Periodically Poled Lithium Niobate (PPLN)

PPLN crystals offer high gain and non-critical quasi phase-matching for a wide range of nonlinear optical interactions, such as difference frequency generation and OPO applications pumped in the near infrared. In addition to single grating devices, where only one interaction is phase-matched, PPLN chips with multiple gratings along the propagation direction, chirped gratings, and fan-out gratings are also feasible.

PPLN devices offered by Crystal Technology are fabricated from our integrated optics substrates using electrical field poling process, and meet stringent criteria for uniformity and crystalline quality. The most popular PPLN part numbers for DFG and OPO applications have various periodicity patterns on the same chip. This enables coarse tuning by translating the chip so that a different grating is utilized. Fine tuning is achieved by adjusting the temperature of the PPLN device. The period required for phase-matching a particular interaction is easily calculated and Figure 1 shows the example of an OPO pumped by a Nd:YAG or Ti:Sapphire laser with output wavelengths ranging from 1.5µm to 4µm.

Applications

- High resolution mid IR spectroscopy
- OPO and DFG for laser science experiments
- Missile counter-measure laser systems

Sellmeier Equation for n_e in Congruent LN

$$f = (T - 24.5°C)(T + 570.82)$$

$$n_e^2 = a_1 + b_1 f + \frac{a_2 + b_2 f}{\lambda^2 - (a_3 + b_3 f)^2} + \frac{a_4 + b_4 f}{\lambda^2 - a_5^2} - a_6 \lambda^2$$

λ = wavelength in µm

Parameter & Value

a_1	5.35583	b_1	4.629×10^{-7}
a_2	0.100473	b_2	3.862×10^{-8}
a_3	0.20692	b_3	-0.89×10^{-8}
a_4	100	b_4	2.657×10^{-5}
a_5	11.34927		
a_6	0.015334		

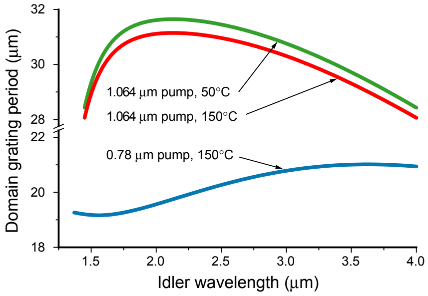
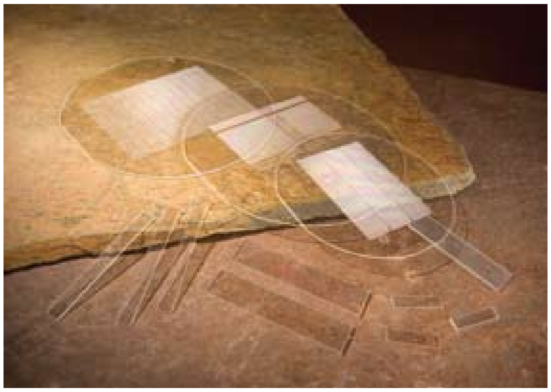


Figure 1. Grating periods required for OPO operation in PPLN

Domain Periods (µm)										Y (mm)	Z (mm)	X (mm)	Part #
25.5	25.9	26.4	26.9	27.4	27.8	28.2	28.7			11.5	0.5	20	97-02182-06
										11.5	1	20	97-02384-06
										11.5	0.5	50	97-02182-08
										11.5	1	50	97-02384-08
28.5	28.7	28.9	29.1	29.3	29.5	29.7	29.9			11.5	0.5	20	97-02182-03
										11.5	1	20	97-02384-03
										11.5	0.5	50	97-02182-07
										11.5	1	50	97-02384-07
30.0	30.2	30.4	30.6	30.8	30.95	31.1	31.2			11.5	0.5	20	97-02256-01
										11.5	1	20	97-02383-01
										11.5	0.5	50	97-02256-02
										11.5	1	50	97-02383-02
18.6	18.8	19.0	19.2	19.4	19.6	19.8	20.0	20.2	20.4	11.5	0.5	20	97-02355-01



PPLN substrate has been etched to reveal domain strips.

