Thermal Crosstalk Investigation in an Integrated InP Multiwavelength Laser

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We numerically investigate the thermal crosstalk effects in an integrated InP multiwavelength laser. The multiwavelength laser under investigation consists of a number of Distributed Bragg Reflector lasers and an Arrayed Waveguide Grating. Each laser generates a fixed wavelength and the Arrayed Waveguide Grating collects the emitted wavelengths leading all of them in a common output waveguide. Temperature distribution and heat flow are obtained through thermal simulations. Our model predicts the thermal crosstalk between lasers in relation to: injected current, distance between lasers and number of lasers. The aim of this paper is to define guidelines to design low thermal crosstalk multiwavelength lasers.

Introduction

The capacity of fiber optic communication systems can exceed 10 Tb/s but dispersive and nonlinear effects represent important limitations. Wavelength division multiplexing (WDM) permits to extend the optical systems capacity because multiple optical carriers at different wavelengths are modulated independently and transmitted over the same fiber. The ultimate capacity of WDM fiber links depends on how closely channels can be packed in the wavelength domain. The minimum channel spacing is limited by interchannel crosstalk. High capacity WDM fiber links require many high performance components. In particular, multiwavelength transmitters (able to generate precise and stable wavelengths) play a crucial role in the modern optical communication systems because they allow the reduction of the signals distance in the wavelength domain. A realistic approach to increase the number of channels in a multiwavelength transmitter is the reduction of the distance between the lasers in the same optical chip. By reducing the distance between lasers, it is possible to increase the density and the complexity of a chip but the drawback to face is the increase of the interaction between components, which causes crosstalk.

Design and numerical model

Fig.1 shows the basic configuration of an integrated InP multiwavelength transmitter. Each laser is a DBR laser. In a DBR the SOA acts as a broadband optical source; the Front Grating (FG) ensures a low reflectivity; the Long Grating (LG) is a uniform grating that can be tailored to reflect a specific wavelength (λ_i). λ_i is related to Λ (LG period) and to the effective index of the grating (n_{eff}). In accordance with the Bragg's law, the *i*-DBR laser generates a specific wavelength $\lambda_i = 2\Lambda n_{eff}$ (1). To evaluate the wavelength shift ($\Delta\lambda_i$) due to temperature variations (ΔT_i), we consider: $\Delta\lambda_i = \gamma\Delta T_i$ (2), where γ is the thermo-optic coefficient.

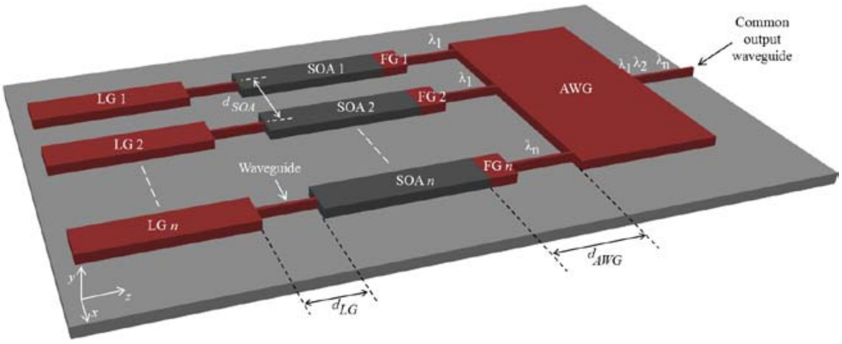

Fig.1: Schematic representation of a multiwavelength transmitter. The distance between the edge of the *i*-LG and the *i*-SOA is d_{LG} while the distance between the edge of the *i*-LG and the AWG is d_{AWG}. d_{SOA} is the distance between the vertical center of two consecutive SOAs. All the SOAs considered in the multichannel transmitter have the same geometrical dimensions.

