Feedback Sensitivity of an External Cavity Unidirectional Semiconductor Ring Laser

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The sensitivity to external optical feedback of an external cavity ring laser is characterized. The multimode laser cavity mainly consists of optical fiber and contains a quantum well semiconductor optical amplifier and a tunable Faraday isolator. Sensitivity to external feedback is experimentally determined by monitoring the output power of the laser for both directions and as a function of the amount of external feedback. It is found that increased intra-cavity isolation results in reduced sensitivity to external feedback. The results are compared to our theoretical model and good qualitative agreement is obtained.

Introduction

Semiconductor lasers are very sensitive to external optical feedback (EOF). For this reason EOF is commonly suppressed by placing a Faraday isolator in series with the laser. Thus, approximately 60dB isolation is required to fully suppress the effects of EOF [1], but monolithic integration of such isolators with the laser greatly complicates the fabrication process [2]. We therefore proposed and modeled an alternate method for obtaining insensitivity of a laser to EOF [3], requiring approximately 10dB of isolation only. In the current work we experimentally verify the principle of feedback insensitivity of an external cavity semiconductor ring laser with weak intra-cavity isolation.

Experimental setup

A schematic representation of the laser cavity is schematically shown in Fig. 1. The laser mainly consists of polarization maintaining fiber (PMF) and a free space optical isolator, as represented by the red lines and blue box in the figure respectively. Outcoupling is provided by 50/50 fused fiber splitters. Gain is provided by a multi quantum well InP/InGaAsP semiconductor optical amplifier (SOA). Finally, tunable isolation is provided by a Faraday rotator and a set of polarizers. The total laser cavity is approximately 4m long and does not contain any wavelength selective element besides the SOA. The laser operation is therefore highly multi-mode.

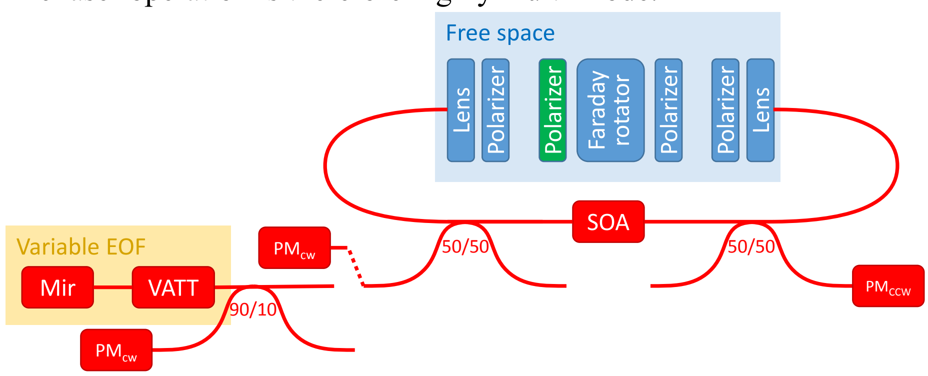

Figure 1: Schematic representation of laser cavity. Free space components are presented in blue, fiber components in red. Variable EOF is accomplished by a variable attenuator (VATT) and mirror (Mir). The variable EOF components and 90/10 coupler are only connected when EOF is applied to the system.

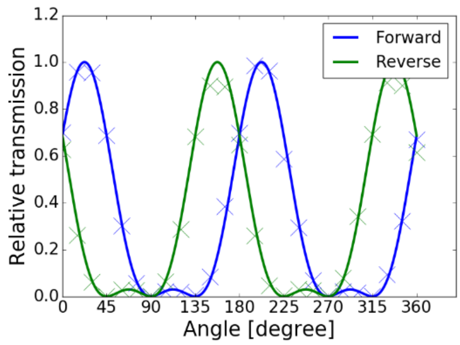

Figure 2a: Transmission of free space part of the cavity relative to its maximum transmission. Experimental data is indicated by crosses, the solid line represents the expected transmission based on the model.

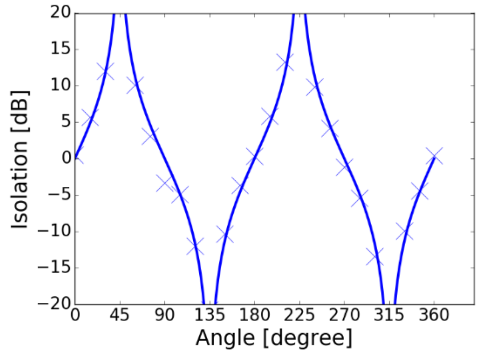

Figure 2b: Isolation provided by the free space part of the cavity. Crosses indicate experimental data, The solid line represents the expected isolation based on the model.

