Extending VCSEL wavelength coverage to the mid-infrared

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Vertical-cavity surface-emitting lasers (VCSELs) are small, semiconductor-based lasers that emit optical beams from their top surface, and one of their main applications is in gas sensing. Gases each have a unique set of energies they can absorb, derived from their molecular structure. These sets of absorption lines are akin to fingerprints, which enables unambiguous and sensitive detection with a suitable tunable laser like a tunable VCSEL.

There are several important gases that are detectable with mid-infrared (mid-IR) light, having wavelengths between 3 and 4 micrometers (microns), including methane, carbon dioxide and nitrogen dioxide. Application-grade VCSELs, however, aren't yet available for this wavelength range, but the increasing need for compact, portable and affordable gas sensors is spurring demand for energy-efficient semiconductor sources of mid-IR light.

Addressing this demand, a group of researchers from the Walter Schottky Institute at the Technical University of Munich (TUM) in Germany set out to develop a concept to extend the wavelength coverage of VCSELs into this important regime, which they report this week in *Applied Physics Letters*, from AIP Publishing.

Typical VCSELs suffer in performance for the relatively long wavelengths of the mid-IR range, in part due to side effects of heating that disproportionally affect IR wavelengths. These effects are minimized by the "buried tunnel junction" configuration of VCSELs, where a material barrier is embedded between the standard p- and n-type materials of the semiconductor. This structuring results in resistancelike behavior for the device and provides tunability of the optical properties in the desired range.

"The buried tunnel junction VCSEL concept has already yielded high-performance VCSELs within the entire 1.3- to 3-micron wavelength range," said Ganpath K. Veerabathran, a doctoral student at the Walter Schottky Institute. "And so-called type-II 'W' quantum well active regions have been used successfully to make conventional edge-emitting semiconductor lasers with excellent performance within the 3- to 6-micron wavelength range."

By combining the tunnel junction VCSEL concept with these conventional edge-emitting laser designs, where the beam is emitted in parallel with the bottom surface, in this wavelength regime, the researchers created a buried tunnel junction VCSEL with a single-stage, type-II material active region to extend the wavelength coverage of electrically pumped VCSELs.

This advance is particularly noteworthy because it's the first known demonstration of electrically pumped, single-mode, tunable VCSELs emitting continuous wave up to 4 microns.

"It marks a significant step from state-of-the-art devices emitting at three microns in a continuous wave, and up to 3.4 microns in pulsed mode, respectively," said Veerabathran. "Further, our demonstration at four microns paves the way for application-grade VCSELs within the entire 3- to 4-micron wavelength range, because the performance of these VCSELs generally improves at shorter wavelengths."

It's important to note that although gas-sensing systems within this wavelength range are already available using other types of lasers, they're considered to be power hogs compared to VCSELs. They also tend to be cost-prohibitive, and are mainly used by industries to detect trace gases for safety and monitoring applications.

"The 4-micron VCSEL demonstrates that low-power, battery-operated, portable and inexpensive sensing systems are within reach," Veerabathran also said. "Once sensing systems become more affordable, there's great potential for deployment by industries, such as the auto industry for emission monitoring and control, and these systems may even find uses within our homes."

Next, the group will focus on making improvements "in terms of the maximum operation temperature and optical output power of the VCSELs," Veerabathran said. "In the future, it may be possible to extend this concept to make VCSELs emit further into the mid-infrared region beyond 4 microns. This would be beneficial because the absorption strength of gases typically becomes orders of magnitude stronger, even for relatively small wavelength increases."

More information: G. K. Veerabathran et al, Room-temperature vertical-cavity surface-emitting lasers at 4m with GaSb-based type-II quantum wells, *Applied Physics Letters* (2017). DOI: 10.1063/1.4975813

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