Nonlinear Dynamics of Semiconductor VCSELs Subjected Orthogonal Polarization Feedbac

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Semiconductor vertical-cavity surface-emitting lasers (VCSELs), leveraging their ultra-low threshold, single-mode operation, and cost efficiency, offer unparalleled control over polarization dynamics enabled by cylindrical symmetry. Their near-degenerate polarization modes – aligned along [110] and [1-10] crystallographic axes – are perturbed by residual strain and voltage-induced anisotropies (elasto- and electro-optic effects), manifesting as cavity dichroism and birefringence. Coupled through shared spatial and carrier dynamics, these modes yield polarization switching, bistability, and oscillations. Crucially, even isotropic optical feedback destabilizes these states, unlocking intricate dynamics for advanced photonics.

In this work, we demonstrate how orthogonal-polarization reinjection via an external ring cavity with a tunable half-wave plate ($\lambda/2$-plate) governs VCSEL dynamics. By rotating the plate angle θ, we achieve deterministic control over ultrafast square-wave oscillations (TE-dominant regime) and pulse multiplicity (TE+TM lasing). Detailed analysis reveals the interplay between reinjection strength and polarization-mode competition as the governing mechanism. This approach establishes orthogonal feedback as a compact, reconfigurable tool for engineering nonlinear dynamics, with direct applications in polarization-multiplexed communications, dual-comb spectroscopy, and high-repetition-rate optical systems.

References

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