Locking Range Dependence on the Grating Characteristics of Distributed Feedback Semiconductor Lasers

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Introduction

Numerous applications of injection-locked semiconductor lasers have been proposed throughout the last 20 years. Applications for broadband fiber-radio access systems in the 25-70 GHz band particularly motivate the present study to fully understand how this optical technique solve the problem of generation, transport, and control of microwave signals. A picocellular system will require low-cost multifunctional elements and it has been proven that locked lasers work as optical narrow-band filters, as amplifiers, as phase modulators, and as key elements for low-phase noise millimeter-wave generation. It is interesting consequently, to fully assess the behavior of injection-locked semiconductor lasers.

One of the most important and practical quantities describing the injection process in a master/slave laser configuration is the locking range as a function of the injection rate. It is then, the purpose of this paper to describe how the locking range of a slave laser depends on its structural composition and how certain gratings favor different applications. To do so, a new method that allows taking into account spatial hole burning has been developed using the coupled-mode theory of DFB lasers.

Frequency and Gain Variations

Favre approach for describing external optical feedback in DFB lasers is adapted here for describing optical injection. In his analysis, the mirror external reflectivity is taken into account for calculating the equivalent facet reflectivity. In our case, the equivalent reflectivity is recalculated to include optical injection:

$$\hat{\rho}_{eq}(z,t) = \hat{\rho} + (1 - \hat{\rho}) \sqrt{\frac{P(z,t)}{P(z)} e^{-j\Omega t}}$$

$P_c/P$ is the local power density ratio between the injected and cavity fields, $\theta = \phi - \phi_i$ is the phase difference between these fields and $\hat{\rho}$ is the amplitude reflectivity of the laser facet. The frequency and gain variations are calculated following Favre’s method and are expressed as:

$$\Delta \omega = (1 + \alpha_p^2 \frac{c}{n_l L} |C|)^2 \frac{P}{P_c} \sin(\theta - \arg C - \tan^{-1} \alpha_p)$$

$$\Delta G = 2 \frac{c}{n_l L} |C| \frac{P}{P_c} \cos(\theta - \arg C)$$

where $\alpha_p$ is the Henry linewidth enhancement factor, $c$ is the speed of light, $n_l$ is the group refractive index, and $C$ is a complex coefficient that only depends on laser intrinsic characteristics; e.g. the grating position with respect to the facet, the coupling strength, the reflectivity, the threshold gain, or phase deviation. For a given injection rate, knowledge of this coefficient is necessary for determining the frequency and gain variations. This coefficient, in general, can be expressed analytically and derived from the eigenvalue equation associated to the coupled-mode equations. In homogeneous Fabry-Perot lasers (fig. 1), it is simply a constant depending on the amplitude reflectivity, whereas in DFB lasers, the coefficient strongly depends on its grating structure. This fact is of great importance for a stable locking range (fig. 2): lasers having a weak coupling ($kz \leq 1$) exhibit an enhanced locking bandwidth and are performant in applications such as amplifiers and optical-phase modulators where given.
frequency detunings must not cause unlocking of the slave laser. For strong coupling ($\kappa L \geq 4$), the bandwidth is largely reduced making this lasers attractive for applications requiring narrow-band filters like dense multi-channel systems.

A stability analysis completed by large-signal dynamical simulations was made for several DFB structures including complex-coupled gratings. Upper limits in the stable locking range as injection rates become larger will be extensively discussed. As opposed to Fabry-Perot lasers, it was confirmed that optical synchronization could be maintained even when the phase relation between the injected and cavity field is such that the mode threshold gain is higher than that of the free-running laser. This is due to the strong mode selection that occurs in DFB lasers and consequently, a symmetrical locking bandwidth is observed. In addition, experimental results testing several applications of injection-locked lasers were carried out and good agreement was found with the proposed model.

**Conclusion**

The synchronization process of DFB lasers has been described taking into account the coupled-wave equations and the spatial hole burning effect that results. The locking bandwidth was deduced in function of the grating parameters so as to highlight its importance in relevant applications. The method advantage is not only limited to the detailed description of injection locking in simple DFB lasers but relies on the possibility of studying different laser structures like those having complex coupling factors or those having different sections. Much of the research motivation is founded on the need to provide reliable and tunable microwave photonic sources that will allow high frequency feeding of antenna arrays.