Thermal analysis of an SOA integrated in SG-DBR laser module

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***Abstract*—We proposed a novel temperature-dependent model of an SOA integrated in SG-DBR laser module based on finite element method (FEM). Static and transient temperature distributions of the integrated module are simulated by numerically solving the thermo-optical coupling equations. Phenomenon of thermal crosstalk was conspicuously observed. Furthermore, thermally induced wavelength drift of the module was obtained by using a temperature-dependent dynamic transfer matrix method (DTMM) based optical model. Thermal effects on optical output properties of the module were observed. Wavelength drift induced by thermal transients in the SOA is as large as 39 pm.**

Keywords—SOA, SG-DBR laser, finite element method, dynamic transfer matrix method, thermal wavelength drift.

I. INTRODUCTION

As a representative monolithically integrated tunable laser transmitter, SG-DBR laser plays a vitally important role in novel dynamic WDM optical networks due to its compelling merits in terms of wide wavelength tuning range, fast and flexible wavelength switching and small volume [1].

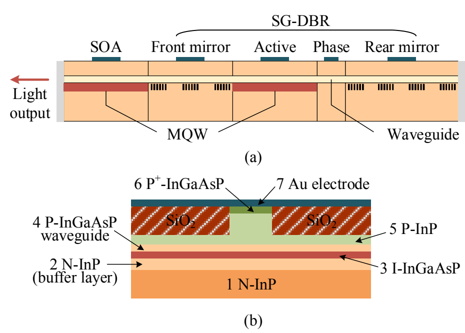

Fig. 1 (a) schematic diagram of the tunable SG-DBR laser integrated with SOA; (b) cross section of the SOA.

SG-DBR lasers are usually integrated with many active and passive devices for novel functions. As shown in Fig.1 (a), an SOA is typically integrated at the output end of an SG-DBR laser to amplify, equalize and modulate the output power [2, 3]. The performance degradation problems of photonic integrated devices that triggered by thermal effects gradually attract investigators to focus on them in recent years. Puttnam et al. confirmed thermal effects caused by wavelength switching would give rise to output wavelength drift when they used an SG-DBR laser to conduct transmission experiments in WDM, the drift would lead to crosstalk in channels and result in increased BER during the transmission [4]. For an SG-DBR laser integrated with an SOA and an EAM, Kozodoy et al. carried out test experiments and found that thermal crosstalk in each integrated device would affect the device performance unfavorably [5]. In our previous work, the thermal effects in SG-DBR lasers was investigated [6]. The aim of this paper is to reveal thermo-optical coupling effects in the SOA integrated at output end of the SG-DBR laser and impact of the effects on device performance.

II. SIMULATION MODEL

Temperature *T(x,y,z,t)*, carrier density *S(z)* and photon density *N(z)* distributions in the SOA are related to each other. The thermal model of SOA contains thermo-optical coupling equations consist of heat conduction equation, carrier density equation and photon density equation that can be worked out *T(x,y,z,t)*, *S(z)* and *N(z)* base on FEM firstly. Corresponding equations are as follows:

$$\begin{cases} \dfrac{\partial T(x,y,z,t)}{\partial t} - \dfrac{K}{\rho C}\nabla^2 T(x,y,z,t) = \dfrac{Q(x,y,z,t)}{\rho C} & (1) \\ \dfrac{dS(z)}{dz} = \Gamma g_{net}(z) S(z) & (2) \\ \dfrac{j}{ed} = g(z) v_g S(z) + R(z) & (3) \\ R(z) = e^{3.9(1-T/T_0)}[AN(z) + BN(z)^2 + CN(z)^3] & (4) \\ g = g_N \dfrac{T_0}{T}\left(N - N_0 \dfrac{T_0}{T}\right) \Big/ [1 + g_{cf} \cdot S(z)] & (5) \\ g_{net} = g - \left(\dfrac{a_0}{\Gamma} + a_N N\right)\dfrac{T}{T_0} & (6) \end{cases}$$

where *(x,y,z)* is the space coordinates, *t* is the time, *K* is the thermal conductivity, ρ and *C* are the density and specific heat respectively, *Q(x,y,z,t)* is the heat generation rate, Γ is the optical confinement factor, g_{net} is the net gain, *j* is the injection current density, *e* is the electron charge, *d* is the thickness of active region, *g* is the gain, *R(z)* is the carrier recombination rate. The other parameters in the equations are obtained from reference [6]. Structure and principle of the SOA and the active section of SG-DBR laser are extremely similar, thus Q_i (i=1~7 refer to different epitaxial layers as shown in Fig.1 (b).) of SOA in equation (1) is similar to that of the SG-DBR laser's [6]. The only difference is Q_3 (for I-InGaAsP active layer of SOA) is:

$$Q_3(z) = \frac{V_j(1-\eta_{sp} f_{sp})}{d} \cdot [edR(z) + (j - edR(z))(1-\eta_i)] \qquad (7)$$

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where V_j is the junction voltage, η_{sp} and η_i are the internal quantum efficiencies of spontaneous emission and stimulated emission respectively, f_{sp} is the ratio of escaped spontaneous emission photons from active region to all the spontaneous emission photons. By coupling the aforementioned thermal model of SG-DBR laser described in [6], then, a more comprehensive model of SG-DBR laser integrated with SOA can be established.