RoHS Compliant

Magnesium-doped Periodically Poled Lithium Niobate (MgO:PPLN)

Applications

- SHG for green and blue generation from IR sources
- Laser Based RGB displays

MgO PPLN material has successfully been used to generate green[1] and blue[2] laser beams with good efficiency. Crystal Technology produces a range of such crystals where all the critical manufacturing steps are performed in house. Our growth method is well developed and geared to high volume production thus lowering manufacturing cost and allowing our crystals to be deployed into mass market application such as laser projection displays and other consumer applications. The purity of starting powders and the crystal growth parameters are tightly controlled to ensure consistent quality guaranteeing stable optical properties. Our research has resulted in crystal growth that is guaranteed to avoid photorefractive damage yielding devices with well controlled refractive index and birefringence.

Our proprietary electric-field poling method ensures good domain fidelity leading to high nonlinear effective coefficients and our MgO:PPLN material has successfully been employed to generate green and blue laser beams by frequency-doubling of semiconductor lasers. Figure 1 shows inverted domain patterns in MgO:PPLN. The high fidelity on both the +Z face as well as the opposite crystal face demonstrates the capability and reproducibility of the poling process.

The standard MgO:PPLN parts have 3 periodicities on a chip to allow the user to optimize operating temperature for the device. Figure 2 shows the frequency doubled power of a single-mode laser at 1064nm as a function of the chip temperature for each of the three periods. Both anti-reflection coated as well as uncoated chips are available in three lengths, 1mm, 3mm and 10mm to support both short and long pulsed sources at various power levels. Custom designs are also available.

MgO:PPLN offers unique advantages for frequency doubling to visible wavelengths because it is a non-critical quasi phase-matching interaction utilizing the highest nonlinear optical coefficient d_{33}. A short crystal ensures high conversion efficiency in ultra-short pulse lasers while minimizing group velocity dispersion.[3] The large nonlinearity together with a long crystal allows high second harmonic generation efficiencies even at modest power levels. A 10mm long crystal for example will generate over 50mW of green light at circulating fundamental power of less than 4W assuming confocal focusing.

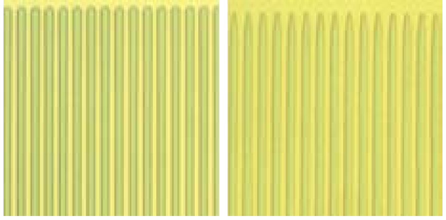


Figure 1. Inverted domain patterns on the two faces of the crystal, demonstrating good fidelity throughout the crystal volume.

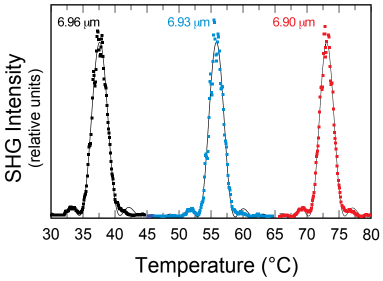


Figure 2. Temperature tuning of 1064nm frequency doubling for three gratings on 10mm chip.

Domain Periods (µm)	Y (mm)	Z (mm)	X (mm)	Part #
6.9 - 6.96 for 1064nm doubling, No AR coating, $d_{eff}>14$pm/V	3	0.5	1	97-03040-01
	3	0.5	3	97-03040-02
	3	0.5	10	97-03040-03
6.9 - 6.96 for 1064nm doubling, DAR, R<0.25% @1064 nm, R<0.5% @532nm, $d_{eff}>14$pm/V	3	0.5	1	97-03038-01
	3	0.5	3	97-03038-02
	3	0.5	10	97-03038-03
5.22 - 5.27 for 976nm doubling, No AR coating, $d_{eff}>14$pm/V	3	0.5	1	97-03043-01
	3	0.5	3	97-03043-02
	3	0.5	10	97-03043-03
5.22 - 5.27 for 976nm doubling, DAR, R<0.25% @976 nm R<0.5% @488nm, $d_{eff}>14$pm/V	3	0.5	1	97-03042-01
	3	0.5	3	97-03042-02
	3	0.5	10	97-03042-03

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Optical Materials for Visible Light Applications

Magnesium-doped Lithium Niobate

While congruently melting lithium niobate (CLN) can be grown at very large size and with excellent quality and uniformity, the material suffers from so-called photorefractive damage.[1,2] This undesirable effect can be avoided by using magnesium oxide (MgO) doped LN.[3,4]

