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Design Of A Femtosecond Blue Pulse Generation System By Pumping Of Kn Crystal With Cr:LiSAF Lasers

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ABSTRACT

In this paper we described and simulated generation of blue pulse (460nm) by nonlinear KN(KNbO3) crystal ,that pumped by femtosecond diode pumped Cr:LiSAF lasers. Our simulation show that, by focusing of laser oscillator output pulses with characteristics such as 860nm wavelength, 200fs,330MHz repetition rate 14o Pico joule(PJ) energy in KN crystal with 3mm length at 22 0C by 15 mm lens in less than 20 micrometer spot size with single pass produce pulses with 42pJ energy ,425fs , 30% optical efficiency and 1% total efficiency.

Key words: Nonlinear optics, Frequency conversion, Femtosecond lasers, KN crystal
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INTRODUCTION

In some application, we need a compact blue pulse source with femtosecond time duration and high efficiency. High efficiency generation a compact and portable blue pulse source with fs pulse duration time is very important. The high peak power and very small duration time of these pulses make them very useful tools for the applications such as time resolve spectroscopy, medicine and undersea communications. The importance of this pulses will be bold if we attention to the difference between the very huge, expensive and low efficiency(less than 0.05%) ultrafast Ti:Sa laser by very compact ultrafast diod pumped Cr:LiSAF lasers with High efficiency (>1%) as pump sources. The initial work on this SHG scheme (Weiner, Kan'an, & Leaird, 1998) used a Kerr-lens modelocked Ti:sapphire laser that produced 120fs pulses at 860nm, with an average power of 300mW and pulse energy of 3.75nJ. In 2003, a conversion efficiency of 57% was achieved for up to 170mW of average power at 430nm in University of St. Andrews, with considerably less (27 times) pulse energy and only 45mW average power. They obtained a 30% conversion efficiency and demonstrated an electrical-blue efficiency of 1% using a diode-pumped femtosecond Cr:LiSAF laser (Benjamin Agate, 2003). In this paper we investigated about second harmonic generation from the pumping of KNbO3 crystal by Cr:LiSAF laser with 860 nm wavelength, 200fs pulse duration, 330MHz repetition rate and 45 mw average power. The main purpose of this paper is determination of the pump laser diameter effect on crystal, crystal length and temperature to conversion efficiency and crystal length effect on output blue pulses time duration.

HARMONIC GENERATOR STRUCTURE

Suitable structure for harmonic generation is using of a nonlinear crystal in the outside of the laser cavity. We can produced SH in one pass by the conFiguration is shown in Fig.1. The laser output is focused by lens on crystal.

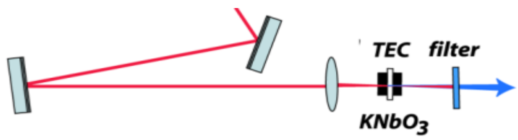

Fig.1 Structure of SH generation outside the cavity by one pass

A flat mirror is used to directing of the laser beam on the crystal surface. It must be used several femtosecond mirrors for dispersion control and avoiding from the increasing of pulse duration. It is necessary to hold the crystal in the special holder for temperature controlling and changing incident angle for increasing the conversion efficiency (Benjamin Agate, 2003).

APPROACH TO KNbO3 CRYSTAL PROPERTIES

Potassium niobate or KN (KNbO3) is one of the first nonlinear crystal that used for SH generation from semiconductor lasers. This crystal has very interesting properties such as very high nonlinear coefficient, tune ability in wide range of temperature, ability of making in long length with good optical quality. The disadvantage of this crystal is ability for making of unsuitable domains that causes from the stress and thermal gradient. Investigations show that we can increase the temperature of this crystal from the room temperature to 180°C in 10 minute without damaging the crystal. The maximum mechanical stress of this crystal is 3KG/cm^2. Therefore, we must attention to these points, temperature rate must be less than 80°C/h and cooling rate must be less than 40°C/h. The other properties of this crystal are shown in table1(Risk, Gosnell, & Nurmikko, 2003).

Table.1 Important parameter of KN crystal

Parameter	Value
Crystal type	Negative, Biaxial
Nonlinear coefficient , d_{32}	18.3 pm V^{-1}
Group velocity mismatch(GVM),α	1.2 psmm^{-1}
Non-critical phasematching (NCPM)	Type I for 860 nm (22^{0}C)
Transmission range	400 nm to 4.7μm
Refractive indices at 860nm (22^{0}C)	n_x=2.1338 n_y=1.2372 n_z=2.2784
Refractive indices at 430nm (22^{0}C)	n_x=2.2771 n_y=1.4145 n_z=2.4974
Damage Threshold	~ 350 MWcm^{-2}

For generation of SH from this crystal after determination of the crystal length, we must change the following parameters to reach the better conversion efficiency: incident bean angle, crystal temperature, cooling method, incident beam spectral bandwidth and lens focusing power (Risk et al., 2003) .

