Study of Optical-feedback Using an Integrated Laser-modulator/amplifier Device

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Abstract: We study optical-feedback effects using an integrated laser-modulator/amplifier. Our experiment and theory are agree well and provide interesting results of feedback effects on optical spectrum, spatial-hole burning, the photon density profile, and the microwave modulation.
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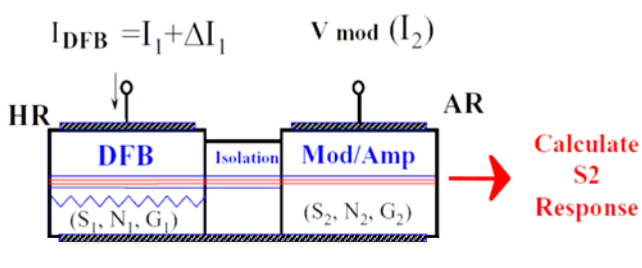
1. Introduction

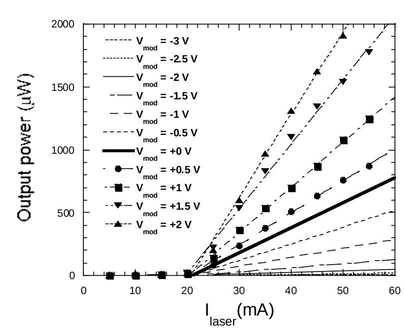
Multi-section photonic devices play an important role in optical networks because of their compactness [1]. In a photonic integrated device, electrodes are isolated between different sections. However, optical isolation between individual devices is difficult, which leads to the optical coupling or feedback between different sections or devices [2-4]. These devices are no longer independent. Optical feedback can deteriorate or improve the overall integrated device performance [5, 6]. Studying the coupling effect helps to better design integrated devices. In an optical transmitter, a semiconductor laser can be integrated with an amplifier or modulator in order to improve the output signal level. In an integrated laser-amplifier configuration, we investigate how the semiconductor amplifier influences the light output, amplified spontaneous emission (ASE) spectra, photon distribution in the laser cavity, and direct modulation response of the laser section through the optical feedback. We report comprehensive results of these effects by using an integrated laser-modulator/amplifier (LMA), which not only simplifies the experiment setup by eliminating the need for an additional lens and isolators, but also removes measurement uncertainties associate with external cavities.

2. Results and Discussions

The block diagram of the two-segment integrated laser-modulator/amplifier is shown in Fig. 1(a). The first section consists of a distributed feedback (DFB) laser. The second section is essentially an electroabsorption (EA) modulator serving a dual purpose (modulator and amplifier), and called as the modulator section in this work. The laser section is 300 μm long and the EA modulator section is 260 μm. The EA section is electrically isolated from the DFB section by an 80 μm isolation section. Two independent electrical contacts control the laser current and EA modulation voltage. An antireflective (AR) coating is placed on the EA modulator side of the cavity, and a high-reflective (HR) coating on the DFB laser side. When we reverse-bias the modulator section, it acts as an electroabsorption section via the quantum-confined Stark effects. When forward-biased, the modulator section acts as an amplifier by current-induced gain and refractive index change [7].



(a)



(b)

Fig. 1 (a) Block diagram of a two-segment integrated laser-modulator/amplifier (LMA). (b) The output power of the LMA is plotted as a function of the laser current at various modulator voltage biases.

The light output of the LMA under different laser currents and modulator voltage biases is shown in Fig. 1 (b). The DFB laser has a threshold around 20 mA. The light output was measured from the AR-coated modulator side, which increases with increasing forward bias and decreases with reverse bias of the EA section. When the laser is biased above threshold, both the laser and modulator sections of the integrated device play an important role. Around threshold, the gain of the EA section is dependent on both laser current and modulator voltage. We also measured the current-voltage (I-V) curves of the modulator section with the DFB laser biases 30, 35, and 40 mA and found that they were almost identical indicating that there is little electrical leakage between the laser and the modulator electrodes. The turn-on voltage of the modulator section was measured to be 0.8V. The gain values are also extracted from Fig. 1(b), which will be used for the theoretical calculation.

