Suppression of modulation instability in broad-area semiconductor lasers by injection of external optical radiation

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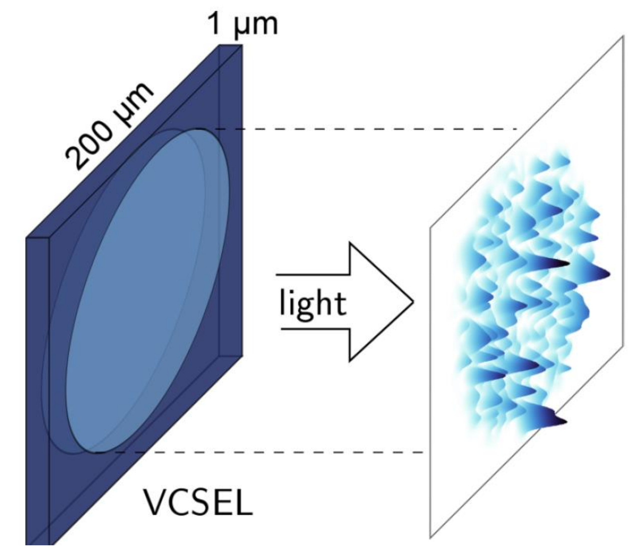
Abstract

This paper investigates the dynamics of a semiconductor laser with a vertical cavity. It is taken into account that for such devices it can be assumed that the polarization infinitely quickly follows the change in the field and it can be adiabatically excluded. An important difference between these devices is the presence of the alpha factor, while it is practically zero for other lasers, therefore, it is necessary to take into account the effect of this parameter on the dynamics of the system. It was found that the system exhibits modulation instability, which is effectively suppressed by optical injection.

Mathematical model



To describe the dynamics of vertical cavity lasers (VECSELs and VCSELs), we use the system of equations:

$$\begin{cases} \dfrac{\partial E}{\partial t} = -[1 + i\theta + 2C(i\alpha - 1)(N-1)]E + i\Delta_{\perp}E + E_{inj}, \\ \dfrac{\partial N}{\partial t} = -\gamma\left[N - I_p + |E|^2(N-1)\right] + \gamma d\Delta_{\perp}N, \end{cases}$$

Here, E the mean-field dynamics of the complex field amplitude, N carrier density, where θ is the cavity detuning parameter, α is the linewidth enhancement factor of the semiconductor, and γ = τp/τN is the carrier decay rate, normalized to the photon relaxation rate. The time, t, is normalized to the photon lifetime, τp = 2Lc/vTc, which depends on the transmissivity factor, Tc, velocity of light, v, and cavity length, Lc. The transverse spatial coordinates (x,y) are normalized to √λ0Lc/2πTc, where λ0 is the central wavelength of the emission. The parameter C represents the interaction between carriers and field, and depends on the laser differential gain and the photon relaxation rate. The pump current, Ip, generates the carriers within the active region, which diffuse in the transverse direction according to the diffusion factor d. External injection is characterized by E_{inj} denotes the injection strength.

Numerical results

The numerical simulation of the system of equations taking into account the injected radiation was carried out by the ADI – alternate directions implicit method using the tridiagonal matrix algorithm. The dynamics is simulated with parameters $\theta = -1.5, a = 1.5, C = 0.6, I_p = 1.9, d = 0.052, \gamma = 1$

