On-Demand Q-Switching Regime in Optically Injected Dual-Section Quantum-Dot Laser

Ana Filipa Ribeiro, Adam F. Forrest, and Maria Ana Cataluna

***Abstract*—Pure Q-switching (self-pulsating) behaviour is shown for the first time in an optically injected two-section quantum-dot laser. Upon CW optical injection, it was possible to switch the operation regime from free-running mode-locking to locked Q-switching. Under this regime, the pulse repetition rate of around 1 GHz was tunable with injection power (by more than 100 MHz) and absorber reverse bias. Moreover, through injection-locking, the Q-switched output was spectrally tunable by around 7 nm, by tuning the master laser. The seamless switch between mode-locking and Q-switching with optical injection as well as the tunability and control afforded by injection-locking could open up a range of applications, such as in multi-modal imaging. On a more fundamental level, this investigation has also generated new insights into the dynamics of quantum-dot lasers and the optical injection process.**

***Index Terms*—Laser mode locking, laser tuning, optical tuning, quantum dot lasers, semiconductor lasers, ultrafast optics.**

I. Introduction

PASSIVE Q-switching (QS) is a self-pulsating regime usually found near the laser emission threshold and is caused by the self-modulation of cavity losses, with repetition rates of 100s of MHz to GHz on semiconductor lasers [1], [2], and broad pulse widths of the order of tens of picoseconds to nanoseconds [3]. In dual-section laser diodes designed and intended for passive mode-locked (ML) operation, QS regimes can emerge as pure QS or QS ML, where the latter is effectively a ML train of pulses periodically modulated in amplitude [4]–[6]. The existence and extent of such QS regimes has been physically linked to the ratio of the loss/gain saturation energies and to the attenuation factor in the cavity [4]–[7]. As QS regimes are typically uncontrollable and might diminish the region of stable ML operation, they are often regarded as unstable regimes to be avoided – and thus considerable amount of work has been developed for QS suppression [8].

Nevertheless, others have shown the versatility of this regime, with published applications on time-domain fluorescence experiments [9].

In free-running quantum-dot (QD) lasers designed for ML operation, QS regimes are most often manifested as QS ML [10], [11]. However, the QS ML range is typically small in these lasers (when comparing to quantum-well lasers), due to the characteristically fast carrier dynamics in QD materials, which suppress the loss modulations of the cavity and strongly dampen the relaxation oscillations [10]. Furthermore, when the structure of a free-running QD laser does have conditions to allow for pure QS to happen, such as when the ratio of absorber to gain sections' lengths is relatively low, this regime may still have a very short operational area – such as reported in [11], where it was only present in a narrow region gain current (a couple of mA), at a fixed reverse bias.

Previous theoretical investigations have predicted the existence of QS ML in a passively mode-locked QD laser under continuous-wave (CW) optical injection [12]. However, until now there have been no experimental demonstrations of QS regimes under such conditions.

In this paper, we show for the first time the possibility to switch from ML to a regime of pure QS upon CW optical injection of a dual-section laser. In this regime, wavelength tunability is also demonstrated via tunable CW injection. The pulse repetition rate under QS is shown to be tunable as well, varying with injection power and absorber reverse bias. The investigation of these results enables a number of further insights on QD laser dynamics under optical injection, such as a physical interpretation of the transition between the free-running ML regime and the injection-locked pure QS regime, considering the mechanisms behind relaxation oscillations and the absorption and gain dynamics of a ML QD laser. This new regime allows the on-demand switch between ML, QS and CW operation (potentially at high speeds), which could be exploited in applications requiring multi-modal laser operation. On the other hand, the tunability in both repetition rate and wavelength allows for even further flexibility, enabling a better match to target applications.