The ASE spectra of the LMA with a 30-mA laser bias and -2, 0, and 1.5 V modulator biases are shown in Fig. 2(a). The spectrum of -2 V is a normal laser spectrum, which is asymmetric with respect to the lasing mode. At a reverse bias, the absorption in the modulator section reduces the reflection of photons back to the laser section, and the spectrum of the whole device is similar to that of a discrete DFB laser. In the spectrum of 1.5-V forward bias, irregular ripples are superimposed on the side modes and the lasing wavelength shifts compared to other spectra. The photon density in the modulator section is comparable to that in the laser section when the modulator is forward-biased. It is due to optical feedback from the modulator, which modifies the laser properties. This behavior comes from the coupling of the optical cavities and is also called optical-crosstalk. We can see some coupled cavity effects at 0-V bias, which are not as strong as those at 1.5 V.

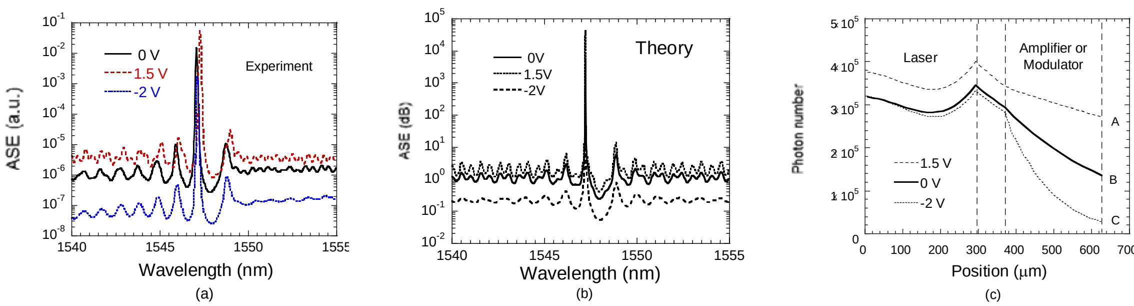


Fig. 2 (a) The measured amplified spontaneous emission (ASE) spectra, (b) the calculated ASE spectra, and (c) the calculated photon distributions of the LMA with 30 mA laser bias and -2, 0, and 1.5 V modulator biases.

To confirm our physical interpretation, we modified the the transfer-matrix model developed in [8] to calculate LMA. We solve the optical field propagation inside the composite cavity for each section including the DFB laser, the isolation, and the modulator/amplifier. By joining these transfer matrices as a building block, a general multi-section integrated device model is obtained, and the threshold gain, lasing mode, and ASE spectra can be calculated. The calculated ASE spectra of this LMA are shown in Fig. 2(b), which agree with our experimental data in Fig. 2(a). The photon density profile at the lasing wavelength of the LMA is shown in Fig. 2(c). Compared with the 0-V modulator bias case, the photon density profile at -2-V bias has a larger absorption in the modulator section and reduces the output photon density, which is represented by point C in Fig. 2(c). The photon number in the laser and isolation section has a slight decrease because of smaller feedback from the modulator back into the laser. For the 1.5-V modulator bias, the photon density in the modulator section is comparable to that of the laser section at 0V. The optical crosstalk between the two sections modifies the photon distribution in the LMA, which is quite different from the other cases. More photons are in the laser section and the overall photon profile is flatter or there is less overall spatial variation or spatial hole burning.

