Wide tuning and multi-wavelength SHG from 2D $\chi^{(2)}$ nonlinear photonic crystal of tetragonal lattice structure

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Abstract: Multi-pairs of SHG were observed in 2D-QPM nonlinear photonic crystal with a spectral tuning range over 150nm by 1.55μm pump OPO. These observations are ascribed to the $\mathbf{G}_{mn}(\phi)$ dispersion in the tetragonal QPM structure.

OCIS codes: (190.4400) Nonlinear optics materials; (160.3730) $LiNbO_3$

The use of quasi-phase-matching (QPM) technique to compensate the refractive index dispersion and to enhance the nonlinear wave interactions has been actively pursued in nonlinear optics. A novel two-dimensional (2D) $\chi^{(2)}$ nonlinear photonic crystal (NPC) has recently been proposed to render multi-wavelengths generation due to a plural form of phase-matching reciprocal lattice vectors ($\mathbf{G}_{mn}$) in the 2D lattice structure [1]. In the case of harmonic generation, the presence of $\mathbf{G}_{mn}$ vectors in the latter can result in QPM for several propagation directions that are off-axis from the fundamental pump beam. Simultaneous third- and fourth-harmonic generation [2], and nonlinear SHG wavelength switching [3] represent the novel optical functionalities that can be realized in the 2D NPC.

We have recently demonstrated a two-step poling method that can be used to fabricate large area 2D-NPC [4]. Restriction on the nucleation and lateral motion of inverted domain by the charged domain boundary allows the fabrication of 2D periodically poled $\chi^{(2)}$ NPC with various geometry lattice structures on $LiNbO_3$. Shown in Fig 1(a) is one such example of 2D-NPC that is capable of phase-matching to the 1.55μm communications band lasers at room temperature. The drawing of Fig. 1(b) represents several routes for QPM-SHG at different pump wavelengths and the corresponding spatial separation of the fundamental and harmonic waves that is unique to the 2D NPC structure.

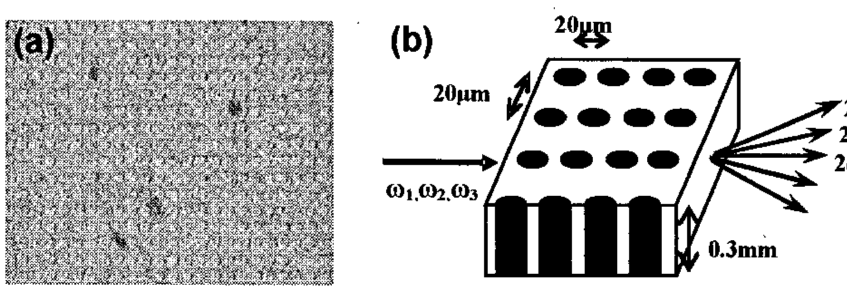

Fig. 1: (a) –Z etched micrograph showing a NPC consisting of 2D distribution of inverted domains. The domains have a periodicity of 20×20 μm^2 on a 300μm-thick Z-cut $LiNbO_3$ substrate. (b) schematic drawing showing multi-wavelength QPM-SHG process in (a)

The SHG measurements were conducted by using a pulsed grating-tuned periodically-poled $LiNbO_3$ optical parametric oscillator operating in the 1.55μm-band spanning a spectral range from 1450 to 1640nm [5]. The SHG intensity distribution in the far-field was recorded as the pump wavelength was changed. The SHG data in Fig. 2 were measured with the pump beam propagating along the crystal's x-axis. At a peak pump intensity of 12.5MW/cm^2, we observed 66mW output power at zero (0°) far-field angle with the 1589nm fundamental pump, while the corresponding values were (16.8mW, ±1.13°) for a 1580nm pump, and (6.4mW, ±2.25°) for a 1563nm pump, respectively. The mirror images in the far-field pattern and the reduction of conversion efficiency are reminiscent of a QPM-SHG mechanism due to the higher-order reciprocal lattice vectors $\mathbf{G}_{1,0}$, $\mathbf{G}_{1,\pm1}$, and $\mathbf{G}_{1,\pm2}$, respectively.

