

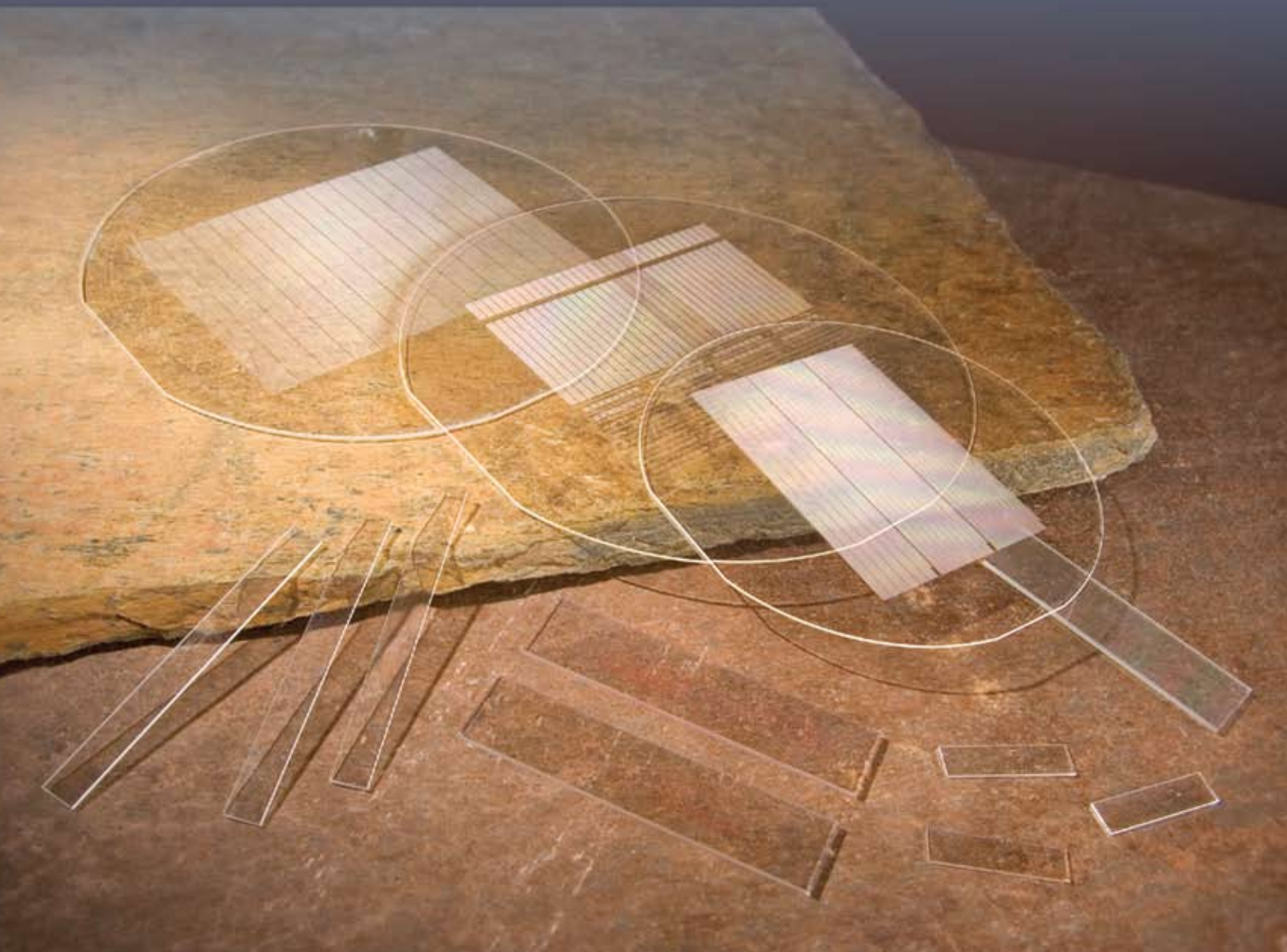


Crystal Technology, Inc.