II. Method

The device under study is a two-section QD laser, with an active region composed of 10 layers of InAs/GaAS QD, grown and fabricated by Innolume (GmbH). The total laser length is 8 mm, with a saturable absorber to total length ratio of around 11%. The back/front facets of the laser were coated with high-reflectivity/low-reflectivity coatings, respectively. The lasing threshold for the QD laser is 110 mA, for a reverse bias of 0V, and approximately 170 mA for a reverse bias of 6.8V, with a recommended maximum operational bias of 300 mA and 8V. When passively mode-locked, under a range of gain current

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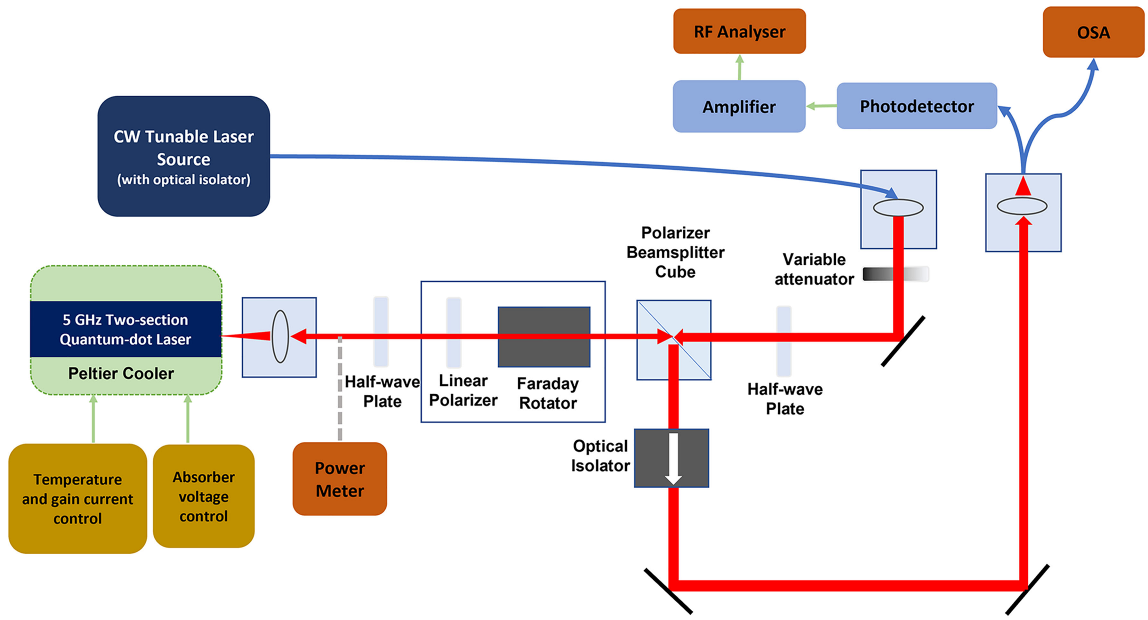

Fig. 1. Schematic representation of the CW optical injection setup. (OSA: Optical Spectrum Analyser).

(I_{gain}) and reverse bias (V_{abs}) values, the QD laser outputs 1260 nm light pulses with few picoseconds duration and at a repetition rate of approximately 5 GHz.

The QD laser was kept at 20°C via a feedback-controlled Peltier cooler and operated at fixed bias conditions (I_{gain} = 190 mA, V_{abs} = 6.8V), situated in a strong mode-locking region. Under these conditions, pulses were emitted with a 5.06 GHz repetition rate, with a full width at half maximum (FWHM) duration of 2 ps (obtained via autocorrelation and assuming a sech^2-shaped pulse), while the optical spectrum was centred at approximately 1255 nm and had a 7 nm FWHM bandwidth.

To perform the optical injection, the output of a tunable narrow-linewidth commercial CW master laser was injected into the gain section of the laser as seen in Fig. 1. The chosen setup is polarization dependent such that the only input to the diagnostics section is the output of the QD laser, with or without CW injection. This beam configuration is based on a one-way optical gate system, formerly applied to double-pass amplifier setups [13], [14].

