1.3 μm high performance epitaxial quantum dot lasers on silicon

F. Grillot[1,2], J. Duan[1], H. Huang[1], B. Dong[1], J. Norman[3], Z. Zhang[4], and J. E Bowers[3,4,5]

[1]LTCI, Télécom Paris, Institut Polytechnique de Paris, France
[2]Center for High Technology Materials, University of New-Mexico, Albuquerque, USA
[3]Materials Department, University of California, Santa Barbara, California 93106, USA
[4]Electrical & Computer Engineering Department, University of California, Santa Barbara, USA
[5]Institute for Energy Efficiency, University of California, Santa Barbara, USA
grillot@telecom-paris.fr

Photonic integrated circuits (PIC) have enabled numerous high performance, energy efficient, and compact technologies for optical communications, sensing, and metrology [1]. A major challenge in scaling PICs is dealing with parasitic reflections that feed light back into the laser increasing noise and, ultimately, causing dramatic coherence collapse [2]. To avoid these destabilizing reflections, expensive and bulky optical isolators must be included between the laser and the rest of the PIC leading to large increases in device footprint for on-chip integration schemes and significant increases in packaging complexity for lasers co-packaged with passive PICs. Fortunately, by transitioning from incumbent quantum well (QW) based lasers to lasers with quantum dot (QD) active regions, feedback tolerance can be dramatically enhanced, and the need for an isolator can be reduced or even eliminated. This work reports on experimental results for highly optimized QD lasers grown on silicon exhibiting ultralow linewidth enhancement factor (LEF) and optical feedback insensitivity [3,4].

Epitaxial QD lasers on silicon are grown using molecular beam epitaxy on optimized GaAs/Si buffers with a threading dislocation density of 7×10^{6} cm^{-2} [5]. These lasers have demonstrated record performance for any epitaxial laser on silicon with threshold currents <5 mA, continuous wave operation up to 105°C, and long device lifetime [5]. The QD active region consists of InAs QDs in $In_{.15}Ga_{.85}As$ quantum wells which are grown at 495°C with a V/III ratio of 10 in the 2 nm well before the dots, a V/III ratio of 35 during dot deposition (nominally 2.55 ML InAs), and a V/III ratio of 35 during the 5 nm of well capping the dots. Each dot layer is spaced by 37.5 nm of GaAs with a 10 nm *p*-modulation doped layer with 5×10^{17} cm^{-3} doping level. These optimized conditions yield a photoluminescence full-width-at-half-maximum (FWHM) of about 30 meV and dot density as high as 6×10^{10} cm^{-2}. Fig. 1 displays the spectral dependence of the LEF of the epitaxial QD laser (blue). Results show that the LEF remains below 0.50 over the operating window with a record value as low as 0.32 measured at the gain peak. As a comparison, we also show the LEF of a heterogeneously integrated QW laser on silicon (red). Within the spectral range, the LEF is found much larger than that of the epitaxial QD lasers with a value at the gain peak of 3.5. In order to evaluate the impact of the low LEF on the reflection sensitivity, we performed high-speed test-bed experiments. Fig. 2 shows the bit error rate (BER) with and without optical feedback under 10 Gbps external modulation after 2 km fiber transmission. Whatever the configurations, BER plots between the free-running and the case for the highest feedback level (-7 dB) overlap hence implying an excellent stability of the QD laser without any performance degradation. Fig. 2 (b) and (c) demonstrate the reflection insensitivity that is also confirmed by the eye-diagram which is open after transmission with optical feedback.

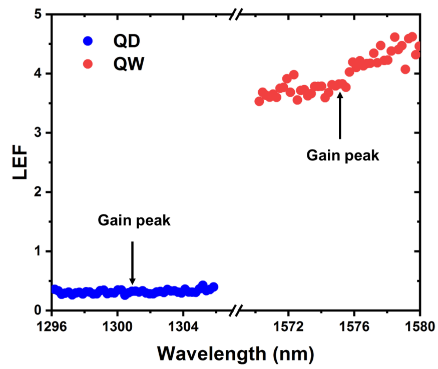

Fig. 1 The measured LEF for the QD (blue) and QW (red) lasers.

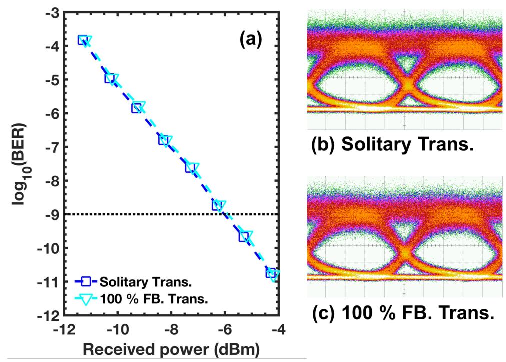

Fig 2 (a) BER for solitary QD laser after transmission and with the highest feedback level (-7 dB). Eye-diagram of the solitary laser (b) and with the highest feedback level (-7 dB) (c).

To summarize, we found that epitaxial QD lasers are capable of achieving much lower values of the LEF than a QW laser heterogeneously integrated on silicon. The degree of feedback tolerance of the QD medium is highly dependent on inhomogeneous broadening due to dot size variations [6], but through careful optimization, epitaxial lasers on silicon can achieve performance suggesting their capability for isolator-free photonic integration.

References

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