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Research in SNR of two-wave mixing in photorefractive Cu:KNSBN crystal

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Abstract: The energy coupling efficiency ξ of two-wave mixing (TWM) in Cu:KSNBN crystals was measured under different experimental configurations, and the signal-to-noise ratio (SNR) of the signal intensities was calculated from the recorded time evolution of the intensities of the two coupling beams. The experimental results show that the energy coupling efficiency ξ increases with the SNR by comparing the values of ξ and the value of SNR of the signal intensities, which is essentially consistent with what was expected in theory for the reflected beams in the crystal affect the volume refractive index grating to a much less degree at the configuration by design.

Key words: photorefractive; two-wave mixing; signal-to-noise ratio (SNR)

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光折变掺铜钾钠铌酸锶钡晶体中双波耦合的信噪比研究

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摘 要: 测量了在不同实验设置下光折变掺铜钾钠铌酸锶钡晶体(Cu:KNSBN)中双波耦合的能量耦合系数 ξ,并从耦合光波强度随时间变化的实验数据中计算了双波耦合信号光的信噪比(SNR)。对比双波耦合能量系数 ξ 和信号光的信噪比(SNR),结果表明与理论预计的一样,随着信噪比的提高双波耦合能量系数 ξ 增大。这是因为设计的实验条件大大地降低了晶体内反射光对立体折射率光栅的影响。

关键词: 光折变;双波耦合;信噪比

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Biography: WANG Deng-ke, male, born in 1981 in Jinhua, Zhejiang, assistant engineer, specializes in physics experiment and laboratory teaching management.

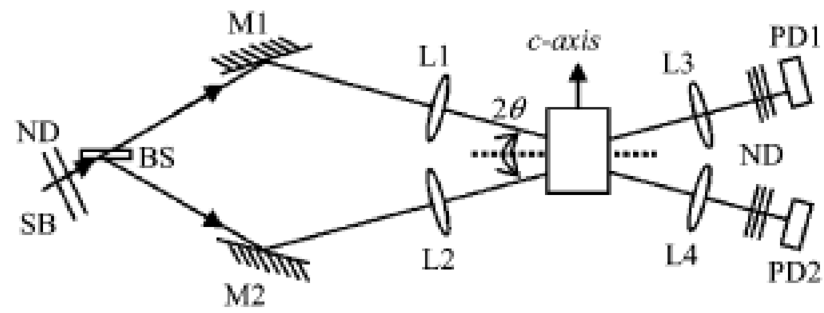
Photorefractive (PR) materials have been intensively studied for the sake of signal processing, coherent optical amplification, imaging and storage[1-3] . Since PR materials could be used as optical image processors, it is necessary to study the role of optical noise in PR crystals . When a PR crystal is illuminated by light, there will be scattered light caused by defects, impurities, and in homogeneities inside the PR crystal, and beam fanning may originate from the light scattering and Two-Wave Mixing (TWM) between the signal beam and the scattered beams[4], and self-defocusing of signal beam caused by the refractive index perturbation Δn (if the Δn is negative) . All these optical signals show up as noise and affect image processing . Some techniques to suppress or reduce optical noise in PR crystals have been reported[5-7] . The origin of noise in the TWM process in PR crystals has been mainly attributed to self-fanning[4] . Vibration is an obvious origin of the noise, which is easily reduced by using a pneumatic isolated optical table .

1 Experiment Introduction

It has been reported that the signal-to-noise ratio (SNR) of photorefractive amplifiers in signal processing applications could be significantly enhanced by tilting or rotating the crystal [8-10] . Using extraordinarily polarized beams, the origin of noise in the TWM process in Cu:KNSBN crystal has been studied and the optical noise was mainly attributed to self-fanning[11] .We believed that part of the optical noise of TWM due to the interactions between the multiple reflected beams and incident beams . We have used several methods to reduce this effect by tilting the crystal, rotating the crystal, and immersing the crystal in liquids with different refractive indices . In this letter we present the relevant experimental results of the energy coupling in Cu:KNSBN crystal .

2 Experimental Setup

In our experiment, we used a cubic Cu:KNSBN (0 .03 % in weight) crystal of dimensions $a \times b \times c = 5$ mm $\times$ 5 mm $\times$ 5 mm . An ordinarily polarized 632 .8 nm He-Ne laser beam was split into a signal beam of intensity I_s and a pump beam of intensity I_p . Two photodiodes were used to record the time evolution of the intensities of the two coupling beams . In our experiments, the experimental set-up was essentially the conventional co-directional scheme for two-wave mixing and we kept $I_s = I_p =$ 1 .5 mW, beam diameter 1 mm and the intersecting angle inside the crystal $2\theta = 20°$. One set of experiment with four different configurations has been conducted to compare with the conventional TWM experiment in air: (a) Tilting the crystal such that the reflected beams were not in the incident plane; (b) Rotate the crystal such that one of the coupling beams was perpendicular to the incident surface in order to make the reflected beams of this beam were only in the incident direction; (c) Immersing the crystal into water of which refractive index 1 .332 (larger than that of air) to reduce the reflected beam intensity at the output face; (d) Using silicon oil with larger refractive index 1 .60 than water instead of water to further reduce the intensities of the reflected beams . Fig .1 shows the setup of experiment, and Fig 2 shows the setup of crystal .