Injection locking was performed by tuning the CW laser in picometer wavelength steps to match one of the optical modes of the free-running QD laser, which are equally distanced at approximately 27 pm, considering a 5.06 GHz repetition rate. The QD laser was considered locked to the CW laser according to the following criteria – first, there were no visible beating notes (between the CW laser and the adjacent QD laser optical modes) in the RF spectrum; second, there was a repetition rate shift followed by a complete suppression of the original repetition rate peak in the RF spectrum and third, there was a significant spectral narrowing and a shift of the optical spectrum to the injection wavelength region. These criteria have been previously applied in the study of CW and dual-tone optical injection in a quantum-dash ML laser [15].

The output of the QD laser, when free-running or injection-locked, was characterized using an optical spectrum analyser, an electrical spectrum analyser. The pulse duration of the laser when free-running and mode-locked was characterized using a commercial autocorrelator (A.P.E. PulseCheck NX). As shown in the schematic diagram, a power meter was used to measure the average power of the CW laser at the input of the QD laser, yielding the launched injection power (P_{inj}) values used and presented in this paper.

III. Q-Switching Regime: Results and Discussion

Under a range of QD laser bias conditions, CW optical injection led to a locked ML regime, which is a well-investigated phenomenon [16]. The complex dynamics involved in the locking and unlocking process in ML QD lasers have already been experimentally studied and reported in the form of injection-locking region maps [17] and will not be covered in this paper. Over the following sub-sections, we will now turn our attention to the new QS regime investigated.

A. *Locked Q-Switching Upon Optical Injection*

When free-running, the QD laser under study has a broad mode-locking region and does not give indication, to the best of our knowledge, of a QS regime in the region near threshold, where it is usually reported.

The free-running mode-locked QD laser (I_{gain} = 190 mA, V_{abs} = 6.8V), was injected at an injection wavelength (λ_{inj}) of 1255.5 nm, within the limits of the free-running optical spectrum at these bias conditions and an injection power (P_{inj}) of 1.7 mW, corresponding to an injection ratio (injection power / average power of free-running QD laser) of 0.9. QS operation begins when the CW laser locks to one of the optical modes of the QD laser. The fibre-coupled average power of the QD laser when

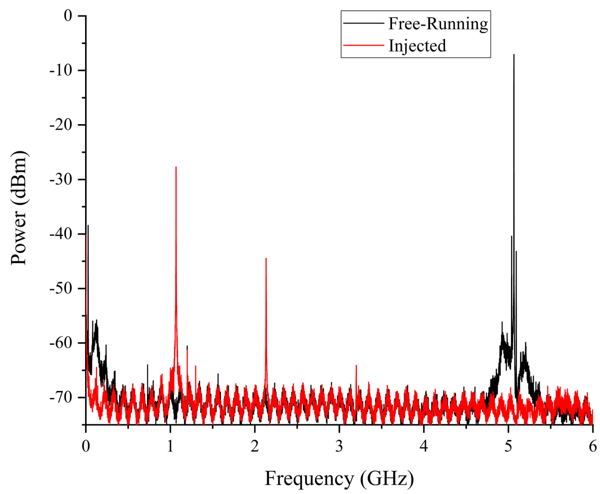

Fig. 2. [$I_{gain} = 190$ mA, $V_{abs} = 6.8$V]: RF spectrum of free-running (Black) and locked QS QD laser ($\lambda_{inj} = 1255.0$ nm, $P_{inj} \approx 1.7$ mW) (Red).

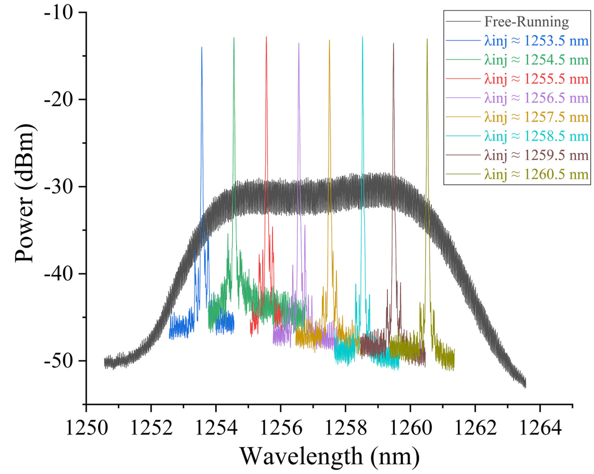

Fig. 3. [$I_{gain} = 190$ mA, $V_{abs} = 6.8$V]: Optical spectrum of free-running (Black) and locked QS QD laser at multiple injection wavelengths (Coloured).

free-running is 1.863 mW, and under injection-locked QS is 0.533 mW.

