Quantum Dot Micropillar Lasers subject to Delayed-Optical Feedback

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Semiconductor lasers are well-known to exhibit highly nonlinear behavior when subject to external optical injection and coupling [1]. Nowadays, the case of microlasers is particularly interesting given that such nonlinearities can be studied at the edge of quantum cavity electrodynamics (cQED). Due to the low mode volumes and characteristic strong photon-cavity couplings of such devices, their dynamics is highly influenced by spontaneous emission noise and single emitter effects. The exploitation of such features brings renewed interest to key applications of delay-coupled systems, like zero-lag synchronization or reservoir computing.

In the present work, we explore the phenomena of delayed optical feedback applied to quantum dot based micropillar lasers, focusing on the dynamics characterization for different key parameters. Our microlasers are based on high-quality, high-β semiconductor GaAs/AlAs micropillar cavities containing a single layer of optically pumped InGaAs quantum dots (QD) as active medium. In those devices lasing is maintained with the gain of only few tens of quantum dots resulting in a few tens of photons in the cavity with sub-μW output power. Therefore, we characterize their emission in a micro-photoluminescence setup by measuring their spectral and correlation signatures.

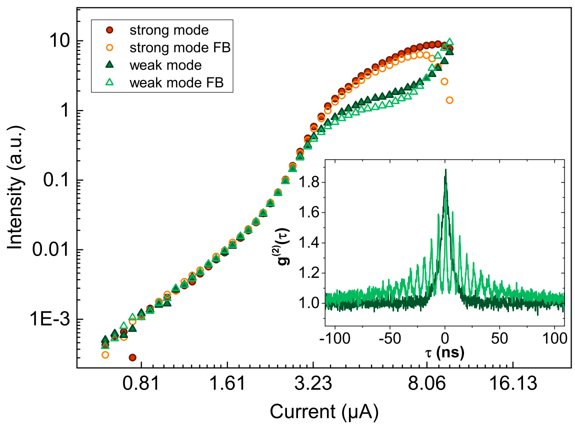

Figure 1: Output intensity of the microlaser plotted over its excitation current. The different curves correspond to the two perpendicular modes (here referred as strong and weak) without and with feedback. The inset shows the second-order autocorrelation function $g^{(2)}(\tau)$ of the weak mode at maximum current. The scenarios without and with feedback are plotted in the respective input-output curves colors.

Figure 1 shows the input-output characteristics of the microlaser. The threshold transition, occurring around 3.2 μA, shows the typical shallow s-shape of high-β lasers. In vertically emitting micropillars, two orthogonally-polarized modes compete for the gain. From numerical modeling we know that gain competition leads to mode-switching dynamics, resulting in an increase of the second-order autocorrelation function $g^{(2)}(0) > 1$ [2]. The bunching at zero delay can rise up to 1.9 (see inset in Fig. 1).

The input-output characteristics is significantly modified by self-feedback (here τ_d = 4.67 ns), i. e., the crossing point of the two competing modes shifts to lower excitation currents. Adding feedback leads to revival peaks caused by chaotic pulsing of the microlaser [3], but also increases both switching timescale and rate which is indicated by a longer decay timescale of the envelope and lower $g^{(2)}(0)$, respectively. Furthermore, switching behavior is explicitly proven by the dips in the crosscorrelation of strong and weak modes in Fig. 2.

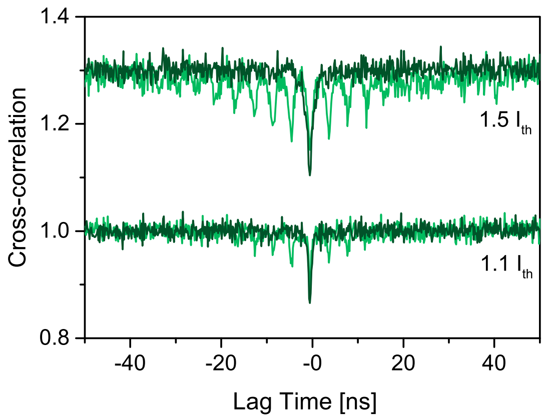

Figure 2: Crosscorrelation of strong and weak modes for two different bias currents. The curves corresponding to $1.5\ I_{th}$ have been shifted upwards for clarity. The scenarios without and with feedback are plotted in the respective colors of the input-output curves (see Fig. 1).

By changing parameters in the external cavity such as cavity length and feedback strength, we can directly manipulate the switching dynamics. Here, increasing those parameters diminishes the decay of the dynamics timescales, which is in contrast to the expectations for classical lasers. Therefore, our findings pave the way for deeper understanding the particular dynamics of high-β microlasers and towards successful external quantum control of nanophotonic systems.

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