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Efficient frequency conversion in optical fibers with tailored birefringence.

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Summary

Four wave mixing in optical fibers has long been recognised as important method of generating new optical frequencies. The process holds promise as a means of wavelength switching for optical communications, but the presence of a nonlinear term in the phase-matching condition normally prevents strong energy exchange between the waves (1). We present here a scheme for optimising the conversion efficiency. The four wave mixing process considered here is called polarisation modulation instability (PMI) where a strong pump wave on one axis of a birefringent fiber results in the growth of two equally detuned sidebands on the other axis. In the absence of any external seed the sidebands start to grow with a frequency shift f_0 where the wavevector mismatch is zero. This mismatch is a function of the power of the pump and the fibre's birefringence, dispersion, and nonlinearity. Our analysis of the evolution of the power in the sidebands utilises three coupled mode equations which describe the interaction of a monochromatic pump, with a pair of sidebands polarised along the orthogonal fibre axis. In the absence of Raman gain, it is possible to solve these equations so that by varying the birefringence along the fibre, the sidebands with a frequency shift of f_0 are phase matched for the entire length of the fibre. Figure 1 shows this calculated birefringence as a function of the normalised fibre length (1).

In the absence of a tailored birefringence, and with no Raman gain, the evolution of the sidebands is spatially periodic with a maximum of about 20% of the power in each sideband, whereas with the tailored birefringence, complete conversion is, in principle, possible with 50% of the original pump power in the Stokes sideband, and 50% in the antistokes sideband. The presence of Raman gain adds an additional mechanism for the transfer of power between the three waves. Although no analytic solutions exist for the evolution equations in this case, complete transfer of power from the pump to the sidebands is still possible for a fiber with a tailored birefringence, but the Raman gain results in stronger growth of the Stokes sideband, and the eventually decay of the anti-Stokes

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sideband. This is shown in Figure 2 where the power evolution is compared for fibres with tailored birefringence without and with Raman gain.

The required variation of the birefringence can be achieved by winding the fibre on a tapered spool, and we have performed experiments to assess the efficiency with which the pump power can be converted into sideband power using the arrangement shown in Figure 3. As an intense pump (700W), pulses from a cavity-dumped mode-locked Krypton laser (λ=647nm) were used. In order to demonstrate the improved conversion of PMI sidebands in fibers with the correct tailored birefringence we prepared two fibers each 2.2m long. With parameters used in our experiment, the actual length of 2.2m corresponds to a normalised length of ξ=8 (see fig.2). The first was wrapped around a spool with a constant diameter of 3cm. The second was wrapped around a spool whose diameter (and therefore its birefringence) changed as a function of fiber length as required by the theoretical investigation (see Fig.1). With this set-up the frequency shift of the sidebands reletive to the pump was about ±5THz. To achieve a higher conversion efficiency a very small seed at the Stokes frequency was used in both cases. With a simple spool, only 8% of the pump power could be converted into the sidebands (with 3.5% in the antistokes), while we have obtained substantially increased conversion efficiency (35% with 8% in the antistokes) using the tapered spool. The results indicate that with further optimisation, greater conversion efficiencies should be possible.

Reference

1. S.G.Murdoch , R. Leonhardt and J.D.Harvey, "Nonlinear dynamics of polarization modulation instability in optical fibres" J. Opt. Soc. Am. B **14**, 3403 (1997).

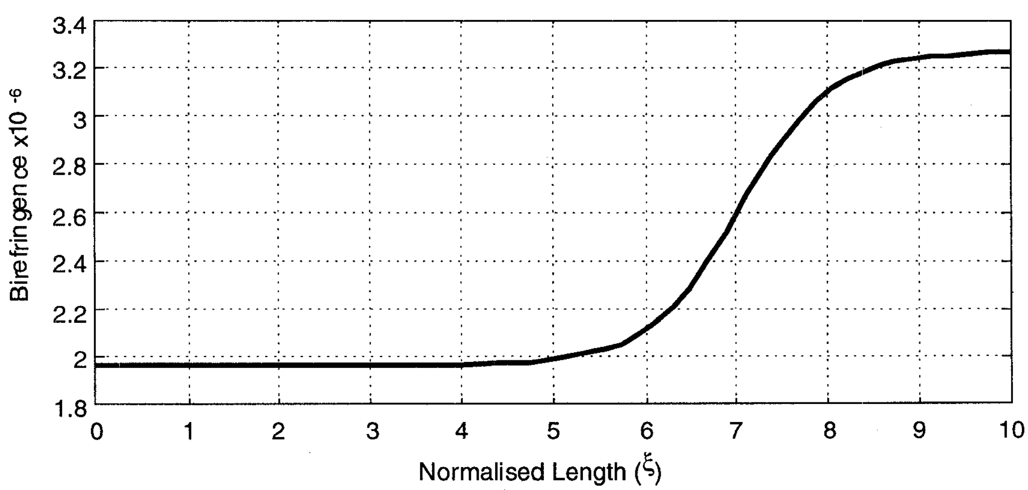

Figure 1: Calculated birefringence for optimal phasematching over the entire length of the fibre as a function of the normalised fibre length.