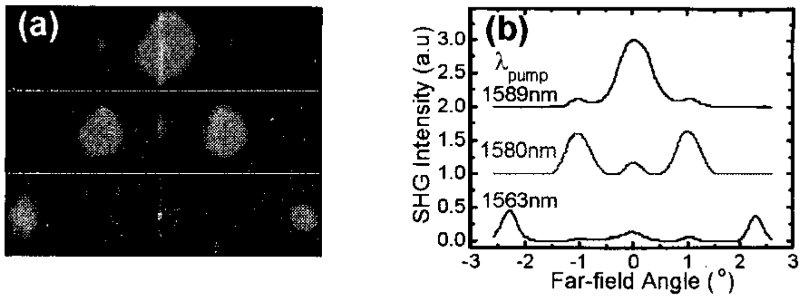

Fig. 2: (a) CCD images and (b) normalized far-field SHG intensity distribution for the sample in Fig. 1(a). The incident wavelengths are, from top to bottom, 1589, 1580, and 1563 nm.

To grant a further understanding of QPM in tetragonal $\chi^{(2)}$ NPC, we azimuthally rotated the sample such that the internal incident angle of the input beam relative to the x (or y) axis of the 2D NPC can be varied. In doing so, the QPM-SHG process can be selectively activated by a suitable reciprocal lattice vector that fulfills the phase-matching condition of $2\mathbf{k}_{\omega}+\mathbf{G}_{mn}(\phi) = \mathbf{k}_{2\omega}$. The normalized SHG spectra in Fig. 3(a) reveal an increase on the phase-matchable wavelengths and the spanning bandwidth with ϕ. Correspondingly the peak intensity of the SHG signals decreases with ϕ for the same $\mathbf{G}_{mn}$ due to an increase of the walk-off angle.

We further applied a ray-tracing method to obtain a quantitative analysis of the spatial distribution of the QPM-SHG process. Data in Fig. 3(b) shows that at $\phi = 0°$ QPM due to $\mathbf{G}_{1,\pm n}$ becomes degenerate and this explains why only three peaks were observed at $\phi = 0°$ as compared to five at $\phi > 0°$. It also illustrates a simple rotation of the 2D NPC can result in an increase of the QPM wavelength span. This could be beneficial to applications in optical information processing.

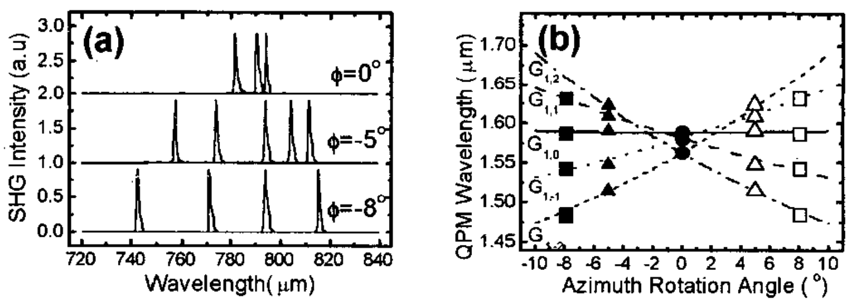

Fig. 3: (a) normalized QPM-SHG spectra measured at sample rotation angles of 0, −5, and −8 degrees. (b) dispersion curves of G_{mn} (ϕ) in the QPM-SHG process. Lines and dots: calculated results; symbols: experimental measurements.

In summary, we have demonstrated simultaneous spatial separation and broad wavelength tunability of QPM-SHG by using NPC that has a 2D tetragonal distribution in $\chi^{(2)}$. These observations are ascribed to the unique dispersion of $\mathbf{G}_{mn}(\phi)$ and non-vanishing $\chi^{(2)}$ ($\mathbf{G}_{mn}$)of the 2D NPC.

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