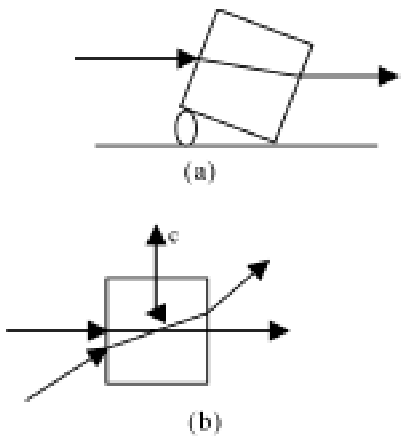


L1, L2, L3, L4: focusing lenses; M1, M2: Mirrors; ND: Neutral density filters; BS: Beam splitter; SB: Signal beam; PD1, PD2: Photodiodes

Fig .1 Experimental setup for TWM in KNSBN crystal

3 Results and Discussion

In order to analyze the signal to noise ratio (SNR), we developed a computer program to calculate SNR of experimental results as follows . The sampling rate was 10/ s . Choose any time interval including N data points (N: any value larger than 1, typical N-value was 100) from the whole data



(a) Tilt the crystal (side view); (b) Rotate the crystal (top view).

Fig.2 Setup of crystal

set, SNR is taken to be I_a/I_{rms}, where I_a is the average intensity value of N data points, I_{rms} is the root-mean-square value of the deviation from I_a. The results of SNR in selected runs are shown in Fig 3, which demonstrates that the SNR was efficiently increased by using these methods.

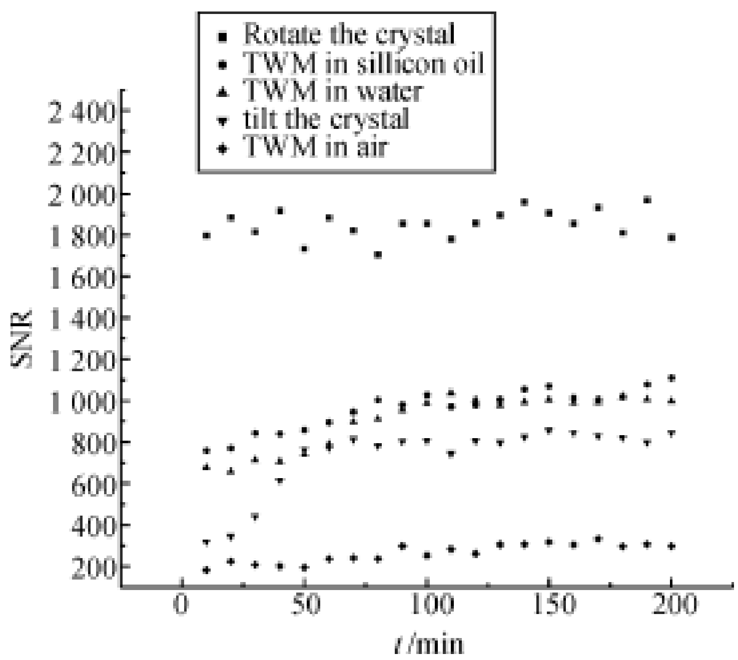


Fig.3 SNR during the TWM process

It s easy to understand the times of reflecting of the light beam in the crystal were greatly reduced by tilting and rotating the crystal. And by immersing the crystal into liquid, the intensity of the reflected beam was reduced. A simple estimation below shows how the intensity of the reflected beam is reduced by immersing the crystal into different liquid. Let n and n_0 be the refractive index of the PR crystal without PR effect and of the medium surrounding the crystal respectively, the intensity ratio between reflected beam at the output face and incident beam at normal incidence is $R = \frac{(n-n_0)^2}{(n+n_0)^2}$. Assuming $n = 2.3$ (a common value of a PR crystal), $n_0 = 1$ (crystal is placed in air), and another case of $n_0 = 1.5$ (crystal is put in a liquid of which the refractive index is 1.5, such as silicon oil), the R value is 15.5% and 4.4%, respectively. We see that the reflected beam is efficiently reduced by putting the crystal in a liquid of higher refractive index than that of air.

As one can see in table 1, no matter to weaken the multiple reflected beams whether by decreasing the reflecting times or reducing the reflecting intensity, the energy coupling efficiency ξ increased with the SNR, though it had different extent of affection on the SNR and ξ when the reflecting beam was reduced in different aspect. According to our expectation, the energy coupling efficiency ξ should increase with SNR because the reflected beams affect the grating to a much less degree. Table 1 lists the values of ξ in different experiments, showing our experimental data are essentially consistent with the expectation.

Table 1 Values of energy coupling efficiency with different TWM configurations

TWM configuration	ξ/%
in air	7.0 ±0.5
crystal tilted	10.9±0.4
in water	13.3±0.4
in silicon oil	17.5±0.3
crystal rotated	12.6±0.2

4 Conclusion

To conclude, we have strong evidences to suggest that part of the optical noise in TWM process is experimentally to be the interaction between the multiple reflected beams and incident beams. The grating suffers less disturbance from reflected beams, then SNR increased and the energy coupling efficiency enhanced correspondingly. However, SNR of TWM in rotated crystal is significantly larger than that of TWM in silicon oil, whereas the energy coupling efficiency of the latter is much larger than that of the former. This phenomenon may due to the special configuration of rotation of the crystal: one beam is normal incident such that the multiple reflected beams are overlapped with the incident beam, and a complex refractive index grating may build up in the crystal.

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