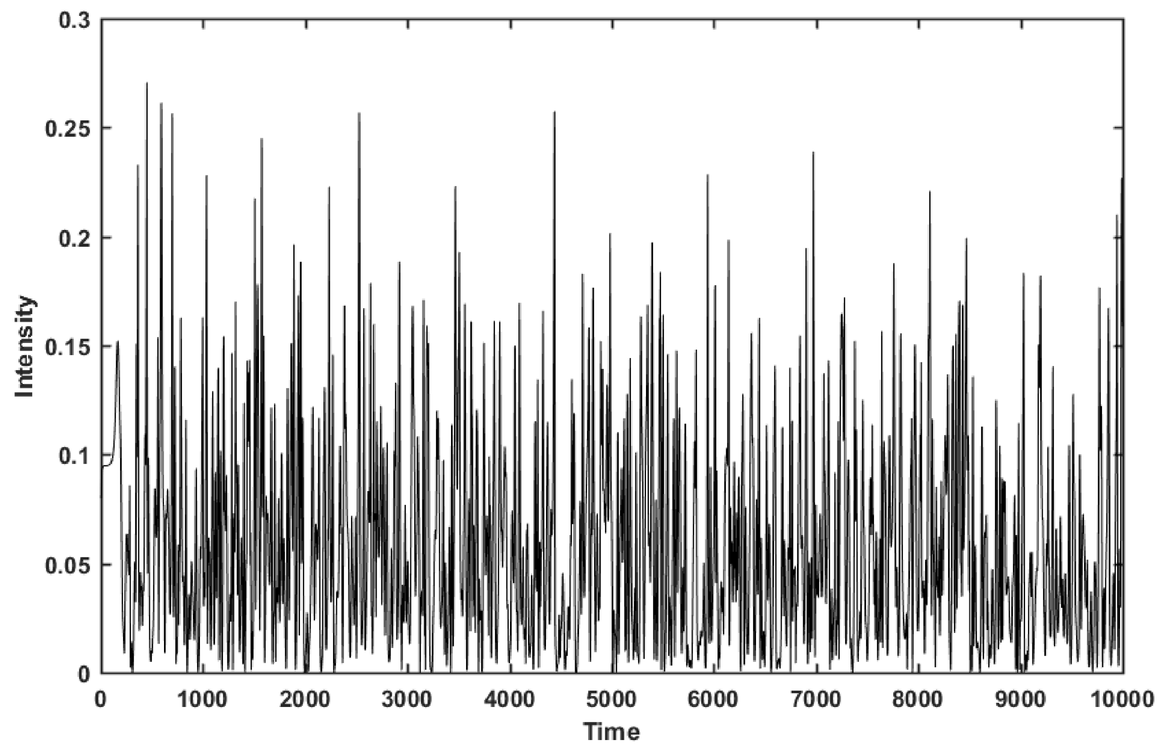


Figure 1. Temporary dependence of intensity

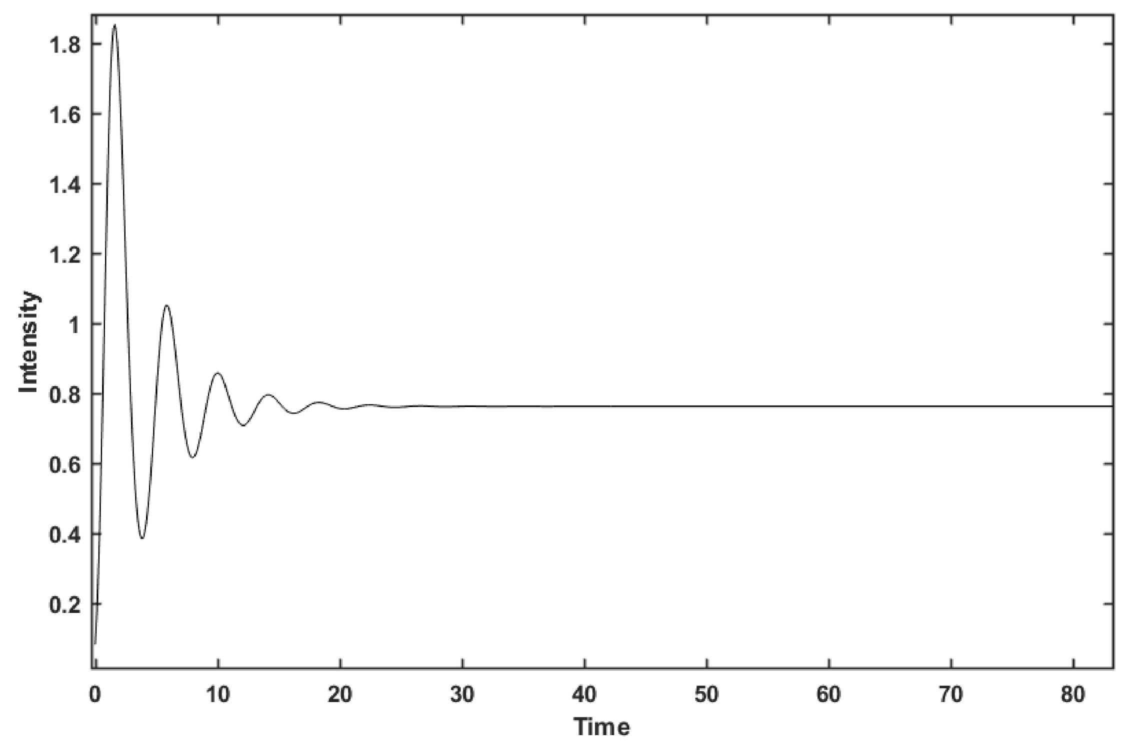


