Research on Characteristics of KT_iOPO_4 Crystal Applied in Red Laser

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Abstract. In this paper, the range of frequency doubling wavelengths is analyzed through KT_iOPO_4 (KTP) dispersion research.The best phase-matching angle of KTP crystal for frequency doubling at 1319nm is calculated as well as the effective nonlinear coefficient.Thus the KTP cutting method is determined.In the experiments,we use the crystal which is 7×7×7mm for frequency doubling at 1319nm to achieve 660nm red laser.Then we get the optical spectrum with a triple prism and measure the two wave energy with two pyroelectric detectors.The frequency doubling efficiency can reach 34.3%.This demonstrates that the experimental system is with good stability.

Introduction

KTP is a new kind of nonlinear crystal material.Because of its excellent performance, KTP has been widely applied to frequency conversion process such as frequency doubling, frequency mixing and parametric oscillation and becomes the choice of main materials in nonlinear experiment of solid-state laser.It has been widely used to generate second harmonic of 1μm Nd laser.The 1319nm infrared laser frequency doubling is an effective way to obtain the red laser [1,2].

Phase-matching Feature Analysis

KTP is a biaxial crystal with transmission range of 350-4500nm. It has the advantages of high hardness, chemical stability, especially a large nonlinear coefficient, acceptance angle and temperature acceptable range [3].It has great advantages especially in second harmonic produced by Nd ion laser with about 1 μm wavelength.Through dispersion equation, we can calculate phase matching of light wave frequency doubling in KTP crystal. Biaxial crystal KTP has the shortest frequency doubling wavelength of 994 nm and harmonic of 497 nm.When less than 994 nm wavelength, there is no type-II phase-matching angle. Type-II phase-matching can gain more effective nonlinear coefficient than type-I , so type-II phase-matching is commonly used in KTP crystal.When the scan values of θ and φ are espectively in $0^0 \sim 90^0$ or $0^0 \sim 180^0$,these angles that make the established equation connect a curve. In the normal dispersion, orientation of principal axis system meets $n_x<n_y<n_z$ and their refractive index meets the relation $n_{2z}-n_{1z}\approx n_{2y}-n_{1y}\approx n_{2x}-n_{1x} << n_{1x}$. According to the theory of the dispersion equation and the refractive index theoretical method of KTP , we can get the frequency doubling phase matching curves, as shown in Figure 1. The figure shows that the best phase-matching angles of waves greater than 1 μm are in XZ plane.

