ECIO 2016
18TH EUROPEAN CONFERENCE ON INTEGRATED OPTICS 2016
18–20 MAY | WARSAW | POLAND

Analysis of Quantum Dot Single Section FP Lasers for Comb Spectra Generation

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There is an increasing interest on Quantum Dot lasers as light source in silicon photonic integrated circuit; one promising application is the use of a QD comb laser as compact WDM source that could replace a DFB array more difficult to integrate with the Si PIC[1]. Many experiments on single section Fabry Perot QD lasers have demonstrated the possibility of generating wide optical comb spectra at telecom wavelengths but there is still a lack of modelling work for providing physical explanations on the capability of the QD lasers of generating phase locked optical modes. We present a Time Domain Travelling Wave model we have recently developed to move the first step in this direction [2]. We discuss here the role of some key QD material parameters such as the large gain compression factor (ε-parameter), the inhomogeneous gain broadening due to QD self-assembled growth process, the homogeneous gain broadening due to polarization dephasing time and the carrier relaxation time.

Numerical Model The spatio-temporal evolution of the optical electric field is described by the slowly varying forward/backward components of the electric field coupled with the slowly varying components of the macroscopic polarization which is the sum of the polarizations of each QD sub-group (ie: QDs with almost the same size) of the inhomogeneous ensemble. The polarization equations are coupled with electron and hole multi-population rate equations and the whole system is then solved with a finite difference scheme [2].

Simulation results and discussion We consider a 500 µm FP laser with 10 QD layers. We analyse the role of the QD material parameters on the phase locking of the longitudinal modes and on the stability of the intensity of the optical lines. The phase locking is evaluated by the possibility of generating narrow pulses after including the numerical group delay dispersion (GDD) compensation of the FP laser output field. If the modes are in a stable phase relation one respect to the other, the GDD compensation corrects the non-linear phase variation and allows the pulse formation . The intensity stability of each longitudinal mode is analysed by calculating the RIN of each single line compared to the RIN of the total power [3]. The numerical results are summarized in the following figures. Fig. 1(a) plots the output power vs time after a current step of 500mA at *t=0s* and Fig. 1(b) is the optical spectrum showing a -10dB bandwidth of 10nm. Fig. 1(c) reports the intensity vs time of each optical line showing that only few modes initially turns on at *t=0s.* These seed modes start transferring the power to the other adjacent modes thanks to the quite large gain compression of the QDs (ε=1.5 10^{-16} cm^3) . This transient concludes at about 250 ns with a rather broad optical spectrum. From this time instant, applying the GDD compensation we can obtain pulses as depicted in Fig. 1(d) and (e).

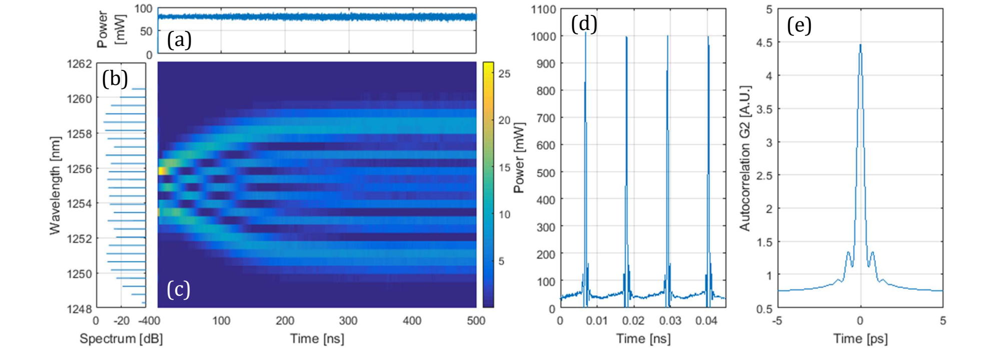


Fig. 1. (a) Power versus time, (b) optical spectrum, (c) mode intensity versus time, (d) pulses after GDD compensation and (e) corresponding autocorrelation.

Fig. 2 reports the calculated RIN of the output power and of the individual spectral lines. In good agreement with the experiments [3] the total RIN is much smaller than the RIN of each single line indicating that the intensity fluctuations of the optical lines are coupled and compensate each other. The comparison of Fig. 2a and 2b evidences that a large ε-parameter increases the RIN because of the stronger coupling among the modes. In Fig. 3 we compare the role of the homogeneous broadening (Fig. 3a), of the inhomogeneous broadening (Fig. 3b) and of the carrier relaxation time from the QD excited state to the ground state (Fig. 3c) on the pulse formation and therefore on the number of phase locked modes of the spectrum. From the comparison we conclude that a very homogeneous material (large homogeneous broadening and small inhomogeneous broadening) is the best case for narrow pulses and therefore for increasing the number of locked modes in the spectrum. A slower relaxation time and a slower gain recovery (respect to the cavity round trip) also inhibit multiple pulse formation and improve pulse stability.

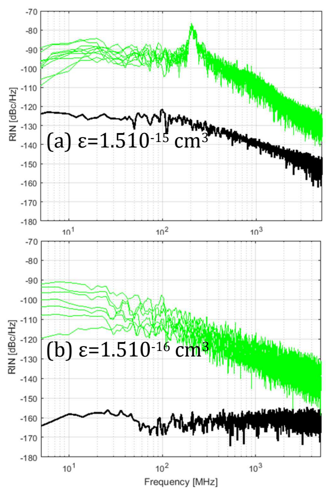
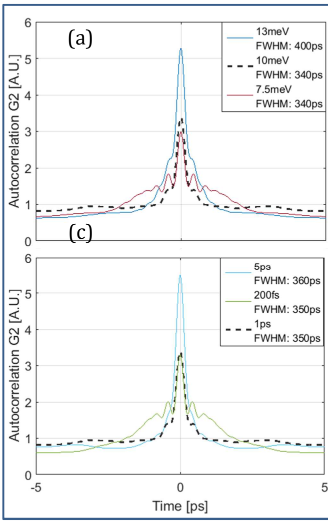


Fig. 2. Calculated RIN of each optical line (green) and total power (black).



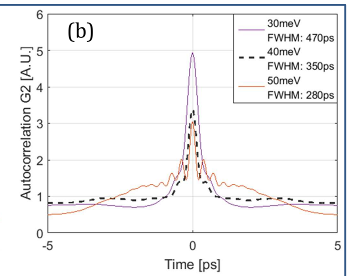


Fig. 3. Autocorrelation of ouput pulses after GDD compensation for different homogeneous broadening (a); inhomogeneous broadening (b) and carrier relaxation time (c).

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