Broadband higher-order harmonic generation in two-dimensional nonlinear photonic crystals

R. T. Bratfalean and N. G. R. Broderick
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK.
Phone: +44 (0)23 80594523, Fax: +44 (0)23 80593142, email: rtb@orc.soton.ac.uk

Since Berger's original description of two dimensional nonlinear photonic crystals (NPC) [1] they have been used in a number of applications such as cascaded higher harmonic generation, transverse beam profiling, multiple wavelength interchange and conical beam generation. The reason for this wide range of uses is that a 2D NPC as compared to a 1D NPC has a greater number of degrees of freedom to quasi-phase-match (QPM) nonlinear interactions. Here we show that in 2D NPCs, cascaded processes, such as 4th harmonic generation (FHG), can have extremely large theoretical bandwidths (> 60nm). Such bandwidths are not to our knowledge possible in other materials highlighting the advantages of engineered materials for nonlinear optics.

Quasi-phase matching in a NPC satisfies momentum conservation with the help of one of the reciprocal lattice vectors (RLV) of the crystal. FHG is a two step process with two QPM requirements and so two different RLVs ($\mathbf{G}_1$ and $\mathbf{G}_2$) are needed as shown in Fig. 1 (insert) where $\mathbf{k}_{1,2,4}$ are the wave vectors for the fundamental, 2nd harmonic and 4th harmonic respectively. For a crystal of length L the bandwidth of such a process is determined by the phase mismatch, $(\Delta\mathbf{k} \cdot L)$, from the ideal case, $(\Delta\mathbf{k} = 0)$. When designing a 2D NPC for FHG two out of the four parameters of the QPM structure are set by the two QPM conditions. So the remaining degrees of freedom can be used to optimise the process for maximal bandwidth. In our scheme we optimise the angle between the two RLVs used, for the maximum bandwidth of the interaction. Fig. 1 shows the bandwidth dependence upon β for the case of FHG of the 1800nm wavelength in lithium niobate at 140° C. In this case the fundamental beam has a divergence of 3.5°. Fig. 1 shows that the spectral width rapidly increases from a typical value of <0.5nm, to a peak value of ~69nm for β≈69°. Similarly the temperature bandwidth increases to more than 63°C for β ≈ 53 degrees. We believe that this type of resonant behaviour is unique to cascaded processes in 2D NPCs and we are not aware of it being described for any other system.

These results can be understood by first considering the simpler situation of a single step QPM process, where a large spectral width can be easily obtained via a non-collinear interaction with a diverging beam. Also required is an additional degree of freedom provided by the QPM structure to compensate for the changing wavelength. Hence a single step nonlinear process with a single QPM constraint can be broadband in both 1D and 2D NPCs, as both have at least two degrees of freedom. For a cascaded two step process, the number of QPM constraints equals the number of parameters in a 1D NPC but is still less than that of a 2D NPC. This means that in some 2D NPCs cascaded QPM schemes can have the necessary flexibility to counterbalance the dispersion properties in the 1-st step of the process with those in the 2-nd step, so to give a large spectral width for the cascaded process as a whole, whereas this is not the case in a 1D NPC.

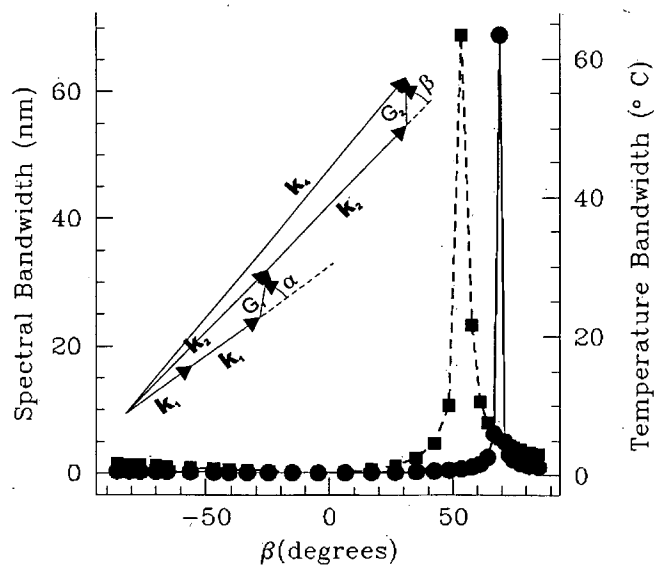

Fig 1. β dependence for the spectral width (circles) and temperature width (squares) for the THG of 1800nm wavelength in LN at 140 degrees Celsius. The inset shows the QPM geometry of the process.

In conclusion we have shown that 2D NPCs can be designed to support FHG cascaded processes, which have bandwidths in excess of 60 nm. These crystals should find applications in areas such as frequency conversion of ultra-short pulses and wavelength tolerant designs. We are currently extending our investigation to 3-rd harmonic generation processes. We also plan to fabricate such crystals and hope to present experimental observations in the future.

[1] V. Berger, Phys. Rev. Lett., **81**, pp 4136 (1998).