Gain flattening of erbium-doped fibre amplifier using fibre Bragg gratings
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A new technique, using fibre-Bragg gratings with different centre frequencies to reflect the different channel signals at different positions, is proposed for flattening the gain spectrum of an erbium-doped fibre amplifier. A designed gain excursion of <0.1dB can be achieved for 16 channel multiplexed signals with 0.1mW input power in the 1532-1562nm wavelength region.

Introduction: Wavelength division multiplexing (WDM) technology has become very attractive for high-speed and high-capacity optical transmission systems. The inherent wavelength dependence of the gain, causing unequal optical signal powers among the WDM channels in cascaded erbium-doped fibre amplifier (EDFA) chains, degrades the performance of optically amplified transmission systems and networks. Several approaches have been proposed to broaden and flatten the gain bandwidth. One approach is to add Al₂O₃ and P₂O₅ to erbium-doped silica glass fibre [1, 2]. Fluoride-based EDFAs have been shown to have better characteristics than silica-based EDFAs in WDM applications [3]. Another approach is to use a gain equalising optical filter such as the Mach-Zehnder optical filter [4], the acousto-optic filter [5] or the long-period fibre-grating filter [6]. Because these filters function primarily as a wavelength-dependent attenuator, the use of the optical filter tends to lower the efficiency and the output power.

In this Letter, we propose a new technique employing the fibre-Bragg grating (FBG) to flatten the signal gain of a WDM system. FBGs with different centre frequencies can be designed at different positions of the EDFA to reflect the signals from different channels. By designing the written position of each FBG for each channel, signals from different channels can attain equal gain in the backward direction without sacrificing the signal-to-noise ratio and the power conversion efficiency.

Theory: The EDFA can be modelled as a homogeneously broadened two-level system. We consider 16 channel signal wavelengths ranging from 1532 to 1562nm with an equal channel spacing of 2nm. The amplified spontaneous emission noises (ASEN) are assumed to be optical beams of effective frequency bandwidth Δνₑ, centred at the wavelength λₑ = νₑλₑ to resolve the ASEN spectrum. Under the steady-state condition, the equations to describe the spatial development of the pump power (P_p), signal power (P_s, s = 1, 16) and ASE power (P_A, k = 1, N) in the EDFA can be written as

\[ a^\pm \frac{dP^\pm}{dz} = (\sigma_{e_k} N_2 - \sigma_{a_k} N_1) \Gamma_k P^\pm_k + 2\sigma_{e_k} N_2 \Gamma_k h \nu_k \Delta \nu_k \]

where N₁ and N₂ are the population densities of the ground level and metastable level. σ_e, σ_a, Γ_k, and h are the emission cross-section, absorption cross-section, confinement factor, intrinsic fibre loss, and photon energy, respectively. The superscript (±) designates the optical beam propagating along the ± direction and \( a^\pm \) is the pump wavelength λₑ, the EDFA length L is 40m. The pump powers P_p = 150mW are launched into the amplifier at z = 0 and L directionally, and the total pump power equals 300mW. The reflectivity of the FBG can be calculated from the coupled-mode equations

\[ \frac{dA^+}{dz} = k(z) \exp \left[ -j \int_0^z B(z') dz' \right] A^+ \]

\[ \frac{dA^-}{dz} = k(z) \exp \left[ j \int_0^z B(z') dz' \right] A^- \]

where A^+ and A^- are the amplitudes of the forward and backward propagating modes along the z direction, k(z) is the coupling coefficient and B(z) represents the phase mismatch of the grating.

References

Fig. 1 Optical spectrum of 16 channel WDM amplified signals without FBGs for −10 dBm input power of each channel

Fig. 2 Optimum written positions of FBGs for different channels, and optical spectrum of 16 channel WDM amplified signals for FBGs shown a) Optimum written positions of FBGs for different channels b) Optical spectrum of 16 channel WDM amplified signals with the FBGs shown in a
Numerical results and discussion: Fig. 1 shows the optical spectra of 16 channel output WDM signals and ASE after the 40m Al co-doped EDFA without the FBG for ~10dBm input power of each channel. The 16 channel WDM signals are allocated from 1532 to 1562nm, and the channel spacing is 2nm. The average signal gain is 20.4dB. The maximum interchannel power difference is < 0.1dB for 16 channel multiplexed signals. The power conversion efficiency of the EDFA with the FBG is equal to that of the EDFA without the FBG. The signal-to-noise ratio of each channel is > 35dB.

Conclusion: A gain flattening method in EDFA's has been proposed for the WDM systems by using FBGs. We have optimized the written positions of the FBG to achieve the maximum flat gain. The signal-to-noise ratio and energy conversion efficiency are not decreased by using FBGs.

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References

High efficiency 0.5W/A at 85°C strained multiquantum well lasers entirely grown by MOVPE on p-InP substrate.

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An efficiency of 0.5W/A, the highest ever reported for conventional quaternary InGaAsP materials, and a high maximum output power of 40mW at 85°C were realised for 1.3μm strained multiquantum well (MQW) lasers entirely grown by MOVPE on p-InP substrate.

Introduction: Passive optical networks (PONs) are very attractive access networks due to their low cost. In the optical network unit (ONU) of this system, 1.3μm laser diodes (LDs) with high output power (>15 mW) and a low driving current are required in the temperature range 40–85°C, because these LDs are needed to compensate for excessive optical link loss (~15dB) caused by a star-coupler. Moreover, from the viewpoint of increased output and reduced costs, the high uniformity of the entire MOVPE process is suitable in the production of these LDs. Considerable effort has been devoted to realising 1.3μm uncooled LDs [1–3], and extremely low threshold currents have been realised for optical interconnection use by employing strained MQWs [3]. However, the operation of these LDs is impaired when output power exceeds 15mW at high temperature.

To improve the high temperature characteristics of long wavelength LDs, carrier injection efficiency needs to be high enough to suppress both carrier overflow into separated confinement heterostructure (SCH) layers and carrier leakage into a current blocking region. Moreover, internal loss principally caused by interband absorption (IBA) [4] should be reduced.

This Letter reports high efficiency and low changes in both efficiency and threshold current successfully attained over a wide temperature range up to 85°C, by designing an SCH structure for high-carrier injection efficiency, and employing a buried heterostructure with low current leakage.

Device structure: The active region consists of seven compressive 0.7%-strained InGaAsP wells separated by λc = 1.13μm InGaAsP barriers and SCH layers for optical confinement. These were grown by MOVPE on a p-InP substrate. To reduce carrier leakage flowing outside the active region, an effective current blocking RIBBPBH (recombination-layer inserted blocking planar buried heterostructure) was introduced as has been previously reported in [3].