Material Engineering for Monolithic Semiconductor Mode-Locked Lasers

This thesis is devoted to the materials engineering for semiconductor monolithic passively mode-locked lasers (MLLs) as a compact energy-efficient source of ultrashort optical pulses. Up to the present day, the achievement of low-noise sub-picosecond pulse generation has remained a challenge. This work has considered the role of the combined ultrafast gain and absorption dynamics in MLLs as a main factor limiting laser performance. An independent optimization of MLL amplifier and saturable absorber active materials was performed. Two promising approaches were considered: quantum dot (QD) or single quantum well (QW) amplifier in tandem with a fast multi-QW electroabsorption modulator (EAM) based on the InP/AlGaInAs/InGaAsP platform for operation in the 1.55 μm telecommunications range.

A butt-joint MOVPE regrowth technique was established for monolithic integration showing high crystalline quality and low internal reflection compatible with the severe requirements of monolithic MLLs. Experimental characterization of static material parameters of the fabricated devices revealed QW-like gain behavior of a self-assembled InAs/InP QD material and low internal efficiency which limited its application in MLLs. Improved QW laser performance was demonstrated using the asymmetric barrier layer approach. The analysis of the gain characteristics showed that the high population inversion beneficial for noise reduction cannot be achieved for 10 GHz QW MLLs and would have required lowering the modal gain or utilizing an extended cavity design. The offset QW design was introduced. The performance of 10 GHz passively MLLs consisting of integrated QW gain section with MQW EAM was demonstrated to allow for 890 fs pulse generation with reduced timing jitter compared to non-integrated QW MLLs owing to the fast EAM recovery.

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