Crystal Technology has done extensive research on growth and characterization methods of MgO:LN. Dozens of crystals have been grown from various starting melt compositions to establish optimal growth parameters for achieving crystals of high optical quality. The OH absorption peak location is a good indicator of the anti-site defect density. Material with a fully shifted OH absorption peak is “above the threshold” and resilient to photorefraction and thus useful for visible light applications. Figure 1 shows an example of an experimental crystal growth run. Only the sample showing a single, shifted peak (green) would be useful. Based on such results, we have chosen a starting melt composition that guarantees all wafers from the grown crystal to be damage-free. Although many publications only state MgO concentration to quantify resilience to photorefractive damage, our research demonstrates that the control of Li/Nb ratio is just as important as the MgO content to guarantee a crystal above threshold, in agreement with a previous report by Furukawa[5].

Phase-matching temperature (SHG to 532 nm using d_{32} or d_{33}) is a sensitive tool to reveal axial composition variations and to distinguish crystals grown from different MgO concentrations. Such measurements resolve differences as low as 0.1 mol% of MgO or Li_2O in the initial melt. Figure 2 shows the results for samples grown from our standard composition as well as samples from another crystal with starting composition different by –0.15 mol% MgO and +0.15 mol% Li_2O. Figure 2(a) shows the birefringent phase-matching of uniformly poled samples while Figure 2(b) shows the quasi-phase-matching temperature for the same samples with periodic grating of 6.9μm. The temperatures increase as the solidified melt fraction increases, indicating composition variations along the growth axis. Such variations are unavoidable for non-congruently melting crystals, but can be reduced by limiting the solidified melt fraction. The narrow acceptance and high sensitivity of the birefringent phase-matching temperature measurements make it an ideal tool to characterize compositional uniformity.

The growth experiments and precision characterization tools have enabled Crystal Technology to optimize the overall growth process. This allows a lower wafer cost while still maintaining the required performance consistency. All wafers are guaranteed to be from a crystal entirely above the damage threshold, and the birefringent phase-matching temperature for every wafer is between 109 °C and 116 °C.

Stoichiometric Lithium Tantalate (SLT)

Crystal Technology produces 3” diameter SLT wafers by the VTE method.[6] This material has been successfully used for high power generation of visible light. Photorefraction, GRIIRA,[7] as well as peak power damage are further reduced as compared to MgO:LN.[8] SLT wafers and PP:SLT devices based on this material will be offered in 2009.

Other Materials

Crystal Technology is continually expanding the product portfolio for periodically poled devices and also offers wafers used to produce such devices. An example is the recently developed superoxidized LN which offers improved properties, but at potentially much lower cost than MgO:LN.[9,10] Our researchers are working to develop a large-scale, low-cost superoxidization process option.

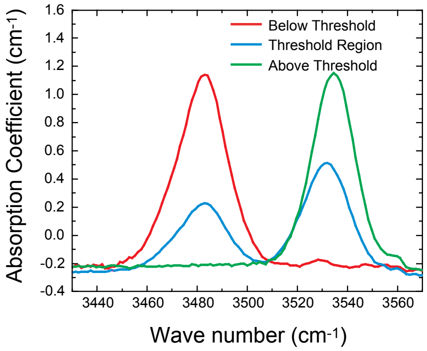

Figure 1. OH absorption peak of 3 different slices from the same crystal.

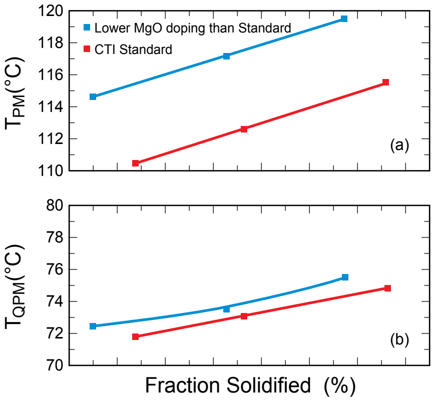

Figure 2. Phase-matching temperature as function of melt fraction solidification for two starting melt compositions. (a): Birefringent phase-matching, (b): Quasi-Phase-Matching for 6.9μm period grating.

Magnesium-Doped Wafers
Orientation: Z-axis

Part #	Thickness	∅
97-03044-01	0.5 mm	76.2 mm
97-03044-02	1.0 mm	76.2 mm

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