Influence of the upper nonlasing state on the route to chaos of InAs/GaAs quantum dot lasers

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Abstract: This paper investigates the route to chaos of a quantum dot laser emitting exclusively on a single lasing state. Results reveal that amplified spontaneous emission from the upper non-lasing state drastically accelerates the destabilization process.

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1. Introduction

InAs/GaAs quantum dot (QD) lasers are energy- and cost-efficient transmitters with outstanding temperature stability and low threshold current hence resulting in a reduced amount of dissipated heat [1]. In order to speed-up the modulation capabilities, QD lasers not emitting on the ground-state ($|GS\rangle$) transition were successfully proposed with experimental demonstrations using different modulation formats [2]. Very recently, the optical feedback dynamics of InAs/GaAs QD lasers emitting exclusively on single lasing states was experimentally investigated [3]. While those emitting on the first excited-state transition ($|ES_1\rangle$) show remarkable high-speed properties, it turned out that in presence of optical feedback, various dynamical states including unwanted chaotic oscillations can easily take place which is detrimental in a high-speed communication system. In this work, we investigate the optical feedback dynamics of an InAs/GaAs QD laser emitting exclusively on $|ES_1\rangle$ transition. Beyond a certain bias current, amplified spontaneous emission (ASE) from the second excited state ($|ES_2\rangle$) also takes place. Our results reveal that the bifurcation point beyond which the laser starts experiencing the route to chaos is drastically altered once after the onset of $|ES_2\rangle$. We believe that such results that are very specific to QD lasers are very important for designing highly feedback-resistant lasers for high-speed communication systems.

2. Laser structure and results

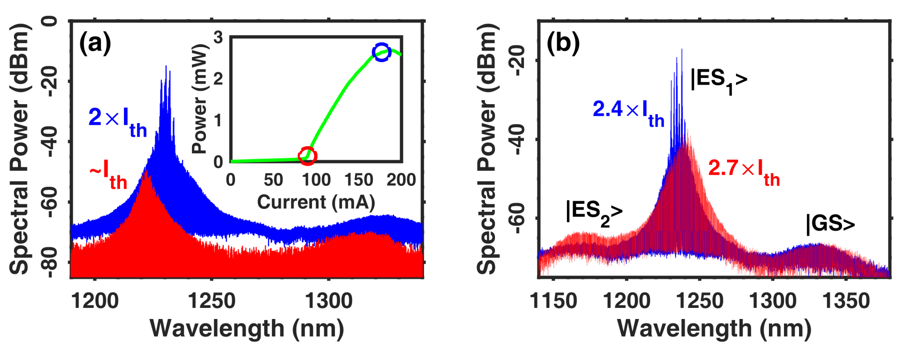

Fig. 1. (a) Optical spectra measured right above the threshold current I_{th} (red) and at $2\times I_{th}$ (blue), the inset depicts the light-current characteristics, the circles indicate the bias currents used for measuring the two optical spectra; (b) Optical spectra measured at $2.4\times$ (blue) and $2.7\times I_{th}$ (red).

The studied device is an InAs/GaAs QD Fabry-Perot (FP) laser operating exclusively on $|ES_1\rangle$. In this work, $|ES_1\rangle$ is selected from the wavelength dispersion across the wafer. The deeply etched active region of the laser is based on dots-in-a-well structure, consisting of 10 layers of InAs dots grown by molecular-beam epitaxy (MBE) embedded in InGaAs quantum wells [5]. Fig. 1(a) displays the optical spectra and the light-current (LI) characteristics (inset of 1(a)) measured at room temperature (293 K). The threshold current I_{th} is about 89 mA, with a slope efficiency of 11%, and the gain peaks at around 1220 nm. Above 190 mA, the laser is affected by thermal effects and the output power starts to roll off. Circles indicate the bias levels used for measuring the optical spectra slightly above I_{th} (red) and at $2\times I_{th}$ (blue).

Near the threshold, while only $|ES_1\rangle$ lasing operation begins, ASE originating from the $|GS\rangle$ transition is visible around 1320 nm. However, at $2\times I_{th}$, $|ES_1\rangle$ takes place at 1235 nm. Fig. 1(b) shows the optical spectra measured at higher biases namely at 2.4× (blue) and $2.7\times I_{th}$ (red). As compared to $2.4\times I_{th}$, results reveal a clear suppression of the dominant FP modes associated to $|ES_1\rangle$. In addition, ASE from $|ES_2\rangle$ pops-up at 1170 nm. Such a spectral signature involving stimulated emission on $|ES_1\rangle$ and ASE mostly from $|ES_2\rangle$ results in a severe modal competition which can drastically affect the optical feedback laser dynamics. In order to confirm such assumption, the QD laser is inserted into a 7-meter long external feedback loop as already described elsewhere [4]. Fig. 2(a) and 2(b) depict the radio-frequency (RF) spectra taken at 1.5× and $2\times I_{th}$ respectively, as a function of the feedback strength ranging r_{ext} from 0 to 4%. Fig. 2(a) shows that a small amount of optical feedback is enough to destabilize the laser. Thus, at r_{ext}=0.8%, the laser passes through the first bifurcation point and then start experiences a typical route to chaos as already demonstrated [3]. Fig. 2(b) obtained at a higher bias confirms this behavior but in this case, the destabilization process is accelerated. Indeed, the first bifurcation point originally measured for a 0.8% optical feedback strength has now decreased down to 0.2% hence meaning that the laser becomes more sensitive to optical feedback. This effect is fundamentally different than what is observed in QW lasers in which ASE from non-lasing states do not play a role in the laser dynamics [6]. To sum, increasing the bias current preserves the route to chaos but increases the contribution of the ASE noise from the upper non-lasing state $|ES_2\rangle$ which accelerates the overall laser destabilization process.

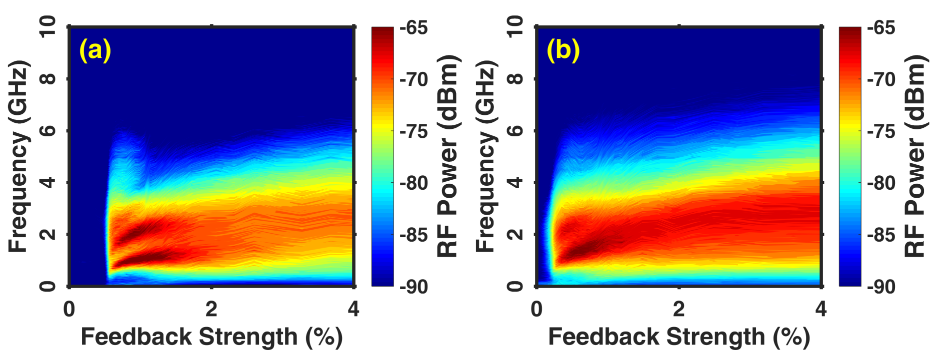

Fig. 2. RF spectra of the laser under optical feedback at (a) 1.5× and (b) $2\times I_{th}$.

3. Conclusions

This paper reports on the influence of the upper nonlasing state in the optical feedback dynamics of a QD laser operating exclusively on a single lasing state. Results reveal that the bifurcation point beyond which the laser experiences the route to chaos appears at a lower feedback rate due to the ASE from the upper nonlasing state. Theses results are very important for designing high feedback resistant lasers for high-speed communication systems.

References

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