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Near- to mid-IR (1–13 μm) III-V semiconductor lasers: introduction to the feature issue

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This feature issue reports on the most recent advances in the field of III-V semiconductor lasers emitting in the near- to mid-IR spectral regions, with a particular focus on devices with an emission wavelength range between 1 and 13 μm.

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Despite development of III-V semiconductor lasers operating at the near- to mid-IR spectral region of the electromagnetic spectrum over the last few decades, significant improvement in laser performance is still needed to enable several major application areas, such as optical communication, sensing, spectroscopy, and imaging. This feature issue covers new research topics and state-of-the-art developments in the area of semiconductor lasers emitting at 1–13 μm and their use for real-world applications.

Different types of semiconductor lasers, including in-plane edge-emitters, distributed feedback (DFB) lasers, quantum cascade lasers (QCLs), and photonic crystal membrane lasers are covered. Among the 10 papers included are two invited mini-reviews written by leading researchers that comprehensively treat the recent progress of QCLs. The remaining eight present important results in subtopics such as edge-emitting lasers using novel materials, DFB lasers, photonic crystal membrane lasers and the laser-based systems for sensing and imaging. The papers present recent III-V semiconductor laser-based cutting-edge technologies developed by world-leading research groups and are firmly believed to be of great interest to the scientific community.

There has been recent and extensive research in the development of QCLs with applications, including standoff detection and free space optical communications, as well as for a number of industrial applications, IR imaging and spectroscopy. Considering this, two mini-reviews in this area are featured. Lyakh *et al.* discuss the progress in high-power quantum cascade lasers made over the last 10 years. Specifically, an overview of the active region, waveguide, and thermal design techniques employed in realizing such devices emitting mid- and long-wave IR spectral regions is provided.

The mini-review contributed by Razeghi *et al.* from the Center for Quantum Devices at Northwestern University highlights the QCL performance achievements of the center to-date. The center has demonstrated high power continuous wave (CW) operation of QCLs covering a wide wavelength range from 3 to 12 μm, with power output of up to 5.1 W at room temperature. The group has also achieved power scaling in pulsed mode operated QCLs resulting in output power of 203 W, electrically tunable QCLs based on monolithic sampled grating design, heterogeneous QCLs with a broad spectral gain, broadly tunable on-chip beam combined QCLs, QCL-based mid-IR frequency combs and fundamental mode surface emitting QC ring lasers. The mini-review is a great overview of the state-of-the-art in QCLs and provides a good summary of the various QCL devices designs.

Recently, there has also been an increasing interest in single-mode mid-IR diode lasers due to a wide range of emerging applications, including trace gas sensing, medical diagnostics and free-space optical communication. Taking this into account, Milde *et al.* present new experimental results on developing tunable high-power GaSb-based single mode laser diodes emitting a wavelength range of 1.8 μm $\leq \lambda \leq$ 2.2 μm. In addition, given the importance of 2–3 μm semiconductor mid-IR lasers for these real-life applications, Ji *et al.* reported InP-based 2.1 μm triangular quantum well lasers grown with bismuth surfactant. By moving away from the antimonide-material system, the authors showed how to realize such long wavelength laser devices through bandgap engineering using InP-based materials. The authors also presented excellent results of bismuth-containing laser devices and their better performance in terms of light output power, internal loss and quantum efficiency relative to the devices grown without bismuth surfactant.

The manuscript submitted by Shterengas *et al.* from the State University of New York at Stony Brook presented results on laterally coupled (LC) DFB GaSb-based type-I quantum well cascade diode lasers using the 2nd and the 6th order gratings to stabilize the output spectrum near 3.22 μm. The laser heterostructure contained three cascades with the grating sections etched adjacent to the waveguide ridge sides. The 2-mm-long 2nd order LC-DFB lasers exhibited >10 mW of CW output power at 20°C in epi-side-up configuration. The devices demonstrated a CW current tuning range of about 3.5 nm at 20 °C.

Zhou *et al.* from the University of Texas at Arlington reported on the optically pumped photonic crystal bandedge membrane lasers on silicon-on-insulator (SOI) and on bulk Si substrates, based on heterogeneously integrated InGaAsP multiple quantum well (MQW) membrane layers transfer printed onto patterned photonic crystal cavities. Single mode lasing under room temperature operation was demonstrated at 1.542 μm, with a side-mode-suppression-ratio (SMSR) of greater than 31.5 dB, for the laser built on SOI substrate. For the laser built on bulk Si substrate, single mode lasing was achieved at 1.452 μm with much lower thermal resistance, as compared to that of the laser built on SOI substrates.

Plasmonic nanolasers or nanosensors based on Fano resonance have received considerable research interest as well. As an example of this effort, this issue features a theoretical paper relating to emerging compact plasmonic nanosensor based on Fano resonance. Ren *et al.* proposed and designed a simple and high-performance plasmonic refractive index sensor in a plasmonic waveguide, which shows excellent performance with high sensitivity and figure of merit. At the same time, this kind of waveguide-based sensor has an inherent advantage to achieve high integration.

Additionally, some papers in this feature issue present an exceptionally wide range of interesting research relating to the use of semiconductor lasers as illumination sources for optical imaging techniques. A range imaging system based on multi-wavelength superheterodyne interferometry using two 1.55-μm lasers to simultaneously provide sub-millimeter depth resolution and an imaging range of tens to hundreds of millimeters is proposed and developed by Li *et al.* The authors believe that their proposed system has the potential to provide high-accuracy 3D models applicable to the fields of computer vision and computer graphic applications, such as 3D human face scanning.

In recent years, sensing of trace-gases, such as carbon dioxide and water vapor by tunable diode laser absorption spectroscopy (TDLAS) has also drawn lots of attention for environmental reasons. Roy *et al.* addresses this issue by presenting experimental results on open-path *in situ* measurements of atmospheric carbon dioxide in heavily industrialized places. The authors used ~2 μm a vertical cavity surface-emitting laser to selectively sense carbon dioxide at this wavelength regime. This is believed to be the first experimental demonstration of a portable TDLAS system deployed in an urban location in India to measure atmospheric carbon dioxide and water vapor under varying traffic conditions.

Despite the fact that the feature was intended to highlight novel results primarily on III-V semiconductor lasers, reports on solid-state lasers with an emission around 3 μm are found to be very interesting for applications like optical communications, laser radar, and range finding. Therefore, we find it worthy to include the paper by Qi *et al.* that discusses enhanced 3 μm luminescence of Dy^{3+}. The authors reported that fluorescence emissions of Dy^{3+} with a high lifetime and large-emission cross section along with the high bandwidth around 3 μm has great potential for mid-IR fiber laser materials.

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