III. Results And Analysis

Length of the SOA is 300 μm. The other parameters in our simulation are obtained from reference [6]. I_{SOA}, I_f, I_a, I_p and I_r are injection currents of the SOA and four sections of the SG-DBR laser respectively, P_0 is optical input power of the SOA. In these cases, by using our model and software COMSOL based on FEM, the static temperature distribution of the module is simulated as shown in Fig. 2.

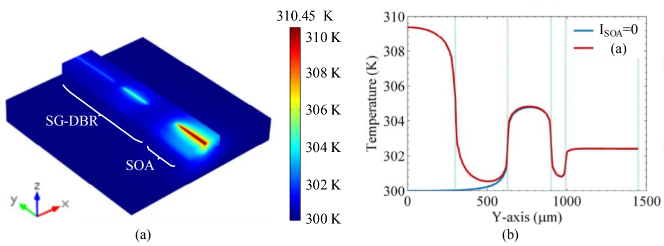

Fig. 2 (a) static temperature distribution when I_{SOA}=180 mA, I_f= I_p= 0, I_a=100 mA, I_r=45 mA and P_0=5.2 mW; (b) longitudinal static temperature distribution across the center of the laser's active region.

Optical output power and thermally induced wavelength drift (red drift) are then obtained by using a temperature-dependent DTMM based optical model [6]. When injection current of the SOA switches, optical power output which is influenced by the thermal effects "switches" accordingly. Fig. 3 manifests optical output power of the SOA with taking thermal effects into account or not when I_{SOA} changes.

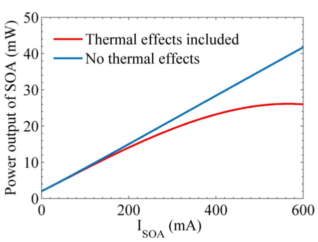

Fig. 3 Optical output power of SOA, with and without thermal effects.

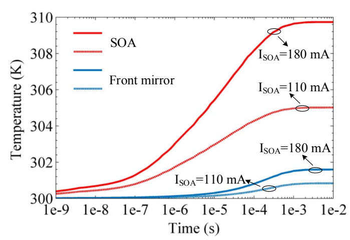

Fig.4 Transient temperature distributions of the SOA and the front mirror section, with I_f= I_p= 0, I_a=100 mA, I_r=45 mA, P_0=5.2 mW.

Next, transient temperature distributions of the SOA and the front mirror section with different injection currents when SOA switches on are calculated, as shown in Fig.4. According to the temperature rise delay in front mirror section (~10^{-6} s), the transient temperature variation in front mirror section is seen that mainly caused by thermal crosstalk from the SOA. Last, the data in Fig. 5 is converted to see thermal wavelength transients and power output variations in that case described in Fig.4. Wavelength drift is found as large as 39 pm, and power output approximately falls from 13.66 mW to 12.93 mW (falls nearly 5.3%) in the time order of 10^{-3} s when I_{SOA} switches from 0 to 180 mA.

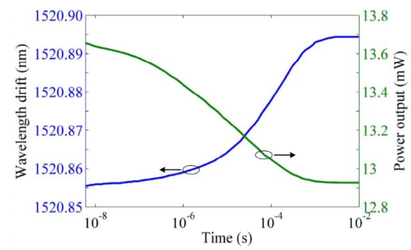

Fig.5 thermal wavelength transients and power output variations when SOA switches on with I_{SOA}= 180 mA.

IV. Conclusions

In this paper, a novel temperature-dependent model of an SOA integrated in SG-DBR laser module has been proposed based on FEM. The static results show the thermal crosstalk between the SOA and the front mirror section of SG-DBR laser, and effects on optical output power of the SOA evidently. The transient results show the thermal transient in the front mirror section is mainly caused by the thermal crosstalk from the SOA with a 10^{-6} s time delay. Wavelength drift induced by the thermal transients in the SOA is as large as 39 pm and decrease of the output power is 5.3 % when I_{SOA}= 180 mA. The proposed model and related results could be helpful to the design optimization and the thermal management of such devices.

Acknowledgment

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