On the dynamics of multimode semiconductor lasers

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***Abstract* — We report numerical results on influence of asymmetric gain saturation coefficient and temperature on the dynamics of InGaAsP Fabry-Perot lasers. Based on the rate equation model multimode case is examined. In the bifurcation analysis the regions with instabilities in the evolution of the mode intensities have been found. Finally, we show that the variation of temperature strongly influences the regions of instabilities.**

***Index Terms* — InGaAsP Fabry-Perot lasers, mode hopping, bifurcation analysis**

I. INTRODUCTION

Semiconductor lasers are a key element for wider applications in different fields as optical communications networks, optical compact disc players, laser printers, ultrafast data processing systems, etc. It is well known that the operation of semiconductor lasers is affected by the phenomena of mode competition [1-3]. These phenomena are more pronounced in the systems with optical feedback when re-injected light induces the optical feedback noise [4]. The single mode operation has been achieved in AlGaAs/GaAs Fabry Perot lasers. Theoretical background for such operation was explained by strong gain suppression effect. A mechanism for multi–mode operation due to the asymmetric gain suppression was introduced in [5,6]. In the present paper, we consider the impact of the asymmetric gain saturation coefficient and temperature on the dynamics of InGaAsP Fabry-Perot lasers. The paper is organized as follows. The device structure and mathematical model are described in Section II. Section III presents a study of the dynamics of a laser under the influence of different parameters. Conclusions are given in Section IV.

II. LASER MODEL AND EQUATIONS

A sketch of the proposed InGaAsP laser is depicted in Figure 1. The front and back facet reflectivities are 20% and 70%, respectively. The length of the active region is 300 μm.

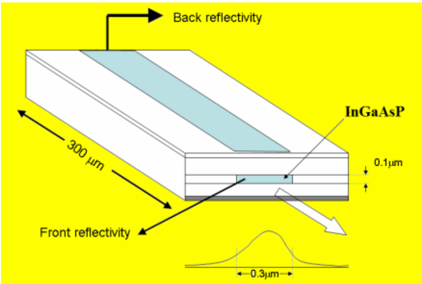

Figure 1. Schematic illustration of InGaAsP semiconductor laser

The theoretical model used in this paper originates from [1,5,6]. The rate equation for photon number S and injected electron density N are represented as follows

$$\frac{dS_p}{dt} = (A_p - BS_p - \sum_q D_{p(q)}S_q - G_{th})S_p + \frac{a\xi}{V}N,$$

$$\frac{dN}{dt} = -\sum_q A_p S_p - \frac{N}{\tau_s} + \frac{I}{e},$$

where p is the mode number. The mode $p=0$ is considered to lie at the center. A_p is linear gain coefficient $A_p = \frac{a\xi}{V}\left[(N - N_g) - b(\lambda_p - \lambda_0)^2\right]$, B is the self-saturation coefficient $B = B_c(N - N_g)$. $D_{p(q)} = \frac{4}{3}B + \frac{H_c(N - N_g)}{\lambda_q - \lambda_p}$ is asymmetric cross – saturation gain coefficient with H_c the main bifurcating parameter considered in this paper. V is the volume of active region. I is the injected current. λ_0 is the wavelength at the gain peak. n_r is the refractive index. The other notations are as in [5]. Finally, we mention that in the simulation we considered 21 modes.

III. RESULTS AND DISCUSSION

Figure 2 shows the classification of the possible states of the laser operations in the plane of two parameters H_c and I. These characteristics show that for small H_c the single mode dominates the operation of the laser. If the coefficient H_c is increased the bistable phenomena is present. When H_c is increased the laser shows multimode hoping.

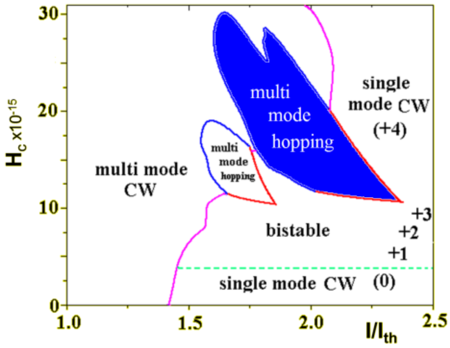

Figure 2. Classifications of the possible states of laser operation in the plane of two parameters $(H_c$-$I)$.

