A breakthrough for terahertz semiconductor lasers

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(PhysOrg.com) -- Potential applications, says an engineering professor, include disease diagnosis and detection of concealed explosives.

Light is nothing short of awesome -- it inspires painters and guides a midnight trip to the bathroom. But visible light occupies just one portion of the electromagnetic spectrum. Farther along the spectrum, radio waves enable the world to talk wirelessly. X-rays make medical imaging possible. Each region of the spectrum promises new technologies, if it can be harnessed.

A team led by Sushil Kumar, assistant professor of electrical and computer engineering, is helping to develop a largely unexploited region of the electromagnetic spectrum.

Working with researchers at MIT and Sandia National Laboratories, Kumar has made a semiconductor laser, also called a quantum-cascade laser (QCL), that emits terahertz (THz) radiation at higher operating temperatures than ever before. He reported his achievement recently in Nature Physics.

The breakthrough moves the technology closer to applications in disease diagnosis; quality control in drug manufacturing; detection of concealed weapons, drugs and explosives; the remote sensing of the earth's atmosphere; and the study of star and galaxy formation.

It also erases doubts that there is a maximum temperature at which coherent THz radiation can be generated from semiconductor chips.

"Terahertz QCLs are required to be cryogenically cooled and improvement of their temperature performance is the single most important research goal in the field," the researchers wrote in *Nature Physics.*

Progress toward a room-temperature THz laser

"Thus far, their maximum operating temperature has been empirically limited, [which] has bred speculation that a room-temperature terahertz QCL may not be possible in materials used at present."

QCLs are attractive because of their size. Traditionally high-power THz radiation was produced by bulky, expensive lasers fueled by a molecular gas such as methane. Advances in semiconductors have made QCLs as tiny as the diode in a laser pointer, but the lasers require temperatures almost 200 degrees below zero to emit terahertz radiation.

His team has raised the QCL's operating temperature, says Kumar, by exploiting its "tunability."

The frequency of light generated in any material is naturally fixed and is determined by the spacing of energy levels at the molecular level. But the spacing of the QCL's energy levels can be tuned, allowing the laser to emit THz radiation. QCLs are made of alternating layers of different semiconductors (such as gallium arsenide and aluminum gallium arsenide) because the thickness of each layer determines the spacing between the energy levels.

Proper tuning, says Kumar, is achieved by injecting electrons into the correct energy level of the semiconductor layers. The process is analogous to fuel injection in an automobile. Electrons (the fuel) hop from one energy level to another in the layered semiconductor to generate power in the form of THz photons.

But the THz photon energy, says Kumar, is much smaller than the thermal energy of electrons at room temperature.

“This makes it very difficult to selectively put electrons in the required energy levels for them to emit THz photons.”

Fuel injection -- using electrons

To raise QCLs’ operating temperature, Kumar’s group has harnessed the “relaxation process.” Electrons tend to dissipate their energy in the form of lattice vibrations at higher temperatures, called “non-radiative relaxation,” which is typically detrimental to laser operation.

Kumar’s group used this natural phenomenon in a controlled manner to inject electrons into the correct energy levels. This scattering-assisted injection technique is less sensitive to the thermal energy of electrons and remains efficient at high temperatures as well.

“This tremendous achievement is very promising for the future of THz laser technologies,” says Alessandro Tredicucci, research director at the National Research Council of Italy and inventor of the first THz QCL. “It shows that the power of quantum design has yet to be fully tapped and encourages people to look for new materials and structures whose relaxation times can be slowed down.”

“It is remarkable how the science of QCLs has progressed hand-in-hand with advancements in crystal growth technology to make such an incredibly complex semiconductor device possible,” says John Reno of Sandia’s Center for Integrated Nanotechnologies, who coauthored the *Nature Physics* article.

More information: www.nature.com/nphys/journal/v … /full/nphys1846.html

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