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Performance limits of erbium-doped fibre amplifiers due to internal Rayleigh backscattering

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ABSTRACT

For gains above ~30dB internal Rayleigh backscattering deteriorates both amplifier gain and noise figure. In high gain applications, increasing the fibre NA and dopant confinement above a critical value is shown to be detrimental.

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Erbium doped fibre amplifiers (EDFAs) are proving vital in the implementation of high capacity communications networks. High gains and near quantum limited noise performance have been demonstrated over ~40nm bandwidth with 980nm pumping giving highest gain efficiency (11dB/mW) and low NF (~3dB). Optimisation of fibre parameters is required to minimise the pump power requirements and enhance reliability of the packaged device. In general gain efficiency is improved and hence pump power requirements lowered by increasing the fibre NA and/or dopant confinement [1].

Rayleigh backscattering (RBS) potentially limits EDFA performance but has not been fully investigated. RBS affects the EDFA gain [2] and can drive ASE sources above threshold. In this communication, both the effects of RBS on amplifier gain and NF and the pump-power requirements for high-gain/low-NF operation are considered. It is shown that, for gains greater than ~30dB, RBS increases the amplifier NF well above the 3dB quantum limit. Additionally, for high gain <u>and</u> low NF applications, RBS limits the fibre NA and dopant confinement.

A three-level model was employed to investigate the EDFA performance with and without RBS [1] and compared with experimental data. RBS caused by the forward- and backward-travelling ASE is added incoherently into the counter-propagating wave. The RBS power (dP_{RBS}) caused by continuous radiation $P(z)$ in an infinitesimal fibre segment dz is given by $dP_{RBS} = \frac{1}{2}\alpha_{RS} S P(z) dz$, where α_{RS} is the Rayleigh scattering coefficient and S

is the fraction of the scattered light captured by the fibre. S and α_{RS} are proportional to $(NA)^2$ [3] and $(NA)^4$ [4], respectively, and, therefore, RBS is expected to be more significant in high NA fibres. Conversely, RBS is length dependent and, for fixed dopant concentration, its impact is expected to be more pronounced in fibres with confined dopant where the fibre lengths are greatly increased.

The EDFA gain and NF are considered in Figure 1 as a function of pump power for (optimum) fibre length of 60m [5]. Fibre parameters are defined by an NA of 0.24, cutoff wavelength of 920nm and a signal absorption of 0.95dB/m @ 1536nm. The solid and dashed curves indicate the theoretical responses with and without RBS, respectively. Feedback into the EDFA due to backreflections was kept below -60dB. Without considering RBS, the NF is predicted to decrease monotonically with pump power, in contradiction with experimental data. However, with RBS included (α_{RS}= -61dB/m), the data and calculated NFs are in very good agreement. In addition, it is noticed that RBS has a minor effect on the amplifier gain ($<$1dB). From Figure 1, it is deduced that for gains in excess of 30dB, RBS increases the NF significantly above the quantum limit.

Figures 2 and 3 represent the effects of fibre NA and dopant confinement on the pump power required to achieve a fixed gain and NF, with (solid) and without (dashed) RBS. From Figure 2, it is seen that without RBS, the pump power decreases monotonically with fibre NA. Inclusion of RBS, however, predicts that for gains greater than ~30dB increasing the fibre NA above a critical value adversely affects the required pump power because both S and α_{RS} increase with NA. For a gain of 35dB and NF of 3.2dB, the critical NA is about 0.25.

From Figure 3, it is deduced that the pump power required to achieve a certain gain and NF increases sharply below a critical dopant confinement since increased dopant confinement, for fixed dopant concentration, greatly increases the EDFA length. For gains greater than ~30dB, there is no benefit from a confined dopant distribution.

In conclusion, the EDFA gain and NF have been evaluated experimentally and theoretically. It is shown that for gains in excess of ~30dB, RBS adversely affects the EDFA noise performance. It is also shown that, for high-gain and near-quantum-limited-noise EDFAs, the required pump power increases sharply above a critical fibre NA and dopant confinement due to internal RBS.

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FIGURE CAPTIONS

Fig.1: EDFA gain and NF versus pump power for optimum fibre length of 60m. Dots correspond to experimental data and are compared with theoretical results with (solid line) and without (dashed line) RBS.

Fig.2: Pump power required to achieve a NF of 3.2dB and various gains versus fibre NA, with (solid line) and without (dashed line) RBS. The fibre is unconfined and the dopant concentration is 10^{24} m^{-3}.

Fig.3: Pump power required to achieve a NF of 3.2dB and various gains versus dopant confinement, with (solid line) and without (dashed line) RBS. The fibre NA is 0.2 and the dopant concentration is 10^{24} m^{-3}.

