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cw and transient characteristics of polarization switching in vertical-cavity surface-emitting lasers

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cw and transient features of polarization switching in VCSELs are investigated experimentally close to the threshold minimum in dependence of temperature and current in order to clarify the interplay of linear anisotropies and nonlinear dispersion.

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Vertical-cavity surface-emitting lasers (VCSELs) are known to be very sensitive to polarization instabilities, i.e. the linear polarization state appearing at threshold is not stable but gives way to the orthogonal one as the current is increased [1,2]. Many aspects of this switching behaviour can be understood by considering linear, but temperature dependent gain or loss anisotropies for the two polarization modes which are frequency split by birefringence [1]. Other aspects require the inclusion of nonlinear dispersion [2]. The interplay between the different effects is still not fully clarified. Furthermore, it was noted that the primary polarization can be recovered after a second polarization switching [1], an intriguing fact which is however poorly investigated.

We performed systematic studies on the polarization properties of small-area commercial VCSELs (8 μm diam., $\lambda \approx 840$ nm) in a temperature interval of about 50 K around the minimum threshold condition. At threshold (between 5.1 and 5.5 mA) single-mode linearly polarized emission on the high-frequency polarization mode is typically found. If the current is increased, switching to the orthogonally polarized low-frequency mode takes place. (In a certain parameter range the low-frequency mode is reached via a more complicated scenario starting with two-frequency emission on both modes at threshold followed by a decay to a single-polarization state and possibly polarization switching.) Increasing the current further, the VCSEL switches back to the high-frequency polarization mode. For increasing temperature this switching point lowers from about 12 mA to 8 mA. For high temperature this second switch takes place in a pure fundamental mode situation, whereas for low temperatures also transverse modes (Hermite-Gaussian TEM_{10} and TEM_{01}) are excited which appear supercritically at a current of around 9.5 mA. In the latter situation a close look shows that there actually two switches which take place some μs's apart, if the current is ramped slowly (ramping frequency 10 Hz). This would correspond to a difference in current of less than 1 μA, which we cannot resolve cw at present. Time resolved observation with a gatable CCD-camera indicate that the different modes switch independently. This underlines the necessity of a sufficient time resolution even in quasi-adiabatic ramping experiments.

The transient behaviour of the polarization switching is investigated by measuring the emitted light with a fast photodetector while the current is slowly ramped. The second polarization switching takes place within a few nanoseconds (less then 7 ns, 20% to 80% level) with a width of the distribution of the switching times being about 30% of the mean. Due to the lower light level at the first switching the switching time could only be determined to be smaller than 40 ns. The short time scale observed hints to the fact that the switching procedure is mainly determined by dynamics and not by thermal effects. Furthermore we find indication for hysteresis of up to 0.2 mA providing a further hint to the relevance of nonlinear dynamical effects connected to saturable dispersion.

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