PHASE-MATCHING AND ANGLE OF INCIDENT BEAM

Intensity of generated harmonic is given by (Risk et al., 2003).

$$I_2 = \frac{2\pi^2 d_{32}^2}{\lambda_2^2 n_2 n_1^2 \varepsilon_0 c_1} . \ell^2 . I_1^2 \mathrm{sinc}^2\left(\frac{\Delta k \ell}{2}\right) \qquad (1)$$

where $\Delta k = 2k_1 - k_2$, I_1 is the pump laser intensity, d_{32} is the nonlinear coefficient, ε_0 is the permittivity of free space, ℓ is the crystal length, λ_2 generated wavelength, n_2 and n_1 are refractive indices in generated wavelength and pump wavelength, respectively. Here C_1 is light speed in pump wavelength. We have max intensity for generated SH when $\Delta k = 0$ or it is phase-matched. If $\Delta k \neq 0$, the intensity of SH is periodic according to the Fig.2 (Benjamin Agate, 2003; Risk et al., 2003).

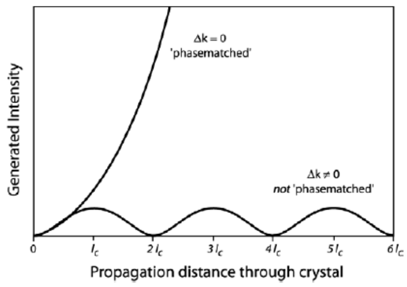

Fig.2 SH intensity versus propagation length in the case of phase-match and non phase-match (Benjamin Agate, 2003).

We defined the coherence length, ℓ_c , this parameter is calculated by $\Delta k . \ell_c = \pi$. Therefore for phase-matching it must be used an isotropic crystal with the thickness equal to coherence length (less than 100 μm). This small thickness is caused small interaction length. The generated output power is decreased. For overcoming to this problem we used the birefringent technique. In this technique, the phase-matching condition, $\Delta K = 0$ leads to the equation $n_2 - n_1 = 0$ and the frequency of ω_1 and the frequency of $\omega_2 = 2\omega_1$ must be propagate in the medium with the same phase velocity and this phoneme can be occurred in the birefringent medium. In the birefringent crystals, there is ordinary refractive index (n_o) and extra ordinary refractive index (n_e). If $n_e > n_0$, the crystal is positive and if $n_e < n_0$, the crystal is negative. The refractive index n_o independent on the light propagation direction but the extra ordinary refractive index n_e dependent on the light propagation direction.
Therefore, by suitable choosing the polarization and the angle of the incident light we can satisfy the phase-matching condition, $n_e = n_0$, and the result of this effect is same light velocity propagation in the two perpendicular polarization directions. For showing this phenomena (phase-matching condition), it was assumed KN crystal have different refractive index on three axes, and they satisfied $n_b > n_a > n_c$, are shown in Fig.3. If the main light polarization in the direction of b axis, the phase-matching condition would be only satisfied for 860nm wavelength and it can be written, $n_c(2\omega_1) = n_b(2\omega_1)$. So the generated light polarization will be in the direction of c axes. The direction of light propagation is in the direction of crystal axis. It is named this noncritical phase-matching (Risk et al., 2003).

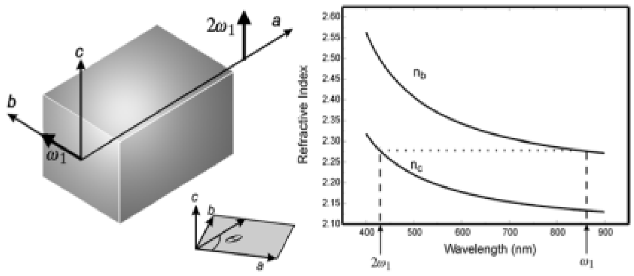

Fig.3 Phase-matching for 860nm wavelength light with the angular tuning of the KN crystal (Risk et al., 2003)

The relation between angular reflective indexes is given by

$$\frac{\sin^2\theta}{n_a^{\ 2}} + \frac{\cos^2\theta}{n_b^{\ 2}} = \frac{1}{n_\theta^2} \qquad (2)$$

where, n_θ is the refractive index in the propagation direction. For $\theta = 0$, $n_\theta = n_b$ and $\theta = 90$, then $n_\theta = n_a$. For the incident wavelength 860nm and the generated wavelength 430nm the phase-matching condition is written as follows:

$$n_\theta(860\,nm) = n_c(430\,nm) \qquad (3)$$

The refractive index for KN are; $n_a(860\,nm) = 2.2372$, $n_b(860\,nm) = 2.2784$, $n_\theta(860\,nm) = n_c(430\,nm) = 2.2771$, the incident angle is 10 degree.

