11:15am - 11:30am

TuN3 The Influence of Wavelength Dependent Distributed Gain on the Optical Bandwidth of Semiconductor Optical Amplifiers

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Introduction: Understanding the wavelength dependence of the gain in semiconductor optical amplifiers (SOAs) operated in saturation is critical for wavelength conversion via four wave mixing [4] and cross gain modulation [2]. As an optical signal propagates through the amplifier and the gain saturates, the wavelength dependence of the material gain will change. In saturation, the local gain depends on local carrier density, local wavelength dependence of the gain peak and wavelength dependence of the saturation power.

In this paper, we show that the distortion of the amplifier gain such as gain flattening with respect to wavelength, can be accounted for by treating the amplifier as cascaded optical filters with gain. The gain shape of each filter section is calculated based on the output power of the previous section and the local carrier density, wavelength dependent gain peak location and wavelength dependent saturation power.

Gain filter section model: In this model, we numerically compute the carrier density from the steady state rate equation for each section, thereby retaining all wavelength dependencies. We allow cubic dependence of the material gain on the wavelength and carrier dependence on the recombination lifetime. This approach differs from models that assume that the material gain is linear in carrier density and the effective carrier lifetime is independent of the carrier density [1].

We divide the amplifier into n power gain sections, where the local wavelength dependent gain of each section is dependent on the local carrier density and the optical power input to that section. The gain for the $i^{\rm th}$ section is

$$G_i(\lambda) = e^{g_i(N_i(P_i^{\rm in}),\lambda)\Delta L}, \tag{1}$$

where g_i is the material gain, ΔL the section length and P_i the input power to the $i^{\rm th}$ section. The overall amplifier gain is a cascade of these wavelength dependent power gain elements and is given by

$$G_{\rm amp}(\lambda) = \frac{P_{\rm out}(\lambda)}{P_{\rm in}(\lambda)} = \prod_{i=1}^{n} G_i(\lambda) \quad . \tag{2}$$

We model cubic wavelength dependence of the material gain [3] and the peak wavelength as a linear function of the carrier density

$$\begin{aligned} g_i(N_i,\lambda) &= a\,(N_i - N_0) - \gamma_1\,(\lambda - \lambda_p(N_i))^2 + \gamma_2\,(\lambda - \lambda_p(N_i))^3\,, & (3)\\ \lambda_p(N_i) &= \lambda_0 + (N_i - N_0)\,b, & (4) \end{aligned}$$

where λ_0 is the peak wavelength at transparency, b the linear gain peak shift parameter, γ_1, γ_2 are empirical constants, N_0 is the carrier density at transparency, a the linear gain coefficient and λ_p the peak wavelength of the current section.

The steady state carrier rate is calculated by numerically solving

$$0 = \frac{I}{qV} - AN_i - BN_i^2 - CN_i^3 - \frac{\Gamma g_i(N_i,\lambda)}{\hbar\omega\tilde{A}} P_i^{\rm in}(\lambda) \tag{5}$$

with injection current I, non-radiative recombination coefficient A, spontaneous recombination coefficient B, Auger recombination coefficient C and effective area $\tilde{A}$.

Results: The computed power gain profile $G_i(\lambda)$ for each of ten sections is shown in figure 1 (a). The total amplifier gain is the product of these gain profiles. These results show that the front end of the amplifier enhances the signals at the peak wavelength. Towards the end of the amplifier, the gain sections flatten out at longer wavelengths and equalize wavelengths that were initially at the input gain peak. This flattening is due to wavelength dependent gain saturation, which pulls the gain peak towards longer wavelengths and saturates the shorter wavelengths.

The final amplifier gain and the gain profile evolution inside the amplifier is shown in figure 1 (b). At the end of the amplifier, the gain starts to flatten out and the width of the flat area increases. This effect can be described by the flattening of the product of the gain sections.

Figure 2 shows the importance of including wavelength dependent gain and carrier rate dependent carrier lifetime in the rate equation (5). The dashed curves are solutions using the carrier rate equation without wavelength dependent gain and carrier rate dependent carrier life time. In figure 2 (a), for an increase in injection current, the dashed curves show a gain peak shift of up to 150nm, but the correct gain peak shift is only 70nm. For the saturated case, figure 2 (b), not only is the gain peak shift for both models different, but the shape of the gain curves changes.