Fig. 2 compares the RF spectra of the laser when free-running versus injection-locked, revealing the appearance of a low-frequency (1.07 GHz) peak, characteristic of QS and the suppression of the 5 GHz mode-locking repetition rate. The side-bands observed around the fundamental repetition frequency, in the free-running case, are believed to be associated with electromagnetic interference from an external source emitting at ∼27 MHz that is being picked up by the setup (this band is heavily used for walkie-talkies and remote control of equipment). Furthermore, these sidebands do not change in frequency when the bias conditions of the QD laser are changed. An evaluation of the RF spectrum of the injection locked laser over a 26 GHz span (not depicted here) shows no other significant RF peaks, which gives an indication of pure QS behaviour (indeed, pure QS is represented solely by a low-frequency peak around 100s MHz – GHz and subsequent harmonics while QS ML shows the expected signs of an amplitude-modulated signal: a peak at the ML repetition rate (and subsequent harmonics) with multiple sidebands separated by the QS frequency [11]).

Fig. 3 shows the optical spectra of the laser under injection-locked QS, in contrast with its free-running ML operation, revealing a significant spectral narrowing, as expected from the transition from a ML to a pure QS regime [5]. Furthermore, as the injection wavelength (λ_{inj}) was tuned, it was also possible to tune the wavelength of the slave laser over 7 nm, as shown in Fig. 3. Under varying injection powers and wavelengths, a broad locked QS region was found near the current threshold region of the QD laser. The locked QS regime has been observed with gain currents from 120 to 190 mA, for reverse bias values in a 1 V range, at the vicinity of threshold.

In order to account for such a stark transition from a ML regime to pure Q-switching, we start by noting that in ML laser diodes, there is already a potential tendency for QS instabilities in regions closer to the threshold [1], [11]. In the results presented here, the operation conditions for which this transition takes place correspond also to a region closer to threshold (with relatively high reverse bias values). Upon optical injection with a narrow-linewidth master laser, the injected photons seed the build-up of laser emission, favoring the modes which are aligned with or closer to the wavelength of injection. As a consequence, there is a significant narrowing of spectral bandwidth, as shown in Fig. 3. Effectively, the regime of operating at a much narrower bandwidth only utilizes a narrow subset of the QD population. As passive QS is akin to a form of undamped relaxation oscillations due to the presence of the saturable absorber, it is helpful to consider the physics of relaxation oscillations in QD lasers [18], [19].

Indeed, it was previously demonstrated that when a QD laser turns on, if inhomogeneous broadening is dominant, this leads to independent oscillations of QDs of different sizes. The overall (spectrally integrated) output then reveals low-contrast relaxation oscillations. This contrasts with the situation where homogeneous broadening dominates, in which case QDs oscillate synchronously, leading to relaxation oscillations with higher intensity modulation [18], [19]. Upon optical injection, the spectrally selected subset of QDs that participate in laser emission will consequently have a narrower size distribution – and thus the effects associated with a broad inhomogeneous broadening are significantly reduced. By itself, this already should lead to more pronounced relaxation oscillations, laying a more favorable foundation for a QS regime to ensue.

In addition to the above effect, it is likely that CW optical injection has the effect of reducing the absorption saturation intensity in the saturable absorber – which, if it becomes small enough, can lead to QS [20]. This occurs through two main mechanisms.

Firstly, as the spectral bandwidth is narrowed upon emission, this also restricts absorption to a narrower subset of QDs in the saturable absorber. With a smaller number of QDs to saturate, the intensity required to saturate the absorber is reduced.

