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Low-Threshold Terahertz Quantum-Cascade Lasers with One-Well Injector Operating up to 174 K

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Abstract: We report operation of $\nu \sim 2.7$ THz quantum-cascade lasers (QCLs) up to 174 K. A new three-well active region, one-well injector scheme is utilized to lower the operating current densities. While the temperature performance of this design is comparable to that of the best published THz QCLs, lower operating current densities make this design a viable alternative.

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OCIS codes: (140.5965) Semiconductor lasers, quantum cascade; (140.3070) Infrared and far-infrared lasers

1. Introduction

Terahertz (THz) quantum-cascade lasers (QCLs) [1] have rapidly covered the frequency range of 1.2 – 5.0 THz ($\lambda \sim 250 - 60 \mu\text{m}$) [2]. They have already been demonstrated in applications such as imaging, spectroscopy, and as local oscillators in heterodyne receivers. There is a strong effort currently to increase their operating temperatures so that cryogenic operation may be avoided.

Currently the best temperature performance of 178 K is obtained by a variant of the original resonant-phonon design [3, 7], which utilizes a one-well injector, two-well active region scheme [4, 5]. A one-well injector active region [6] limits the optical losses in the active region of a THz QCL due to the absence of intersubband absorption in the injector region where most of the electron population is located. Additionally, it affords superior injection selectivity for the resonant-tunneling transport in the cascaded structure thereby maximizing population inversion in the active region.

2. Results

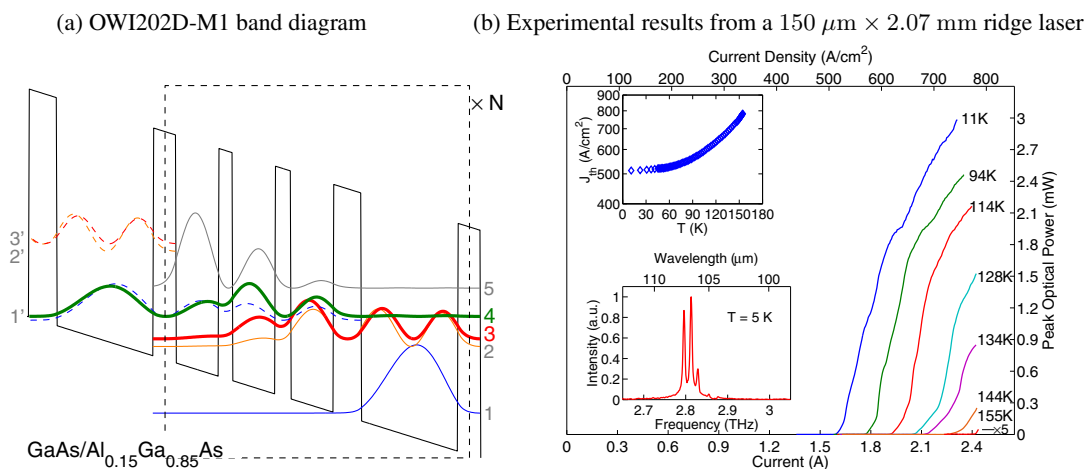


Fig. 1. (a) Conduction band diagram for a one-well injector, three-well active region that is similar to a previously published design [6]. The radiative transition is from $4 \rightarrow 3$ ($\nu \approx E_{43}/h \approx 2.8$ THz) and $E_{21} \approx \hbar\omega_{LO}$. (b) Experimental results from a metal-metal waveguide [7] ridge laser in pulsed operation. For this device $T_{\text{max}} \sim 155$ K and $J_{\text{th},5\text{K}} \sim 510$ A/cm².

Figure 1 shows the conduction band diagram and experimental results from OWI202D-M1, a one-well injector, three-well active region design. This design is similar to that of the first published one-well injector design [6] but modified for a higher frequency operation. The key characteristic of this design is a three-well active region, which allows the $4 \rightarrow 3$ radiative transition to be made more diagonal and hence reduce the low-bias parasitic leakage current channels [6]. Therefore, the operating current densities in the structure are lowered. However, for this design, an upper parasitic level 5 exists in the active region, which gets populated with electrons at higher temperatures and hence lowers the amount of population inversion that could be obtained.

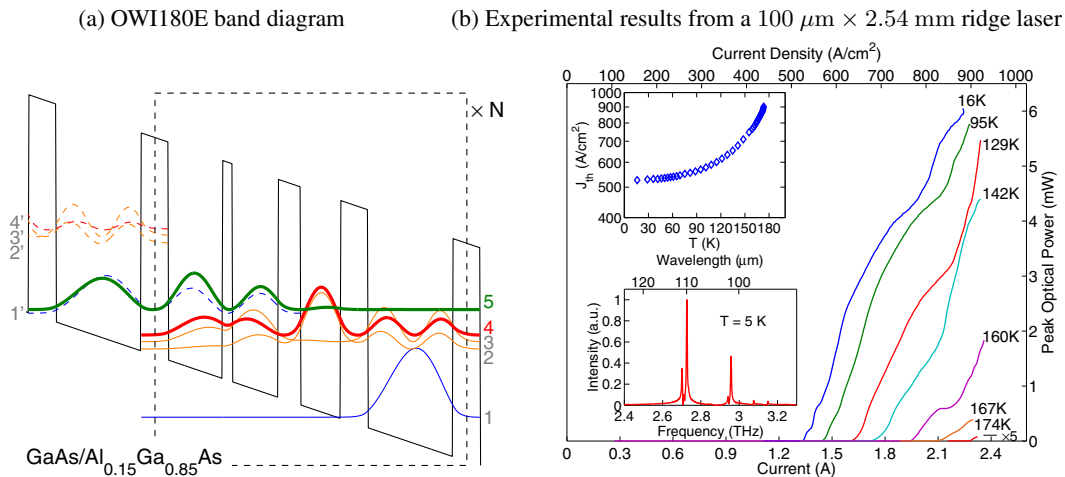


Fig. 2. (a) Conduction band diagram for a new one-well injector, three-well active region design. The radiative transition is from $5 \rightarrow 4$ ($\nu \approx E_{54}/\hbar \approx 2.7$ THz) and $E_{21} \approx \hbar\omega_{LO}$. (b) Experimental results from a metal-metal waveguide [7] ridge laser in pulsed operation. For this device $T_{\max} \sim 174$ K and $J_{\text{th},5\text{K}} \sim 525$ A/cm².

In figure 2, conduction band diagram and experimental results from a new design is presented. Superficially, this design looks similar to the previous one shown in Fig. 1, with one-well injector and three-well active region. However, in this structure, named OWI180E, the radiative transition takes place between the top two levels of the triplet states in the three-well active region. This eliminates the upper parasitic level 5 from the original design of Fig. 1 and hence achieves superior temperature performance.

The maximum operating temperature of 174 K for OWI180E (Fig. 2) is a validation of the advantage of this new design and it is comparable to the best published results for THz QCLs so far [5]. Additionally, its operating current density range of $\sim 500 - 900$ A/cm² is significantly lower than the $800 - 1400$ A/cm² range for the two-well active region design in Ref. [5] due to the additional well in its active region. Further optimization of the design will likely lead to even higher operating temperatures.

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