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Tunable second order susceptibility gratings

for harmonic generation in optical fibres.

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Abstract

Optically written tunable $\chi^{(2)}$ gratings for 1% efficient second harmonic generation are described. The operating wavelength of the grating is step-tunable from 1.050μm to 1.078μm by modification of the grating period using fibre birefringence.

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Summary

Growth of second harmonic (SH) from 1064 nm light in optical fibres up to final efficiencies of around 1% has been observed by several workers[1,2,3]. We were the first[2] to identify the mechanism for this unusual phenomenon in terms of an optically-written defect grating in the fibre with a $\chi^{(2)}$ modulated at the phase mismatch period between pump and SH light. The orientation of the $\chi^{(2)}$ grating is determined by the periodically reversing internal dc field that arises via a third order nonlinear interaction between pump and SH light[3].

In this paper we report that $\chi^{(2)}$ aligns with the direction of the SH seed polarisation, and that SH conversion can be achieved at wavelengths other than the writing wavelength by tuning the grating via birefringence, stretching or self-phase-modulation. The gratings were produced by launching Q-switched mode-locked pulses from a Nd-YAG laser into a P-doped germanosilicate single-mode (at 1064 nm) optical fibre. A KDP crystal was inserted between the laser and the fibre in order to provide a mixture of 4% SH at 532 nm and 96% pump at 1064 nm. This was then used to seed the fibre grating (Fig 1). Three separate writing combinations were tried (see figure 3). SH conversion efficiencies of 1% were obtained at input powers of 400W when the SH seed was removed after 15 minutes of writing.

Phase-matched SH conversion is obtained when the grating vector K matches the difference in propagation constants between the doubled pump and the free SH waves, i.e., when $K = 4\pi(N_s - N_p)/\lambda_p$, where N_s and N_p are the mode indices of the SH and pump, and λ_p the pump wavelength. This condition is satisfied at the writing wavelength but can also be obeyed at other wavelengths in birefringent fibres. We used a bow-tie fibre with a beat length of 2.3 mm at 1064 nm and hence a difference in propagation constants between the polarisation axes of 2.73 mm^{-1}. Fig. 2 shows how changes in N_s, N_p, λ_p, the grating spacing, and the pump polarization can lead to phase-matched SH generation at new wavelengths. When the pump polarization is orthogonal to its writing direction one obtains a conversion peak at either 1050nm or 1078nm, depending on whether the axis of writing was fast or slow. The results shown in Fig.3 were obtained by scanning the pump wavelength around 1064 nm (the writing wavelength) and measuring the SH conversion efficiency. The additional peaks indicate further resonances obtained from the SH E_{21} mode.

Small changes in the grating vector can be produced by stretching the fibre under tension. This both increases the grating period and changes the effective index of the fibre. A shift of 0.8nm resulted from an axial stress of 196 kN/mm^2. The operating linewidth of the grating is dependent on the writing laser linewidth which can be increased from 7GHz to 31GHz in 10cm of fibre by self-phase-modulation. This reduces the grating length and increases the bandwidth. We have produced gratings which phase match to SH over linewidths varying from 0.05nm to 0.24nm around the writing wavelength.

REFERENCES

1. Österberg U. and Margulis W., Opt Lett 12 57 (1987).
2. Farries M.C, Russell P.St.J., Fermann M.E. and Payne D.N., Electr Lett 23 322 (1987).
3. Stolen R.H. and Tom H.W.K., to be published in Opt Lett.