Secondly, as the CW optical injection is always present, the absorber will experience partial bleaching of the (already

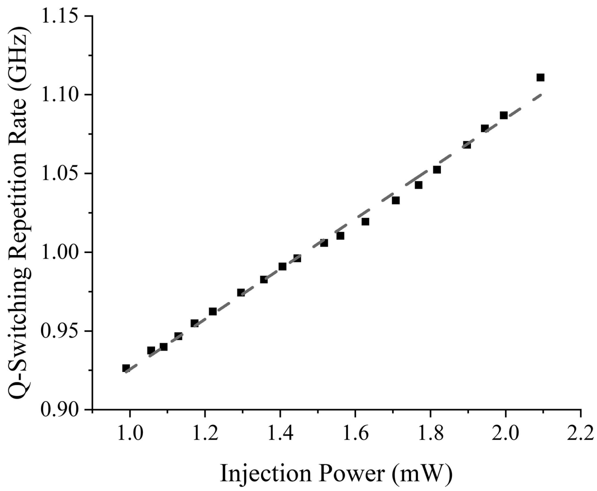

Fig. 4. [$I_{gain} = 190$ mA, $V_{abs} = 6.8$V]: QS repetition rate of locked QS QD laser ($\lambda_{inj} \approx 1255.0$ nm) as a function of injection power (P_{inj}). The dashed line corresponds to a linear fit of the QS repetition rate vs injection power.

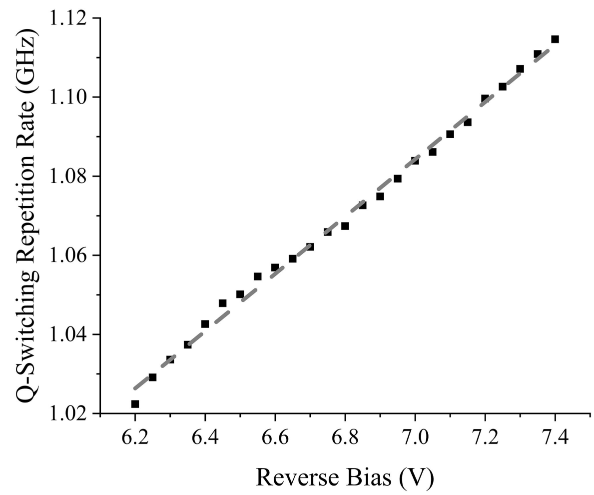

Fig. 5. [$P_{inj} \approx 1.7$ mW] QS repetition rate of locked QS QD laser as a function of the QD laser reverse bias (V_{abs}) [$I_{gain} = 190$ mA]. The dashed line corresponds to a linear fit of the QS repetition rate vs reverse bias.

few) spectrally aligned QDs [21] (partial saturable absorber bleaching was also previously reported as the main culprit for a range of dynamic behaviours in a dual-section InGaN laser diode under CW optical injection [22]). This would reduce even further the number of QDs which can act as absorption centers, thus further decreasing the absorption saturation intensity.

It should also be added, although not depicted here, that by tuning the injection wavelength while the QD laser remains locked to the master laser, it becomes possible to switch the regime of the QD laser from pure Q-switching into CW operation, before causing the unlocking between the master laser and the QD laser.

B. Influence of Injection Power on Repetition Rate

To evaluate the influence of the injection power on the QS regime, the QS repetition rate was characterized for injection power (P_{inj}) values from 0.99 mW to 2.09 mW and is shown in Fig. 4. The injection wavelength (λ_{inj}) was kept constant while sweeping the injection power. The range of injection powers where the data was obtained was restricted to the values shown in Fig. 4 to avoid damage to the laser and to avoid unlocking the QD laser from the CW laser.

As shown in Fig. 4 the QS repetition rate increases with injection power in a linear trend with a slope of approximately 159 MHz/mW.