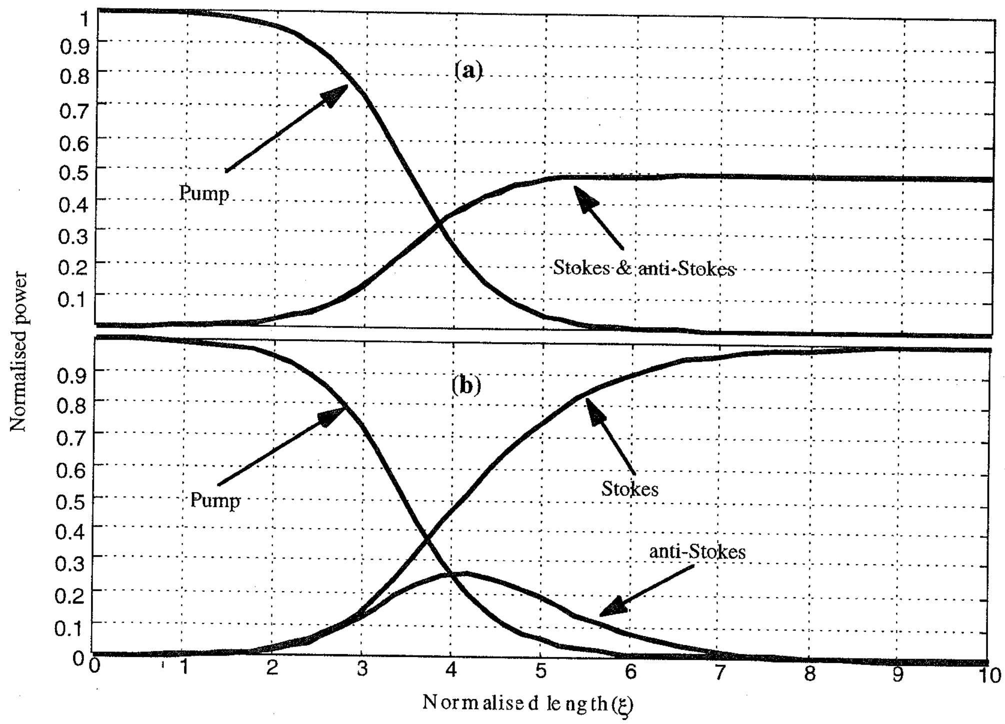

Figure 2: Calculated power conversion to the stokes and antistokes PMI sidebands considering a fibre with tailored birefringence: (a) without Raman gain, (b) with Raman gain.

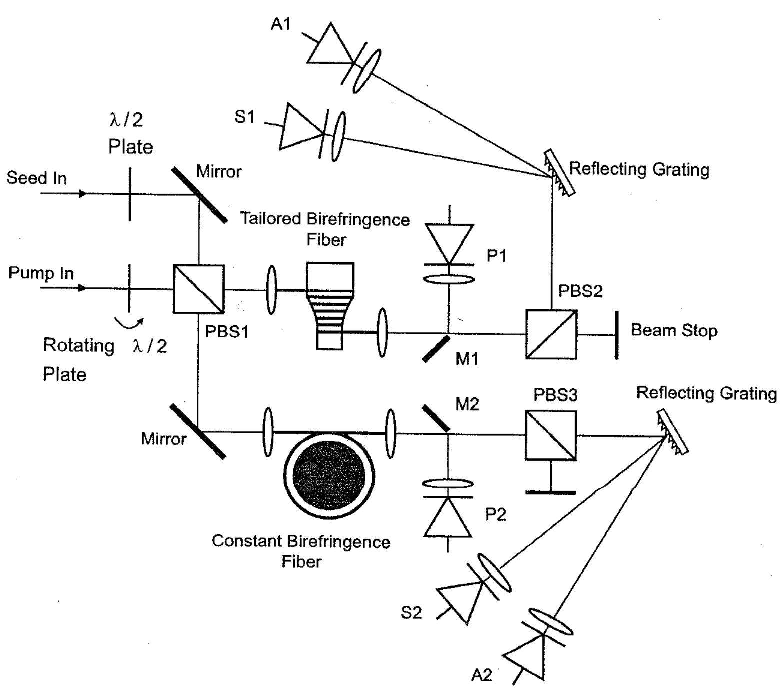

Figure 3 Experimental arrangement for observation of enhanced power conversion in four wave mixing experiments using a tailored birefringence fibre