Barrier Height Effects on 1.3-micron InGaAsP Quantum Well Lasers: Experiment and LASTIP Simulation

Sebastian Mogg[a], and Joachim Piprek[b]

[a]Laboratory of Semiconductor Materials, Department of Electronics,
Royal Institute of Technology, Stockholm, S-164 40 Kista

[b]Department of Electrical and Computer Engineering,
University of California at Santa Barbara, Santa Barbara, CA 93106

We present a theoretical study of barrier height effects on the high-temperature performance of 1.3 µm strained layer InGaAsP/InP quantum well lasers. Broad-area Fabry-Pérot lasers with a barrier bandgap of 1.29 eV were fabricated and their pulsed light-current characteristics were measured in a temperature range from 20 °C to 80 °C. Based on our experimental results we analyze the effect of the barrier bandgap using the commercial laser simulation software LASTIP [1]. Figure 1 depicts the active region energy diagram including quasi Fermi levels as calculated near lasing threshold. The laser model calculates all relevant physical mechanisms, including their dependence on temperature and local carrier density, self-consistently. The strained quantum-well optical gain computation is based on the 4 x 4 kp method considering valence-band mixing effects and a non-Lorentzian line broadening model. A drift-diffusion model including thermionic emission at hetero-interfaces is used for the calculation of the carrier transport.

Careful adjustments of material parameters, in agreement with data reported in the literature, are performed in order to reproduce the measurements. Simulated and measured *L-I* characteristics at different stage temperatures are shown in Fig. 2. In the simulation we have stepwise reduced the barrier bandgap to find an optimum design for high-temperature operation. Lowering the barrier height in the active region leads to an improved performance of our laser with respect to threshold current and slope efficiency (Fig. 3). An optimum barrier bandgap range of 1.21 - 1.24 eV is identified for our laser. This is partially attributed to the non-uniform carrier-distribution across the quantum-wells, which is known to affect the laser performance substantially [2]. Figure 4 shows the MQW electron density for different barrierlayer bandgaps. The higher the barrier bandgap the more non-uniform is the distribution of the carriers due to the larger energy barrier for thermionic emission between the quantum wells. As a result, Auger recombination is strongly non-uniform within the active region. Figure 5 plots the current loss mechanisms versus barrier bandgap at high temperature. Auger recombination is the dominant current loss mechanism for all barrier bandgaps and shows a minimum at an intermediate bandgap. Vertical leakage is of little importance at room temperature but becomes significant at elevated temperatures. It increases with higher barrier bandgap due to the more non-uniform MQW carrier distribution (Fig. 5).

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[1] LASTIP 5.4.2 by Crosslight Software Inc., 2000.

[2] J. Piprek, P. Abraham, and J. E. Bowers, "Carrier non-uniformity effects on the internal efficiency of multi-quantum-well lasers", *Appl. Phys. Lett.*, vol. 74, pp. 489-491, 1999.

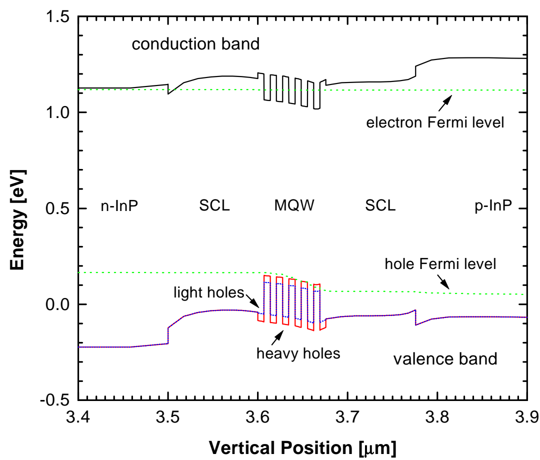

FIG. 1: Energy band diagram of the laser structure at lasing threshold.

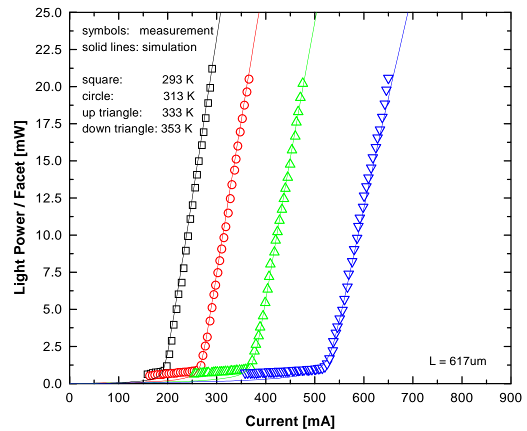

FIG. 2: Pulsed laser power versus current (L-I) characteristics at various temperatures (symbols: measurement, lines: simulation).

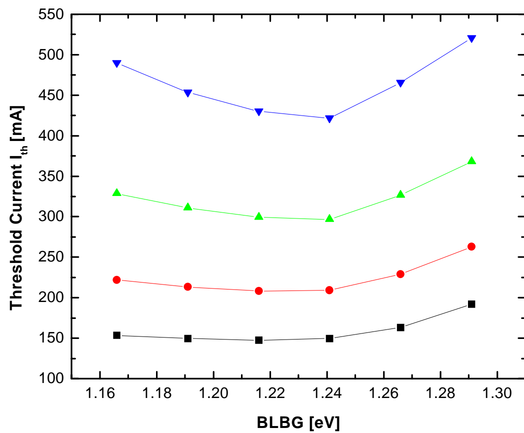

FIG. 3: Variation of threshold current I_{th} (left) and slope efficiency η (right) with device structure for several different temperatures.

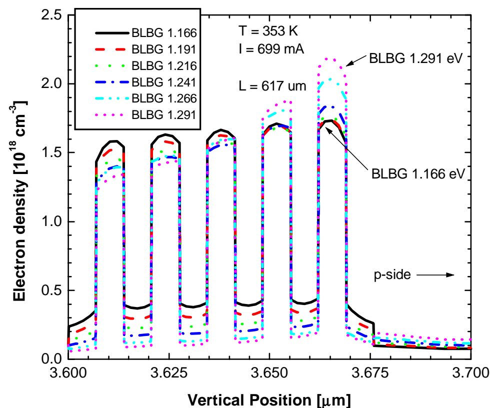

FIG. 4: MQW electron density $n(y)$ along the laser axis for different barrierlayer bandgaps.

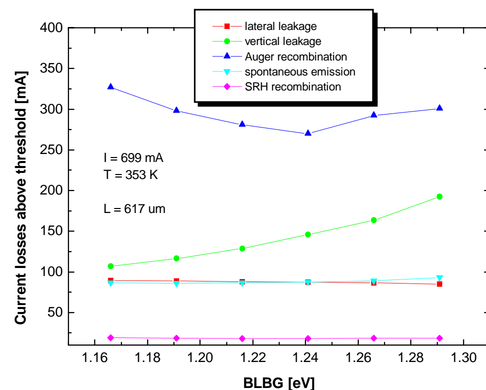

FIG. 5: Computed current loss versus barrier bandgap at high injection.