Investigation of the influence of alpha factor on the dynamics of wide-aperture semiconductor lasers

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ФИАН САМАРА

Introduction

In this paper, a model describing a wide-aperture laser with a vertical resonator (VCSEL) is analyzed. For such devices, it can be assumed that polarization follows the field change infinitely quickly and it is possible to exclude it adiabatically. The model includes the basic physical processes, as well as diffusion and the Henry factor, which determines various undesirable properties of the laser and is characteristic of semiconductors.

Mathematical model

To describe the dynamics of vertical cavity lasers, we use the system of equations:

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

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 is the carrier decay rate, normalized to the photon relaxation rate. 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, I, 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.

Homogeneous steady-state and linear stability analysis

The homogeneous solution $(E_{0,}N_0)$ of equations is readily obtained by setting equal to zero the time derivatives and neglecting the Laplacian operator. What one obtains is

$$|E_{inj}|^2 = |E_0|^2\left[\left(\theta + 2C\alpha(N_0 - 1)\right)^2 + \left(1 - 2C(N_0 - 1)\right)^2\right], \quad N_0 = \frac{I + |E_0|^2}{|E_0|^2 + 1} \quad (2)$$

System parameters

$\theta = -1.5, C = 0.45, I_0 = 4, d = 0.052, \gamma = 10, \alpha = -5$

The linear stability of a homogeneous solution is analyzed by studying the response of the system to small perturbations in the vicinity of stationary values. Let's assume that

$$\begin{cases} E = E_0 + \delta E_0 \exp(\lambda t + i(q_x x + q_y y)), \\ E^* = E_0^* + \delta E_0^* \exp(\lambda t + i(q_x x + q_y y)), \\ N = N_0 + \delta N_0 \exp(\lambda t + i(q_x x + q_y y)), \end{cases}$$

Substituting expressions into system , we obtain the following characteristic equation: $\lambda^3 + a_1\lambda^2 + a_2\lambda + a_3 = 0,$

The homogeneous steady state will be unstable against spatially modulated perturbations if at least one solution of equation has a positive real part for a nonvanishing value of q. In particular, the boundary for a instability in the plane $(E_0$, q) (see figure 1) is characterized by a_3=0 According to the Routh–Hurwitz criterion, the unstable domain corresponds to the parameter subspace where a_3<0