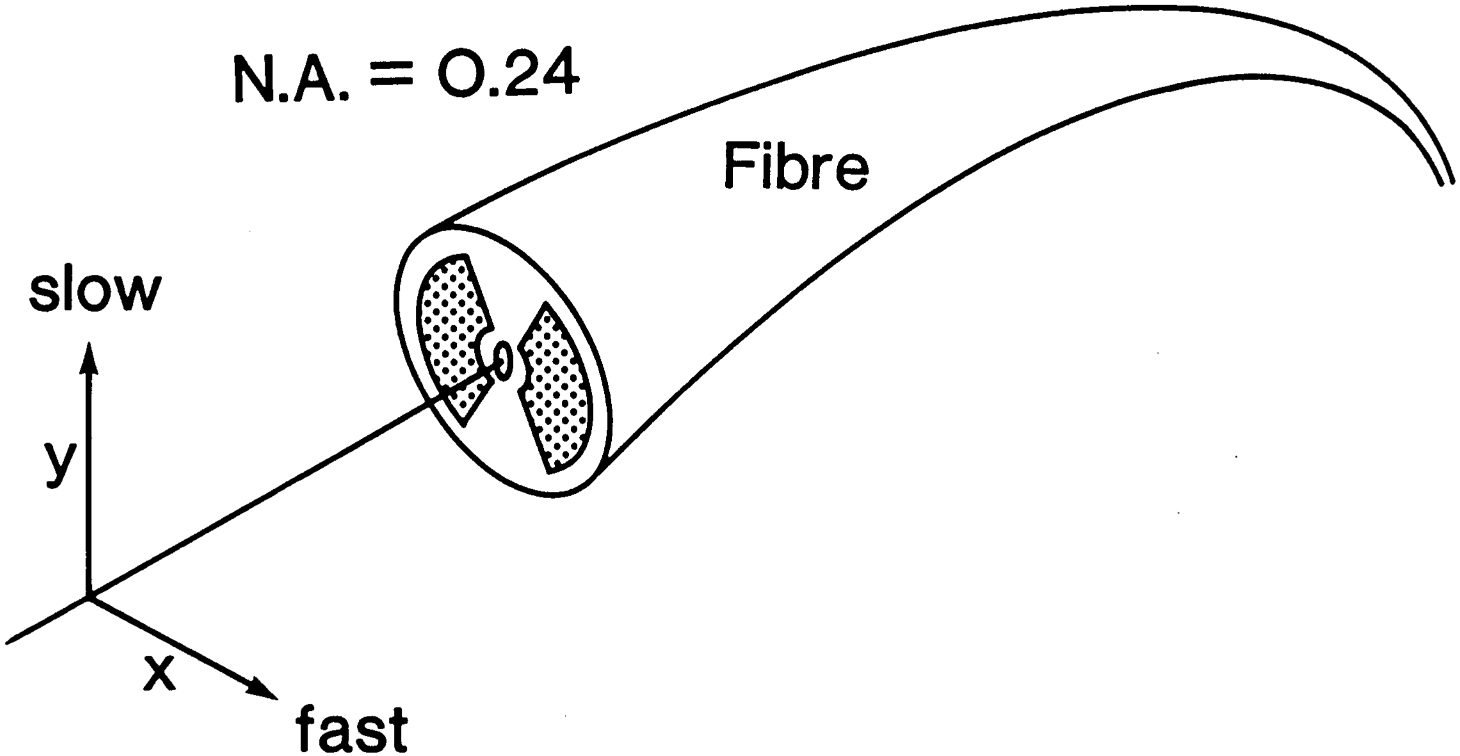
FIGURE CAPTIONS

1. The fibre geometry. Fabrication constraints meant that the core was elliptical with an aspect ratio of 2.5:1. Since the fiber N.A. was high (0.24), form birefringence dominated over stress, and the bow-tie fast/slow axes were reversed from their more usual positions.