In order to understand this trend, it is useful to revisit the physics of QS, where the process of pulse generation relies on the interplay of both gain and absorption dynamics and saturation and where the pulse builds up every time from the photons available in the cavity prior to the threshold condition being met. If there is no optical injection, this pulse build-up relies on the existing spontaneous emission [23], [24]. With optical injection, and as injection power is increased, the higher number of seed photons available helps to reduce the build-up time of optical pulses, as well as leading also to a faster gain recovery time. Moreover, as the CW injection power increases, the corresponding (background) CW component of the absorption becomes even more bleached [21], thus making it easier to saturate the absorber at the onset of pulse generation. As a result of all these effects, the time between the onset of pulses reduces and thus the repetition rate increases. This was indeed also previously demonstrated theoretically [25], [26].

C. Influence of Reverse Bias Conditions on Repetition Rate

The optical injection process has been shown to be a complex multi-variable system, dependent not only on injection wavelength and injection power, but also on the bias conditions of the injected laser. As such, the QS repetition rate was obtained for a varying reverse bias (V_{abs}) of the locked QS QD laser, at an injection power (P_{inj}) of approximately 1.7 mW and is shown in Fig. 5. The range of reverse bias values where the data was obtained was restricted to the values shown in Fig. 5 to avoid unlocking the QD laser from the CW laser.

As seen in Fig. 5 the QS repetition rate has a linear increase with reverse bias with a slope of approximately 72 MHz/V. Caution must be taken when analysing these results, as a change in the reverse bias may change multiple parameters of the absorption and gain dynamics of the QD laser such as the ratio of the loss/gain saturation energies and the absorber recovery time. Moreover, as reverse bias is increased, there is a reduction of the maximum achievable bleaching of the ultrafast component of the absorption [27], contributing also to higher overall losses (which are typically manifested in an increase of threshold current with increasing reverse bias in two-section lasers). When considering the formation of pulses under a QS regime, it is known that the optical pulse reaches its peak when the decreasing population inversion reaches the threshold point [23], [24]. If this peak point is met at a higher threshold, then for equal levels of population inversion, this would equate to the peak of the pulses being emitted increasingly earlier for higher values of absorber reverse bias – thereby increasing the frequency of pulsations.

IV. Conclusion and Outlook

Pure QS behaviour has been identified for the first time in an optically injected QD laser accompanied by a wavelength tunability over a few nanometres. The effect of reverse bias and injection power on the QS repetition rate were studied and the newly found trends will certainly help further the studies of the optical injection dynamics in QD lasers.

Overall, these findings suggest that optical injection increases the versatility and usability of the QD laser and could have implications on the understanding of the complex dynamics of the optical injection process of QD lasers, particularly the stark transition from ML to QS upon injection locking.

As a result of this investigation, it is feasible to optically control the QD laser into switching between a CW operation and the self-pulsating regime shown above, by controlling the injection power and wavelength, thus forming a type of 'pulse-on-demand' single laser system, similar to the one seen in [28]. These systems have many applications, particularly in the bio-photonics realm, where the dual-switchable regimes can be used, for example, as a way of optically trapping cells in the CW regime and dissecting them in the pulsed regime, as seen in [29]. Being able to controllably switch between CW, ML or QS operation in a single laser provides huge versatility that can be further extended and explored in applications which may benefit from a multi-modal laser.

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References

[1] U. Bandelow, M. Radziunas, A. Vladimirov, B. Hüttl, and R. Kaiser, "40 GHz mode-locked semiconductor lasers: Theory, simulations and experiment," *Opt. Quant. Electron.*, vol. 38, no. 4, pp. 495–512, Mar. 2006, doi: 10.1007/s11082-006-0045-2.

[2] C. Hönninger, R. Paschotta, F. Morier-Genoud, M. Moser, and U. Keller, "Q-switching stability limits of continuous-wave passive mode locking," *J. Opt. Soc. Amer. B*, vol. 16, no. 1, pp. 46–56, Jan. 1999, doi: 10.1364/JOSAB.16.000046.

