# The Effect of Vibration on Two-Wave Mixing in a Photorefractive Crystal

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We measured the signal beam intensity of two-wave mixing in a $BaTiO_3$ crystal which was subjected to a small vibration along the C-axis. The grating vector formed by the interference of the two beams was also along the same axis. The signal intensity as a function of vibration amplitude follows the prediction of a theory using a convolution of the vibration pulse and the grating itself. This approach may provide a probe to unveil various light-grating interaction mechanisms within photorefractive crystals.

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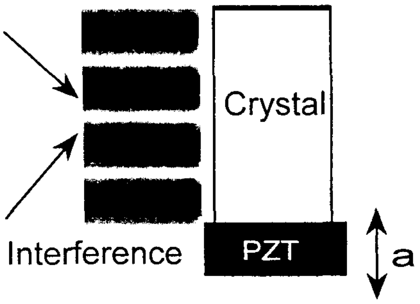
## I. Introduction

Since the discovery of photorefraction, much research interest has been directed toward various applications such as two-wave mixing (TWM), four-wave mixing, anisotropic diffraction, beam fanning and phase-conjugation [1-6], etc. All of these applications involve using photorefraction to store a grating or a series of gratings in a photorefractive crystal. As one might imagine, these gratings are very sensitive to vibration. Understanding the impact of vibration to the above phenomena may help us realize the fundamental limitations in their applications and may also provide a probe to unveil various light-grating interaction mechanisms within photorefractive crystals. Eventually this may lead to some means for controlling photorefraction. Several papers have reported their studies of vibration effects on photorefractive crystals [7], but none of them discuss how photorefractive grating is affected by vibration. In this paper, we theoretically analyze the vibration effect on a photorefractive crystal, and demonstrate experimentally a method for controlling the strength of multiple gratings inside a crystal by applying a vibration signal to the crystal.

## II. Experiment

The experiment was conducted by applying a small vibration along the c-axis of $BaTiO_3$, which coincides with the grating vector formed by two laser beams as shown in Fig. 1, and then measuring the signal beam intensity as a function of the vibration amplitude. The crystal with dimensions of 5 mm x 5 mm x 5 mm ($a \times b \times c$) was mounted on a Burleigh model P2-91 PZT translator. The optical lay-out is illustrated in Fig. 2. An




FIG, 1. The direction of applied vibration is along that of the grating vector.

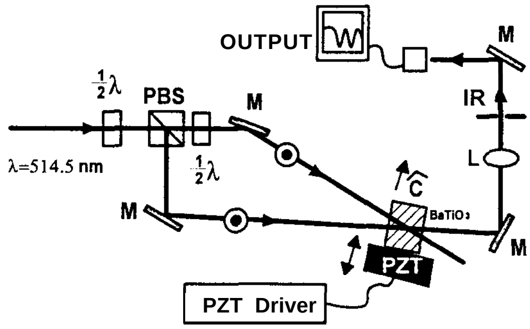



FIG. 2. Experimental setup.

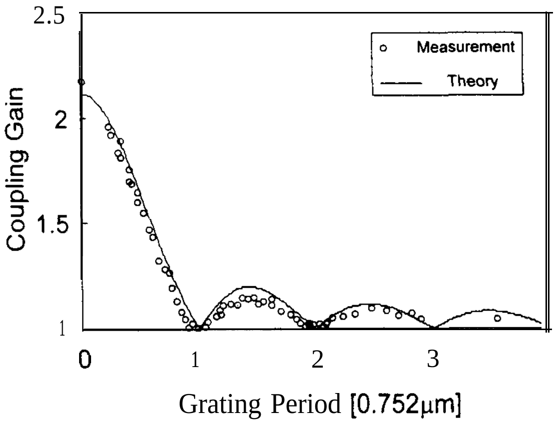



FIG. 3. Coupling gain as a function of vibration amplitude in the unit of grating period. The solid line is from the theoretical calculation and the circles represent the experimental data.

argon laser was directed to a beamsplitter; the transmitted beam reflected from Mirror 1 interfered with the reflected beam from the beam splitter and formed the grating in the crystal. In order to avoid the beam fanning effect associated with the e-rays within the crystal, we used a half-wave plate to adjust the polarization of the reflected beam so that both beams were o-polarized as they entered the crystal. Two irises (IR1 and IR2) were used to remove stray light and noise. Fig. 3 shows the measured coupling gain of two-wave mixing as a function of vibration amplitude. The incident conditions were as follows: The vibration frequency of the PZT was 2KHz; the full incident angle outside the crystal was 40°; the intensities of the pumping beam $I_1$, and the signal beam $I_2$ were 160 $\mathrm{mw/cm^2}$ and 32 $\mathrm{mw/cm^2}$, respectively. The measurement data in Fig. 3 show that the coupling gain drops quickly to zero as the vibration amplitude increases. The coupling gain rebounds to a secondary maximum at a slightly larger amplitude and the cycling behavior continues.

