Hybrid mode-locking in a 40 GHz monolithic quantum dot laser

E. V. Viktorov [1], *P. Mandel* [1], *A. G. Vladimirov* [2], *M. Wolfrum* [2], *G. Fiol*[3], *M. Kuntz*[3], *D. Bimberg*[3]

1. Optique Nonlinéaire Théorique, Université Libre de Bruxelles,
Campus Plaine, C.P. 231, Boulevard du Triomphe
2. Weierstrass Institute for Applied Analysis and Stochastics, Mohrenstr. 39, 10117 Berlin, Germany
3. Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany

Mode-locked semiconductor lasers are efficient sources of short optical pulses ideal for applications in high speed telecommunication systems. Especially promising for telecom applications is the new generation of quantum dot mode-locked lasers (QD-MLL) which demonstrate important advantages over the standard quantum well devices [1]. However, performance improvement is still an ongoing issue, in particular for the efficiency of hybrid mode-locking, – a commonly used technique to improve characteristics and synchronize the mode-locked pulses – namely the dependence of the locking regime on the frequency and power of the applied external signal. Based on our previous results on passive mode-locking in quantum dot lasers [2], we study experimentally and theoretically a monolithic two-section hybrid mode-locked quantum dot laser with periodically modulated reverse bias applied to the saturable absorber section.

Experimental investigations have been carried out with a 40 GHz QD-MLL module, comprising a standard single mode fiber pigtail and a microwave port. It is based on a two-section QD laser diode having a 4 µm wide ridge waveguide structure. 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 diode has a typical threshold current density of 360 A/cm² at room temperature with the absorber not being connected. In order to investigate the locking performance the optical output of the laser diode was measured using a high speed photodetector and an electrical spectrum analyzer. For various operating parameters (current through gain section, reverse bias applied to absorber section) the external frequency was varied around the cavity round trip frequency and e.g. the locking range was determined.

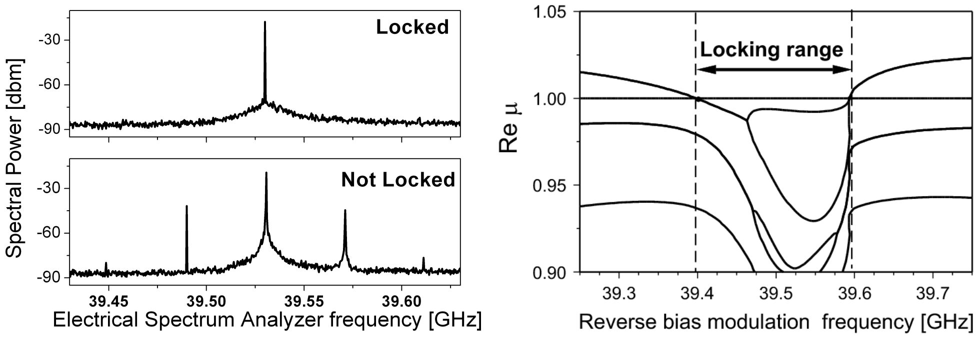

Fig. 1 Left: the graphs show the experimentally obtained regions; upper graph shows the case were the optical output is locked to the external frequency, the lower were the external signal is out of the locking range. Right: real parts of the numerically calculated Floquet multipliers μ describing stability of a locked regime. The condition $Re\mu<1$ defines the locking range.

Our theoretical model of a quantum dot laser is based on a set of delay differential equations governing the time evolution of the electric field envelope, carrier densities in the wetting layers and occupation probabilities of the quantum dots in the gain absorber sections [3,4]. The external modulation of the absorber section is introduced through the dependence of carrier relaxation rate in the wetting layer on the reverse bias voltage. We investigate the dependence of the locking range to external RF signal on the parameters of the model equations and study numerically bifurcations responsible for de-synchronization outside the locking range. Based on our numerical analysis we propose some recommendations to improve hybrid mode-locking efficiency of a quantum dot laser. In particular, we show that inclusion of an additional spectral filtering section into the laser cavity can lead to enlargement of the locking range.

References

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