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Original research article

Fabrication of KDP crystal prisms for second harmonic generation

Vinh Trung Phan*, Trang Thuy Phuong Do, Thanh Mai Ho, Dat Tan Nguyen, Binh Van Le, Anh Thi Quynh Le, Phuong Ai Duong, Dat Thanh Huynh

Faculty of Physics-Engineering Physics, University of Science, Vietnam National University, Ho Chi Minh City, Vietnam

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ABSTRACT

Single KDP crystals were grown from an aqueous solution by the slow cooling method. They were cut into triangular prism-shaped blocks whose angles were determined by type II phase-matching condition for the second harmonic generation (SHG). The 1064 nm laser was shone into the KDP crystals and was partially converted to the 532 nm light. The power of remaining 1064 nm beam was much higher than that of 532 nm SHG beam. Total internal reflection occurred inside the KDP crystals for the 1064 nm beam. The 532 nm beam passed through the crystals and was recorded by a detector. The KDP crystal prisms have two functions: help to measure the output 532 nm radiation accurately, and adjust the power of 532 nm beam by changing the point of incidence of the 1064 nm beam, which improves convenience of the frequency doubler in optical devices.

1. Introduction

Second harmonic generation (SHG) was first achieved by P. A. Franken, A. E. Hill, C. W. Peters, and G. Weinreich at the University of Michigan, Ann Arbor (USA) in 1961. They found that the 694 nm radiation from a ruby laser was converted into the double-frequency radiation – 347 nm. Many important applications have been developed from the SHG effect, such as frequency doublers, high power laser frequency converter for fusion research [1], surface morphology of optical materials, nonlinear optical microscopy used biomedical engineering, etc [2].

Potassium dihydrogen phosphate (KDP) is considered one of the most typical nonlinear optical materials because of its significant advantages. KDP crystals can be easily grown in large sizes from an aqueous solution. However, it yields relatively low SHG efficiency due to its low nonlinear coefficient. For example, d_{36}(KDP, 1064 nm) = 0.39 pm/V, d_{36}(ADP, 1064 nm) = 0.47 pm/V, d_{33}($LiIO_3$, 1064 nm) = 4.5 pm/V, and d_{33}($KTiOPO_4$ or KTP, 1064 nm) = 10.7 pm/V [3]. Many studies have conducted the doping of organic substances into KDP crystal to improve the nonlinear optical coefficient. Parikh et al. [4] reported that the relative SHG efficiencies of the undoped and 0.3 wt% and 0.4 wt% L-arginine doped KDP crystal are 1.00, 1.33 and 1.74, respectively. Mohd. Shkir et al. [5] found that 2.5 mol% Glycine doped KDP single crystal has SHG efficiency higher than that of pure KDP crystal. In addition, KDP crystals with incorporated dye have high nonlinear optical response [6,7].

Another approach to SHG research is to study its mechanism more deeply and the factors that influence it. W. Wang et al. [8] investigated the dependence of the phase-matching angle on temperature in type I SHG of KDP crystal. They found that when the temperature of KDP crystal changes by 1 °C, the phase-matching angle will vary by approximately 100 µrad. Hai Tao Liu et al. [9] performed simulation of the influence of surface topography on the deformation, stress and SHG of KDP crystal. Michel Rérat et al. [10] used the Coupled Perturbed Hartree-Fock/Kohn-Sham scheme to calculate dispersion of the SHG d_{xyz} and d_{zxy} tensor

* Corresponding author.
E-mail address: ptvinh@hcmus.edu.vn (V.T. Phan).