[3] M. J. Heck *et al.*, "Observation of Q-switching and mode-locking in two-section InAs/InP (100) quantum dot lasers around 1.55 μm," *Opt. Exp.*, vol. 15, no. 25, pp. 16292–16301, Nov. 2007, doi: 10.1364/OE.15.016292.

[4] M. B. Flynn, L. O'Faolain, and T. F. Krauss, "An experimental and numerical study of Q-switched mode-locking in monolithic semiconductor diode lasers," *IEEE J. Quantum Electron.*, vol. 40, no. 8, pp. 1008–1013, Aug. 2004, doi: 10.1109/JQE.2004.831623.

[5] X. Li *et al.*, "Investigation of regime switching from mode locking to Q-switching in a 2μm InGaSb/AlGaAsSb quantum well laser," *Opt. Exp.*, vol. 26, no. 7, pp. 8289–8295, Mar. 2018, doi: 10.1364/OE.26.008289.

[6] M. J. Strain, M. Zanola, and M. Sorel, "Ultrashort Q-switched pulses from a passively mode-locked distributed Bragg reflector semiconductor laser," *Opt. Lett.*, vol. 37, no. 22, pp. 4732–4734, Nov. 2012, doi: 10.1364/OL.37.004732.

[7] D. Rachinskii, A. Vladimirov, U. Bandelow, B. Hüttl, and R. Kaiser, "Q-switching instability in a mode-locked semiconductor laser," *J. Opt. Soc. Amer. B*, vol. 23, no. 4, pp. 663–670, Apr. 2006, doi: 10.1364/JOSAB.23.000663.

[8] L. Drzewietzki, S. Breuer, and W. Elsäßer, "Suppression of Q-switching instabilities of passively modelocked semiconductor lasers by a passive electrical circuit," *Electron. Lett.*, vol. 47, no. 17, pp. 988–989, Aug. 2011, doi: 10.1049/el.2011.1802.

[9] D. R. Matthews *et al.*, "Technique for measurement of fluorescence lifetime by use of stroboscopic excitation and continuous-wave detection," *Appl. Opt.*, vol. 45, no. 9, pp. 2115–2123, Apr. 2006, doi: 10.1364/AO.45.002115.

[10] E. A. Viktorov *et al.*, "Stability of the mode-locked regime in quantum dot lasers," *Appl. Phys. Lett.*, vol. 91, no. 23, Dec. 2007, Art. no. 231116, doi: 10.1063/1.2822808.

[11] A. G. Vladimirov *et al.*, "Dynamical regimes in a monolithic passively mode-locked quantum dot laser," *J. Opt. Soc. Amer. B*, vol. 27, no. 10, pp. 2102–2109, Oct. 2010, doi: 10.1364/JOSAB.27.002102.

[12] N. Rebrova, G. Huyet, D. Rachinskii, and A. G. Vladimirov, "Optically injected mode-locked laser," *Phys. Rev. E*, vol. 83, no. 6, Jun. 2011, Art. no. 66202, doi: 10.1103/PhysRevE.83.066202.

[13] V. Bolpasi and W. von Klitzing, "Double-pass tapered amplifier diode laser with an output power of 1 W for an injection power of only 200 μW," *Rev. Sci. Instrum.*, vol. 81, no. 11, Nov. 2010, Art. no. 113108, doi: 10.1063/1.3501966.

[14] A. F. Forrest, M. Krakowski, P. Bardella, and M. A. Cataluna, "Double-pass amplification of picosecond pulses with a tapered semiconductor amplifier," *Opt. Exp.*, vol. 27, no. 21, pp. 30752–30762, Oct. 2019, doi: 10.1364/OE.27.030752.

[15] E. Sooudi *et al.*, "Optical frequency comb generation using dual-mode injection-locking of quantum-dash mode-locked lasers: Properties and applications," *IEEE J. Quantum Electron.*, vol. 48, no. 10, pp. 1327–1338, Oct. 2012, doi: 10.1109/JQE.2012.2210389.

