Strong asymmetry of mode-locking pulses in quantum-dot semiconductor lasers

***M. Radziunas*[1]*, A.G. Vladimirov*[1]*, E.A. Viktorov*[2]*, G. Fiol*[3]*, H. Schmeckebier*[3]*, D. Bimberg*[3]**

1. Weierstrass Institute, Mohrenstrasse 39, D-10117 Berlin, Germany

2. Optique Nonlinéaire Théorique, Université Libre de Bruxelles, B-1050 Bruxelles, Belgium

3. Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The advantages of self-assembled quantum dot (QD) materials can be exploited in multisection mode-locked (ML) lasers which are able to generate stable high intensity picoseconds and sub-picosecond pulses [1]. In this work, we study experimentally and theoretically, strongly asymmetric ML pulses generated by an edge-emitting QD ML laser consisting of a reverse biased saturable absorber (SA) and a forward biased gain section. To describe dynamics of this device we use the traveling wave model [2], which takes into account carrier exchange between the carrier reservoir (CR), ground state (GS), and excited state (ES) of the QDs [3].

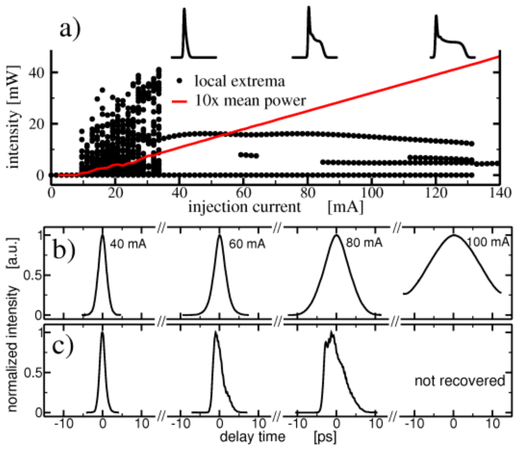

Fig. 1 Calculated (a) and measured (b,c) ML pulsations for different gain section injection currents and fixed voltage of the SA section. (a): Calculated local minima and maxima (bullets) and time-averaged value (solid line) of the emitted field intensity in dependence on I_G. Top: ML pulsations at I_G = 40, 80 and 120 mA. (b): Experimental autocorrelation measurements. (c): Corresponding pulse shape reconstructions using FROG technique.

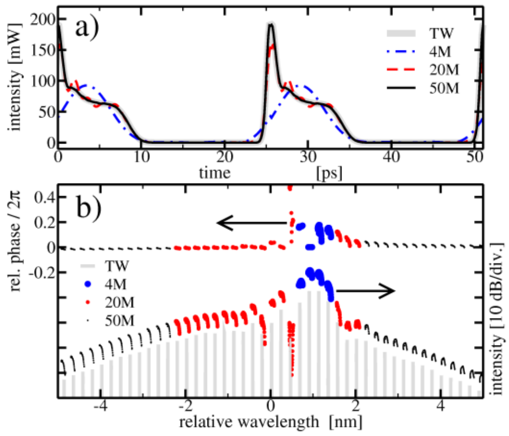

Fig. 2 Modal analysis of a simulated ML regime. (a): Calculated time trace of the emitted field intensity (thick gray) and its reconstruction using 50, 20 and 4 modes with largest amplitudes (thin). (b): Bullets give a parametric representation of the modal phases (above) and amplitudes (below) vs. modal wavelengths. Optical spectrum of the emitted field is shown by solid line. Bullets of different size indicate modes used for the field reconstruction in panel (a).

Our particular attention is drawn to the study of the pulses having a broad trailing edge plateaux (TEP) [4]. The theoretical and experimental results on formation and broadening of TEP with an increase of the injection currents I_G is represented in Fig. 1. Our theoretical analysis shows that the TEP in QD lasers arise mainly due to non-instant carrier transitions between the CR, ES and GS of the QDs. These multiple finite-time transitions slow-down the carrier exchange between the electrically pumped CR and the photon generating GS of QD, act as a filtering, and lead to a homogenization of the carrier and photon distributions along the gain section. To reveal the role of separate optical modes in ML regimes with strongly asymmetric pulses we have performed a modal analysis [5]. This analysis reveals a role of a few most powerful central modes (blue curve and bullets in Fig. 2): the strong asymmetry in the pulse shape appears not only due to larger amplitudes of these modes but also due to specific phase relations between these modes and the rest of the optical spectrum. The pulses with a strongly enhanced TEP can be represented as a superposition of a usual pulsating ML state formed by a large number of longitudinal modes and phase-shifted pulsations comprising only a few optical modes.

References

[1] E.U. Rafailov et al., "High-power picosecond and femtosecond pulse generation from a two-section mode-locked quantum-dot laser," Appl. Phys. Lett. **87**, 081107 (2005).
[2] U. Bandelow et al., "Impact of gain dispersion on the spatio-temporal dynamics of multisection lasers," IEEE JQE **37**, 183 (2001).
[3] A. Markus et al., "Two-state switching and dynamics in quantum dot two-section lasers," J. of Applied Physics **100**, 113104 (2006).
[4] M. Radziunas et al., "Strong pulse asymmetry in quantum-dot mode-locked semiconductor lasers," to appear in Appl. Phys. Lett. **98**(4) (2011).
[5] M. Radziunas and H.-J. Wünsche, Chapter 5 in, *Optoelectronic Devices - Advanced Simulation and Analysis,* J. Piprek ed. (Springer Verlag, New York 2005).