High-Performance Optically Pumped Band IV Semiconductor Lasers Using an Integrated Absorber Structure Combined with Novel QW Active Regions*

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There is significant interest in extending the maximum room-temperature operating wavelength of high-power, semiconductor lasers further into the longer wavelength range of the 2–5 µm mid-IR region. At the present time, a number of groups have successfully demonstrated room temperature, CW, watt-class diode lasers which operate near ~2 µm, but it has not yet been possible to achieve such high performance for CW diode lasers which operate near ~4 µm. Many commercial and military applications would benefit from the availability of room temperature, high-power, CW semiconductor laser systems that can cover the entire mid-IR spectrum. In particular, high-power, high-brightness 4-µm semiconductor lasers would be very useful as Band IV sources in advanced infrared countermeasure applications. Antimonide-based semiconductor lasers, both electrically and optically pumped, have already exhibited high power operation [1-4], but for practical insertion into actual systems applications, they should also have high power conversion efficiency and good beam quality at mid-IR wavelengths. The short-term system requirements for high-power, CW or quasi-CW lasers operating near 4 µm are being addressed by the development of cryogenically cooled, optically pumped semiconductor laser (OPSL) based systems. While the first generation of OPSLs were based on straightforward variations of diode laser designs, it is now realized that high-performance OPSLs must be designed with specific consideration given to the detailed physics of operation of optically pumped lasers.

In all optically pumped 4-µm lasers reported to date, the laser active regions must meet the dual requirements of high gain and low loss at mid-IR wavelengths, combined with sufficient absorption of the optical pump at shorter wavelengths for efficient power conversion. To effectively absorb a large fraction of the incident optical pump radiation, the laser active region is typically designed to be relatively thick. For previously demonstrated double heterostructure (DH) OPSLs [1], this means using greater than 1-µm-thick InAsSb active regions. For typical quantum well (QW) OPSLs, often >50 QWs are used, since the pump absorption in each QW is relatively small. The fractional pump absorption is even further reduced when 2-µm pumping is used instead of 1-µm pumping in order to reduce the quantum defect and to improve the power conversion efficiency. For many system applications, the combination of high power, high power efficiency, and good beam quality is required to meet source brightness requirements and pump power limitations. Since the carrier-induced refractive index change in 4-µm laser active regions is roughly 10 X greater than that found in typical 1-µm GaAs-based lasers, the 4-

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μm optical mode experiences a strong antiguiding effect in the laser which degrades the beam brightness. Designing a QW OPSL structure, which uses only a few QWs, can significantly reduce this antiguiding effect and can also reduce the possibility of filamentation.

Previously, we had demonstrated a novel OPSLs structure which employed a relatively thick quaternary GaInAsSb integrated absorber (IA) layers immediately adjacent to type-II GaInSb/InAs quantum well regions to address these issues. For the OPSL structures in which we have incorporated such GaInAsSb IA regions, we have determined that these dual requirements can be met while maintaining efficient high-power laser operation. Furthermore, this IA design has been found to be quite robust. By finely adjusting the QW layer thicknesses, the laser wavelength is easily tuned. We have obtained emission wavelengths (from several different OPSL structures) which range from about 3.6 – 4.8 μm. The characteristic temperature for lasing, $T_{o,}$ is typically around ~ 45 K. By bounding the QWs with AlGaAsSb barrier layers, we found that it was possible to increase T_o ~ 65 K, but with some decrease in absolute efficiency [5]. Finally, by modifying the waveguide design, which is feasible with the IA OPSL structure, it has been possible to reduce the far-field divergence in the fast dimension from 90- to 65-degrees FWHM. Recently, we have demonstrated "Al-free" IA OPSLs with even further reduced far-field divergence.

In this talk, we will describe efforts at further increasing the operating temperature of these mid-IR OPSLs through a better understanding of both the transport properties in the GaInAsSb IA layers and the gain properties of the type-II QWs. To this end, modified QW designs have been investigated. These include the "M" QW IA structures (GaInSb/InAs/GaInSb), where the order of the QW layers is reversed as compared to the normal "W" (InAs/GaInSb/InAs) structures. OPSLs that utilized this "M"-QW structure were found to operate quite efficiently. We believe that these are the first OPSL results obtained with such an "M" active regions.

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