Theoretical Modeling of Tunable Three-Section Slotted Fabry-Perot Lasers

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***Abstract*—We present a time-domain traveling wave dynamic model for simulation of wavelength tunable three-section slotted Fabry-Perot semiconductor lasers. The slot structure is characterized by using the boundary conditions of the optical fields propagating through the slot facets. Static and dynamic wavelength switching characteristics are simulated. Good agreements have been found between the simulation results and the experimental measurements.**

Keywords—Slotted Fabry-Perot Laser, modeling, time-domain, wavelength switching.

I. INTRODUCTION

Wavelength tunable semiconductor lasers are attractive in various application, such as dense wavelength division multiplexed (DWDM) systems, optical transmission networks [1]. In the past few years, new types of laser structures fabricated by etching discrete perturbing slots into the Fabry-Perot laser ridge were proposed and demonstrated [2-5]. The merits of the slot structure are its fabrication simplicity and low cost as there is no epitaxial re-growth in the fabrication process and only standard photolithography is required for the approximately 1μm wide slots. Among the different kinds of SFP lasers, the three section SFP (3s-SFP) laser is attractive as only two single slots were etched into the laser ridge. And discrete tuning over 25 available channels of the 100GHz ITU grid were achieved with the SMSR greater than 30dB and the linewidth less than 800kHz [4, 5].

As shown in Fig. 1, the 3s-SFP laser consists of three active sections separated by two single slots etched into the laser ridge. The width of the slots is 1μm. Both facets of the device are cleaved to form three FP cavities. By changing the current injected into each section, the lasing wavelength can be tuned.

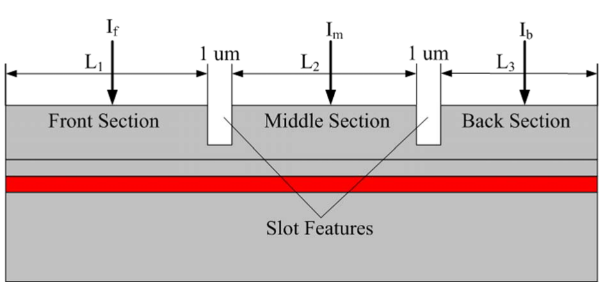

Fig. 1 Structure of the 3s-SFP laser.

Recently, we developed a time-domain traveling-wave (TDTW) model to simulate the 3s-SFP laser. Both the static and dynamic characteristics of this laser are simulated [6] .

II. SIMULATION MODEL

The TDTW model is based on solving the time-dependent coupled-wave equations at discrete points along the laser cavity [7]. The cavity are divide into subsections with length of Δs. The forward and backward traveling optical fields in the waveguide are represented by F and R respectively. Fig. 2 depicts the discretization scheme of this model and the reflection and transmission of the optical field at both facets of a slot, where $r^{\pm}{}_{f}$ and $r^{\pm}{}_{b}$ represent the reflectivity of the front and back facet, respectively and the superscripts "-"and "+" represent reflectivity looking from the left and right side of a facet, respectively. n and m denote the time and space step, respectively. The transmissivities of the facets are represented as t_f and t_b. The boundary conditions of the optical fields at the left and right facets can be described as:

$$\begin{cases} F_m^n = t_f F^{-n}{}_m + (-r_f{}^+) R^{+n}{}_m \\ R_m^n = r_f{}^- F^{-n}{}_m + t_f R^{+n}{}_m \\ F_{m+1}^n = r_b{}^+ R^{+n}{}_{m+1} + t_b F^{-n}{}_{m+1} \\ R_{m+1}^n = t_b R^{+n}{}_{m+1} + (-r_b{}^-) F^{-n}{}_{m+1} \end{cases} \tag{1}$$

where the superscripts "-" and "+" in the optical field represent optical field in the left and right side of a slot facet, respectively.

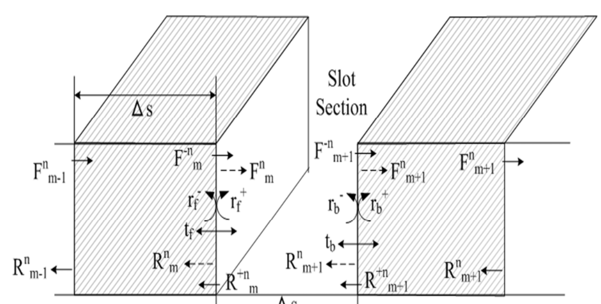

Fig. 2 Discretization scheme for the TDTW model and the reflections and transmissions at both facets of a slot.

III. Results And Analysis

The parameters of the 3s-SFP laser structure used in the simulation are obtained from [3, 4]. Fig. 3(a) and Fig. 3(b) show the wavelength and the SMSR tuning curves as a function of the current applied to the front section and the total current applied to both the middle and the back section equally, respectively. It is clear that the good SMSR (> 40dB) can be achieved in the center area of each mode and the wavelength tuning range is found to be approximately 12nm from 1543nm to 1555nm. Fig .4 plots the superimposed spectra of the eight lasing modes from λ_2 to λ_9 in Fig. 3(a). As shown in Fig. 4, the output mode power increases with the increase of the tuning current. The mode power variation is found to be approximately 6dB.

The wavelength switching dynamics are simulated and shown in Fig. 5. By changing the current applied on the front section, the emitted wavelength is switched between mode λ_2 to mode λ_8 [see Fig. 3(a)] and the switching time is approximately 2.6ns for forward switching and 4.6ns for backward switching. These results are in qualitative agreement with experimental results presented in [4].

