FREQUENCY DOUBLING OF 1·319 μm RADIATION IN AN OPTICAL FIBRE BY OPTICALLY WRITTEN $\chi^{(2)}$ GRATING

Indexing terms: Optical fibres, Frequency multipliers

Frequency doubling of 1·319 μm radiation by an optically-written $\chi^{(2)}$ grating in a single-mode optical fibre is reported. A peak power of 25 mW at 659 nm was generated in 13 cm of fibre. Phase matching is achieved by periodic modulation of the nonlinear susceptibility. Third harmonic generation of ultraviolet radiation is shown to be responsible for the creation of defect centres.

Introduction: Efficient frequency doubling of 1·064 μm radiation in optical fibres has been reported by a number of groups[1,2] and was analysed in our earlier paper.[2] The effect relies upon the excitation of a periodic array of aligned defect centres. The defect centres are polarised to produce a second order nonlinear susceptibility which is periodic along the axis of the fibre. This period exactly matches the coherence length between the pump and second harmonic wave and hence provides for phase-matched second harmonic generation. Previous work on SHG gratings in fibres has used 1·064 μm or shorter wavelength radiation. We report here for the first time phase-matched frequency doubling of 1·319 μm radiation in an optical fibre.

Experiment: Mode-locked and *Q*-switched pulses from a Nd-YAG laser operating at 1·319 μm were passed through an $LiIO_3$ crystal to generate the seed second-harmonic at 659 nm. Both 1·319 μm and 659 nm of peak powers 520 W and 0·3 W respectively were coherently launched into the silica fibre, which was codoped with Ge and P_2O_5 and had a single-mode cutoff of 850 nm. After 3 hours the $LiIO_3$ crystal was removed and it was observed that the SH power generated in the fibre had grown from an initial 2 μW to 25 mW peak power (Fig. 1). The active length of the fibre was 13 cm, as determined by cutting back the fibre.

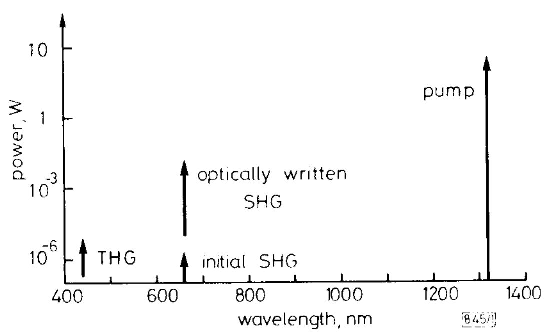

Fig. 1 *Harmonic generation in an optical fibre pumped at 1·319 μm*

Mixing between the pump 1·319 μm and the seed 659 nm waves via the third-order nonlinearity in the fibre generates a DC electric field.[3] The field is periodic in space with a period given by the phase mismatch vector between the pump and the probe. The period was calculated as 64 μm in this fibre. Defects are aligned in the DC field to give a permanent $\chi^{(2)}$ grating. The periodic $\chi^{(2)}$ grating generates a phase-matched second harmonic at 659 nm when pumped at 1·319 μm.

Defects can be created in a fibre with wavelengths below 550 nm but 659 nm does not produce significant defect centres. However it was observed that a peak power of approximately 10 μW of third harmonic at 439 nm is also generated in the fibre.

The third harmonic power is given by

$$P_{3\omega} = \frac{4P_\omega \omega^2 \chi^{(3)2} l^2}{c^4 \varepsilon^2 A^2} \quad (1)$$

where l is the interaction length for THG, ω is the pump frequency, A is the fibre spot area, and $\chi^{(3)}$ is the third-order susceptibility (10^{-22}).

The third harmonic generation is not phase-matched and therefore only builds up over the coherence length of 15 μm. We calculated the peak third harmonic power as 27 μW ± 20% which is in good agreement with the measured values.

Defect creation in phosphorus doped fibres is highly sensitive at this wavelength.[4] It is therefore thought that short wavelength light produced by THG in optical fibres is responsible for the creation of defects which are then aligned by the DC field to produce a net dipole moment and hence a $\chi^{(2)}$ in the fibre.

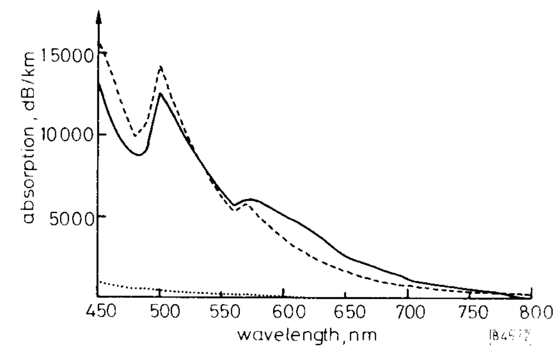

Fig. 2 *Increase in optical absorption during writing process or by excitation by 457 nm light*

- - - - fibre with 1·319 μm pumped SHG grating
——— fibre irradiated with 457 nm
······ non-irradiated fibre

Further evidence for the creation of defect centres by third harmonic generation is given by the increase in the fibre loss at wavelengths below 600 nm (Fig. 2). A similar fibre was exposed to an equivalent average energy at 632 nm. No change in the absorption was observed as a result of this irradiation. However, exposing the same fibre to 457 nm light induced an absorption identical to that of the grating. These induced absorptions are typical of those obtained by UV or gamma ray excited defects in fibres.

The conversion efficiency at 1·319 μm is weak compared with reported 5% conversion at 1·064 μm. This is partly due to the weak seed light of 0·3 W and also the smaller third-order nonlinearity at this wavelength, resulting in a DC field during the writing process of the order of 10 V/m.

Conclusions: We have demonstrated for the first time second harmonic conversion from 1·319 μm to the red 0·659 μm. The optically written defect centres are not easily excited by these wavelengths. However, there is significant third harmonic generation at 439 nm, which is shown to have sufficient energy to excite defect centres in the P_2O_5-Ge doped silica fibre. A considerable improvement in conversion efficiency may be expected with higher seed intensities.

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