Utilizing the Complex Dynamics of InAs/GaAs Quantum Dot lasers for Ultrafast Devices

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Abstract: The nonlinear dynamics of InAs/GaAs quantum dot lasers emitting exclusively on single lasing states, either ground or excited state, is investigated. While a laser emitting on the ground state is of importance for the development of isolator-free transmitters, lasers emitting on the excited states are essential for chaos-based applications, microwave photonics, and self-pulsating devices.

Semiconductor lasers are well established practical devices, widely used in optical communications, optical signal processing, integrated photonics, material processing and life science applications [1]. While solitary semiconductor lasers emit a stable output, under external optical feedback (EOF) they display a wide range of dynamics, which can be exploited for practical applications [1]. In this context, quantum dot (QD) lasers have attracted lots of attention for nonlinear dynamical studies. Indeed, owing to the tight confinement of the carriers, QD lasers constitute a class of oscillators exhibiting outstanding characteristics in terms of temperature stability, threshold current, suppression of filamentation, gain dynamics and optical nonlinearities [2,3]. As such, QD lasers are energy- and cost-efficient devices with a reduced amount of dissipated heat, being particularly important for emerging applications such as integrated nonlinear photonic chips [4]. Solitary dynamics of QD lasers can display three regimes of operation, depending on the bias conditions and the mirror coatings: (i) ground state (GS) lasing; (ii) dual state emission showing an interplay of the dynamics between the GS and the first excited state (ES), being the normal case, and (iii) ES lasing. While optical feedback dynamics of QD lasers has been intensively investigated in the context of the dual-state dynamics [5], none of this work focused on the dynamics of QD devices emitting exclusively on single lasing states. Here, we compare for the first time the dynamics of two InAs/GaAs QD Fabry-Perot (FP) lasers having the same active region, but emitting exclusively on either the GS or the ES without exhibiting any GS-ES interplay dynamics, where ES and GS lasing take place simultaneously.

The active region of both devices consists of a dot-in-well (DWELL) structure, including 10 InAs dot layers grown by molecular beam epitaxy (MBE), and embedded within InGaAs QWs [6]. The lasers are left as-cleaved and cavity lengths are both up to 1 cm, whereas the ridge waveguide (RWG) etched through the active region is 2 μm wide. The first FP laser emits at 1300 nm on the GS transition, whereas the second is emitting at 1230 nm on the ES transition. Fig. 1 shows maps of the complex dynamical states output from the 2 types of lasers upon varying the external cavity length L_{ext} and the feedback strength level ξ_f. The red-dashed lines depict the boundaries between the short cavity regime (SCR) and long cavity regime (LCR). Increasing ξ_f reveals the existence of multiple dynamical states such as steady (S), periodic (P), frequency-locking (FL), regular pulse package (RPP), quasi-chaos pulse package (QCPP), and chaotic (C) states [7,8]. Our results prove that QD lasers emitting exclusively on the GS state are much more stable, since no chaotic state was found for all feedback strength level used. The GS laser remains in his steady-state condition, provided the feedback strength does not exceed 0.3, which is already much larger compared to any typical reflection levels in a typical transmission system. In contrast, the QD lasers emitting exclusively on the ES state can be driven into many different dynamical regimes, including chaotic states. While a GS laser is of great importance for the development of isolator-free transmitters in short-reach networks, an ES laser on the other hand can be essential for applications taking advantages of chaos such as chaos

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lidars, chaos radars, and high-speed random number generations [8]. The difference has been attributed by us to the carrier dynamics, which in the case of the GS laser involves transport, capture, and relaxation, hence leading to a larger damping rate, stabilizing the laser and preventing the development of complex dynamics. In conclusion, although our GS and ES QD lasers are made from the same active medium, their feedback dynamics is observed to be enormously different. Thus, through proper quantum engineering of the fundamental bound states, QD lasers exhibiting different nonlinear properties can be fabricated with of largest importance for the aforementioned applications.

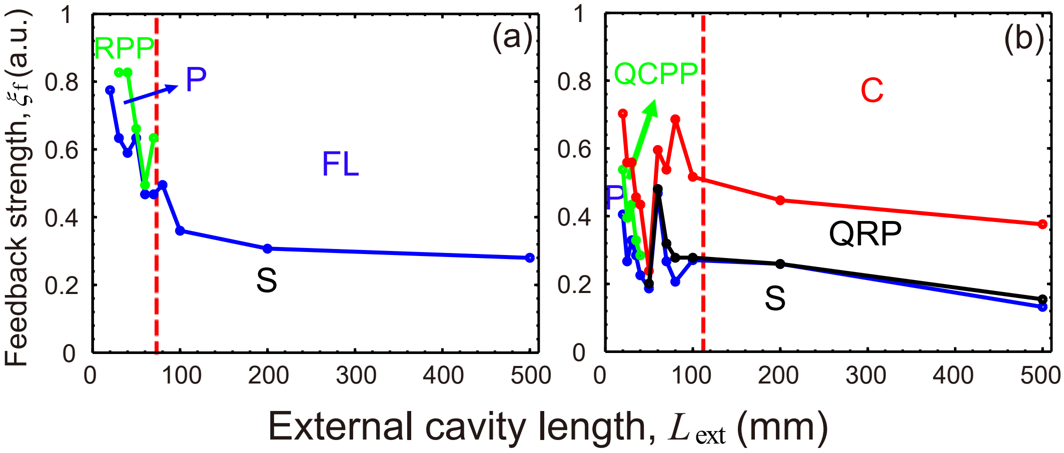

Figure 1: Maps of the complex dynamical states for (a) GS and (b) ES QD lasers measured both at $1.7 \times I_{th}$ under different feedback conditions. Red-dashed lines depict the boundaries between the short and long cavity regimes. S: steady; P: periodic; FL: frequency-locking; RPP: regular pulse package; QCPP: quasi-chaos pulse package; C: chaos.

This work investigates for the first time the dynamical states and the spectral characteristics of optical feedback of InAs/GaAs QD lasers emitting exclusively on single lasing states. The GS laser is shown to be almost insensitive to optical feedback and a pure chaos-free operation was found, which favors such lasers for less complex high-speed transmission links operating without isolator. In contrast, the ES laser exhibits a plethora of complex dynamics thus being useful for microwave photonics, chaotic lidars and radars as well as high-speed random bit generations.

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