Design optimization of on-chip III-V/SiN quantum well/dot lasers

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We performed a parametric study of the design of an integrated III-V/SiN distributed feedback (DFB) quantum well (QW) and quantum dot (QD) lasers involving detailed and comprehensive modeling and multi-objective performance optimization. The study aims to maximize the potential laser linewidth reduction in InP/Si lasers coupled with SiN microring resonators. The design of the complex structures in such devices requires a large parameter space to explore for design engineering. This investigation and the formulated theory serve as an analytical tool for parametric studies to produce timely results for design engineering and optimization.

Fig. 1(a) shows a sketch of the coupled III-V/SiN DFB QW/QD laser under investigation. The parametric study here is enabled by following the microscopic laser theoretical formulation provided in [1] that includes multimode laser interaction, quantum-optical contributions from spontaneous emission, and composite laser/free-space eigenmodes to describe outcoupling and coupling among components within an extended cavity. Fig. 1(b) and its inset show the linewidth full-width half-maximum (FWHM) and the optical power, respectively, of the III-V/SiN QD laser as a function of the current density for different QD densities (top, for 5 QD layers) and QD layers (bottom, for a dot density of $4{\times}10^{14}$ m^{-2}). Increasing the QD layers or density resulted in higher optical powers and efficiencies. At a sufficiently high current, significant linewidth reduction, up to seven orders of magnitude, occurred. It was found that increasing the QD layers/density made locking easier with the SiN resonator. Moreover, increasing the QD density had stronger effects than the number of layers. Fig. 1(c) shows the results of the same investigation over the QW device. Increasing the QW layers yielded higher optical powers but also, contrary to QDs, lowered the efficiency and made it harder to be locked. The difference in linewidth performance between the QW and QD lasers is attributed to the difference in their linewidth enhancement factors, being near zero in the latter, as a result of the frequency pulling being dependent on carrier density in QWs, while being independent in QDs due to their symmetric carrier density distribution. Lastly, we performed a design-operation optimization via a genetic algorithm and the technique in [2], aimed to maximize the output power and wall-plug efficiency (WPE) and minimize the input current/power. Fig. 1(d) depicts the 4-D optimization space for the QW (left) and QD (right) laser, along with the Pareto frontier and optimal point. The optimization results show that minimizing the number of QW layers and moderate current injection are recommended since the added benefits of increasing either do not outweigh the associated power consumption increase and reduction in efficiency. Conversely, maximizing the number of QD layers yields optimal performance when injected with a low current. Overall, these results provide important insights for the design engineering of integrated III-V/SiN QW/QD lasers and show the potential for achieving Hz-level lasing.

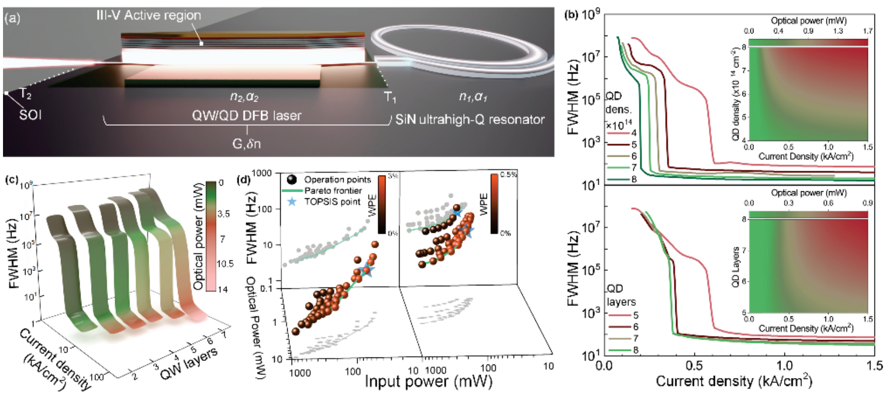

Fig. 1 (a) Sketch of the integrated III-V/SiN DFB QW/QD laser. (b) Linewidth FWHM of the III-V/SiN QD laser as a function of the current density for different QD densities (top) and QD layers (bottom). The inset shows the output power for each case. (c) Optical power and linewidth FHWM of the III-V/SiN QW laser as functions of current density and number of layers. (d) Pareto frontier and optimal point of the QW (left) and QD (right) laser diodes.

References

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979-8-3503-4599-5/23/$31.00 ©2023 IEEE