The isolator is implemented in free space. Its directionality is provided by a Faraday rotator which rotates the plane of linearly polarized light by $\pm 45^o$, depending on the propagation direction of the light. At both sides of the Faraday rotator is a polarizer. The transmission of the polarizers is $\cos^2\theta$, where θ is the angle between the state of polarization of the incoming light and the polarizer. The polarizers therefore convert the polarization rotation into a direction-dependent loss. One of the polarizers is oriented manually during the experiments and is indicated in green in Fig. 1. The other polarizer is aligned to the axis of the PMF and is fixed during the experiment. Finally, polarizers are placed at both fiber to free space interfaces to ensure alignment to the principle axis of the PMF and the polarization maintaining SOA.

It was confirmed that the free space part of the isolator provides the expected isolation by measuring its forward and reverse transmission for polarizer angles ranging from 0 to 360 degrees. The result of this experiment is shown in Fig. 2a as crosses. The transmission values resulting from the model are shown as a solid line in the same figure. As can be seen good agreement is obtained.

Isolation can be defined as $I = T_{fwd}/T_{rev}$ and is shown in Fig. 2b. Ideally, we would be able to change the amount of intra-cavity isolation without affecting the insertion loss (T_{fwd}) of the isolator. The current setup does not allow for this. Figs. 2a and 2b show that a very wide range isolation values can be achieved for angles between 0 and 45 degrees. Insertion loss changes by approximately 30% in this range.

To provide EOF, the laser is coupled to a reflecting circuit consisting of PMF. The light first passes through a 90/10 fiber fused coupler where 10% of the laser light is coupled to a power meter. The remaining 90% of the light is passed through a variable attenuator with insertion loss of approximately 1.5dB, to allow for various amounts of EOF. Finally the light is reflected by a silver coated cleaved fiber with a reflection of approximately -1.4dB. This results in a total maximum power reflection of approximately -5.4dB.

Experimental results

Since both the isolator transmission in both the forward and the backward direction is dependent on the setting of the polarizer, it is expected that the laser power in both the forward and backward directions is dependent on the angle of the polarizer. We verified this experimentally by monitoring the output power of both the clockwise (CW) and counter clockwise (CCW) directions using the power meters in the setup. The results are presented as LI curves for a number of angles of the polarizer in Fig. 3a. Slope efficiency and threshold depend on the polarizer angle due to the change in cavity losses.

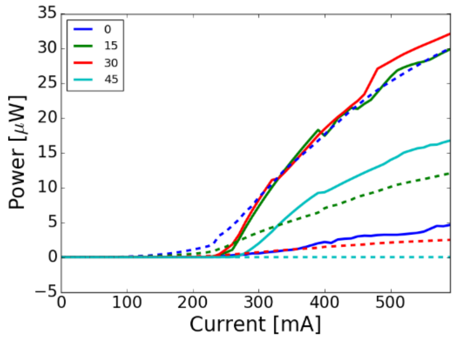

Figure 3a: LI curve of the laser for four settings of the polarizer angle. Solid lines represent the CW direction, dashed lines the CCW direction.

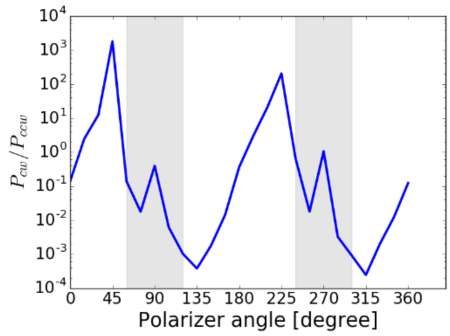

Figure 3b: Directionality of the laser as a function of the polarizer angle. Grey regions indicate subthreshold operation with large experimental errors.

Figure 3b shows the relative output power from both sides of the laser as a function of the polarizer angle for an SOA current of 400mA. It shows a very similar trend as Fig. 2b, indicating the directionality indeed follows the amount of isolation. The directionality is periodic with angle 180 degrees, which stems from the periodicity of the transmission of the polarizers. The figure does not show this periodicity perfectly, because of the limited accuracy in the setting of the tunable isolator. Furthermore, the power ratio at 0^o is not 1 as would be expected when there is no isolation. We attribute this to a systematic error in the polarizer angle. Finally, the peaks at 90^o and 270^o clearly deviate from the expected trend. Within the grey regions, the laser is below threshold and only low power levels of amplified spontaneous emission are observed. Also in these regions the experimental errors in the power levels are large.

