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Dynamics of epitaxial quantum dot laser on silicon subject to chip-scale back-reflection for isolator-free photonics integrated circuits

Bozhang Dong[1,∗], **Jun-Da Chen**[2], **Justin C. Norman**[3], **John E. Bowers**[3], **Fan-Yi Lin**[2], **and Frédéric Grillot**[1,4]

1. LTCI, Télécom Paris, Institut Polytechnique de Paris, 19 Place Marguerite Perey, 91120 Palaiseau, France
2. Institute of Photonics Technologies, Department of Electrical Engineering, National Tsing Hua University, Hsinchu 300, Taiwan
3. Institute for Energy Efficiency, University of California, Santa Barbara, California 93106, USA
4. Center for High Technology Materials, University of New-Mexico, Albuquerque, New-Mexico, 87106, USA
∗ e-mail: bozhang.dong@telecom-paris.fr

Silicon-based epitaxial quantum dot (QD) lasers with strong tolerance for back-reflections have paved the way for developing isolator-free photonics integrated circuits (PICs). This remarkable feature is attributed to the peculiar benefits of QDs, including a large material gain, a strong damping, and a small linewidth enhancement factor [1]. The laser performance can also be optimized by applying p-modulation doping in the active region [1]. In a previous study, the sensitivity of epitaxial QD lasers on silicon subject to short- and long-delay optical feedback were performed [2]. On the top of that, a further investigation of the feedback dynamics on the intra- and inter-chip scale is of significant importance for photonic integration applications.

This paper reports on a study on the pulsation dynamics of a 1.3 μm Si-based p-doped epitaxial QD laser under strong optical feedback both in short-cavity regime (SCR) and long-cavity regime (LCR). More details of the laser studied can be found elsewhere [2]. In this study, the SCR and LCR is defined as the ratio of f_{RO}/f_{ext} being <1 or >1, respectively, with f_{RO} the relaxation oscillation frequency of the solitary laser and $f_{ext} = c/2L_{ext}$ the external cavity frequency [3]. The feedback strength r_{ext} is defined as the ratio of the reflected power to the laser output power. By increasing r_{ext} to ∼70% (∼ -1.55 dB), these results confirm that the QD devices operating at $4.4\times I_{th}$ under $30°C$ exhibit strong tolerance for back-reflections and do not emit chaotic oscillations. This is confirmed by tracking the full transition from SCR to LCR through the increase of the external cavity length L_{ext} from 4 to 50 cm. Fig.1(a) and (b) depict the pulsation states and corresponding oscillation frequencies of the laser under different feedback conditions, respectively. The vertical red dashed lines correspond to the condition $f_{RO}/f_{ext} = 1$ hence indicating the frontier between the SCR and LCR. By increasing r_{ext} in LCR, the laser system firstly enters into a quasi period-one (Q1, black) oscillation state in which the oscillation frequency coincides with f_{ext} (black curve shown in Fig. 1(b)). Further increasing r_{ext}, the self-pulsation frequency f_{sp} (yellow curve shown in Fig. 1(b)) approximates f_{RO} (black dashed line in Fig. 1(b)) is excited while f_{ext} still exists, hence the laser enters into quasi-periodic (QP, grey) oscillation state. Shortening the L_{ext} into SCR, the laser oscillating at f_{ext} exhibits a period-one (P1, red) oscillation. Then,the regular pulse package (RPP, yellow) dynamics takes place for f_{RO}/f_{ext} <0.5. To sum, the QD laser remains in the solitary state (S) up to r_{ext} of 45% in the SCR. In this regime, the increase of the r_{ext} associated with the onset of pulsation dynamics with decreasing L_{ext} suggests that these devices are highly reflection-resistant on the scale of PICs.

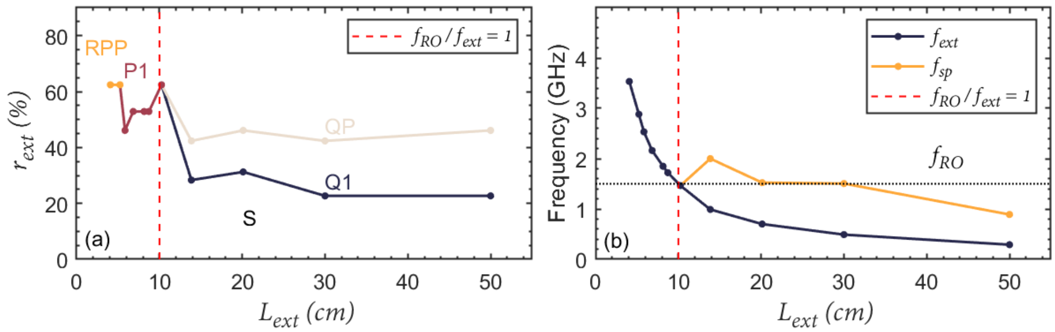

Fig. 1 (a) Mapping of the dynamical states under different feedback conditions, and (b) the oscillation frequency f_{sp} (yellow) and f_{ext} (black) as a function of L_{ext}. The p-doped QD laser operates at $4.4\times I_{th}$ under $30°C$.

To conclude, the observed high tolerance for chip-scale back-reflection points out the potential of epitaxial QD lasers on silicon as ultra-stable light sources applying to isolator-free PICs. The analysis of the pulsing dynamics is also strongly driven by the growing interest in the integrated microwave photonic technology.

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