# Temperature Variation of Gain in a 1480nm-pumped Erbium-doped Fibre Amplifier

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## Introduction

The excellent performance of erbium-doped fibre amplifiers[1] (EDFA) has been confirmed by many recent experiments[2] and there is little doubt that EDFAs will soon be used in practical applications. Although an understanding of the amplifier temperature characteristics is indispensable in any application, surprisingly only one measurement has been reported to date. This measurement[3] used the 0.6$\mu$m pump band and reported no significant temperature dependence of either the gain or the amplified spontaneous emission (ASE) spectrum. However, when resonantly pumped at the more practical wavelength of 1.48$\mu$m, the situation is different. In this case, temperature-dependent gain characteristics are expected owing to a combination of the proximity of the pump and signal energies and the temperature-dependent distribution of ions within the metastable and the ground levels.

For 1.48$\mu$m pumping, we have measured both the amplifier gain and spectral absorption and emission cross-section data for temperatures in the range −40°C to 60°C, corresponding to the maximum likely temperature excursion of most systems. Within this range the gain change was only 1.5dB, which is in good agreement with a prediction based on the measured absorption and emission cross-sections.

## Experiment

The erbium-doped fibre used in the experiment was germano-silicate fibre with an NA of 0.2, a cutoff wavelength of 1300nm and erbium localized in the central region of the fibre core. The absorption and emission cross sections at −40°C and 60°C were obtained based on those at room temperature[4] and the relative changes of absorption and fluorescence spectra at these temperatures. The unsaturated gain of a 16.3m-long EDFA, the whole of which was contained in an oven, was measured using the copropagating pump scheme. Two 1.48$\mu$m high-power LDs were employed to give a launch power of 28mW. The signal wavelength was 1.535$\mu$m.

## Theory

Since for resonant pumping both the pump and signal transitions are between the $^4I_{13/2}$ metastable- and $^4I_{15/2}$ ground-levels, we have employed a two level model rather than a three level model[5]. The equations for the population inversion and the evolution of pump and signal power along the fibre are:

$$\frac{dN_2}{dt} = (\beta W_p + \alpha W_s)(N_{tot} - N_2) - -(W_p + W_s - 1/\tau_f)N_2 \quad (1)$$

$$\frac{dP_p}{dz} = \eta_p \sigma E(\lambda P_p[N_2 - \beta(N_{tot} - N_2)] \quad (2)$$

$$\frac{dP_s}{dz} = \eta_s \sigma E(\lambda P_s[N_2 - \alpha(N_{tot} - N_2)] \quad (3)$$

where

$N_2$ is the population density of the metastable level,

$N_{tot}$ the total erbium concentration,

$W_p$ and $W_s$ the pump and stimulated emission rates[5] and

$\alpha$ is given by $\sigma_A(\lambda_s)/\sigma_E(\lambda_s)$ and

$\beta$ by $\sigma_A(\lambda_p)/\sigma_E(\lambda_p)$,

where $\sigma_A(\lambda)$ and $\sigma_E(\lambda)$ are absorption and emission cross sections at wavelength $\lambda$.

The parameter $\tau_f$ is the metastable lifetime and $\eta_{p(s)}$ is the overlap of the pump (signal) field with the erbium distribution.

The temperature-dependent gain of an EDFA results from the temperature dependence of $\sigma_A$ and $\sigma_E$. It should be noted that the measured $\sigma_A$ and $\sigma_E$ reflect the distribution of ions in the ground and metastable levels at a given temperature. The above equations were solved numerically taking account of ASE.

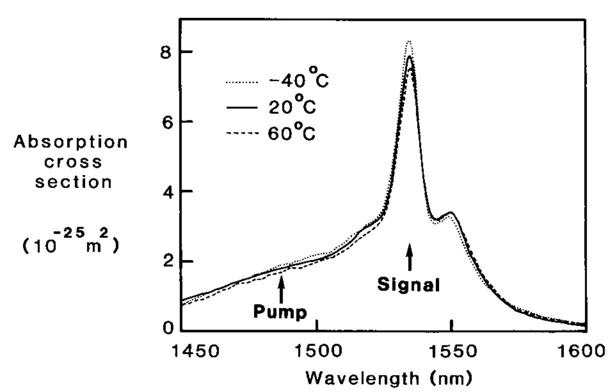


Figure 1: Absorption cross section at −40°C, 20°C and 60°C

## Results and Discussion

Figures 1 and 2 show the temperature dependence of $\sigma_A$ and $\sigma_E$ respectively. At the signal wavelength (1.535$\mu$m), $\sigma_A$ and $\sigma_E$ decrease with temperature, whilst at the pump wavelength (~1.48$\mu$m), $\sigma_A$ is found to decrease and $\sigma_E$ increase. As a result, the amplifier gain was found to decrease from 21.6dB to 20.1dB on increasing the temperature from −40°C to 60°C, as shown in Figure 3.