We then apply EOF to the laser, ranging from -5dB to -65dB as seen from the laser output. This is done for three settings of the variable polarizer: 0, 15, 30 and 45 degrees, corresponding to 0, 5, 11 and 40 dB of isolation and 3, 1.6, 1.6 and 3 dB insertion loss, respectively. For each value of the EOF the output power in both propagation directions is measured. The resulting powers are presented in Figs. 4a and 5a for the CW and CCW directions, respectively. Finally, these values are compared to the theoretical predictions obtained from [3] and which are shown in Figs. 4b and 5b.

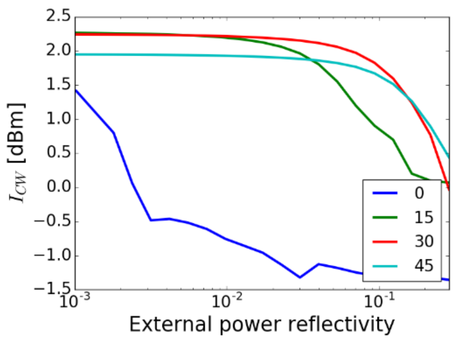

Figure 4a: Measured CW laser power as a function of the external reflectivity and for a number of polarizer angles in degrees as indicated in the legend.

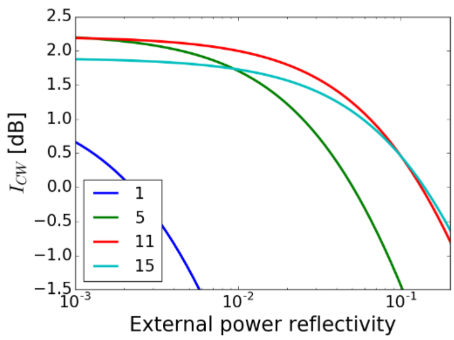

Figure 4b: Simulated CW laser power as a function of the external reflectivity and for a number of isolation values in dBs as indicated in the legend

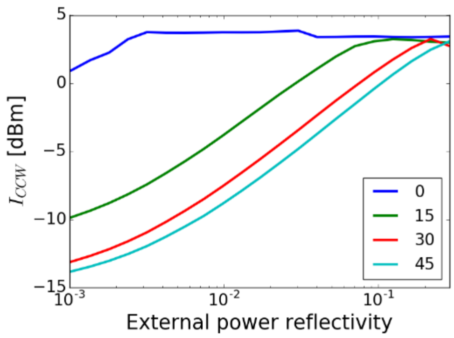

Figure 5a: Measured CCW laser power as a function of the external reflectivity and for a number of polarizer angles in degrees as indicated in the legend.

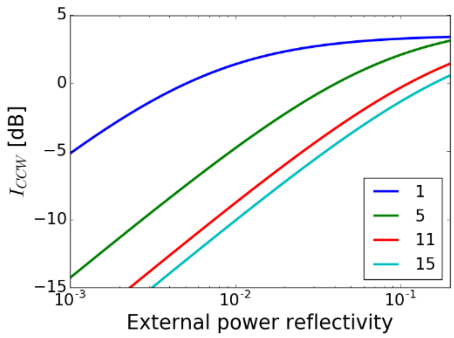

Figure 5b: Simulated CCW laser power as a function of the external reflectivity and for a number of isolation values in dBs as indicated in the legend.

From the figures it is apparent that as expected, small amounts of EOF do not have an effect on the laser. After a certain threshold, increased EOF results in an increase in CCW power at the expense of reduced CW power. The threshold at which the effect of EOF becomes apparent in the output power depends on the value of intracavity isolation as is most clearly seen in Fig. 4a. Qualitative agreement with our rate equation model is obtained as is evidenced by the similar trends in Figs. 4a and 4a and Figs. 5a and 5b, even though the model assumes a single mode laser. Because the laser is multi-mode we did not perform a linewidth or relative intensity noise measurement, which would allow further comparison to [3].

Conclusion

In this paper we have studied the impact of EOF on a multi-mode ring laser with intracavity, tunable isolator. Qualitative agreement with our theoretical model is obtained for the trends of unidirectionality and the corresponding insensitivity for EOF in terms of the CW and CCW output powers. If the laser is implemented as a photonic integrated circuit, the cavity will become much shorter, opening the road to a single mode laser with greatly reduced sensitivity to EOF.

References

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[2] Stadler et al., IEEE Photonics Journal, vol. 6, pp. 1–15, Feb. 2014.
[3] Van Schaijk et al., IEEE Journal of Selected Topics in Quantum Electronics, vol. 24, 2018.