The effect of gain dispersion on pulse amplification in semiconductor laser amplifiers is investigated theoretically. A novel phenomenon, referred to as carrier-induced group-velocity dispersion, is shown to influence considerably the amplified pulse. Chirped input pulses are predicted to be compressed in the presence of carrier-induced dispersion even when the amplifier operates far below saturation. The dependence of the compression factor on device parameters such as the pulse width, the amplifier gain, and the linewidth enhancement factor are studied using a simple analytic model. The results are important for optical communication systems as they imply that semiconductor laser amplifiers can be used to compensate simultaneously for the effects of both fibre loss and fibre dispersion when used as in-line amplifiers.

Semiconductor laser amplifiers have attracted considerable attention as they are capable of providing high single-pass gain (∼30 dB) over a wide bandwidth (∼5 THz) in the form of a compact and efficient device. For input pulses wider than a few picoseconds input pulses are amplified without significant changes in the pulse shape and spectrum as long as the amplifier operates in the linear regime (no gain saturation). When the amplifier operates in the saturation regime, both pulse broadening and narrowing can occur depending on the operating conditions. At the same time, pulse spectrum is considerably broadened as a result of the frequency chirp imposed on the amplified pulse by carrier-induced self-phase modulation. Both spectral and temporal changes are attributed to gain saturation. For ultrashort input pulses temporal and spectral changes can occur, in principle, even in the linear regime (pulse energy well below the saturation energy) because of gain dispersion. The effects of gain dispersion become particularly important for femtosecond pulses. Such effects have not attracted much attention, partly because an experimentally reported distortionless amplification for pulses as short as 3 ps.

This paper shows that both pulse broadening and narrowing can occur in the presence of gain dispersion because of a novel physical phenomenon that appears to remain unnoticed so far. It is referred to here as the carrier-induced group-velocity dispersion (GVD) as it has its origin in the finite gain bandwidth of semiconductor laser amplifiers. More specifically, the frequency dependence of gain results in a frequency dependence of the refractive index because of carrier-induced index changes governed by the linewidth enhancement factor.
where $C$ is a chirp parameter. Eqn. 4 can be solved analytically for such input pulses, and the solution is

$$A(L, t) = A_0 \exp \left( \frac{1 - i C g_0 L/2}{1 + i C^2} \right) \exp \left( -\frac{1 + i C t^2}{1 + i C^2} \right),$$

(7)

where $Q = \frac{d^2 g_0}{dL} L (1 - i C)$. The pulse broadening factor $f_B$, defined as the ratio of the output to input pulse widths, is given by

$$f_B = \left[ \frac{1 + 2D(1 + 2C) + D'(1 + 2C(1 + C))}{1 + D(1 + C^2)} \right]^{1/2},$$

(8)

where $D = \frac{d^2 g_0}{dL} L = \frac{d}{dL} \ln (g_0)$. $g_0 = \exp (g_0 L)$ is the single-pass gain of the amplifier for CW input. Fig. 1 shows variation of $f_B$ with $D$ for several values of the chirp parameter $C$ by choosing $\alpha = 6$ as the representative value. Pulse broadening occurs for $C = 0$ (unchirped input pulse) and for positive values of $C$. However, the amplified pulse can exhibit considerable narrowing for negative values of $C$. Such a narrowing is similar to the case of optical fibres which can compress a chirped input pulse (without amplification) as long as $\beta_2 C < 0$. Interestingly, pulses emitted by semiconductor lasers are generally chirped such that $C$ is negative. Such pulses can potentially be amplified and compressed if the amplifier gain $g_0 L$ and the pulse width are optimised to correspond to a value of $d^2 g_0/2 D$ that corresponds to a minimum in Fig. 1.

![Fig. 1: Broadening factor against $d^2 g_0/2$ for $\alpha = 6$ and several values of the chirp parameter $C$.](image)

The optimum value $D_{\text{opt}}$ of $D = d^2 g_0/2 D$ can be obtained by setting $d^2 g_0/2 D = 0$ in eqn. 8 and requiring that $f_B$ corresponds to a minimum value $f_B^\text{opt}$. The compression factor defined as $1/f_B^\text{opt}$ is shown in Fig. 2 together with $D_{\text{opt}}$ as a function of the chirp parameter $C$. Solid and dashed lines correspond to $\alpha = 6$ and $\alpha = 4$, respectively.

![Fig. 2: Compression factor against $C$ under optimum condition](image)

The optimum value $D_{\text{opt}}$ of the dispersion parameter $D = d^2 g_0/2 D$ is shown on the right-hand scale. Solid and dashed lines correspond to $\alpha = 6$ and $\alpha = 4$, respectively.

**References**