CALCULATION OF EFFICIENCY, POWER AND DURATION OF OUTPUT PULSES

In the short pulse regime the conversion efficiency is calculated as (Weiner et al., 1998).

$$\frac{E_{2\omega}}{E_{\omega}} \cong \frac{\gamma E_{\omega}}{\alpha} tg^{-1}\left(\frac{L}{b}\right) ,\gamma = \frac{4\omega_0^2 d_{eff}^2}{n^2 c^3 \varepsilon_0 \lambda_{\omega}}$$

where $b = 2\pi W_0^2 n/\lambda$, and ω_0 is the incident pulse frequency and W_0 is the incident beam diameter. According to the equation (4), the efficiency dependent to the incident pulse diameter, the pulse energy and the crystal length. It is assumed the pulse energy is 140pJ. The efficiency can be increased by changing the crystal length and incident pulse diameter. The crystal length is assumed 3mm. The simulation results are shown in Fig.4. If we want to have the efficiency greater than 30 % the incident beam diameter must be less than 20 micrometer.

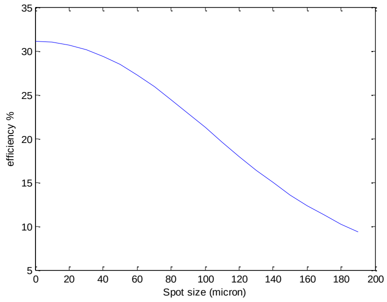

Fig.4 Conversion efficiency versus incident beam diameter with 140pJ incident pulse energy, 3mm KN crystal length and 860nm incident beam wavelength

Simulation results for different incident beam radius in terms of the crystal length are shown in Fig.5. The optimum crystal length is 3mm and the incident beam radius is less than 2 micrometer. It cannot significantly influence on the efficiency increasing the crystal length. The other important parameter to increase the efficiency is the temperature of the crystal. The experimental result shows that the optimum temperature is 22°C.

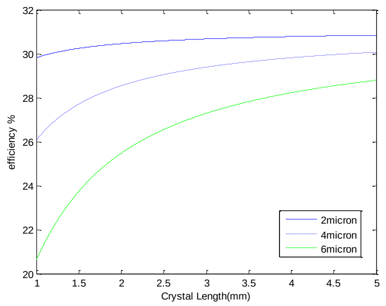

Fig.5 Conversion efficiency versus crystal length for different incident beam radius (2,4 and 6 µm) for KN crystal with 860nm incident beam wavelength and constant 140pJ incident energy

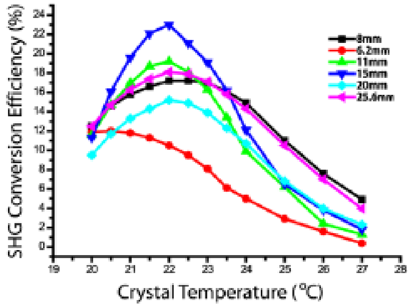

Fig.6 Conversion efficiency versus KN crystal temperature (Benjamin Agate, 2003)

The pump laser average power, the crystal length, and the incident beam radius used in simulation are 45mW, 3mm, and 5 µm, respectively. The phase matching angle is 59.9°. The generated beam average power is 13mW. Experimental result of KN crystal shows it has 75fs2mm-1positive dispersion. The output pulses time duration versus the crystal length is demonstrated in Fig.7. According to it, the pulses duration is equaled 200fs. Finally these results show good agreement with other group experimental data (Agate, Kemp, Brown, & Sibbett, 2002).

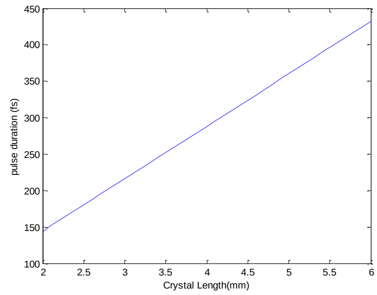

Fig.7 Output pulses time duration versus crystal length for KN crystal with 860nm incident beam wavelength,75fs^{2}mm^{-1} positive dispersion,45mW for pump laser average power and 13mW generated beam average power

CONCLUSIONS

The incident angle, the optimum temperature of the crystal, the incident beam radius, and the crystal length were determined. The conversion efficiency can be high. Our results were demonstrated 330MHz for repetition rate and 680w for peak power. The output pulse duration was 475fs for 3mm crystal length and the crystal will not be damaged.

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