Tunable second order susceptibility gratings
for harmonic generation in optical fibres.

M.C. Farries, M.E. Fermann, P.St.J. Russell, D.N. Payne.

Optical Fibre Group
Dept. of Electronics and Computer Science
University of Southampton
Southampton S09 5NH, U.K.
Tel: (0703) 559122.

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 1.050$\mu$m to 1.078$\mu$m 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. We were the first 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.
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 $\mathbf{K}$ matches the difference in propagation constants between the doubled pump and the free SH waves, i.e., when $\mathbf{K} = 4\pi(N_S-N_P)/\lambda_p$, where $N_S$ and $N_P$ are the mode indices of the SH and pump, and $\lambda_p$ 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 $N_S$, $N_P$, $\lambda_p$, 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 E21 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/mm². 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

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 $\lambda_p$. 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.
The graph shows the relationship between $\lambda_p$ (nm) and $K$ (mm$^{-1}$). The data points indicate that stretching at 196 kN/mm$^2$ and broadening due to S.P.M. cause a decrease in $\lambda_p$. The 2.3 mm beat length birefringence is also indicated on the graph.