Stability of the modelocking regime in quantum dot laser

E.A. Viktorov, Paul Mandel
Optique Nonlinéaire Théorique, Université Libre de Bruxelles, Campus Plaine CP 231, B-1050 Bruxelles, Belgium
M. Kuntz, G. Fiol, and D. Bimberg
Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany
A. G. Vladimirov, M. Wolfrum
Weierstrass Institute for Applied Analysis and Stochastics, Mohrenstrasse 39, D - 10117 Berlin Germany

Passively and hybrid mode-locked (ML) quantum dot (QD) lasers are efficient sources of short pulses ideal for applications in high speed communication systems. The parameter range for which stable ML can be achieved is of importance for virtually all applications. Different regimes of operation can be distinguished for passively ML devices: non-lasing, Q-switching, mode-locking modulated by Q-switching, pure mode-locking, mode-locking with a cw offset and finally cw lasing. In lasers based on quantum dots the Q-switching instability is suppressed due to the strong damping of the relaxation oscillations induced by the fast carrier capture rate from the wetting layer to the dots [1].

We study the stability of the modelocking regime in quantum dot lasers both theoretically and experimentally. Experimental investigations have been carried out with a 40 GHz QD-ML module, having a standard single mode fiber pigtail and a microwave port, which is based on a two-section QD laser diode, comprising a short (100 µm) reverse bias absorption section and a long (900 µm) forward bias gain section. The rear facet (near the absorber) is high-reflection (HR) coated, while the front facet is as cleaved. The active zone of the device contains 15 layers of self-organized InAs quantum dots emitting at 1.3 µm embedded in InGaAs quantum wells. The mesa is defined by a 4 µm wide ridge waveguide etched through the active layer. The diode has a typical threshold current density of 360 A/cm² at room temperature with the absorber not being connected.

Two scenarios are possible for the low gain current instability edge of mode-locked QD devices: modulated ML or a hysteresis between ML and non-lasing states, depending on the design and operational parameters of the QD device. We observe a small region of modulated mode-locking at low gain currents, also known from QW based devices. The ML quality of a device can be judged best from the radio frequency (RF) spectrum taken with a fast photo-detector and an electrical spectrum analyzer. We observe an increase of the Q-switching frequency with increasing gain current, until there is a sharp transition to pure mode-locking

In order to explain these instabilities, we used a model for mode-locking in quantum dot lasers, described in [1], and the parameters which are conventional for QD materials and geometry. The model predicts a hysteresis between the ML and non-lasing states, strong damping of the Q-switched modulation, and rich dynamics including chaos.

The change of the ML dynamics can be traced with decreasing reverse bias at fixed injection current. Starting with a strong reverse bias, the ML pulse is stable and has a symmetric profile. Reducing the reverse bias, the ML pulse remains stable, but an asymmetry in the profile develops. This asymmetry is associated with the appearance of the unstable cw steady state in the vicinity of the pulse trajectory in phase space. This steady state has one unstable direction and an infinity of stable directions and is therefore a saddle point. Decreasing further the reverse bias leads to the sudden onset of a small amplitude chaotic modulation of the pulse power. The shape of the pulse is no more symmetric, but chaotically modulated. Still, small amplitude perturbations do not affect the averaged pulse duration and the repetition rate. The saddle point approaches the ML limit cycle. This contact point defines an instability which affects the profile but not the pedestal of the pulse and interpulse motion. This instability scenario is in agreement with our experimental findings.

References

1. E. A. Viktorov, Paul Mandel, A.G. Vladimirov, and Uwe Bandelow, "Model for mode locking in quantum dot lasers", Appl. Phys. Lett. **88**, 201102 (2006)