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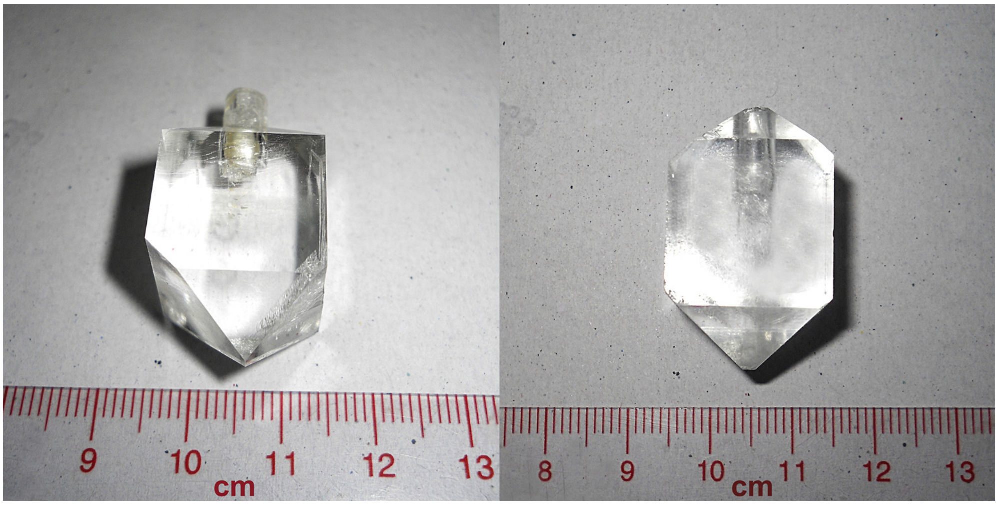

Fig. 1. Single KDP crystals.

components of KDP crystal as a function of frequency. YinBo Zheng et al. [11] discussed the influence of polarization orientation on bulk damage performance of type I KDP doubler under different wavelengths pulses, namely 1064 nm, 532 nm, and 365 nm. Zhenxu Bai et al. [12] demonstrated a high energy 532 nm hundred picoseconds laser based on stimulated Brillouin scattering pulse compression and SHG of type II phase-matching KDP crystal. The SHG conversion efficiency was 55.4%. Basically, these works are very useful to better understand the technical, empirical, and theoretical issues of SHG.

In the present paper, an idea of the investigation of SHG is proposed. Single KDP crystals were cut into triangular prism shape. Dihedral angles of the prism were determined by type II phase-matching condition for SHG and total internal reflection with the wavelength of 1064 nm. The 1064 nm laser was partially converted to 532 nm light in the medium. The difference between the propagation direction of the remaining 1064 nm beam and the 532 nm beam is significant. Hence, the 532 nm beam could be recorded more accurately. A special feature of the triangular prism-shaped KDP crystal is its adjustable SHG efficiency, which cannot be obtained with conventional shapes of the KDP crystal.

2. Theory and experiment

2.1. Growing single KDP crystals

KDP powder was dissolved in distilled water to form a saturated solution at 50 °C. The solution was poured into a tank containing a KDP seed. These solution tanks were put into a crystallization system. The temperature of solution would be lowered 0.5 °C for 3 h. The seed would gradually grow up to be a large-size single KDP crystal (Fig. 1).

2.2. The SHG phase-matching conditions of KDP crystal

The SHG coefficient is determined by the theoretical expression [Ref [13]]:

$$e_{SHG} = \frac{P_{2\omega}^{out}}{P_{\omega}^{in}} = \frac{8}{\pi c}\left(\frac{\mu_0}{\varepsilon_0}\right)^{\frac{3}{2}} \frac{\omega^3 d^2 L}{[n_o(\omega)]^2} P_{\omega}^{in} \left(\frac{\sin\frac{\Delta k.L}{2}}{\frac{\Delta k.L}{2}}\right)^2 \tag{1}$$

where c is speed of light in vacuum, ε_0 is vacuum permittivity, μ_0 is vacuum permeability, ω is angular frequency of input laser, 2ω is doubling angular frequency of output radiation, d is nonlinear coupling coefficient of crystal, L is length of crystal, $n_o(\omega)$ is ordinary refractive index of crystal with wavelength of input laser and Δk is the magnitude of wave vector mismatch between the incident waves (ω) and second harmonic wave (2ω):

$$\Delta k = k_{\omega} + k_{\omega} - k_{2\omega} \tag{2}$$

e_{SHG} reaches to its maximum value when Δk = 0 which is called “The phase-matching condition”.

KDP is a negative uniaxial crystal whose phase-matching conditions are:

$$k_{\omega}^{o} + k_{\omega}^{o} = k_{2\omega}^{e} \text{ or ooe} \tag{3}$$

$$k_{\omega}^{o} + k_{\omega}^{e} = k_{2\omega}^{e} \text{ or ooe or eoe} \tag{4}$$

where o and e stand for ordinary and extraordinary, respectively.

The conditions (3) and (4) are satisfied if the angles between direction of the incident beam (the 1064 nm laser beam) and the