Designing the active region of mode-locked interband cascade lasers

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Interband cascade lasers (ICLs) have already been proven as a promising mid-infrared (MIR) source desirable for many applications in medical diagnostics, trace-gas analysis, pollution monitoring and molecular spectroscopy. Their application potential originates mostly from unique operational characteristics as, e.g., single mode, continuous-wave and high power operation at elevated temperatures in the range from below 3 to about 6 μm [1,2], broad spectral tunability [3,4], and low threshold currents and hence small electrical power consumption [5] when compared to the main competitor which are quantum cascade lasers.
A device that has not yet been realized is a mode-locked interband cascade laser. Such a source is of great interest for dual-comb spectroscopy, where two mode combs with a slightly different spacing are used to sample a wide spectral range [6]. While this is in principle possible with two Fabry-Perot lasers, the stable phase relation between the modes in a mode-locked device offers significant advantages for the practical implementation of dual comb spectroscopy. Passive mode-locking can be achieved by the insertion of a saturable absorber into the laser resonator. In semiconductor lasers, the saturable absorber can be realized by the application of reverse bias, which in case of ICL requires very careful band structure engineering since alignment of the levels in the minibands used to carrier transport depends on the polarity and the magnitude of the internal electric field. In addition to possible applications in mode-locked lasers, engineering of the active regions towards smaller oscillator strength is also beneficial for Q- or gain switched lasers.
In this work, we present results of theoretical modelling in the framework of eight-band k·p theory of the ICLs‘ band structure under external electric field performed in order to investigate the effect of the bias value and direcion, i.e. from normal lasing conditions as in the gain section to the reversed bias of the absorber part. We present several solutions of the respectively modified type-II QWs of InAs/(In,Ga)(As,Sb)/AlSb materials’ system which allow obtaining the demanded lifetime (oscillator strength) ratio in the two parts of the mode-locked laser.

[1] J. Scheuermann, R. Weih, M. von Edlinger, L. Nähle, M. Fischer, J. Koeth, M. Kamp, S. Höfling, Appl. Phys. Lett. 106, 161103 (2015).
[2] M. Dallner, J. Scheuermann, L. Nähle, M. Fischer, J. Koeth, Sven Höfling, M. Kamp, Appl. Phys. Lett. 107, 181105 (2015).
[3] Y. Jiang, L. Li, Z. Tian, H. Ye, L. Zhao, R. Q. Yang, T. D. Mishima, M. B. Santos, M. B. Johnson, and K. Mansour, J. Appl. Phys. 115, 113101 (2014).
[4] M. von Edlinger, J. Scheuermann, R. Weih, L. Nähle, M. Fischer, S. Höfling, J. Koeth, M. Kamp, Proc. SPIE 9370, 9370A (2015).
[5] I. Vurgaftman, W. W. Bewley, C. L. Canedy, C. S. Kim, M. Kim, C. D. Merritt, J. Abell, J. R. Lindle, and J. R. Meyer, Nat. Commun. 2, 585 (2011).
[6] G. Villares, A. Hugi, S. Blaser and J. Faist, “Dual-comb spectroscopy based on quantum-cascade-laser frequency combs”, Nature Communications 5, 5192 (2014).

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