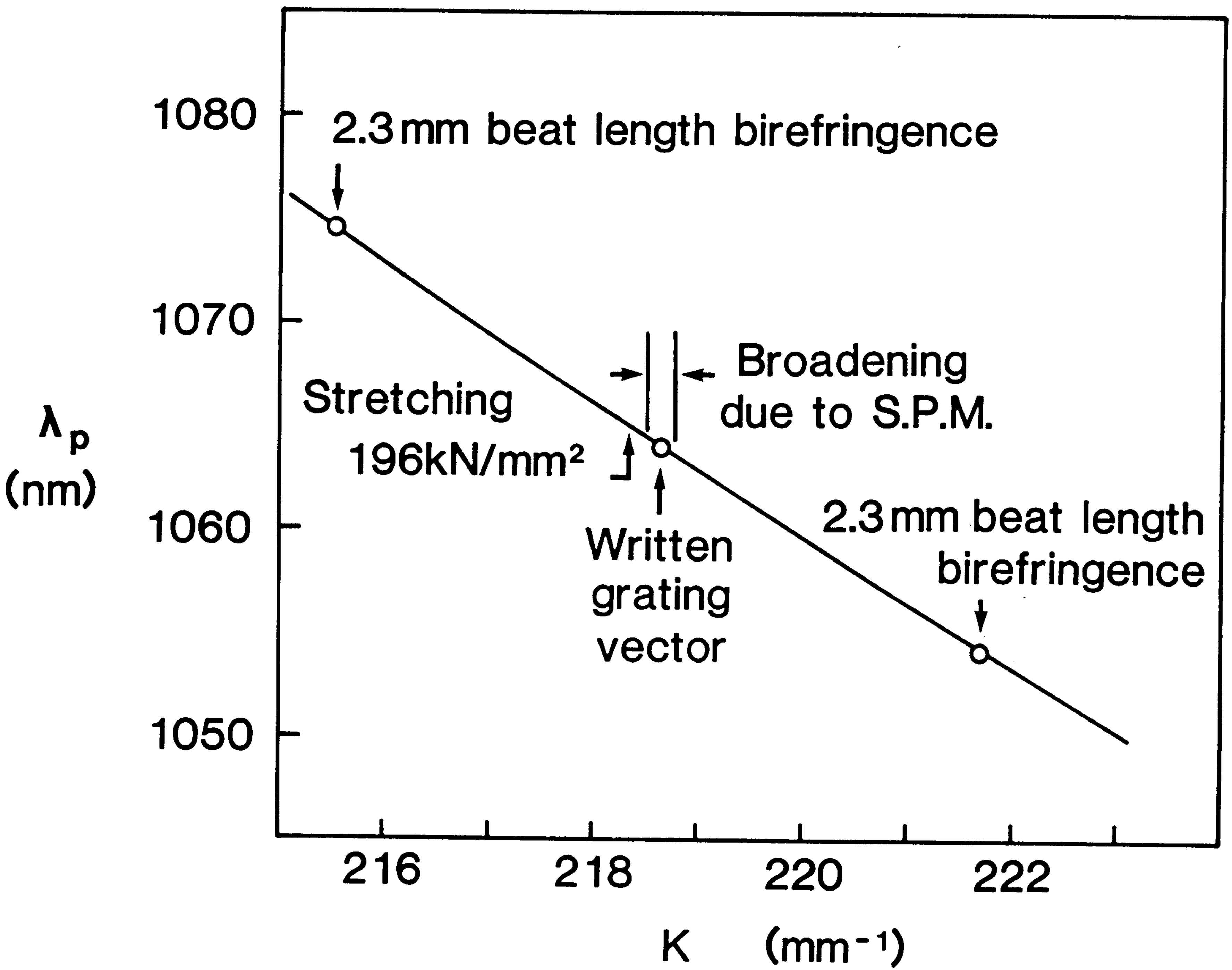
2. The tuning that can be achieved by self-phase-modulation (SPM) of the writing light, mechanical stretching and a birefringence of beat-length 2.3 mm.

3. SH conversion efficiency versus read-out λ_p. In each case the polarization of the read-out pump is parallel to the SH seed polarization. The writing polarizations were (see insets):
   - (a) Pump on slow birefringent axis of the fibre, SH seed on the fast axis;
   - (b) Pump and SH seed on fast axis;
   - (c) Pump on fast axis, SH seed on slow axis.

