VERY-LOW THRESHOLD LOOP-MIRROR SWITCH INCORPORATING AN EDFA

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ABSTRACT

Fast, very-low threshold optical pulse switching in a non-linear loop-mirror incorporating an EDFA is reported using an amplifier gain of 46dB at 1.535μm. For a 336m Sagnac loop the input switching power is 200μW, which is 5x10^3 lower than the best previously reported.

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INTRODUCTION

All-optical switching devices based on ultra-fast optical non-linearities are of considerable interest for use in high-speed optical signal processing and telecommunications systems. Several switching schemes utilising $\chi^{(3)}$ in optical fibres[1-4] have been reported, but, although fast, they have large switching thresholds (100 -1000W) and suffer from environmental instability. Recent work[5-7] has concentrated on the fibre Non-Linear Optical Loop Mirror (NOLM) (or non-linear Sagnac interferometer), since the configuration is inherently a balanced interferometer and therefore environmentally stable. Consequently, longer fibre lengths can be used and the switching threshold reduced to 10-100W, a figure which is unfortunately still too high for practical application.

In the NOLM approach, a fibre Sagnac interferometer is constructed using a coupler having an unequal splitting-ratio at the operating wavelength. Pulses propagating in opposite directions around the loop have different amplitudes and therefore accumulate a net phase difference due to the optical Kerr effect. On recombination of the pulses at the coupler they are routed to one or the other of the NOLM outputs, depending on their acquired intensity-dependent phase-difference. Thus pulse switching between outputs occurs as a function of the intensity of the input pulse. Unfortunately, in this scheme 100% amplitude switching is not possible owing to the necessity for an unequal splitting ratio in the coupler.

A solution to the latter problem is to introduce a non-reciprocity into the loop by placing an optical amplifier close to one end (Figure 1). Counter-propagating pulses in the loop then differ in amplitude by the gain of the amplifier, since one pulse is amplified on entering the loop and the other on exiting. Consequently, a 50:50 coupler can now be used and full-contrast pulse switching is possible. In a recent demonstration[8] employing an Nd^{3+}-doped fibre amplifier with a gain of 6dB, a switching threshold of a few watts was obtained. In this paper we have exploited the high gain available from an erbium-doped fibre amplifier to construct an amplified NOLM which can be switched with a power of only 200μW from a diode laser operating at 1535nm, a figure more than three orders of magnitude lower than the best previously reported. We believe this device makes non-linear fibre switching and pulse shaping a practical reality.

THEORY

Referring to Figure 1, in a Sagnac loop operating at wavelength λ and incorporating an EDFA with gain G, the net phase difference $\Delta\phi$ accumulated between counter-propagating pulses on re-entering the coupler is:

$$\Delta\phi(t+\delta) = \frac{\pi}{\lambda A_{eff}} n_2(G-1)I_s(t)L \ , \qquad (1)$$

where $n_2 \approx 4 \times 10^{-20}$ m^2/W is the non-linear refractive index of the fibre, L the loop length, A_{eff} the effective mode area, δ the loop transit time and $I_s(t)$ the amplitude of the pulse launched into the loop at time t. We have assumed the light to be plane polarised and the device to be polarisation preserving. Note that an additional linear phase-shift can be obtained by polarisation manipulation within the loop[9] and in this way the port from which the switched output is obtained can be reversed.

The light transmitted from the loop output port is given by:

$$I(t+\delta)=GI_s(t)\sin^2(\Delta\phi(t+\delta)/2) \qquad (2)$$

Full amplitude switching is obtained when $\Delta\phi(t) = (2n+1)\pi$, $(n = 0,1,2...)$. For n=0 full amplitude switching is obtained for:

$$I_s(t) = \frac{\lambda}{n_2 L(G-1)} \qquad (3)$$

Thus the high gain available in an EDFA (G>40dB) reduces the required input switching power from the W to the μW regime.

EXPERIMENT

The experimental configuration used to investigate the switching properties of the NOLM incorporating an EDFA is shown in Figure 1. The Sagnac loop was constructed from 306m of non-polarisation-preserving fibre having a mode-spot area of 40×10^{-12} m^2 at a wavelength of 1.535μm. Mechanical polarisation controllers were used to adjust the reflection and transmission properties of the loop, although these can be dispensed with if polarisation-preserving fibre is employed. Since it had a similar mode spot-size to the loop fibre, it was possible to splice the 30m-long EDFA (germano-silicate host glass, 100ppm Er^{3+}, λ_{co} 930nm, NA = 0.19) directly to the end of the loop. Up to 60mW of pump at 980nm from a Ti:Sapphire laser was launched into the amplifier whose length was chosen to be optimal for high gain at 1535nm. At a gain of 46dB an ASE background of 2mW was observed.

A switching pulse of 10-20ns duration with 1ns rise and fall times was obtained from a 1535nm DFB laser diode. Up to 150μW peak power in 10ns pulses at a repetition rate of 10kHz could be launched into the loop-mirror input before amplifier saturation effects became evident, although this could be increased if higher levels of pump power were available.