Eq. (2) is the relation between the wavelength shift of the *i*-DBR laser and the temperature variation in the *i*-LG section. The coefficient γ for the InP is 0.11nm/ºK [1]. In general, ΔT_i is affected by the heat coming from all the SOAs simultaneously injected. To calculate the temperature in the *i*-LG section, we consider the matrix formalism (3) and its expansion (4):

$$\begin{pmatrix} T_1^{LG} \\ T_2^{LG} \\ \vdots \\ T_n^{LG} \end{pmatrix} = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \dots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2n} \\ \dots & \dots & \dots & \dots \\ \alpha_{n1} & \alpha_{n2} & \cdots & \alpha_{nn} \end{pmatrix} \begin{pmatrix} I_1^{SOA} \\ I_2^{SOA} \\ \dots \\ I_n^{SOA} \end{pmatrix} \tag{3}$$

$$T_i^{LG} = \alpha_{i1} I_1^{SOA} + \alpha_{i2} I_2^{SOA} + \ldots + \alpha_{in} I_n^{SOA} \tag{4}$$

The coefficients α_{ij} in eq. (4) depend on the *i*-LGs – SOAs distance and also depend on the thermal properties of the materials involved in the structure. To calculate these coefficients, we consider the heat transfer equation. The fundamental law governing the heat transfer is the first law of thermodynamics, commonly referred to as the principle of conservation of energy. We simplify the heat transfer equation by considering the steady state regime [2], so that the equation governing the pure conductive heat transfer in a solid become:

$$C_p \rho \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q = 0 \quad (5) \qquad \text{with} \qquad Q = \frac{I^2 R}{hwl} \quad (6)$$

where k [W/(m·K)] is the thermal conductivity, ρ [kg/m^3] is the material density, C_p [J/(kg·K)] is the specific heat capacity at constant pressure, T [K] is the absolute temperature. Q [W/m^3] contains the heat sources. In eq. (6) R is the resistance of the material (it depends on geometry and resistivity of the materials involved in the device), and h, w, l are respectively the thickness, the width and the length of the laser section under investigation. I is the injected current. In our model, we neglect the effects of the heat transfer from the SOAs to the *i*-FGs sections because the length of the *i*-LG is typically ten times shorter than the length of the *i*-LG sections. A change in temperature in the *i*-FG section produces negligible effects in the behavior of the *i*-DBR laser.

Simulations and Results

As initial investigation, we consider the SOAs far enough to each other so that the *i*-SOA affects only the *i*-LG section**.** Fig. 2 (left) shows the temperature distribution (*yz* cross section) for a single SOA calculated by solving eq. (5) for three values of injected current. The SOA length (*z* direction) is 400 µm.

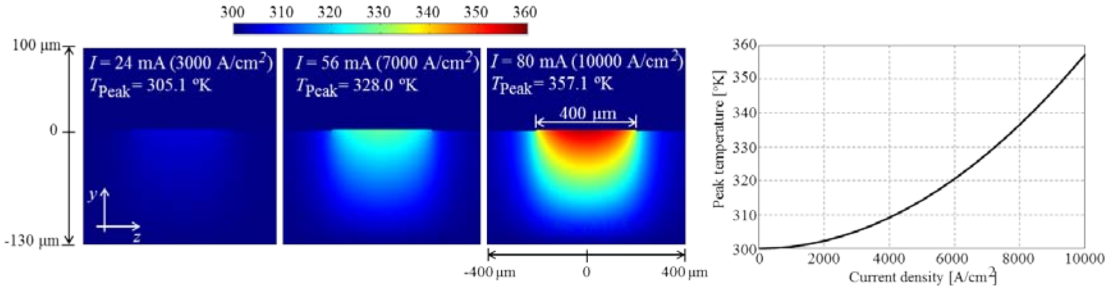

Fig. 2: (left) Temperature distribution in the *yz* cross section for three values of injected current, (right) Peak temperature *vs* injected current density in a single SOA.

Fig. 2 (right) reports the peak temperature in a single SOAs as a function of the injected current. The relation between injected current and peak temperature is quadratic because it depends on the Joule's effect as reported in eq. (6).

The temperature distribution in the *z* direction is useful to calculate both d_{LG} and d_{AWG}, as defined in Fig. 1, because the temperature distribution is symmetric with respect to the *z*-center of the SOA.