### III. The principle

The initial grating formed by the interference of the two light beams can be represented as

$$g(x) = A + B\cos\left(\frac{2\pi}{\Lambda}X\right), \tag{1}$$

where A represents the grating period in the crystal; A and B are the DC amplitude and AC amplitude of the interference grating respectively, and the initial phase of the grating is neglected. The corresponding index change can be expressed as

$$\mathbf{n(X)} = n_0 + m\Delta n\cos\left(\frac{2\pi}{\Lambda}X + \phi\right), \tag{2}$$

where $n_0$, An, and $\phi$ are background refractive index, saturation refractive index change, and phase difference between the interference fringes and index grating, respectively. $m$ is the modulation depth of interference and it depends on the intensity ratio between the two writing beams. The vibration pulse is defined as the dwell time for the interference fringe at each spatial coordinate point along the C-axis. For simplicity, we treat the vibration pulse as the form shown in Fig. 4. This simplifies the calculation but does not affect the essence of the result. Thus the pulse is written as a rectangle function,

$$\mathbf{h(X)} = \frac{1}{a}rect\left(\frac{x}{a}\right), \tag{3}$$

where a is the vibration amplitude. When the crystal vibrated at a speed much faster than the response speed of the crystal, the AC amplitude can be written as

$$\left|\frac{1}{a}\int_{-\infty}^{\infty} rect\left(\frac{x}{a}\right)\cdot B\cos\left(\frac{2\pi x}{\Lambda}\right)dx\right| = \left|\frac{B\sin\left(2\pi\frac{a}{\Lambda}\right)}{2\pi\frac{a}{\Lambda}}\right|, \tag{4}$$

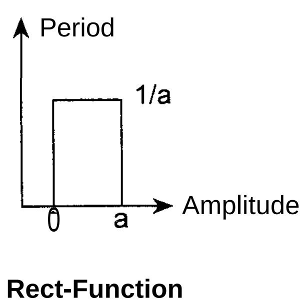



FIG. 4. Vibration function is simplified as a rectangle function.

The corresponding saturation amplitude of the refractive index change is

$$\Delta n' = \Delta n \left| \mathrm{sinc}\left(2\pi \frac{a}{\Lambda}\right) \right| . \tag{5}$$

Eq. (5) can be treated as that the degraded refractive index change which is a convolution of the grating with the vibration pulse:

$$\Delta n = \Delta n \cdot \left| \cos\left(\frac{2\pi}{\Lambda} X\right) * \frac{1}{a}\, rect\, \left(\frac{x}{a}\right) \right| , \tag{6}$$

where * denotes convolution. Eq. (5) indicates that the grating strength decreases and when oscillates as the vibration amplitude increases. In addition, no refractive index change happens when the amplitude satisfies

$$\boldsymbol{a} = n\Lambda, \qquad \mathrm{n} = 1, 2, 3, \ldots . \tag{7}$$

The refractive index change is an important parameter corresponding to the coupling coefficient and the relation can be written as

$$\gamma = \frac{\pi \Delta n}{\lambda} . \tag{8}$$

Therefore, the coupling coefficient is affected as the crystal vibrates. Eq. (8) can be applied to diffraction, four-wave mixing and two-wave mixing in photorefractive crystals. In two-wave mixing, the coupling gain is [2]

$$G = \frac{I_a(z)}{I_d(0)} = \frac{1 + m}{1 + me^{-\gamma z}} e^{-\alpha z} \tag{9}$$

where $I_d$ is the intensity of the amplified beam. $\alpha$ is the absorption coefficient of the crystal. m is the intensity ratio, $m = \frac{I_1(0)}{I_2(0)}$. As the vibrating signal is applied to the crystal, the coupling coefficient changes to

$$\gamma_v = \gamma \ . \ \mathrm{si}\left( : \frac{a}{\Lambda}\right) . \tag{10}$$

The coupling gain of the amplified beam is rewritten as

$$\mathbf{G} = \frac{1 + m}{1 + me^{-\gamma_v z}} \mathrm{e}^{-\alpha z} . \tag{11}$$

Eq. (11) shows how the vibration affects the amplification of the TWM. A theoretical result derived from Eqs. (10) and (11) is shown as the solid line in Fig. 3. In the calculation, the fitting coupling coefficient without vibration is $\gamma = 3\ \mathrm{cm}^{-1}$ and interaction length is 5 mm. The theoretical curve fits the experimental data fairly well.

## I-V. Discussion

To discuss the effects of the vibration, two important parameters are introduced in the following.

(1) The ratio of the vibration frequency to the speed of the crystal $R_f$ is an important parameter. If $R_f \ll 1$, the formation of the index grating is not affected by the vibration. If $R_f \gg 1$, the grating will be washed-out, but it depends on the ratio between the vibration amplitude and the grating spacing.

(2) The ratio between the vibration amplitude and the grating space $R_\Lambda$ is the other important parameter for analyzing the vibration effect as the vibration frequency is much faster than the speed of the grating formation. If $R_\Lambda < 1$, the coupling coefficient decays as the vibration amplitude increases. If $R_\Lambda = n\Lambda, n = 1, 2, 3, \ldots$, the coupling coefficient is zero, and it means that visibility of the grating is zero. If $R_\Lambda > 1$, the coupling coefficient damps as the vibration amplitude increases. Therefore, a grating with small grating spacing is more sensitive to vibration than a grating with large grating spacing, and when the vibration amplitude is just a few times the length of the grating space, the index grating is washed-out.

## V. Conclusion

In conclusion, we have presented experimental results which reveal the impact of vibration on two-wave mixing. More specifically, we have measured the signal beam intensity as a-function of vibration amplitude and explained the experimental results in terms of a simple theoretical model. This model can be used to describe the effects of vibration on wave-mixing in a photorefractive crystal.

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