QUANTUM TECHNOLOGY, INC.

DATA SHEET 706

APRIL 1988

SECOND HARMONIC GENERATION BY ANGLE TUNING IN TETRAGONAL PHOSPHATES & ARSENATES

A. INTRODUCTION:

Non-linear optics is a powerful method for extending the limited fixed frequency output available from lasers. Since the first experiment by Franken in 1961, the field has progressed at a rapid rate to the point that tunable coherent radiation can be obtained over the spectral region from 190nm to 7000nm with high peak powers, narrow bandwidths and good conversion efficiency.

B. SECOND HARMONIC GENERATION (SHG)

The second harmonic power generated by a single mode, gaussian beam of angular frequency ω and power P incident along the principal axis of a plane-parallel slab of length L of a non-linear crystal is given in MKS units by

$$P_{2\omega} = \frac{JP_{\omega}^{2} L^{2} d^{2} \sin^{2}\psi}{W_o}\left[\frac{\sin(\Delta KL/2)}{(\Delta KL/2)}\right]^{2} \text{---} (1)$$

where J is a constant determined by the crystal's dielectric constant at the fundamental frequency ω, d is the coefficient of second harmonic generation determined by the material's non-linear susceptibility, W_o is the minimum beam radius and ψ the angle between the crystal optic axis and fundamental beam under phase-matching conditions. Because of dispersion, there is usually a wave-vector mismatch ΔK between fundamental and second-harmonic beams.

For fixed ΔK, the function

$$\left[\frac{\sin(\Delta KL/2)}{(\Delta KL/2)}\right]^{2} \text{--------------------} (2)$$

undergoes oscillation as a function of crystal length with period $2\pi/\Delta k$. Half this distance is called the coherence length and is the distance from the input at which the second-harmonic power is a maximum. Typically the values of coherence length range from a few millimeters to several centimeters. For normal incidence, the coherence length is given by

$$\ell = \lambda_1/4(n_{2\omega}-n_{\omega}) \text{----------------} (3)$$

where the n_i are the refractive indices at the second harmonic and the fundamental wavelength λ_1.

C. PHASE-MATCHED SHG

It follows from equation 1 that for efficient second harmonic conversion, the wave vector mismatch ΔK between the interacting waves should be zero. This is termed phase-matching. Because of the dispersion of the refractive index between the fundamental and second harmonic wavelengths, phase-matching is difficult to achieve in an isotropic crystal. However, in an anisotropic crystal, it is often possible to obtain $\Delta K = 0$ by a suitable choice of direction of propagation and polarization. Depending upon the choice of polarization, two types of phase-matching are possible in birefringent crystals. SHG with fundamental waves of parallel polarization is termed Type I phase-matching. SHG with fundamental waves of orthogonal polarization is termed Type II phase matching.

D. PHASE MATCHING UNIAXIAL CRYSTALS

For a beam propagating in a uniaxial crystal such that the wave normal of the beam makes an angle ψ_m with the optic axis of the crystal, the generated extraordinary ray sees a refractive index intermediate between n_o and n_e according to

$$\frac{1}{\left[n(\psi_m)\right]^2} = \frac{\operatorname{Cos}^2 \psi_m}{n_o^2} + \frac{\operatorname{Sin}^2 \psi_m}{n_e^2} \text{ ----(4)}$$

In a negative ($n_e < n_o$) uniaxial crystal of KDP type ($\bar{4}2m$), the index matching conditions are,

Type I $\quad n_{2\omega}(\psi_m) = n_{1\omega}$

or $\quad n_{e2}(\psi_m) = n_{o1}$ ---------(5)

By combining equation (5) with equation (4), the phase matching angle ψ_m is given by

Type I

$$\operatorname{Sin}^2\psi_m = \frac{(n_{o1})^{-2} - (n_{o2})^{-2}}{(n_{e2})^{-2} - (n_{o2})^{-2}} \text{ ------- (6)}$$

The index matching conditions are

Type II

$$n_{2\omega}(\psi_m) = \frac{1}{2}\left[n_\omega(\psi_m) + n_{o\omega}\right] \text{--------- (7)}$$

The index matching angle ψ_m for this case is given by

$$\left[\frac{\operatorname{Cos}^2\psi_m}{(n_{o2})^2} + \frac{\operatorname{Sin}^2\psi_m}{(n_{e2})^2}\right]^{-\frac{1}{2}} = \frac{1}{2}\left\{n_{o1} + \left[\frac{\operatorname{Cos}^2\psi_m}{(n_{o1})^2} + \frac{\operatorname{Sin}^2\psi_m}{(n_{e1})^2}\right]^{-\frac{1}{2}}\right\} \text{--(8)}$$

E. TUNING ANGLES

Single crystals of tetragonal phosphates and arsenates belong to the $\bar{4}2m$ symmetry and are uniaxial and optically negative. Angle tuning (type I) will be discussed in this data sheet while angle tuning (type II) will be discussed in data sheet 715. Crystallographic orientations for angle tuning (type I) and temperature tuning of these crystals of KDP family are shown in Fig. 1.