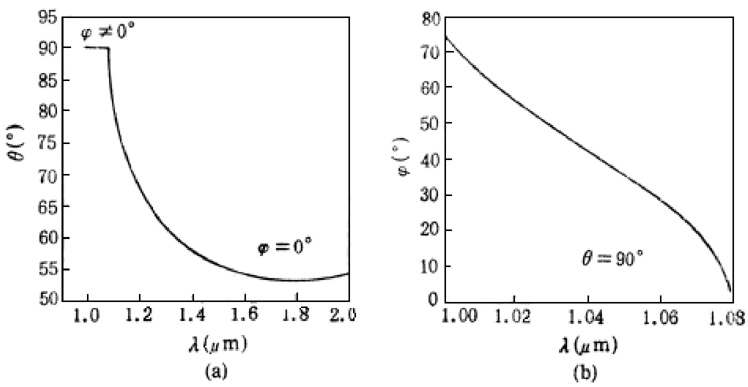

Fig.1 The best phase-matching angle curves in KTP crystal for frequency doubling

Phase-matching Angle Calculation

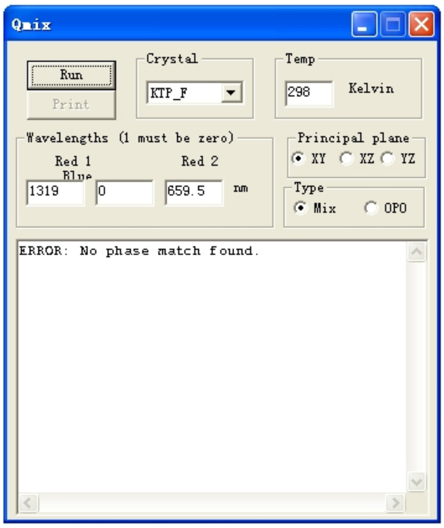

Fig. 2 Calculation in the XY plane

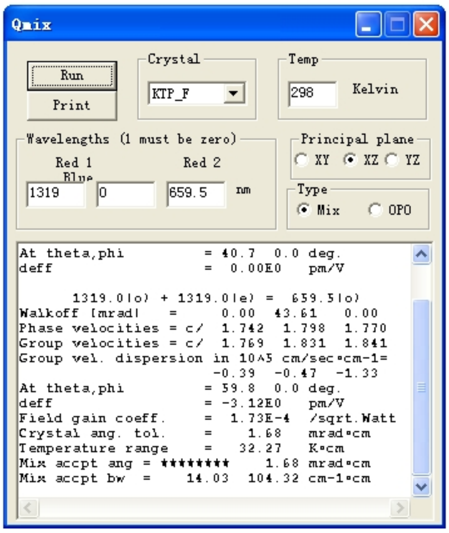

Fig.3 Calculation in the XZ plane

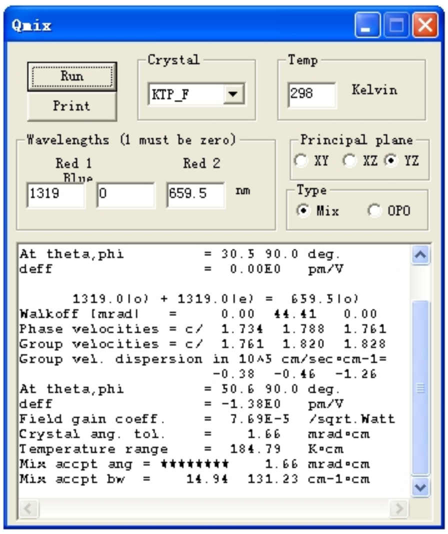

Fig.4 Calculation in the YZ plane

KTP crystal used in the experiments is grown in molten salt method with dimensions of 7×7×7mm.We use specialized software to calculate the phase-matching angle of KTP.The calculation result of the crystal cut in XY plane is no phase-matching angle as shown in Figure 2.The result of the crystal cut in XZ plane is that θ=59.8°, φ=0°, d_{eff}=6.49×10^{-12}m/v as shown in Figure 3. The result in YZ plane is that θ=50.6°, φ=90°, d_{eff}=4.78×10^{-12}m/v as shown in Figure 4.KTP in XZ and YZ planes has phase-matching angles for frequency doubling of 1319 nm. Through the comparison of nonlinear coefficient, we decided to cut the crystal in XZ plane for nonlinear coefficient larger, with the phase-matching angle of θ=59.8°, φ=0°.

Experimental Study

Experimental Device. The laser used in the experiment is electro-optic Q-switched Nd:YAG laser at 1319nm. We using external cavity frequency doubling to obtain 660nm red laser. In the experimental system we use a three-dimensional adjustment frame to fix the frequency doubling crystal, so that rotation and tilt adjustment for KTP is feasible.This method makes nonlinear interaction angle of the base frequency light and crystal to achieve the best match.It also realizes frequency doubling efficiency maximization.The laser is not entirely 660nm red light across KTP.Because the frequency doubling effect for crystal to laser is not one hundred percent,the laser output contains two lines of 1319nm and 660nm. The dispersion prism is used to separate the two lasers.The system contains nonlinear crystal KTP of dimensions 7×7×7mm and phase-matching angle θ=59.8° , φ=0° and dispersion prism of K9 glass substrates and corners 60°.

Spectral Measurement. The spectrometer used in measurement is manufactured by Ocean Optics,which takes use of optical fiber to conduct laser,with models for the HR4000,a resolution of 0.02nm and spectral range of 200-1100 nm.Because the laser is very strong, in order to avoid fiber broke, let laser on a diffuse reflection screen, then optical fiber accepts the reflected laser from diffuse reflection screen. Such it will not damage the fiber to get measured spectrum. Figure 5 shows the red spectral measurements for 660.97nm on the spectrometer software interface.