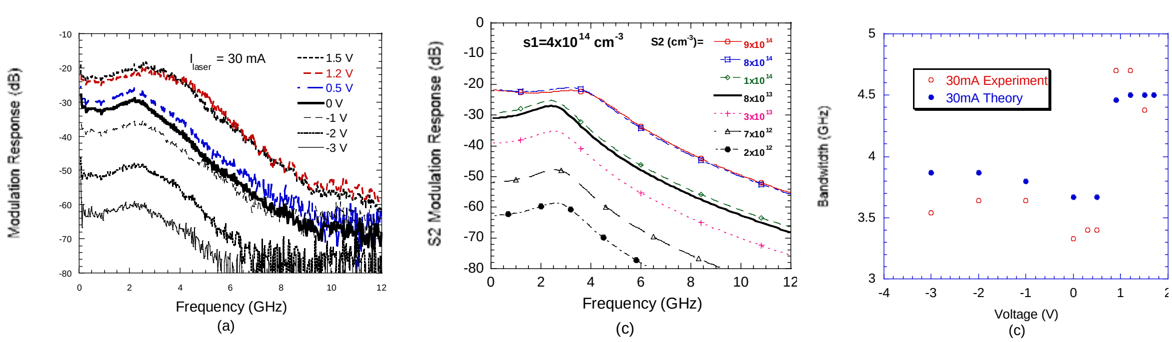


Fig. 3 (a) The modulation responses of the LMA at 30 mA laser current and different modulator voltage biases. (b) The calculated modulation responses at I=30 mA or $S_1 = 4 \times 10^{14} cm^{-3}$, (c) The bandwidth versus bias-voltage at 30mA.

We applied a dc bias and a small ac signal directly on the DFB laser to generate ac modulated optical signals. The modulator section is forward or reverse dc biased acting as an amplifier or an absorber to study the feedback on the laser modulation response. The modulated light is measured from the AR side. Our scheme is to study the effects of spatial hole burning and optical feedback. Fig. 3(a) shows the modulation response of the laser section at 30mA laser bias. If we forward-bias the modulator section, it functions as an amplifier. When at low positive bias, the amplifier is not turned on, it uniformly amplifies the modulation response, which shifts the modulation response up 3 dB since the feedback photon from the amplifier is not very large. When the amplifier is turned on, it not only shifts the response up by 10 dB, but also modifies the frequency response and increases the bandwidth by around 20 % due to optical feedback. When the modulator is reverse-biased, it is an absorber and the crosstalk in the device is greatly reduced. The modulation response just shifts downward with very little modification on the frequency response spectrum. The modification is small because the 0-V case already has a small crosstalk.

To better explain our high-speed data, we develop a small-signal modulation rate-equation model, which is shown in Fig. 1(a). The model has two sections. The first section is the laser section, which has a photon density S_1 a carrier density N_1, and a positive gain G_1. The second section is an amplifier/modulator section and has a photon density S_2, a carrier density N_2, and a positive or negative gain G_2. The small RF signal is only applied on the laser section. The dc positive or negative voltage is applied to the amplifier/modulator section. The photon density S_2 is modulated because two sections are strongly coupled, which is modeled with a coupling factor k_c. The photon density of both sides can be calculated. Only the frequency response of S_2 corresponds to the output of our measurement, which is plotted in Fig. 3(b). The summary of bandwidth versus bias-voltage at 30 mA is shown in Fig.3(c). When we reverse bias the second section, the photon density S_2 is much smaller than S_1, which causes the lower modulation responses with respect to 0V-bias. But the laser section encounters less feedback and the shape of the modulation response of the whole device is only determined by the laser section. Therefore, the bandwidth is almost the same for reverse bias. For the strong forward-bias case, the modulation response is modified by S_2 due to feedback or coupling. The bandwidth is also improved. This is not only because the feedback increases the effective photon density in the laser section, it also reduces spatial-hole burning effects of this LMA and flattens the photon density, which is shown in Fig. 2(c). Both theory and experiment show about 20% bandwidth improvement at the 1.5V bias compared with that at 0V bias. If we further increase the positive bias voltage, more photons are in the laser section and the gain saturation effect will limit photon density from further increase and limit further the bandwidth improvement.

In conclusion, we have investigated experimentally and confirmed theoretically important effects due to optical feedback in an integrated laser-amplifier. The optical feedback changes both dc and ac performance of the laser section such as ASE spectra, longitudinal photon density profile, and the modulation response.

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