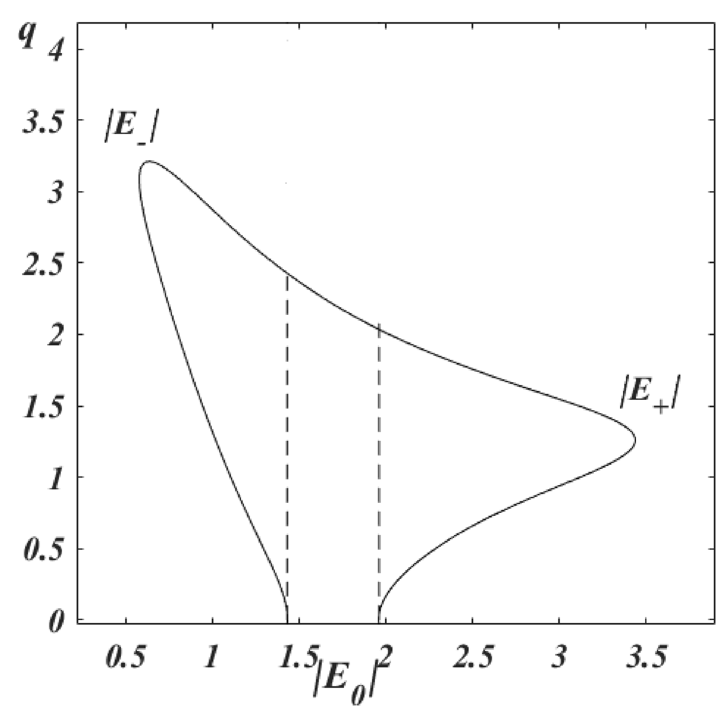

Figure 1. The instability domain

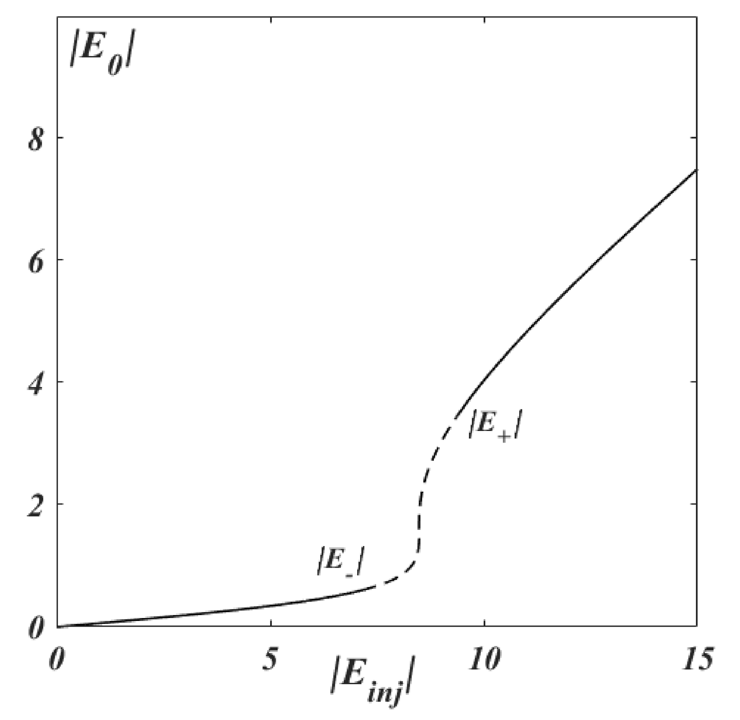

Figure 2. Example of S-shaped steady-state curve

The intersection of the instability domain with the axis q = 0, if present, corresponds to those values E_0, which the homogeneous stationary solution is unstable against a plane-wave perturbation.
This area of instability is limited in Figure 1 by dotted lines. The area beyond these limits is defined by two limit values$|E_{\pm}|$, which determines the unstable area S- curve in Figure 2.

Accordingly, the unstable region is shown in Figure 2 by a dotted curve, and the stable-solid.
You can confirm these results by taking a solution that satisfies the implicit expression (2) and obtain dispersion curves (Figure 3 and 4).

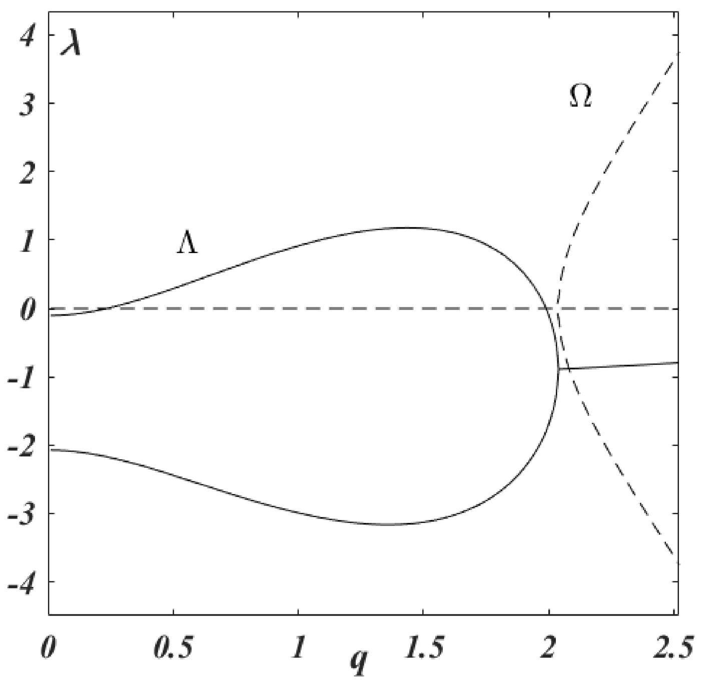

Figure 3. Real Λ and imaginary parts Ω of the roots of the characteristic equation for $|E_0|$=2.04 , corresponding to instabilities