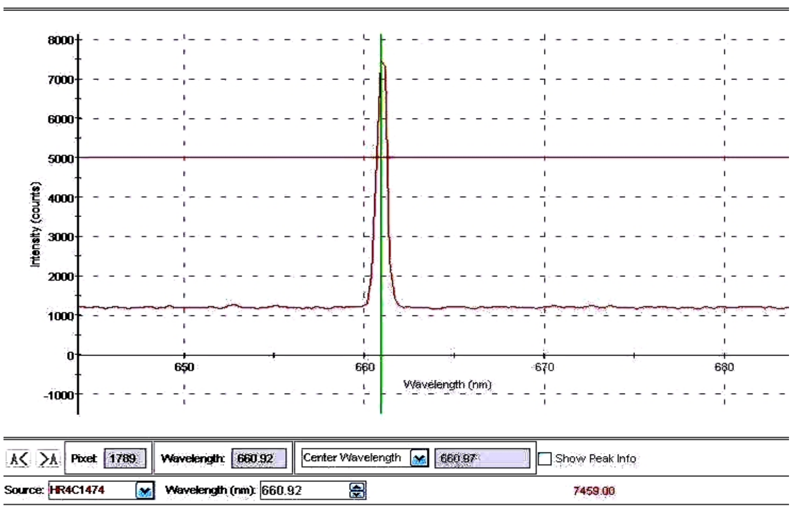

Fig.5 The red spectral on the spectrometer software interface

Frequency Doubling Efficiency Measurement. The method that two pyroelectric detectors respectively accept 1319 nm and 660 nm laser can measure the crystal frequency doubling efficiency.

The measured frequency doubling efficiency can reach 34.3%. The frequency doubling efficiency of KTP crystal under the less energy input shows the approximate linear upward trend.When the input power reaches a certain value, the frequency doubling efficiency is no longer rising and basic remains unchanged.It is shown in Table 1 and Figure 6.There are many factors that influence frequency doubling efficiency, including angle matching as one of the most important factors, the quality of the crystal and the quality of the coating, etc. In addition, the absorption of basic frequency wave or harmonic wave causes temperature rise.That will lead to problems such as the thermal stress and thermal gradient, thus the phase-matching angle of crystal changes and relative refractive index inhomogeneity will result in the decrease of frequency doubling efficiency [4].

Tab.1 Frequency doubling efficiency measurement

Injection voltage(V)	660nm（mJ）	1319nm（mJ）	Efficiency（%）
680	11.6	43.2	21.2
700	16.6	43.6	27.6
720	21.7	45.3	32.5
740	25.2	48.3	34.3
760	27.2	54.2	33.4
780	29.6	60.6	32.8

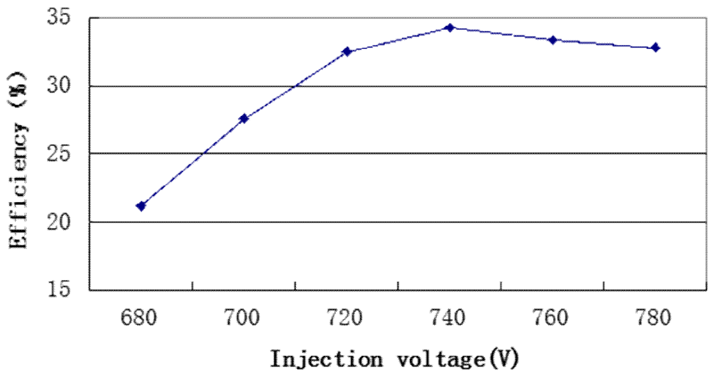

Fig.6 frequency doubling efficiency curve

Conclusions

In this paper,the best phase-matching angle for 1319nm is calculated based on the dispersion characteristics of the KTP crystal. The result is θ=59.8°，φ=0°. Using a form of KTP external cavity frequency doubling, we ultimately achieve a 660nm red light output. When injected voltage into the system reaches 740V,the frequency doubling efficiency of KTP crystal can reach 34.3%.This shows the excellent properties of KTP as doubling crystal for 1.3 micron laser.Further the experiments show that when the pumping voltage variation, frequency doubling efficiency changes.Frequency doubling efficiency exists extreme value within the scope of the measuring.

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