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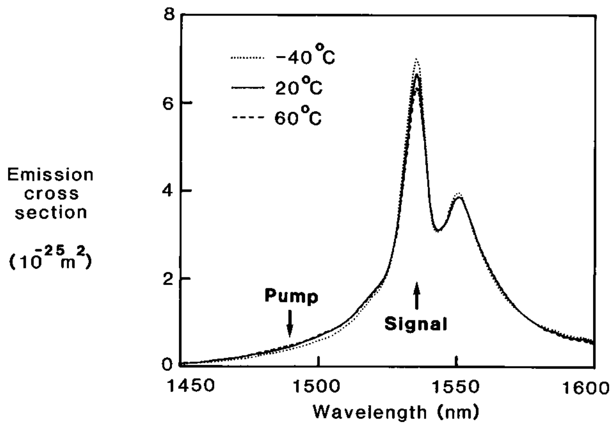


Figure 2: Emission cross section at −40°C, 20°C and 60°C

These results are confirmed theoretically. The solid line in Figure 3 is the numerical solution of Equations (1-3), where the erbium distribution is approximated by a top-hat profile occupying 50% of the core area and having a local concentration $N_{tot} = 1.7 \times 10^{18} cm^{-3}$. This gives[6] $\eta_p = \eta_s = 0.48$. Additionally, the measured values of $\sigma_A$ and $\sigma_E$ from Figures 1 and 2 and the previously determined value[5], $\tau_f$ = 12ms are employed. For simplicity, the change in cross-section at each wavelength was assumed to be a linear function of temperature, with coefficients determined by cross sections at −40°C, 20°C and 60°C. The inset of Figure 3 is the ASE spectrum at −40°C and 60°C. Although the ASE power was higher at the low temperature, its profile remained similar.

## Conclusion

We have measured for the first time the change in gain with temperature for a resonantly-pumped EDFA and temperatures in the range −40 to 60°C. The gain change in this temperature range was from 21.6dB to 20.1dB. In addition, we have measured emission and absorption cross-section data for the same temperature range. A theoretical model of the amplifier employing this data predicts a similar gain dependence on temperature. We envisage that these results will be invaluable in designing amplifier chains involving AGC.


## Acknowledgements

This work was supported by Pirelli General plc. Thanks are due to N. Chinone of Hitachi Ltd for providing the signal LD.


## References


1. R. J. Mears et al.: Electron. Lett., Vol. 23, 1987, p. 1026.
2. for example: S. Saito et al.: OFC'90, Paper PD2, 1990; N. Edagawa et al.: OFC'90, Paper PD3, 1990; H. Nishimoto et al.: IOOC'89, Paper PDA-8, 1989.
3. N. Edagawa et al.: IEICE Tech. Rep., OQE88-123, 1989 (in Japanese).
4. W. L. Barnes et al.: To be published.
5. P. R. Morkel et al.: Opt. Lett., Vol. 14, 1989, p. 1062.
6. E. Desurvire et al.: J. Lightwave Technol., Vol. LT-7, 1989, p. 835.


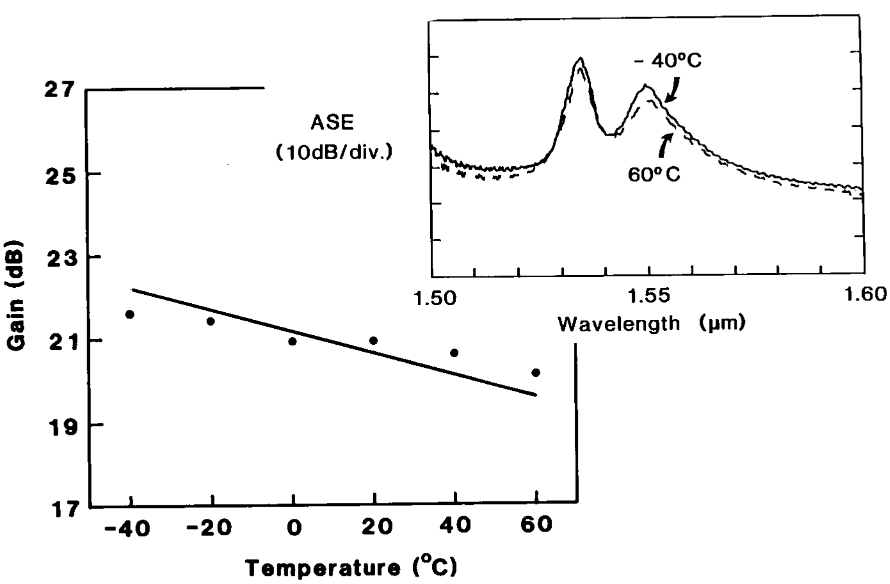


Figure 3: Temperature dependence of gain and ASE spectrum at −40°C and 60°C (inset). The solid line is theoretical value.