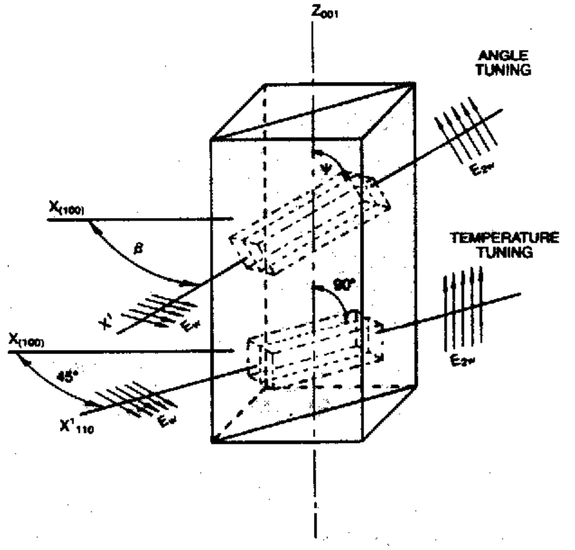


Fig. 1 Crystallographic orientations for angle and temperature tuning.

For fixed crystal length, the SH conversion efficiency is very sensitive to the index matching angle ψ_m. These angles are computed from the refractive indices of these crystals and are shown in Figures 2 and 3.

The useful SHG region obtainable by orientation of the crystal bar with respect to the optic axis is shown in Fig. 4.

ELECTRO-OPTIC PARAMETERS:

Table I shows the electro-optic properties and SHG performance of some of the crystals.

GENERAL FEATURES:

Maximum interaction of the propagating beam with the non-linear medium takes place when the beam propagates in the 110 plane. When the propagating beam is incident at an angle of 90° to the optic axis, optimum efficiency is obtained. This is the orientation for temperature tuning. In angle tuning, the beam makes an angle depending upon the frequency of the laser. In general, it is preferable to use temperature tuning (TT) over angle tuning (AT) as the latter method gives lower efficiency due to the

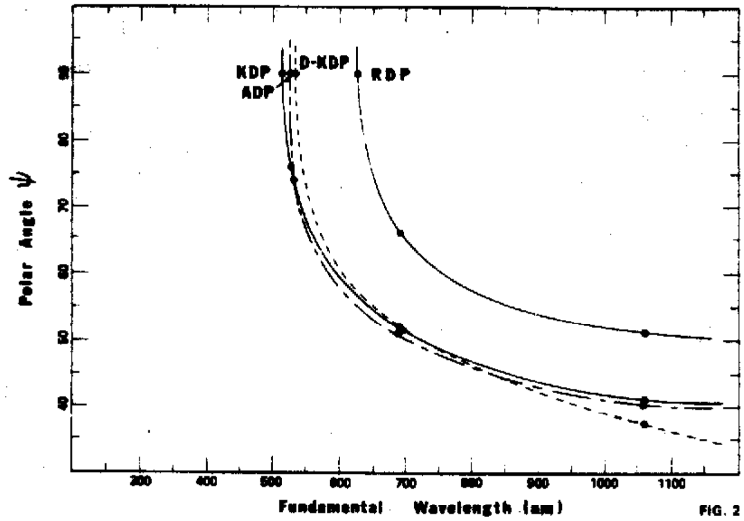


FIG. 2

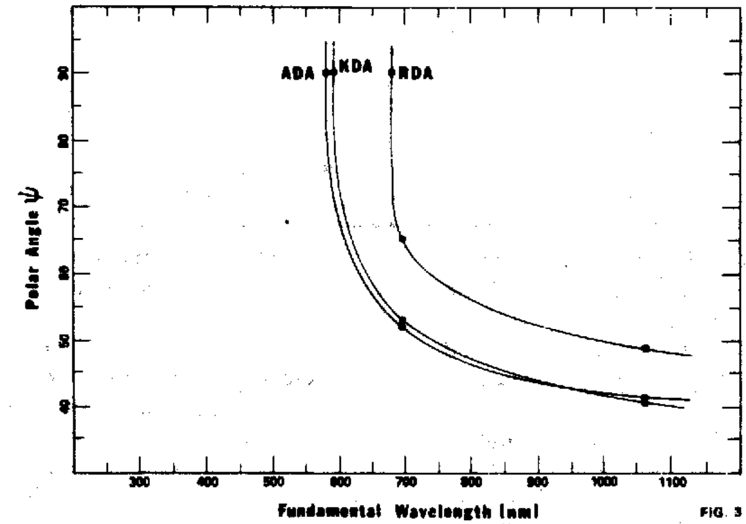
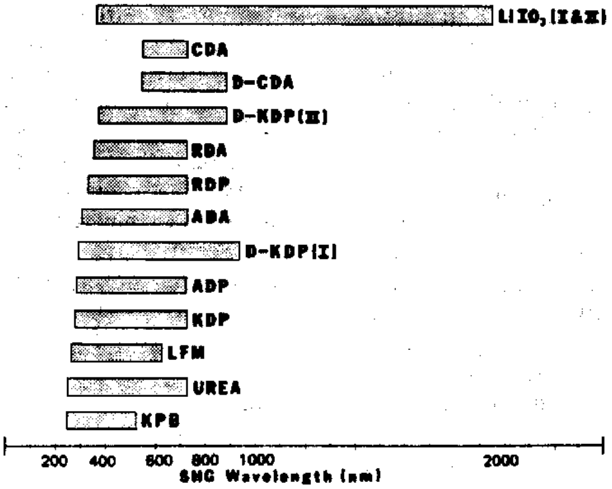


FIG. 3



Useful SHG wavelengths for Angle Tuning.