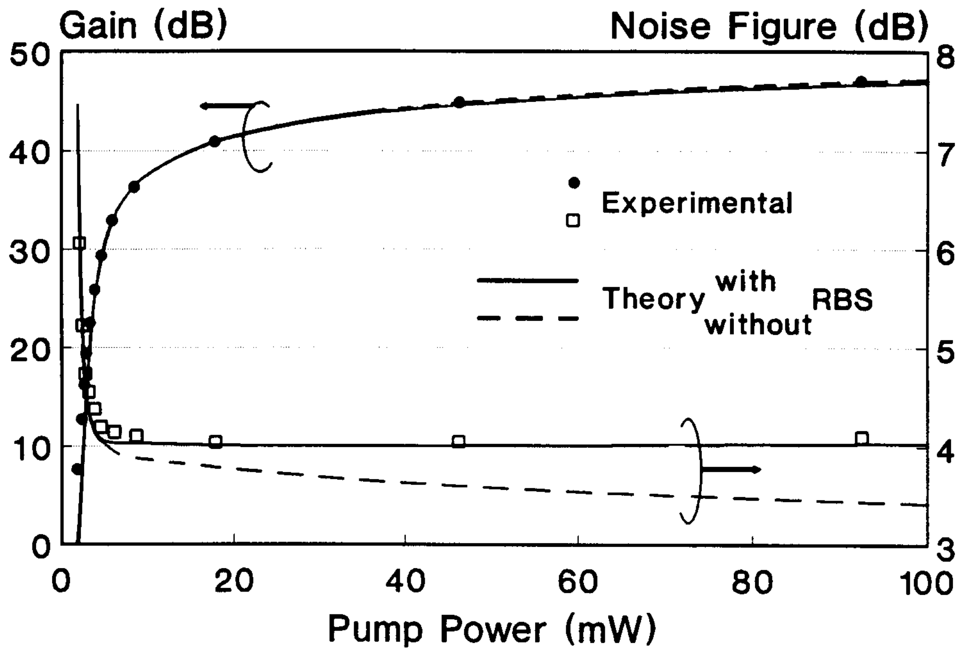
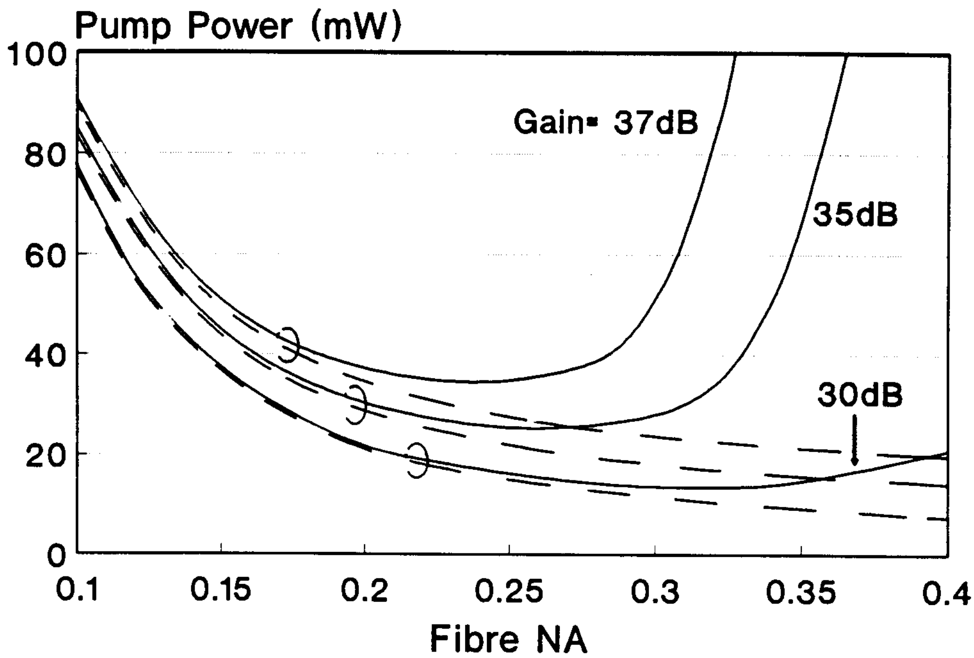

Gain (dB)
Noise Figure (dB)
50
40
30
20
10
0
8
7
6
5
4
3
0
20
40
60
80
100
Pump Power (mW)
Experimental
Theory with without RBS

FIGURE 1.



Pump Power (mW)
100
80
60
40
20
0
Gain= 37dB
35dB
30dB
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Fibre NA

FIGURE 2

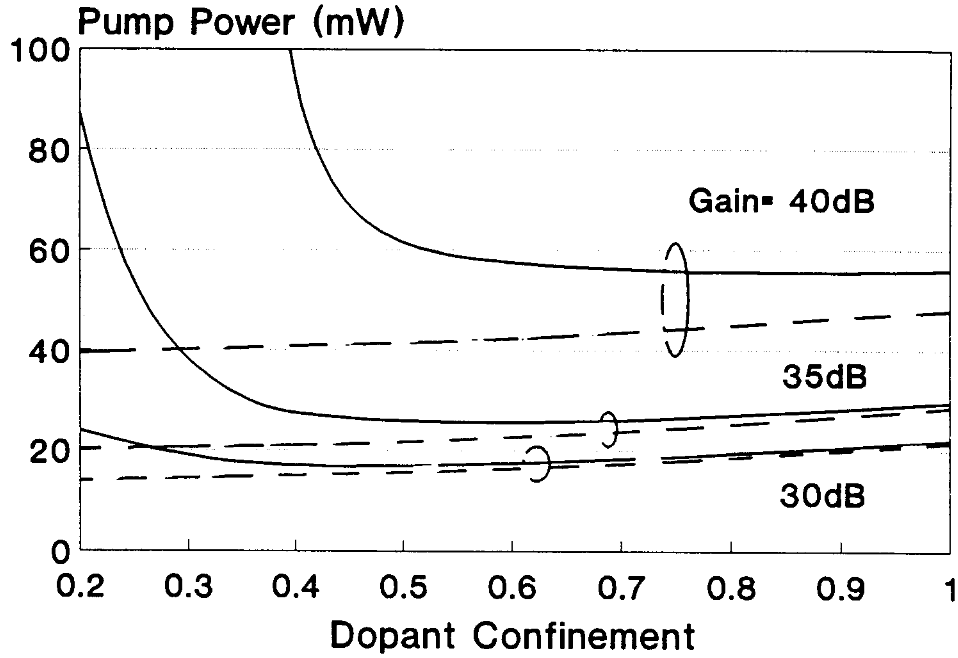

Pump Power (mW)
100
80
60
40
20
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Dopant Confinement
Gain= 40dB
35dB
30dB

FIGURE 3.