Time Domain Numerical Study of Two Semiconductor Optical Amplifiers Laser Cavity Structures

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Abstract **– In this paper, we develop a time domain model of a Semiconductor Optical Amplifiers Fiber Cavity Laser (SOA-FCL). The time domain characteristics of two different cavity configurations (bidirectional and one-way cavity) are compared. The study shows that one-way cavity is less noisy compared to the bidirectional cavity which presents higher output power.**

Index terms **– Semiconductor Optical Amplifiers, Bidirectional Fiber Cavity Laser, One-way Fiber Cavity Laser.**

I. Introduction

All-fiber lasers may be configured in one of two fundamental configurations; bidirectional cavity (Fabry-Pérot cavity) or ring cavity. Previous studies were conducted to examine Passive Optical Networks (PON) using bidirectional cavities [1] as well as fiber sensor applications using fiber ring laser cavities [2], [3]. Using SOAs as the gain medium in such applications can bring more compact, lighter and lower cost designs working over a wide range of wavelengths [4]. For instance, SOA fiber cavity laser (SOA-FCL) permits various applications such as direct modulation and switching. It is considered a colorless, self-tuning and self-seeded source [1], [5], [6].

This paper develops a time domain model of an SOA-FCL. It compares the characteristics of two different types of cavity structures, bidirectional and one-way (ring-type cavity). The use of a time domain model permits the analysis of transitory regime, especially in applications where the current or the wavelength of the laser cavity are dynamically switched.

II. Fiber Laser Cavity

Fig. 1 shows two cavity structures where in (a) the optical field propagates in a bidirectional way simultaneously in every optical component, whereas in (b) the optical field propagates only in the positive direction through the SOA and in a bidirectional way in other components. In the two cavity structures, the SOA is modeled based on reference [7] enabling time-domain analysis over a wide optical bandwidth and above pico-second time scales. In each structure, the lasing effect is obtained from the propagation of the amplified spontaneous emission (ASE) generated by the SOA which interacts coherently after amplification with itself at each round trip. The ASE is considered as a white noise source limited in bandwidth by the sampling rate of the simulation (200 GHz in our case). A filter inside each cavity limits the noise bandwidth and is mainly used to select a given lasing wavelength range. After several round trips (~ hundreds), a laser signal is self-established and a steady state is reached.

The behavior of the cavity is highly affected by the SOA. This study tends to solve the propagation equation in the SOA while taking into account the propagation outside the SOA. To do so, the SOA is divided into eight sections in which we solve the rate equation and calculate the optical field in the two propagation directions [7]. Outside the SOA, the fiber link is considered ideal but brings a propagation delay, the coupler is also ideal, the mirrors bring losses and the optical bandpass filter bandwidth is 100 GHz. The model can take into account any cavity length however, this study adapts a cavity length equal to 10 m. In the "Bidirectional cavity", the optical field is injected in both directions leading to a coupling and beating between positive and negative direction fields through the SOA carrier density. In the "One-way cavity", the optical field propagates in the SOA only in the positive direction, preventing such coupling and beating between fields.

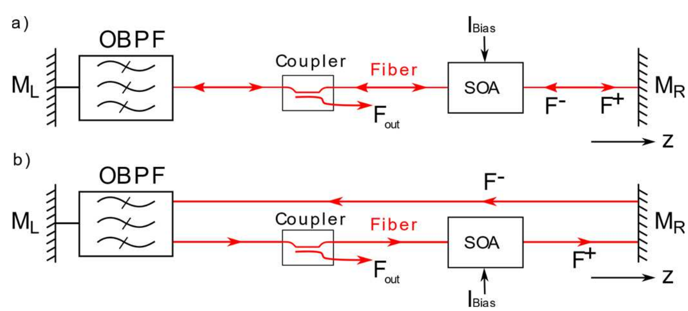

Fig. 1. a. Bidirectional SOA Fiber Laser Cavity
b. One-way SOA Fiber Laser Cavity
L_1=9m and L_2=1m in our simulation

III. Simulation Results And Discussion

Fig. 2a shows the time domain step response of the cavity output power ($P_{out}(t) = |F_{out}(t)|^2$) while the bias current (I_{Bias}) is set from 0 to 180mA for bidirectional cavity and to