An EPCOS Company

PPLN

Periodically Poled Lithium Niobate



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

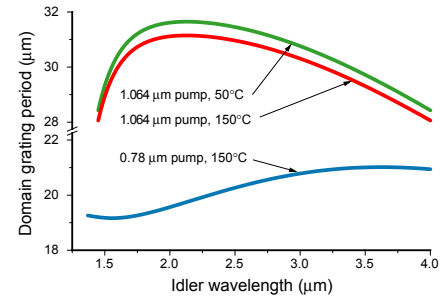
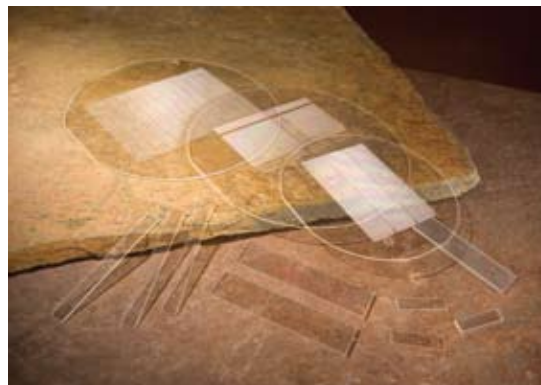


Figure 1. Grating periods required for OPO operation in PPLN

Sellmeier Equation for n_e in Congruent LN		Parameter & Value	
$f = (T - 24.5^\circ\text{C}) / (T + 570.82)$		a_1	5.35583
$n_e^2 = a_1 + b_1 f + \frac{a_2 + b_2 f}{\lambda^2 - (a_3 + b_3 f)^2} + \frac{a_4 + b_4 f}{\lambda^2 - a_5^2} - a_6 \lambda^2$		b_1	4.629×10^{-2}
$\lambda = \text{wavelength in } \mu\text{m}$		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

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.



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

MgO PPLN material has successfully been used to generate green¹ and blue² 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.

Applications

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

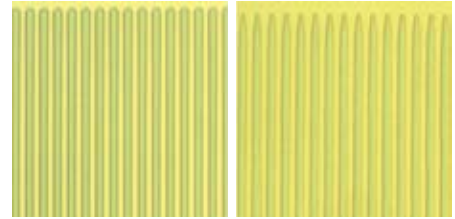


Figure 1. Inverted domain patterns on the two faces of the crystal, demonstrating good fidelity throughout the crystal volume.

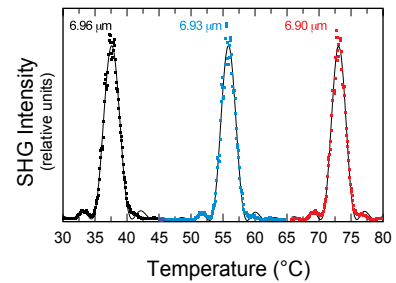


Figure 2. Temperature tuning of 1064nm frequency doubling for three gratings on 10mm chip.

Domain Periods (μm)	Y (mm)	Z (mm)	X (mm)	Part #
6.9 - 6.96 for 1064nm doubling, No AR coating, $d_{\text{eff}} > 14\text{pm/V}$	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, $d_{\text{eff}} > 14\text{pm/V}$	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, $d_{\text{eff}} > 14\text{pm/V}$	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, $d_{\text{eff}} > 14\text{pm/V}$	3	0.5	1	97-03042-01
	3	0.5	3	97-03042-02
	3	0.5	10	97-03042-03

REFERENCES

1. H. Furuya, A. Morikawa, K. Mizuuchi, and K. Yamamoto, Jpn. J. Appl. Phys., Part 1 45, 6704 (2006).
2. M. Maiwald, S. Schwertfeger, R. Guther, B. Sumpf, K. Paschke, C. Dzionk, G. Erbert, and G. Trankle, Opt. Lett. 31, 802 (2006).
3. M. A. Arbore and M. M. Fejer, Opt. Lett. 22, 13-15 (1997).

Optical Materials for Visible Light Applications

Magnesium-doped Lithium Niobate

While congruently melting lithium niobate (CLN) can be grown at large size and with excellent uniformity, the material suffers from photorefractive damage.¹ This undesirable effect can be avoided by using magnesium oxide (MgO) doped LN.^{2,3}

Crystal Technology has done extensive research on growth and characterization of MgO:LN.⁴ 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 threshold” and resilient to photorefractive and thus useful for visible light applications. Figure 1 shows absorption spectra of crystal samples with different compositions. 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 free of photorefractive. Although it is common to state only the MgO concentration for a photorefractive resistant material, our research confirms that precise control of the Li/Nb ratio is also necessary to guarantee a crystal above threshold.⁵

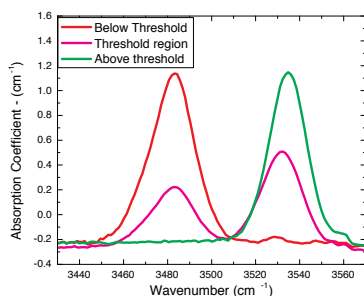


Figure 1. OH absorption peak of 3 slices from the same crystal.

