Quantum dot lasers for next generation optical networks

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The concept of introducing an atomic-like density of states surrounded by a conventional semiconductor material was predicted to result in a revolutionary approach enabling the development of smaller devices with low-noise and increased power efficiency [1]. Applications of QD lasers include but are not limited to coherent systems, optical interconnects within multi-core architectures, radars as well as sensing components essential for oil and gas exploration [2,3]. In this work, we bring novel insights in QD laser physics by focusing on the spectral linewidth and light complexity in the presence of optical perturbations.

Investigation of the spectral linewidth is numerically performed using a semi-classical model in which the equations of motion for carriers are microscopically motivated, whereas the electric field is modeled classically based on Maxwell's equations [3]. Fig. 1(a) shows a schematic of the QD laser model. The QD ground state (GS) is described by its occupation probability $\rho(t)$ whereas the excited and quantum well states are combined into a single reservoir charge carrier density $N(t)$. The complex electric field $E = Ae^{i\phi}$ is described by its amplitude A and phase ϕ. Fig. 1(b) displays experimental (symbols) and semi-analytical data (solid line) for the QD laser. At low injection currents below 1.5 $\times J_{th}$, the system is dominated by spontaneous emission noise. At $J \approx 75\text{mA} \approx 1.5 \times J_{th}$, a minimal laser linewidth as low as 200 kHz is unveiled whereas at higher injection currents, the laser line rebroadens, such that its value is doubled at $J \approx 3_{th} \approx 150$ mA. We intuitively explain the linewidth rebroadening process in QD lasers through a dynamically growing linewidth enhancement factor that is caused by the increasing scattering rates between the QD and the reservoir states. The effect of the gain compression on the linewidth is also investigated. Fig. 1(c) shows the total linewidth as a function of the injection current for various values of the gain compression factor ε. The rebroadening is found to strongly depend on ε and can be predominantly attributed to the dependence of the scattering rates on the carrier density and the injection current.

In a second part (results not shown here), we report on a systematic analysis of the influence of optical feedback in InAs/GaAs QD lasers epitaxially grown on silicon [3,5]. The boundaries associated to the onset of the critical feedback level corresponding to the first Hopf bifurcation are extracted with respect to the onset of the first excited state (ES) transition. Experiments reveal that such QD lasers are highly stable under optical feedback due to the small linewidth enhancement factor and the high QD size uniformity. On the other hand, we also prove that the critical feedback level strongly depends on the ES-to-GS lasing threshold ratio, which can be considered as a figure of merit, thus a laser having a fast switching dynamics with respect to the injection current is more susceptible to being highly destabilized by parasitic reflections. To sum, this work brings novel insights in understanding QD physics which can be useful for designing the next generation of QD lasers for data optical networks as well as for integrated photonics.

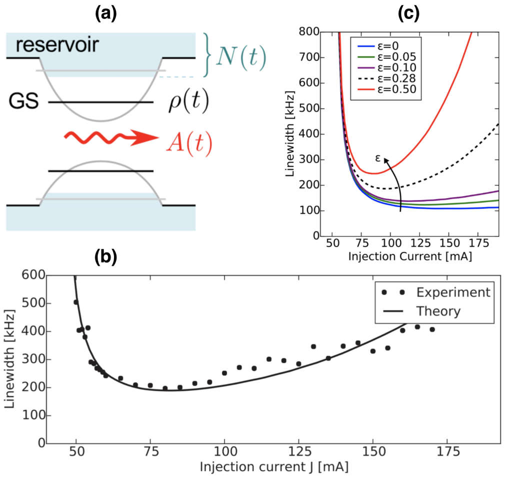

Figure 1.

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