level accuracy over kilometer distances. The team has demonstrated the system in the lab over a range of 1 m, and presented their work at the SPIE Annual Meeting (San Diego, CA; August 3–8; paper #5190-38).

The Modulation Sideband Technology for Absolute Ranging (MSTAR) sensor approach implements a two-color metrology system using phase modulation of a single laser. Integrated-optics modulators operating at 40 GHz produce multiple sidebands on the output of a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser operating at 1.32 µm. A simple demodulation scheme eliminates the need for high-speed photodetectors and signal processing, and the long coherence length of the narrow-linewidth laser enables operation over long distances.

In the MSTAR configuration, the laser light is split into measurement and local arms, each of which is upshifted by acousto-optic modulators and phase modulated by polymer-based integrated optics devices (see figure). After collimation, the central part of the measurement beam travels to the target retroreflector through an annular mirror that returns the outer annulus of the beam, which acts as the reference. A beamsplitter mixes the returning measurement beam with the collimated local beam; the inner core component is directed to the target detector and the outer annulus goes to the reference detector.

The measurement and local beams mix at the detectors to generate the down-converted frequencies that are processed to yield the data. Phase measurement using the carrier and a number of sidebands enables the measurement of the phase gradient versus the optical frequency, which is essentially the group delay. The combination of high-speed modulation (40 GHz) and high phase resolution (0.3 mrad) lead to an absolute range resolution of about 100 nm, sufficient to resolve the integer-wavelength ambiguity of the optical phase.

“Although originally motivated by the demands of large, space-based optical systems, we see MSTAR as a general-purpose instrument with a wide variety of possible applications,” says Lay.

While the system performance has been demonstrated over a range of 1 m in the lab, there are no major obstacles to scaling the performance to much longer distances. Further work includes miniaturizing the beam-launcher optics into a robust package and stabilizing the laser frequency.

— Kristin Lewotsky

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The nanophosphor-based light sources offer several advantages, including negligible optical backscattering due to the small diameter of the dots and direct white-light emission from a single-size dot without the need to blend two or more colors. In addition, optical transparency in the 450- to 700-nm regime eliminates self-absorbance of emitted light. “The next step will be to increase the concentration of the quantum dots in the encapsulant to obtain further increases in light output while extending the understanding of quantum-dot electronic interactions at high concentrations,” says Wilcoxon.

The group is also working to improve long-term stability of the nanophosphors at the expected operating temperatures (100 to 150°C) and to produce QDs with broad energy range and strong emission in cheaper, non-toxic materials such as silicon. — Phillip Espinasse