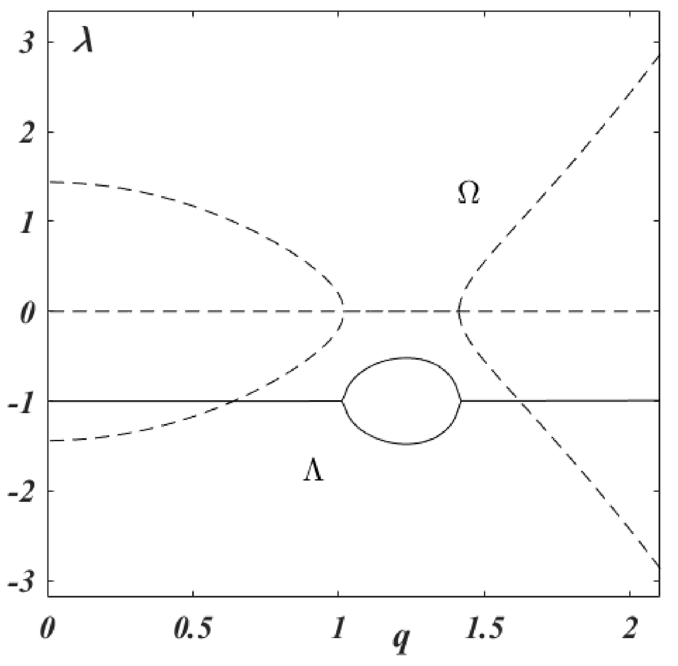

Figure 4. All $\Lambda < 0$ for $|E_0|$=5.16 , corresponding to stability.

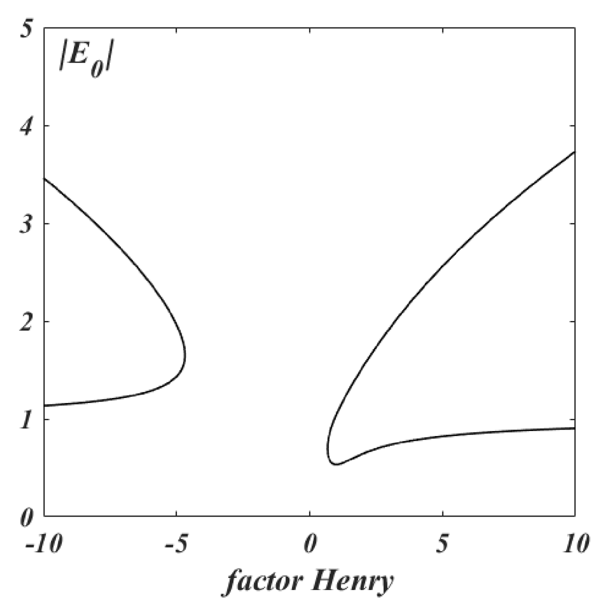

Figure 5. Area of unstable values$|E_0|$, when varying the alpha parameter

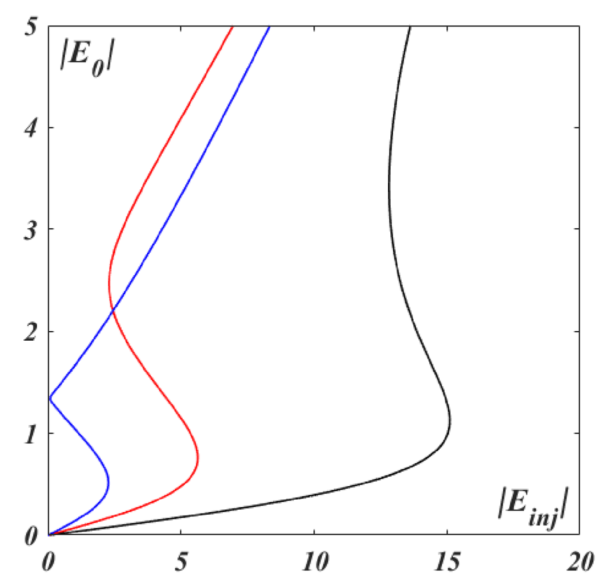

Figure 6. S- curve for $\alpha = -10$ black line, $\alpha = 5$ - red line, $\alpha = 1.5$ –blue line

Previously, it was found that the dynamics of wide-aperture semiconductor lasers is subject to instabilities that form spatial structures [1]. This instability tends to manifest itself under conditions where the input-output curve of a homogeneous stationary solution has an S-shape [2]. This is possible by adding external optical injection to the system. In addition, for semiconductor lasers, it is necessary to take into account the presence of the linewidth increase factor α (also called the Henry factor or alpha factor), which determines the dependence of the refractive index on the carrier density in the semiconductor [4]. Therefore, it is of interest to investigate how the alpha factor affects the s-curve.

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