Phase-Matched Three-Wave Mixing in Poled Optical Fibres

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Introduction

It is now well known that high-intensity light may be used to write second-order non-linear gratings into optical fibres[1,2,3]. The process is thought to be due to the alignment of defect centres[3], a view which is supported by the recently demonstrated fibre poling technique[4]. In this, even stronger second-order non-linearities are generated by applying external electric fields to the fibre. Fibre poling has produced second-order non-linearities only ten times lower than in KDP[4] and uniformly poled fibres have been employed as electro-optic modulators[5]. Efficient second-harmonic generation has been demonstrated in poled fibres by employing mode-interference gratings (MIGs) for phase-matching[6]. MIGs can maintain coherent in-phase propagation of the pump and SH-light in up to 10cm of fibre, limited only by fibre non-uniformities. Here, we demonstrate for the first time that MIGs may also be employed for phase-matching general three- wave mixing processes in poled optical fibres. The phase-matching conditions for TWM may easily be estimated from measurements of the wavelenghts where phase-matched SHG is obtained.

Experiment

We used a D-shaped GeO_2-doped silica fibre with an internal electrode4 and an elliptical core of aspect ratio 1.7. The core area was $9\mu m^2$ and the GeO_2-concentration was 15 mole%. The fibre was excitation poled[6] with 40mW of light at 488nm and a poling field of $140V/\mu m$. The polarisation of the defect excitation light was aligned with the poling field. Care was taken to keep the launching conditions constant during the poling process. Mode-beating then leads to the formation of MIGs[6]. The MIGs were studied by measuring the SH-conversion efficiency as a function of pump wavelength, where the pump light polarisation was again aligned with the poling field.

As shown in Figure 1 phase-matching was obtained at 1.0335 and $1.0509\mu m$. At both wavelengths the pump was propagating in the E_{11}-mode and the SH was propagating in the E_{12}-mode. Using a simple slab waveguide analysis of the dispersion properties of the fibre[6], the two phase-match peaks can be related to MIGs generated by interference between the blue E_{21} and E_{24}-modes and by interference between the blue E_{11} and E_{14}-modes.

TWM was studied by launching both infrared pump-light at $1.064\mu m$ from a YAG laser and wavelength-tunable light from a dye laser into the fibre. For simplicity, we consider only the case where phase-matched SHG and TWM is obtained with the same set of modes and the same MIG, i.e. the SH and the TWM-signal as well as the respective pump waves for the two processes are assumed to propagate in the same modes. Neglecting the dispersion of the fibre, the frequencies ν_{TWM} at which phase-matching is obtained for TWM are given by

$$\nu_{TWM} = 2 * (\nu_{SHG} - \nu_{YAG}) + \nu'_{YAG} \qquad (1)$$

where ν_{YAG} is the optical frequency of the YAG laser and ν_{SHG} stands for the frequencies at which phase-matching is obtained for SHG. Thus a MIG producing phase-matched SHG can in general also produce phase-matched TWM for the same set of propagating waveguide modes.

Figure 1: SH and corresponding TWM signal as a function of pump-wavelength around the vicinity of the phasematch peaks related to MIGs 1 and 2. In the case of the TWM-signal light of $1.064\mu m$ is also launched into the fibre.

As shown in Figure 1 phase-matched TWM is obtained at 1.0043 and $1.0385\mu m$, which is in good agreement with Equation (1). Note that the conversion efficiencies for phase-matched SHG and TWM were the same and that conversion efficiencies up to 1% with a pump power of 150W could be obtained. By mixing the YAG-laser wavelength with wavelengths around 700nm blue light was generated, where the conversion efficiencies under phase-match conditions were typically 3 times lower compared to the generation of green light.

Conclusion

In conclusion we have demonstrated TWM in poled optical fibres by employing MIGs for phase-matching. Since the conversion efficiencies could be substantially improved upon by using optimised fibre designs[6], poled fibres also have a great potential as parametric amplifiers and oscillators, where phase-matching techniques as demonstrated here could be employed.

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References

1. Margulis, W. and Sterberg, U. , J. Opt. Soc. Am. B, Vol. 5, 1988, pp. 312.
2. Farries, M. C. , Russell, P. St. J. , Fermann, M. E. and Payne, D. N. , "Second-harmonic generation in an optical fibre by self-written F(2) grating", Elect. Lett., Vol. 23, 1987, pp. 322–324.
3. Stolen, R. H. and Tom, H. W. K. , Opt. Lett., Vol. 12, 1987, p. 585.
4. Bergot, M. V. , Farries, M. C. , Fermann, M. E. , Li, L. , Poyntz-Wright, L. J. , Russell, P. St. J. and Smithson, A. , "Generation of permanent optically-induced second-order non-linearities in optical fibres by poling", Opt. Lett., Vol. 13, 1988, pp.592–594.
5. Li, L. and Payne, D. N. , "Permanently-induced linear electro-optic effect in silica optical fibres", Proc. IGWO '89, Houston, Vol. 4, 1989, pp. 130–133.
6. Fermann, M. E. , Li, L. , Farries, M. C. , Poyntz-Wright, L. J. and Dong, L. , "Second-harmonic generation using gratings optically written by mode interference in poled optical fibres", Opt. Lett, Vol. 14, 1989, pp. 748–750.

PHASE-MATCHED THREE-WAVE MIXING AND SECOND HARMONIC GENERATION

21·0 to 8·0