Figure 2. Temporary dependence of intensity with $E_{inj} = 0.1$

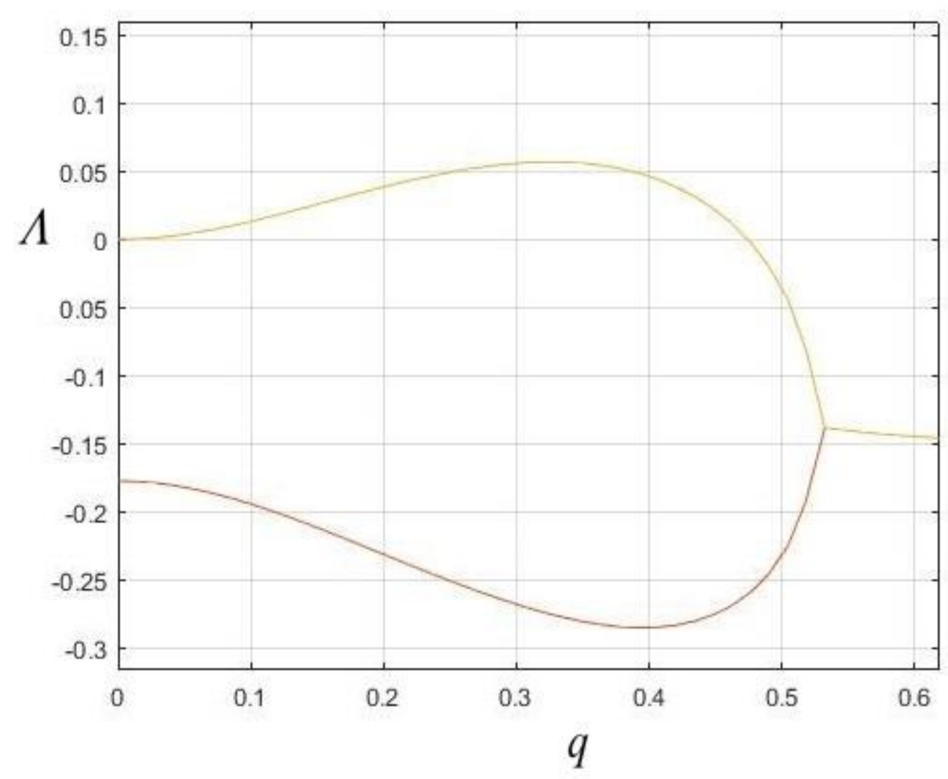
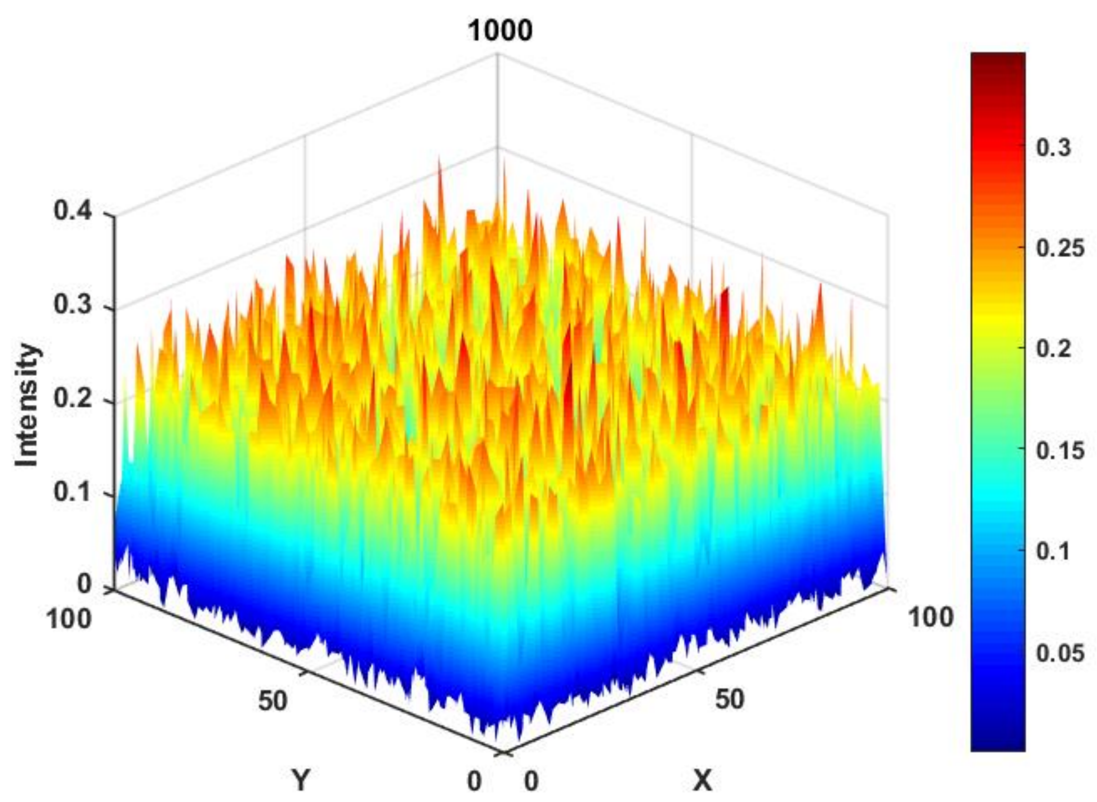