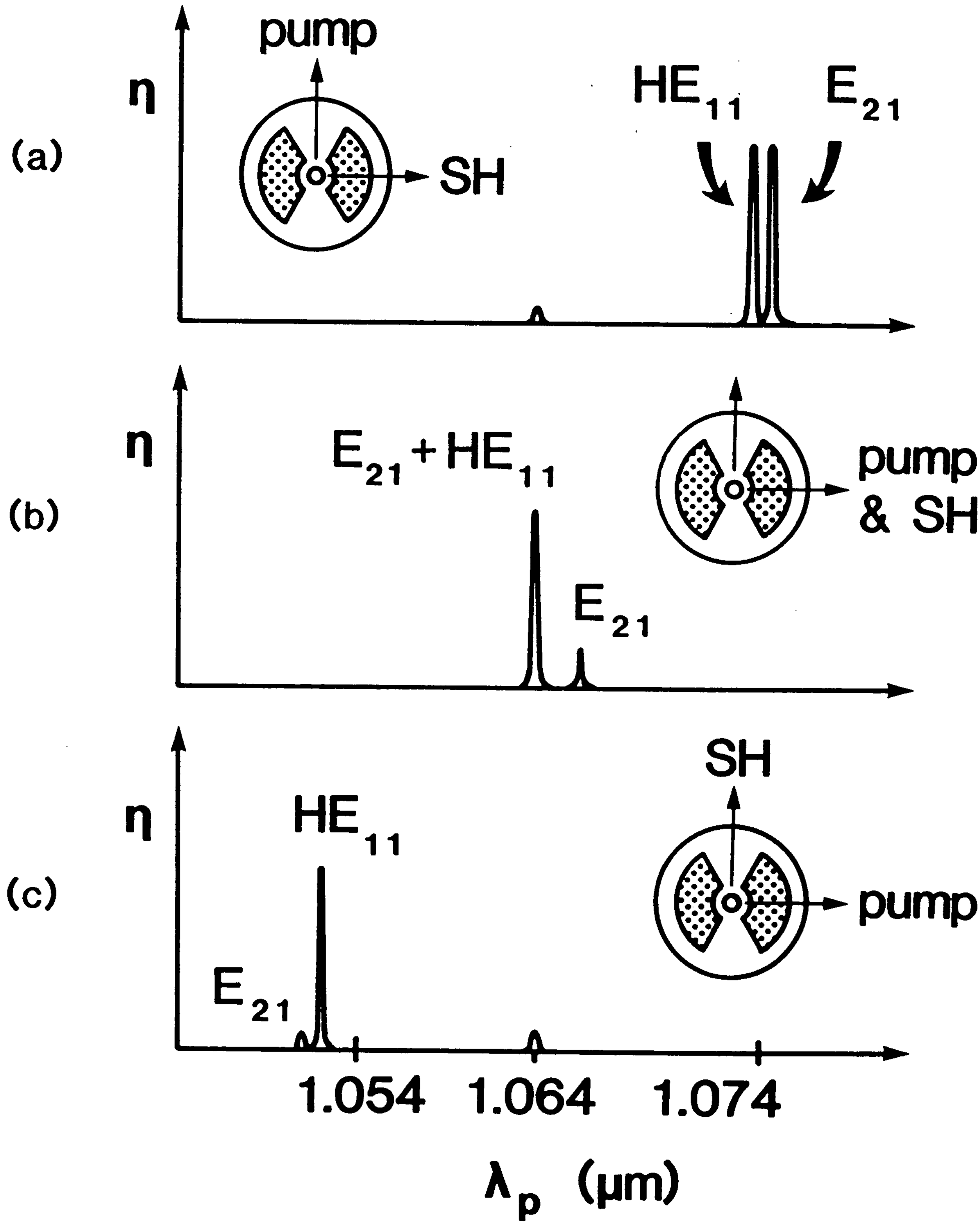
   The mode-types of the generated SH signal are indicated beside each peak.



N.A. = O.24
Fibre
slow
y
x
fast



2.3mm beat length birefringence
Stretching
196kN/mm²
Broadening
due to S.P.M.
Written
grating
vector
2.3mm beat length
birefringence
1080
1070
1060
1050
λp
(nm)
216
218
220
222
K (mm⁻¹)



(a)
η
pump
SH
HE11
E21
(b)
η
E21 + HE11
E21
pump
& SH
(c)
η
HE11
E21
SH
pump
1.054
1.064
1.074
λp (μm)