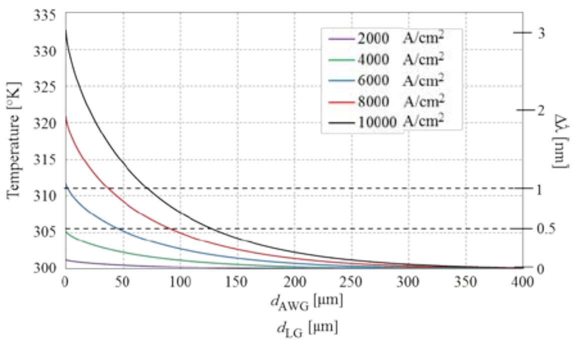

Fig. 3: Temperature distribution in *z* direction from the *z*-edges of the SOA.

Fig. 3 reports the temperature distribution in the *z* direction from the *z*-edges of the SOA (z = ±200µm) for five values of injected current. Its maximum value is important to define the distance between components.

We quantify the thermal crosstalk with the wavelength shift caused by the heat transfer from the SOA to the other components, in accordance with eq.(2).

For example, from Fig. 3 let us consider a current density I = 10000 A/cm^2. In that case the minimum distance between the SOA and the other components is 75 µm and 125 µm to obtain, respectively, a maximum wavelength shift of 1 nm and 0.5 nm.

A typical value of injected current for a SOA with the dimensions reported above is 6000 A/cm^2: in this case a distance of 50 µm is enough to ensure a wavelength shift less than 0.5 nm.

As anticipated, the reduction of the distance between SOAs also effects the heat transfer. Let us consider the cases of two SOAs and three SOAs electrically pumped in the same time. In order to evaluate d_{SOA} we consider the cross section *xy*. We consider the same value of current simultaneously in all the SOAs.

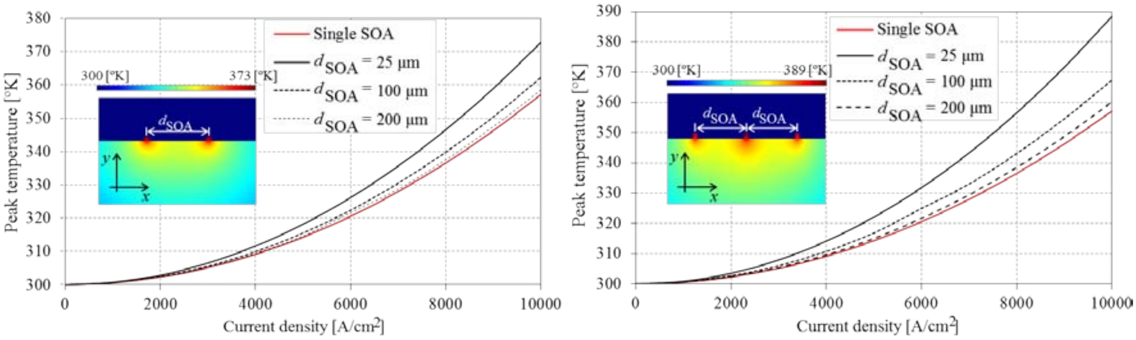

Fig. 3: Behavior of the peak temperature as function of the distance between (left) two SOAs and (right) three SOAs.

In Fig. 3 (left) the structure is perfectly symmetric and the peak temperature is the same for both SOAs. The SOAs influence themselves and the their peak temperature is higher than the case of single SOA (red line).

In Fig. 3 (right) the central SOA suffers the effect of two lasers and then its peak temperature increases rapidly. The red line in Fig 3 (left and right) is the same curve reported in Fig. 2 in which only one SOA is considered.

We define two (or more) SOAs “isolated” when the curve “Current density *vs* Peak temperature” looks like the situation in which there is only one SOA. For instance from Fig. 3 (left), in case of I = 10000 [A/cm^2], the proper distance to consider a good isolation between SOAs is at least 200 μm.

Conclusion

This paper investigates the thermal crosstalk effects in an integrated InP multiwavelength laser. We quantify the thermal crosstalk with the wavelength shift caused by the heat transfer from the SOA to the other components. The analysis with a single SOA shows a trade-off between “wavelength shift” induced by the thermal transfer and “distance” between components (indicated with d_{LG} and d_{AWG}).

The simulations also show the effects related to the peak temperature in a SOA when more than one SOA is injected. In general, the peak temperature in the *i*-SOA depends on: a) injected current in the *i*-SOA, b) distance between *i*-SOA and the nearest SOAs c) number of SOAs simultaneously injected.

References

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