Figure 3. The curves indicate the main Lyapunov exponents of the linearized system in dependence on the lateral perturbation wave number



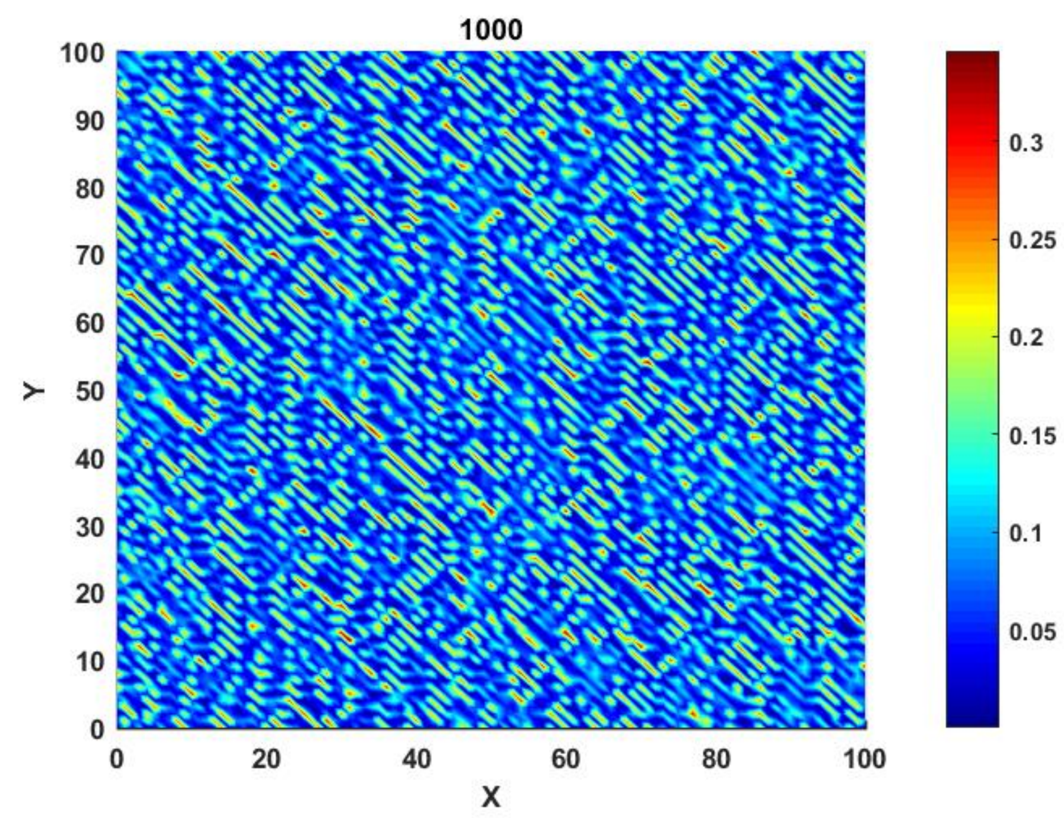


Figure 3. Laser output dynamics: transverse intensity profile.