RESULTS

Transmitted pulse shapes obtained at the Sagnac-loop output port for 20ns square input pulses at 1kHz are shown in Figure 2. For convenience, the loop was tuned to reverse-switching[9] using the polarisation controllers. The effect of this bias is to cause the switch to transmit low-level signals and block (i.e. route to the other port) high levels, rather than the reverse. Thus the rising edge of the pulse in Figure 2 is transmitted linearly up to the switching level, whereupon the pulse intensity falls as power emerges from the other port once the non-linear regime is entered. The centre of the pulse is therefore sliced out and appears at the other (input) port. The effect is dramatic and can be used to convert the rising edge of a square pulse into a short pulse. For example, Figure 2(d) shows a 1ns pulse sliced from a 20ns pulse.

Figure 3 shows the experimental and calculated power input/output transfer characteristics of the switch, normalised to account for 3dB losses in the loop. It can be seen that the agreement is excellent and the full output extinction is obtained for only 200μW of input pulse power, whereas for a 100μW pulse input the switch output is 2W.

CONCLUSIONS

We have demonstrated that the high-gain characteristics of the EDFA can radically improve the characteristics of hitherto impractical non-linear devices and allow switching using diode lasers at levels of around 200μW. This is an improvement of 5 x 10^3 over the best previously-reported fibre switch. The amplified Sagnac switch thus has potential as an amplifying pulse discriminator and shaper, as well as an amplifying MUX/DEMUX if used in two-wavelength mode.

ACKNOWLEDGEMENTS

We would like to thank John Minelly for supplying the fibre coupler and Janet Townsend for fabricating the fibre.

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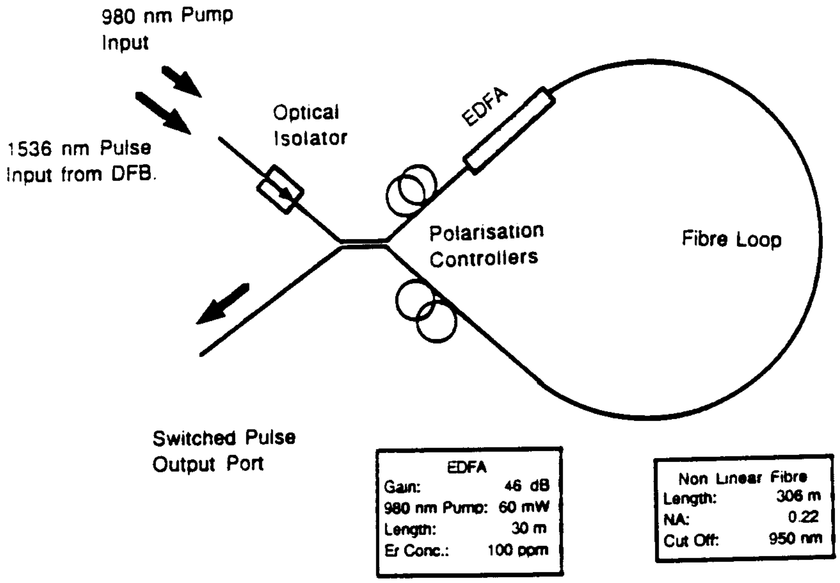

Figure 1 Experimental configuration of an amplified non-linear loop mirror

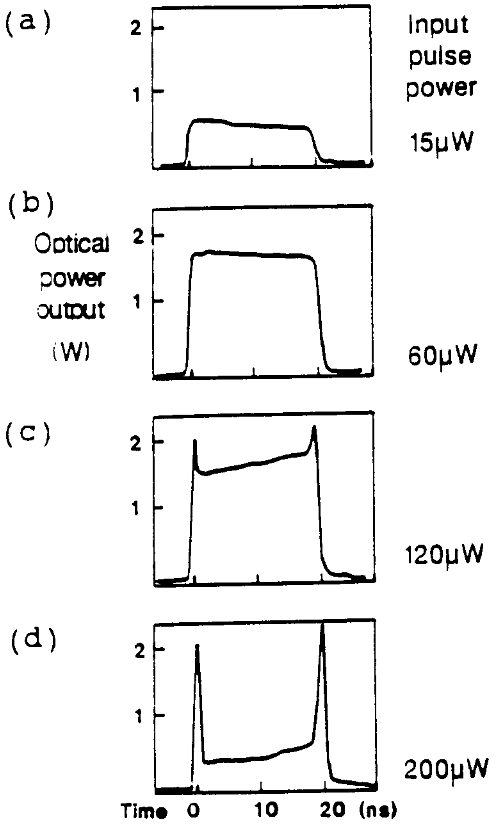

Figure 2 Loop mirror output for input peak pulse powers shown

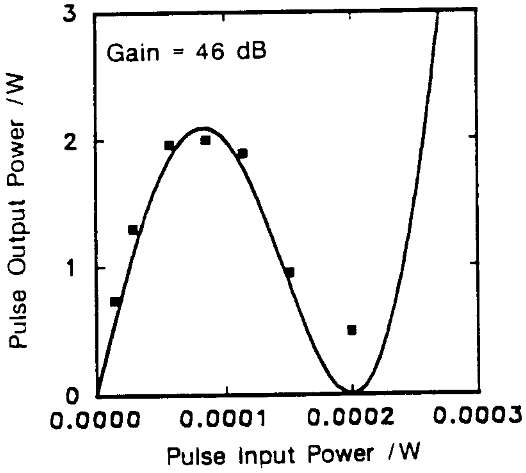

Figure 3 Input/Output power transfer function for amplified non-linear loop mirror