Building a bright future for lasers

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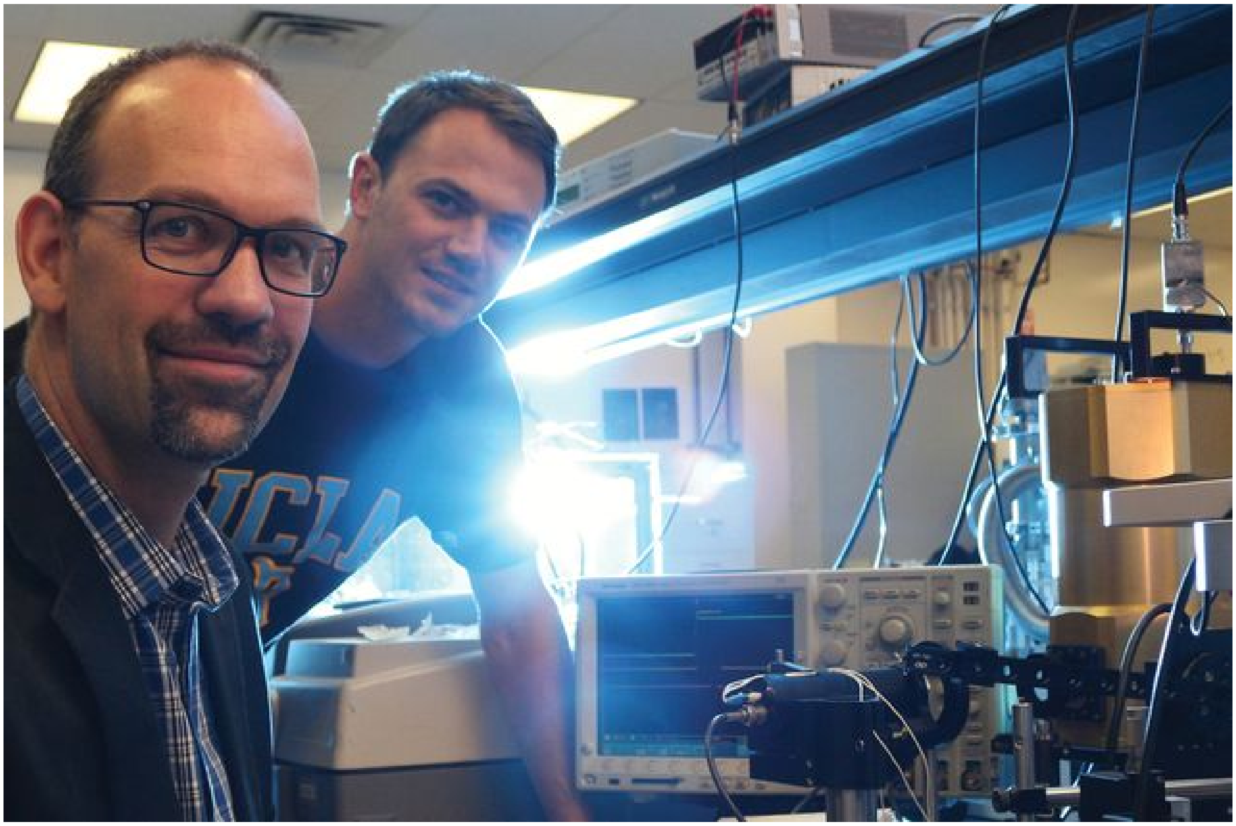

Professor Benjamin Williams, at left, and 2016 Ph.D. graduate Benjamin Burnett at work in the Terahertz Devices and Intersubband Nanostructures Laboratory. Credit: Art Montes de Oca

Invisible to the human eye, terahertz electromagnetic waves can "see through" everything from fog and clouds to wood and masonry—an attribute that holds great promise for astrophysics research, detecting concealed explosives and many other applications.

Terahertz lasers can produce photons with frequencies of trillions of cycles per second—energies between those of infrared and microwave photons. These photons, however, are notoriously difficult to generate—and that's where UCLA associate professor of electrical engineering Benjamin Williams comes in. He and his research group at the UCLA Henry Samueli School of Engineering and Applied Science are hard at work exploring "one of the last frontiers of the electromagnetic spectrum," as Williams describes it.

Most optical and infrared lasers operate by electrons transitioning between two energy levels in a semiconductor crystal and emitting a photon. However, this process is not so easily extended to the terahertz range.

"If you want to make terahertz radiation, you need a very low-energy photon, so you need two energy levels that are very close together, and that's hard to do with the semiconductors that nature gives us," said Williams.

He and his collaborators at the Terahertz Devices and Intersubband Nanostructures Laboratory instead produce terahertz photons by engineering artificial materials that mimic the energy levels of atoms. These so-called "quantum cascade lasers" are made by arranging different semiconductors in layers—some only a few atoms thick—to form quantum wells. Quantum wells are like tiny "boxes" that confine electrons to certain energy levels chosen by design. As an electron transitions between different energy levels, it emits photons. A single electron can cascade between the many quantum wells in a quantum cascade laser and trigger the emission of multiple terahertz photons, thereby producing a powerful laser beam. Another advantage of quantum cascade lasers is that the frequency of the emitted photons can be modulated.

"Instead of being limited to the band gap that nature gives you, we can change the width of these quantum wells to choose the effective band gap [and change the photons' frequency]. That's a very powerful concept," said Williams.

While quantum cascade lasers are both powerful and tunable in frequency, a significant disadvantage has been their low beam quality.

"Think of a laser pointer, which has a very nice beam, "Williams said. "The beam goes where you want it, and it looks like a nice spot. You're not wasting the light."

Terahertz lasers, on the other hand, often have beams that are highly divergent, meaning that the light beam spreads out and accordingly becomes less powerful. In some cases, the beam of a terahertz laser diverges so much that only 0.1 percent of it ends up where it was initially intended to go.

A major achievement of Williams' lab has been creating a type of terahertz quantum cascade laser that possesses both an excellent beam pattern and high power.

"Our innovation was to make an artificial surface that's made up of lots of little laser antennas [metal structures that each function like a quantum cascade amplifier]. The net effect is a mirror that reflects terahertz light as it amplifies and focuses it at the same time," said Williams. "We believe that this ability will allow us to create lasers with control of nearly all of the properties of the light—its wavelength, amplitude, phase, and polarization."

Williams and his team are also exploring how quantum cascade lasers can be designed to operate at room temperature. Currently, scientists must cool their lasers down to 77 Kelvin (-321°F), a step that limits the lasers' use outside of a laboratory. Now, Williams is investigating building those lasers using quantum dots instead of quantum wells. While quantum wells confine electrons' motion in only one dimension, quantum dots restrict their motion in all three dimensions. The extra confinement in quantum dots is predicted to drastically reduce how much the electrons scatter, which would allow these lasers to work at room temperature.

"We're currently working with Diana Huffaker [professor of electrical engineering at UCLA], who grows quantum dots," said Williams. "[Her work] would allow us to do the same kinds of quantum engineering with quantum dots that we presently do with quantum wells."

Provided by University of California, Los Angeles

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