[16] T. Habruseva, G. Huyet, and S. P. Hegarty, "Dynamics of quantum-dot mode-locked lasers with optical injection," *IEEE J. Sel. Topics Quantum Electron.*, vol. 17, no. 5, pp. 1272–1279, Sep.–Oct. 2011, doi: 10.1109/JSTQE.2011.2123875.

[17] T. Habruseva *et al.*, "Bistable regimes in an optically injected mode-locked laser," *Opt. Exp.*, vol. 20, no. 23, pp. 25572–25583, Nov. 2012, doi: 10.1364/OE.20.025572.

[18] M. Grundmann, "How a quantum-dot laser turns on," *Appl. Phys. Lett.*, vol. 77, no. 10, pp. 1428–1430, Aug. 2000, doi: 10.1063/1.1290716.

[19] M. Grundmann, "Relaxation oscillations of quantum dot lasers," *Electron. Lett.*, vol. 36, no. 22, pp. 1851–1852, Oct. 2000, doi: 10.1049/el:20001320.

[20] U. Keller *et al.*, "Semiconductor saturable absorber mirrors (SESAM's) for femtosecond to nanosecond pulse generation in solid-state lasers," *IEEE J. Sel. Topics Quantum Electron.*, vol. 2, no. 3, pp. 435–453, Sep. 1996, doi: 10.1109/2944.571743.

[21] A. Tierno, T. Ackemann, C. G. Leburn, and C. T. A. Brown, "Saturation of absorption and gain in a quantum dot diode with continuous-wave driving," *Appl. Phys. Lett.*, vol. 97, no. 23, Dec. 2010, Art. no. 231104, doi: 10.1063/1.3524824.

[22] X. Zeng *et al.*, "Solitary pulse-on-demand production by optical injection locking of passively Q-switched InGaN diode laser near lasing threshold," *Appl. Phys. Lett.*, vol. 106, no. 7, Feb. 2015, Art. no. 71101, doi: 10.1063/1.4907638.

[23] O. Svelto, "Transient laser behaviour," in *Principles of Lasers*, 4th ed. Boston, MA, USA: Springer, 1998.

[24] A. Siegman, "Laser Q-switching," in *Lasers*. Melville, NY, USA: Univ. Science Books, 1986.

[25] M. M. Ibrahim, "On injection-locking of inhomogeneously pumped semiconductor lasers," *Opt. Quantum Electron.*, vol. 28, no. 8, pp. 1049–1054, Aug. 1996, doi: 10.1007/BF00278275.

[26] M. Ibrahim and M. Alhaider, "Injection-locked passively Q-switched lasers," *IEEE J. Quantum Electron.*, vol. 18, no. 1, pp. 109–112, Jan. 1982, doi: 10.1109/JQE.1982.1071369.

[27] M. Rossetti, P. Bardella, and I. Montrosset, "Time-domain travelling-wave model for quantum dot passively mode-locked lasers," *IEEE J. Quantum Electron.*, vol. 47, no. 2, pp. 139–150, Feb. 2011, doi: 10.1109/JQE.2010.2055550.

[28] J. Robertson, T. Ackemann, L. F. Lester, and A. Hurtado, "Externally-triggered activation and inhibition of optical pulsating regimes in quantum-dot mode-locked lasers," *Sci. Rep.*, vol. 8, no. 1, pp. 1–9, Aug. 2018, doi: 10.1038/s41598-018-30758-2.

[29] J. Ando, G. Bautista, N. Smith, K. Fujita, and V. R. Daria, "Optical trapping and surgery of living yeast cells using a single laser," *Rev. Sci. Instrum.*, vol. 79, no. 10, Oct. 2008, Art. no. 103705, doi: 10.1063/1.2999542.

[30] A. F. Ribeiro, A. Forrest, and M. A. Cataluna, "Tunable operating regimes in passively mode-locked QD laser under CW optical injection," in *Proc. IEEE 27th ISLC*, Potsdam, Germany, 2021, pp. 1–2.