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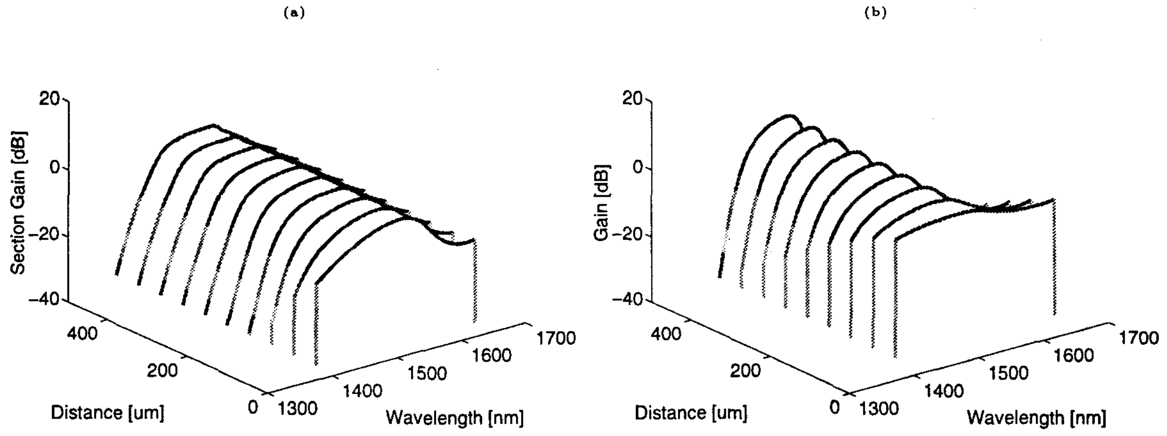

Figure 1: (a) Section gain and (b) total amplifier gain as a function of wavelength in the amplifier.

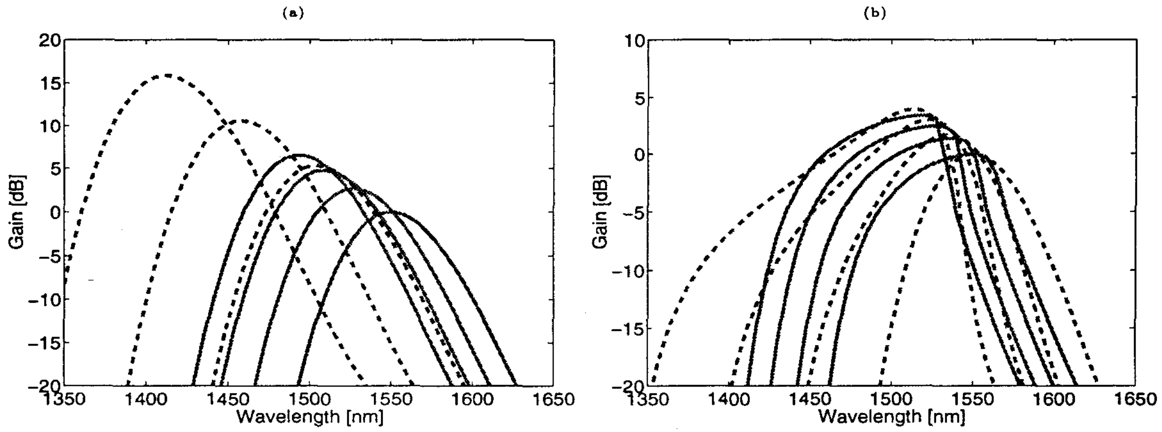

Figure 2: Gain as a function of wavelength in an semiconductor optical amplifier for (a) unsaturated case, (b) saturated case for normalized bias current I_0, $1.5I_0$, $2I_0$ and $2.5I_0$. Dashed curves do not account for wavelength dependency of the gain and carrier rate dependent lifetime in the carrier rate equation.

Conclusions: To accurately model SOAs in saturation, it is important to retain all wavelength dependencies. Modeling the amplifier as a system of cascaded optical filters lends insight into the gain falttening mechanisms in saturation.

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References

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