Typical examples of pulse traces of the photon number of different modes and different injected currents are shown in Figure 3. For an injected current of 1.1 I_{th} the multimode CW operation can be observed with mode +1 to be dominant (see Fig 3 a). An increase of current to 1.4 I_{th} leads to the hoping phenomenon. As a result the mode +4 becomes dominant (see Fig. 3 b). In Fig. 3 c) the transient exchange between mode +2 and mode +3 takes place with a hoping time of order of 0.5 ns. Figure 3 d) shows the oscillations of different modes for a high injected current.

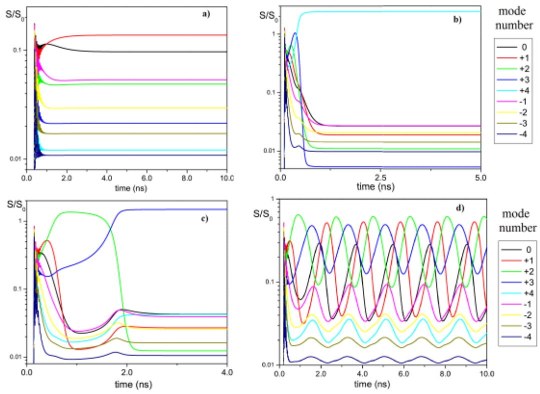

Figure 3. Pulse traces of the photon number of different modes for different injected current a) I=1.1 I_{th}, b) I=1.4 I_{th}, c) I =1.6 I_{th}, d) I =2.1 I_{th}.

The Figure 3 c) shows an example of the mode hoping phenomenon that can occur in the laser when coefficient *Hc* is large. The origin of this phenomenon can be understood from Figure 4. This figure plots the variation of the photon number for different modes when the injected current is increased. For lower injected current the mode *p=0* is dominant (black line). An increase of current leads to the suppression of asymmetric gain of mode *p=0* and the mode +1 become dominant (red line). With increasing the injected current the other modes +2, +3 and +4 switch to be dominant. Finally, at the end the lasing mode hops back to the *p=0* mode.

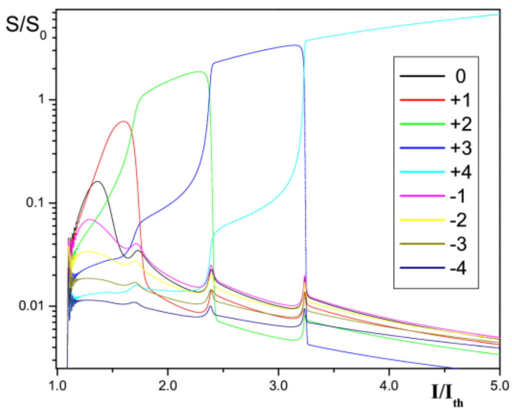

Figure 4. Variation of the photon number of different modes with increase of the injected current *I*.

Now we consider the influence of temperature on the laser dynamics. Figure 5 shows that an increase of temperature by 1^0C increases strongly the region of multi-mode hoping.

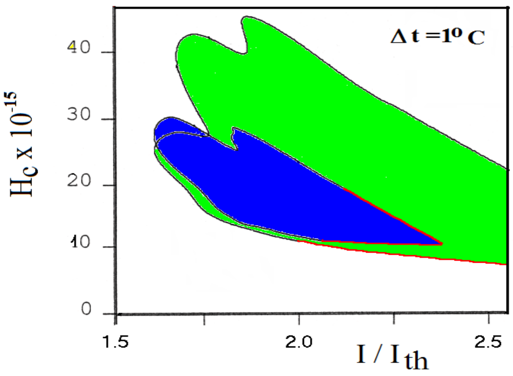

Figure 5. The influence of temperature on multi-mode hopping phenomena in InGaAsP semiconductor lasers. The temperature difference between two regions is $\Delta t = 1^0 C$.

IV. CONCLUSION

We have studied the dynamics of multimode FP semiconductor lasers. The dynamics of FP lasers strongly depend on the asymmetric cross saturation gain coefficient and temperature. In the bifurcation analysis the laser operations are classified into stable single mode, stable multimode, hopping multimode and bistable. Finally, we have shown that the InGaAsP lasers exhibit stable single mode under high currents. We believe that our work provides a good basis for future studies and, in particular, provides some pointers for more detailed investigations of mode hoping phenomena and its avoidance in different systems.

ACKNOWLEDGMENTS

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