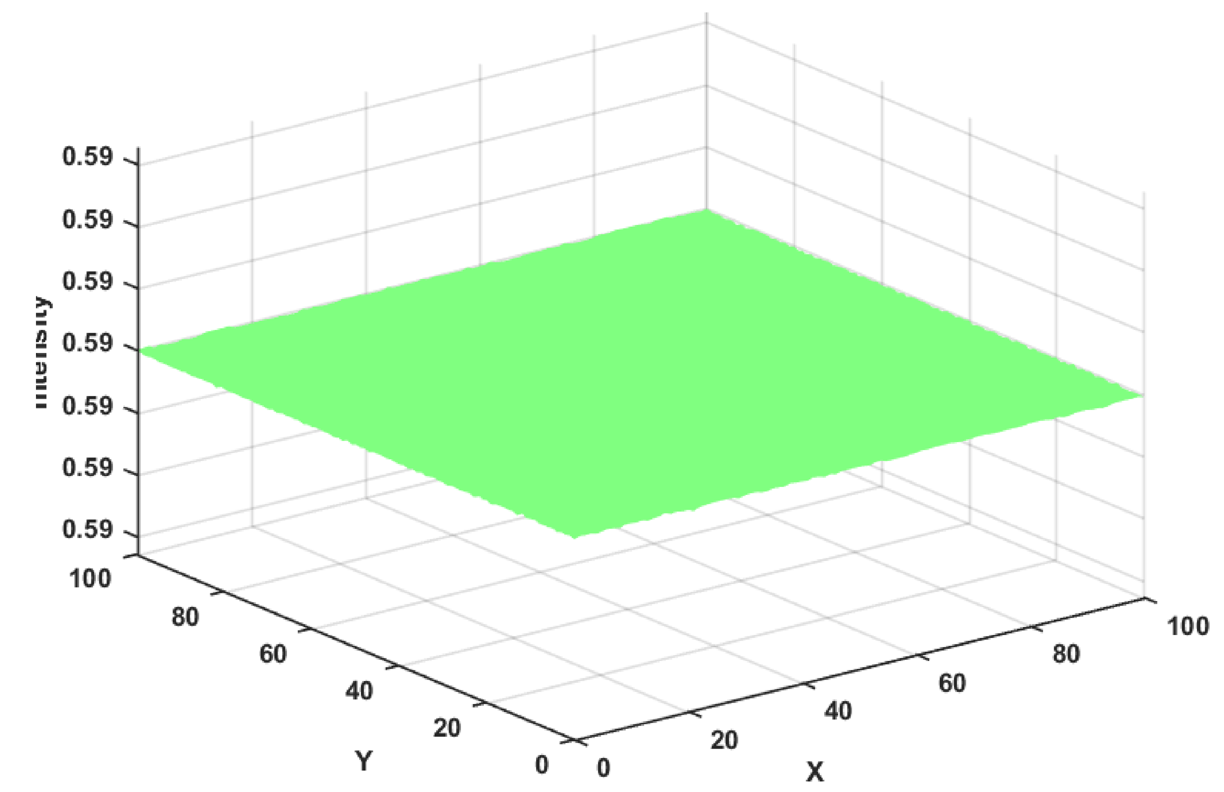


Figure 4. Laser output dynamics: transverse intensity profile with $E_{inj} = 0.1$

Conclusion

Vertical cavity semiconductor lasers are key sources of coherent light, their main advantage being compact size, high light conversion efficiency and low lasing threshold. But VCSELs are usually prone to dynamic space-time instabilities, which are chaotic fluctuations and result in poor spatial beam quality even in the absence of any external disturbance. This is primarily due to the modulation instability arising from strong nonlinear effects inside the cavity. In the presented work, we study the space-time dynamics of a vertically emitting laser with and injection of external optical radiation. It is shown that injection effectively suppresses modulation instability.

References

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