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Ultrafast dynamics of semiconductor disk lasers

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Passively modelocked optically pumped semiconductor disk lasers (SDLs) [1] based on InGaAs quantum wells (QWs) such as vertical external-cavity surface-emitting lasers (VECSELs) or modelocked integrated surface-emitting lasers (MIXSELs) are an appealing ultrafast laser technology for applications that require compelling combinations of short femtosecond pulses and gigahertz pulse repetition rates. Recent development of pulse shortening strategies resulted in record-short 107-fs pulses from a VECSEL [2] and 253-fs pulses from a MIXSEL [3]. However, this progress in shorter pulse durations has come with the trade-off of significantly lower optical-to-optical pump efficiency even below 1% and only moderate average output power of around 100 mW so far.

Here, we develop a rate equation model to investigate the carrier dynamics in the SDL gain and absorber QWs with the aim to better understand the underlying physical reasons for this trade-off. In contrast to *ab initio* approaches [4], our goal is to simplify the model and still obtain full agreement with our experimental results.

In particular, we measured the fluence-dependent reflectivity of a pumped VECSEL with different probe pulse durations and remark that small signal gain is not significantly affected by the pulse duration, while short pulses are decreasing the macroscopic gain saturation fluence (Fig 1(a)). An energetic pulse generates a spectral hole in the QW population: for pulse durations shorter or comparable to the intraband relaxation time, the created hole cannot be refilled during the interaction of the pulse with the QW. This causes an anticipated gain saturation that is fully reproduced by our model (Fig 1(a)).

Fig. 1. (a) Measured and simulated gain saturation curves of an optically pumped VECSEL probed at different pulse durations. (b) Measured and simulated saturation curve for a MIXSEL that generates 184-fs pulses. The maximum reflectivity is reached at the fluence F_0 in good agreement to the actual modelocking fluence. (c) Pump-probe measurement of a gain QW. Intraband relaxation with fast recovery of 300-400 fs (close-up in the inset) is followed by a slow relaxation with a 140-ps time constant, corresponding to the carrier lifetime.

In addition, we observe that in a modelocked cavity the combined effects of gain and absorber saturation define an optimum pulse fluence F_0 , where the effective pulse amplification is maximized. A reduced gain saturation is translated in a decreased F_0 and limits the maximum achievable pulse energy. We measured the reflectivity saturation curve of a MIXSEL that generated record-short pulses of 184 fs and extracted an F_0 comparable to the fluence observed in actual modelocking experiments (Fig. 1(b)). This result is fully reproduced by the rate equation model such that we can obtain reliable predictions of the modelocked power outputs with the model parameters obtained through a fit to the experimental saturation curve.

Furthermore, we measured a carrier lifetime of only 140 ps for our gain QWs (Fig. 1(c)), meaning that most of the electron-hole pairs optically created through continuous wave pumping spontaneously recombine before having been used for pulse amplification, decreasing the overall pump efficiency. With our model, we can explore the efficiency dependence on the pulse duration, pulse repetition rate and the influence of the saturable absorber.

We conclude that fundamental quantum well (QW) properties are limiting the power performance of our ultrafast SDLs: spectral hole burning is preventing full amplification of energetic short pulses, while the low efficiency is a consequence of the short carrier lifetime in the conduction band.

References

- [1] U. Keller, *et al.*, "Passively modelocked surface-emitting semiconductor lasers," *Phys. Rep.* **429**, 67-120 (2006).
- [2] D. Waldburger, *et al.*, "High-power 100 fs semiconductor disk lasers," *Optica* **3**, 844-852 (2016).
- [3] M. Mangold, *et al.*, "Sub-300-femtosecond operation from a MIXSEL," *Opt. Express* **23**(2015).
- [4] J. Hader, *et al.*, "Ultrafast non-equilibrium carrier dynamics in semiconductor laser mode-locking," *Semicond. Sci. Technol.* **32** (2017) 013002 (24pp).