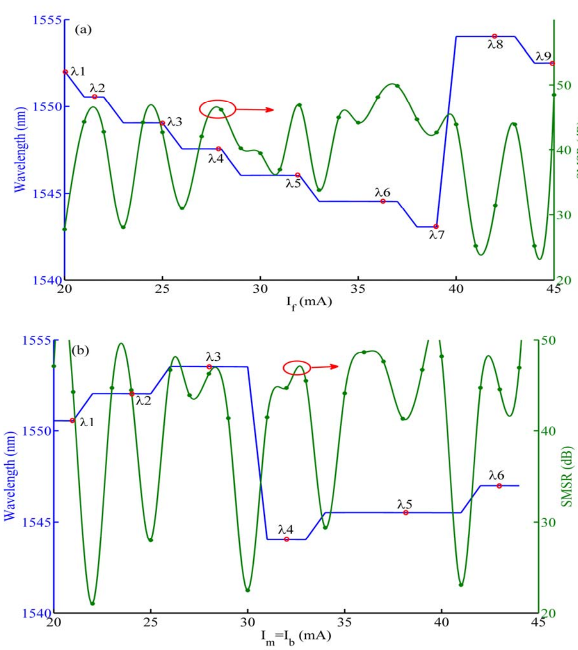

Fig. 3 Wavelength (blue line) and SMSR (green line) tuning curves versus (a) current across the front section and (b) total current across both the middle and the back sections equally.

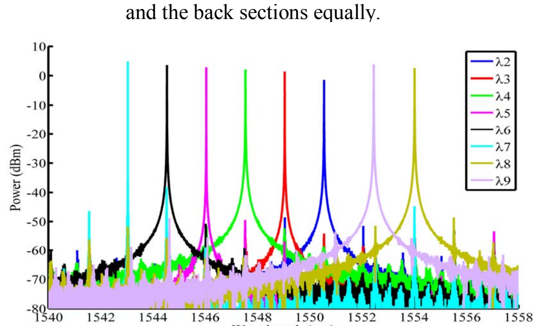

Fig. 4 Superimposed spectra of eight modes

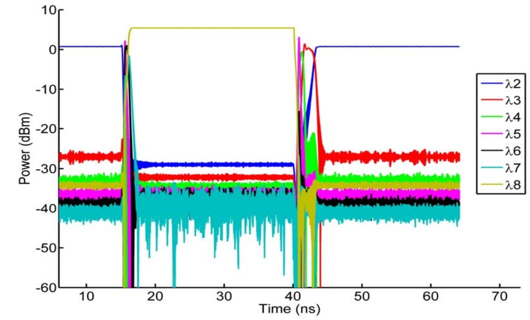

Fig. 5 Switching transients of the SFP laser between λ_2 to λ_8 .

IV. Conclusions

In this paper, we have developed a comprehensive time-domain traveling-wave model for the simulation of the 3s-SFP laser. Both static and dynamic performances have been investigated. Simulated results have been found to be in good agreement with the experimental measurements, which show that this model is a useful and suitable tool to study the characteristics of the 3s-SFP lasers, and also to design devices with specifically required characteristics.

Acknowledgment

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References

[1] J. Buus and E. J. Murphy, “Tunable lasers in optical networks,” *IEEE J. Lightw. Technol.*, vol. 24, no. 1, pp. 5–11, Jan. 2006.

[2] S. Osborne, S. O’Brien, K. Buckley, R. Fehse, A. Amann, J. Patchell, B. Kelly, D. R. Jones, J. O’Gorman, and E. P. O’Reilly, “Design of single-mode and two-color Fabry-Perot lasers with patterned refractive index,” *IEEE J. Sel. Topics Quantum Electron.*, vol. 13, no. 5, pp. 1157–1163, Apr. 2007.

[3] S. O. Brien, F. Smyth, K. Shi, J. O. Carroll, P. M. Anandarajah, D. Bitauld, S. Osborne, R. Phelan, B. Kelly, J. O. Gorman, F. H. Peters, B. Roycroft, B. Corbett, and L. Barry, “Design, Characterization, and applications of index-patterned Fabry-Perot Lasers,” *IEEE J. Sel. Topics Quantum Electron.*, vol. 17, no. 6, pp. 1621–1631, Nov/Dec. 2011.

[4] K. Shi, F. Smyth, D. Reid, C. Browning, B. Roycroft, B. Corbett, F. Peters, and L. Barry, “Fast switching slotted Fabry–Perot laser for phase modulated transmission systems,” *IEEE J. Lightw. Technol.*, vol. 28, no. 23, pp. 3409–3416, Dec. 2010.

[5] K. Shi, F. Smyth, D. Reid, B. Roycroft, B. Corbett, F. H. Peters and L. P. Barry, “Characterization of a tunable three-section slotted Fabry-Perot laser for advanced modulation format optical transmission,” Opt. Comm., vol. 284, no. 6, pp. 1616–1621, Mar. 2011.

[6] J. L. Zhao, K. Shi, Y. L. Yu, and L. P. Barry, “Theoretical analysis of three-section slotted Fabry-Perot Lasers based on time-domain traveling-wave model,” *IEEE J. Sel. Topics Quantum Electron.*, in press.

[7] L. M. Zhang, S. F. Yu, M. C. Nowell et al, “Dynamic analysis of radiation and side-mode suppression in a second-order DFB laser using time-domain large-signal traveling wave model,” *IEEE J. Quantum Electron.*, vol. 30, no. 6, pp. 1389–1395, Jun. 1994.