

## Hexagonally-poled lithium niobate (HEXLN)

Graeme W. Ross, Neil G. Broderick, Herman L. Offerhaus, Peter G.R. Smith, David J. Richardson  
and David C. Hanna

*Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, United Kingdom.*

*Tel : + 44 (0)2380 593144, Fax : + 44 (0)2380 593142*

*[gwr@orc.soton.ac.uk](mailto:gwr@orc.soton.ac.uk)*

**Abstract:** We report the fabrication and nonlinear optical characterisation of 2-D hexagonally-poled lithium niobate (HEXLN). The various reciprocal lattice vectors of the 2-D format permit multiple noncolinear quasi-phase matching geometries. Second-harmonic conversion efficiencies > 60% are observed.

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OCIS Codes: (190.4400) Nonlinear optics, materials; (190.4410) Nonlinear optics, parametric processes; (230.4000) Microstructure fabrication; (230.4320) Nonlinear optical devices

The concept of quasi-phase matching (QPM) nonlinear optical processes by periodically inverting a material's nonlinear susceptibility ( $\chi_2$ ) is a familiar one in 1-D : a well known example is periodically-poled lithium niobate (PPLN) which is commonly used for optical frequency conversion applications. A recent proposal [1] has generalised this concept and introduced the notion of a 2-D "nonlinear photonic crystal" (NPC) in which  $\chi_2$  changes sign periodically across the plane of the sample. Here we report the demonstration of such a 2-D NPC, hexagonally-poled lithium niobate (HEXLN), and describe its fabrication and phase matching characteristics.

Phase matching may be considered in terms of momentum conservation of the interacting photons and the reciprocal lattice vectors (RLVs) of the periodic structure. The reciprocal ( $k$ -space) lattice of a 2-D hexagonal lattice is also hexagonal. In contrast with 1-D PPLN, 2-D HEXLN has RLVs at numerous angles which permit noncolinear 2-D QPM across the plane.

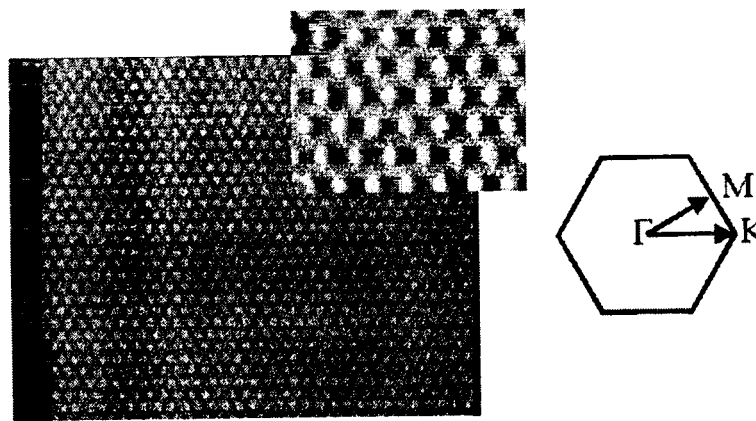


Fig. 1. Photograph of the HEXLN crystal showing the excellent uniformity and detailed structure (inset). The period of the domain-inverted pattern is  $18\mu\text{m}$ . The first Brillouin zone is illustrated on the right.

Engineering of the HEXLN structure was achieved via room-temperature electric-field poling of a 0.3mm thick, z-cut wafer of  $\text{LiNbO}_3$ . A patterned electrode was defined on the -z face using photoresist and liquid electrodes. The x-y orientation of the hexagonal array (period  $\Lambda_{\text{HEXLN}}=18\mu\text{m}$ ) was carefully aligned to coincide with the crystal's natural preferred domain wall orientation: at room temperature ( $\sim 20^\circ\text{C}$ )  $\text{LiNbO}_3$  has crystal class  $3m$  and shows a tendency for domain walls to form parallel to the y-axis and at  $\pm 60^\circ$ . The resulting domain pattern was found to be uniform across the sample dimensions of 14 x 7mm (x-y) as shown in figure 1. The inset shows a magnified section which shows the honeycomb structure clearly.

The QPM properties of HEXLN were characterised using the output from a high-power erbium-fibre chirped pulse amplification (CPA) system as a source of fundamental radiation at  $1.536\mu\text{m}$ . Pulses of 4ps duration at a repetition-rate of 20kHz and up to 300kW peak power were incident on the polished x-face of the sample which was placed in an oven and mounted on a rotation stage. The observation of noncolinear second-harmonic generation, and simultaneous third and fourth-harmonic generation at different angles, indicates 2-D QPM. With the fundamental beam propagating along the crystal x-axis, two second-harmonic beams emerge at  $\pm 1.1^\circ$ , symmetrically placed about the transmitted fundamental. The total second-harmonic output power demonstrates a conversion efficiency of over 60%, corresponding to an internal conversion efficiency of  $\sim 80\%$  (40% in each beam) [2]. A wide temperature tuning bandwidth is also observed. As the HEXLN crystal is rotated, phase matching via different RLVs is observed as shown in figure 2. Measurements of the angular dependence of the second-harmonic process on fundamental input angle shows good overall agreement with theory - even for the higher order Fourier coefficients - indicating the high quality of the domain structure. The inversion symmetry of the data results from the hexagonal symmetry of the poled material.

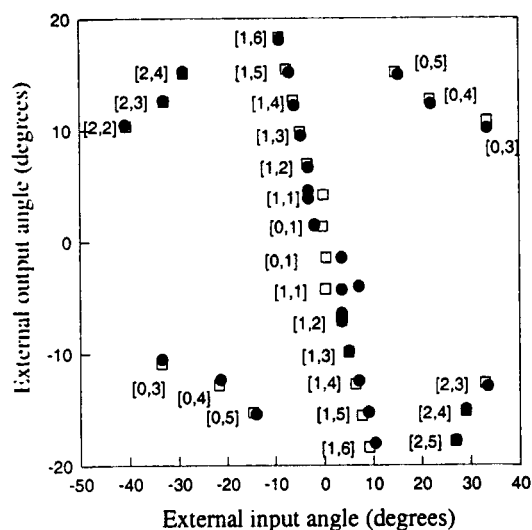


Fig. 2. Graph of the experimental (solid circles) and theoretical (open squares) output angles for the second harmonic as a function of the external input angle of the fundamental. 0° indicates propagation in the  $\Gamma\text{K}$  direction.

[1] V. Berger, "Nonlinear photonic crystals," Phys. Rev. Lett., **81**, 4136-4139 (1998)

[2] N.G.R. Broderick, G.W. Ross, D.J. Richardson and D.C. Hanna, "HeXLN: a 2-dimensional nonlinear photonic crystal," postdeadline paper PD1, OSA Topical Meeting on Nonlinear Guided Waves and Their Applications, Dijon, France (1999)