200mA for one-way cavity. The findings indicate that the bidirectional cavity experiences a higher peak than the one-way cavity just after the current has been set. Both cavities power decrease with the same slope, mainly linked to the cavity length and SOA saturation properties. After about 13 µs, a steady state seems to be reached for both cavities without having the same final behavior. In addition, the field frequency analysis for bidirectional and one-way cavity of the 165th iteration (last simulated round trip, considered as steady-state) is shown in Fig. 2b. The results demonstrates that the laser peak for both cavities clearly stands out from noise by more than 20 dB over the simulation bandwidth. The examinations also indicate that the one-way cavity is less noisy than the bidirectional one for higher frequencies. Moreover, the optical power P_{out} as a function of I_{bias} (P-I plot) is shown after stabilization (average value of P_{out} over the last simulated round trip) in Fig. 2c. The threshold for bidirectional and one-way cavity are respectively 110 and 120 mA. Besides, the power of the bidirectional cavity is higher than the one-way cavity at the same bias current. Both differences can be explained due to the fact that the optical field in the bidirectional cavity experiences twice the SOA gain as compared to the one-way cavity while all losses remain the same. This curve also explains the choice made in this study to compare 200 mA for bidirectional cavity and 180 mA for one-way cavity as both have the same mean optical output power.

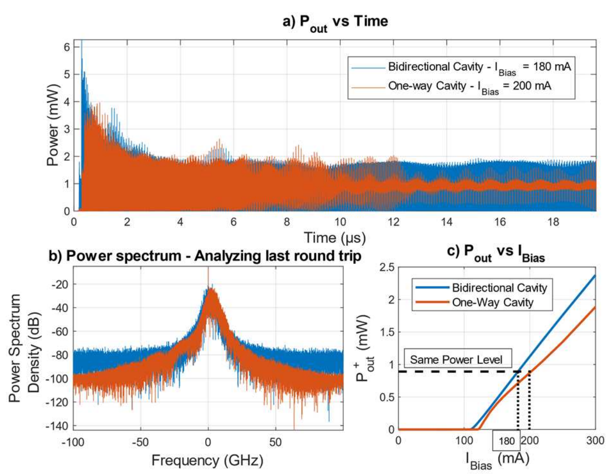

Fig. 2. a. Time domain analysis of 165 round trips for different I_{bias} and cavity structures. b. Frequency analysis for the last round trip (steady state). c. P_{out} vs I_{Bias} for Bidirectional and One-way Cavity.

Fig. 3 shows the probability density function (PDF) which represents the probability distribution of $P_{out}(t)$ at different round trips for both cavity structures. As noticed for the one-way cavity, the PDF of $P_{out}(t)$ is concentrated around 0.98 mW (after stabilization), whereas the bidirectional cavity starts to decrease before it increases again. To quantify the difference between the two cavities, Fig. 4 shows the standard deviation with respect to I_{Bias} calculated at steady state.

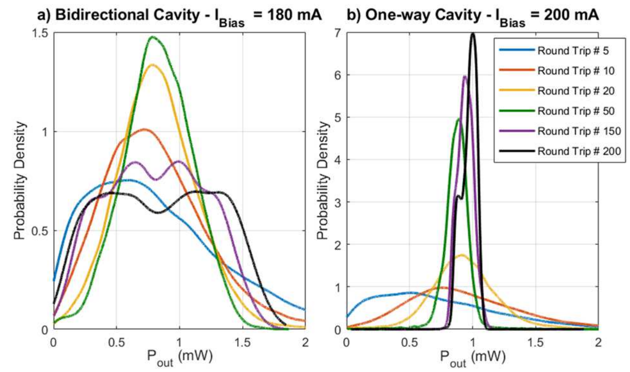

Fig. 3. Probability density function of $P_{out}(t)$

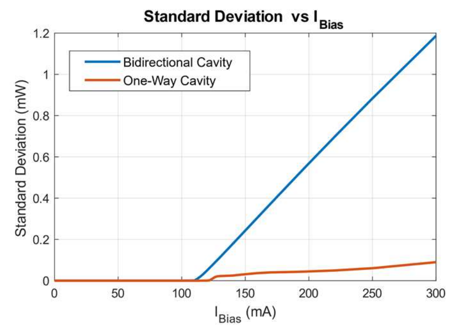

Fig. 4. Standard Deviation vs I_{Bias} for Bidirectional and One-way Cavities.

IV. Conclusion

In this study, we develop a theoretical framework for two different types of cavity structures using a SOA-FCL. Primary results show that the one-way cavity presents lower optical output power and lower noise level in comparison with the bidirectional cavity.

Acknowledgment

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