Phase-matching temperature (SHG to 532 nm using d_{32} or d_{33}) is a sensitive characterization tool to reveal axial composition variations and to distinguish crystals grown from different compositions. Such measurements resolve differences as low as 0.04 mol% of MgO in the melt.⁴ Figure 2 shows the results of phase matching temperature as function of solidified melt fraction for crystals grown from different MgO concen-

trations in the melt, ranging from 4.9 to 6.0 mol%. In this range, the phase-matching temperature decreases with increasing MgO concentration. For every grown crystal, the temperature increases with increasing solidified melt fraction, indicating that the magnesium concentration decreases during growth, consistent with a distribution coefficient higher than 1.⁶

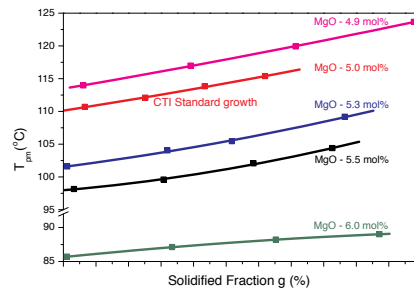


Figure 2. Birefringent Phase-matching temperature as function of solidified melt fraction for different starting melt compositions, including CTI standard composition at MgO 5.0 mol%

The impact of different Li/Nb ratios for the same initial MgO concentration on the phase-matching temperature is smaller, but clearly measurable. While a certain variation from top to bottom of a grown crystal is unavoidable, this effect is controlled in our growths to minimize the impact on the customer's application. The quasi-phase-matching temperature for 1064nm SHG for example varies by less than 4°C for any crystal produced with our standard wafer material.

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 photorefractive 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. This material has been successfully used for high power generation of visible light.⁷ Photorefractive, GRIIRA,⁸ as well as peak power damage are further reduced as compared to MgO:LN.⁷ CTI started delivery of SLT wafers and PP:SLT devices in 2009.

Materials Research

Crystal Technology is continually expanding the product portfolio for periodically poled devices and wafers used to produce such devices. A recent breakthrough allows production modified CLN with lowered absorption from 2.5µm to 2.8µm, making OPO oscillation possible at these wavelengths. Another example is superoxidized LN which offers improved photorefractive properties over CLN.^{9,10} Scaled-up processes are under development to provide this material at reasonable cost.

Products

To see the latest product offering, please visit our website. Double-side polished Z-axis oriented 3" diameter wafers of MgO:LN can be supplied with attractive volume discounts. Other orientations or increased wafer size (100mm) can be supplied on demand.

Part #	Orientation/ Thickness	Ø
MgO:LN		
97-03044-01	Z-axis / 0.5 mm	76.2 mm
97-03044-02	Z-axis / 1.0 mm	76.2 mm
SLT		
97-03022-02	Z-axis / 1.0 mm	76.2 mm

REFERENCES

- F. Jermann, M. Simon, and t. E. Kratzig, *J. Opt. Soc. Am. B* **12**, 2066 (1995).
- J. L. Nightingale, W. J. Silva, G. E. Reade, A. Rybicki, W. J. Kozlovsky, and R. L. Byer, *Proc. SPIE* **681**, 20-24 (1986).
- D. A. Bryan, R. Gerson, and H. E. Tomaschke, *Appl. Phys. Lett.* **44**, 847 (1984).
- D. H. Jundt, M. C. C. Kajiyama, D. Djukic, and M. Falk, *Journal of Crystal Growth*, In Press, Corrected Proof (2009).
- Y. Furukawa, K. Kitamura et al., *Applied Physics Letters* **77**, 2494-6 (2000).
- S. I. Bae, J. Ichikawa, K. Shimamura, H. Onodera, and T. Fukuda, *Journal of Crystal Growth* **180**, 94-100 (1997).
- D. S. Hum, R. K. Route, G. D. Miller, V. Kondilenko, A. Alexandrovski, J. Huang, K. Urbaneck, R. L. Byer, and M. M. Fejer, *Journal of Applied Physics* **101** (2007).
- Y. Furukawa, K. Kitamura, A. Alexandrovski, R. K. Route, M. M. Fejer, and G. Foulon, *Applied Physics Letters* **78**, 1970-2 (2001).
- M. Falk, T. Wöike, and K. Buse, *Applied Physics Letters* **90**, 251912-3 (2007).
- I. Breunig, M. Falk, B. Knabe, R. Sowade, K. Buse, P. Rabiei, and D. H. Jundt, *Appl Phys. Lett.* **91**, 221110 (2007).