FIG. 4

Note: All crystals are oriented for Type I phase matching except those indicated as II, oriented for Type II condition.

TABLE I

Material	Refractive Index			Non-Linear Susceptibility		Nominal Damage Threshold		Linear Absorption	Temperature Acceptance	Angular Acceptance	Length Used	Typical SHG Efficiency
	λnm	n_o	n_e	d x 10^{12} meters/volts d_{14}	d_{36}	t_p(ns)	I(GW/cm^2)	(% per cm)	ΔT·d (o_c-cm)	Δψ·d (mr·cm)	(cm)	(%)
ADP	347	1.55	1.50						0.8	32.0	6.0	23%
	530	1.53	1.48									
	694	1.52	1.48	0.48	0.49			3 %				
	1060	1.51	1.47	0.55	0.56	60.0	0.5					
KDP	347	1:54	1.49						3.5	1.0	2.5	20%
	530	1.51	1.47			0.2	17.0					
	694	1.51	1.47	0.47	0.47	20.0	0.4	2.4%				
	1060	1.49	1.46	0.49	0.47	0.2	23.0	3 %				
D-KDP	347	1.53	1.49									
	530	1.51	1.47					0.6%				
	694	1.50	1.46	0.46	0.50				6.7	1.7	3.8	25%
	1060	1.49	1.46	0.50	0.50	10.0	0.5	0.6%				
RDP	347	1.53	1.60					1.5%				
	530	1.51	1.48								2.0	20%
	694	1.50	1.47			10.0	0.2	1 %				
	1060	1.50	1.47	0.56	0.48	12.0	0.3	4 %				
RDA	347	1.60	1.56					5 %	3.3	40.0	2.0	25%
	694	1.55	1.50		0.42	10.0	0.35	3.5%				
CDA	347	1.60	1.57									
	530	1.57	1.55									
	694	1.56	1.54						5.8	70.0	3.0	22%
	1060	1.55	1.53		0.43	10.0	0.5	4 %				
D-CDA	347	1.59	1.57									
	530	1.57	1.55					0.4%				
	694	1.56	1.54						6.0	70.0	3.0	30%
	1060	1.55	1.53		0.43	12.0	0.36	0.6%				

presence of beam walk-off. However the range of tuning obtainable by TT is limited to about 10 nm when the temperature is raised from say 0°C to 100°C. The only exceptions are crystals ADP and ADA where the range of two times this figure is obtainable.

Angle tuned SHG crystals are oriented within 10 minutes of the correct polar angle for a given frequency. However the crystal cell should be mounted in an optical mount and fine-tuned to within 10 seconds for optimum setting.

Most gimbal mounts are limited to angular adjustment of about 10°, therefore, it is a normal practice to use five differently oriented crystals to cover the entire visible range as in the case of KDP for dye laser application. Since the slope of the tuning curve is different at different frequencies, greater alignment accuracy is needed say at 530 nm as compared to 1060 nm, since the range covered is narrower as the angle is varied near about 79° (KDP) at 530 nm. Only vignetting of the incident beam limits the range of frequencies that can be obtained with a single AT crystal. In the case of LFM crystal, only one crystal is required to cover the visible range, since the angle of orientation varies only from 39° to 50°. It is conceivable to use one KDP crystal to tune the angle from 90° to 50° to cover the partial visible range from 5200 to 6900. However the crystal cross-section would be increased considerably to prevent vignetting the beam. Fresnel reflection losses are also increased and the material costs increase substantially to the point that it is cost - effective.

In angle tuning, the alignment of the angle ψ is critical. Usually a line is drawn on one of the side faces of the crystal to mark the position of the optic axis. The crystal should be fine-tuned about an axis perpendicular to this face. Rotation of the crystal about an axis perpendicular to the polished face or the third face is not as critical as the fine tuning of ψ . Most non-linear crystals are hygroscopic and shatter due to thermal shock. These crystals are therefore mounted on a heat sink in a hermetically sealed housing. These cells are normally filled with an inert fluid or dry nitrogen.

In a laboratory environment, where the temperature is likely to fluctuate by more than ½ °C, retuning the angle is often required. This may be avoided by a combination of temperature tuning and angle tuning. The crystal is operated at a temperature of 40° C to eliminate the effect of severe fluctuation in ambient temperature on the crystal.

For dye laser frequencies, crystals can be cut to angle-match down to the UV range, thus extending the tunable range beyond the visible. The most popular crystals for angle tuning in the UV range are LFM and UREA.

References

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