ISCMP Varna '98

Proceedings of the
Tenth International School on
Condensed Matter Physics

THIN FILM MATERIALS AND DEVICES – DEVELOPMENTS IN SCIENCE AND TECHNOLOGY

Varna, Bulgaria 1 – 4 September 1998

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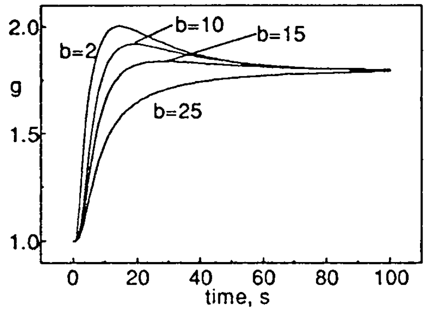

Figure 5: Amplification, g, for various time constants, b, of the circular birefringence.

Next, we investigated the influence of the time constant, b of CB on the amplification, while a was held constant (fig. 5). The higher rate of increase in CB causes higher values of g. It should also be noted that if we change the sign of CB, the curve for g is the same, but is mirror reflected to g=1. The same behavior occurs when only the sign of LB is changed.

4. Conclusions

In a polarisation holographic grating recorded with two circularly polarised waves (left and right) for a material with linear and circular birefringence, an energy transfer occurs between the recording waves. When the signs of the changes in the linear and the circular birefringence are the same, amplification of the weaker beam occurs. Otherwise, the energy transfer is from the weaker to the stronger beam. The amplitude as well as the speed of change of the circular birefringence is important in respect of the values of wave coupling. The higher circular birefringence causes a higher energy transfer. On the other hand the diffraction efficiency of such a grating decreases when the circular birefringence increases. This is related to the polarisation state of interference pattern, and its reflection in the material.

5. References

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6. Acknowledgements

This work was funded by the National Fund "Scientific Investigations", contract F-629. The author is grateful to Dr. P. Sharlandjiev for his assistance.

TWO WAVE MIXING IN THIN FILMS WITH LINEAR AND CIRCULAR BIREFRINGENCE

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ABSTRACT

A model of a polarisation holographic grating, recorded in material with linear and circular birefringence, is numerically investigated. Two waves with circular polarisation, left and right, form the grating. A thin layer approach is used (Jones matrices) to describe the properties of the grating. The influence of circular birefringence on the value of the diffraction efficiency, and its important role in the energy transfer between beams, are studied.

1. Introduction

Two-wave mixing is a physical process, which takes advantage of the nonlinear response of some materials to the illumination of light. Under appropriate conditions, it is possible to interchange energy between light waves. This is a particular case of self-diffraction, where the diffraction order of one of the waves is propagating parallel to the diffraction order of the other wave. Then, if the waves propagating in the same direction are in phase, an amplification of one of the beams at the expense of the other occurs. It has been shown[1,2] that energy transfer is possible if there is a phase shift between the interference pattern and the modulation of the optical constants of the sample. Typical examples are photorefractive crystals [2,3] where optically generated charge carriers migrate when the crystal is exposed to a spatially varying pattern of illumination with photons of sufficient energy. An analysis of the diffraction has been made by Huang and Wagner [4,5]. Their theoretical consideration is for the case when the recording waves have orthogonal linear or circular polarisation and the media exhibit a linear photoinduced anisotropy. In this paper, we present a numerical model for the recording of a polarisation holographic grating in material with linear and circular birefringence, as well as the diffraction properties of the grating and the conditions for energy transfer.

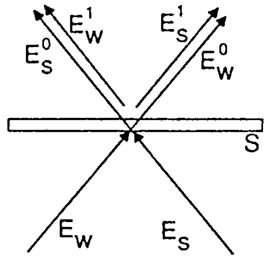

Figure 1: Two-wave mixing

2. Experimental Method

Two waves of arbitrary polarisation form the interference pattern on the sample "S" (fig.1). In general, they have different intensities. Let the stronger beam be E_S and the weaker – E_W. Then their diffraction orders after interacting with the grating are E_W^0, E_S^0, E_S^1, etc.

Firstly, we describe the interference pattern on the sample in terms of the Stokes parameters (S_0, S_1, S_2, S_3). The polarisation of this field varies along each period of the pattern. Then, using the material constants, i.e. the linear and circular birefringence (LB and CB), we form the matrix of the change of optical index, Δn. We use the amplitude transmittance (thin layer) approach $\Delta T=e^{-i\Delta nk}$, where $k=2\pi/\lambda$, and ΔT is the matrix of the photoinduced change in optical transmittance. By applying a fast Fourier transform on the articles of ΔT, we calculate Jones matrices for each diffraction order. This method is suitable for different states of polarisation of the recording beams, and also for different polarisation responses and shifted scalar responses of the material. However, we limited the present investigation to the case when E_W and E_S have left and right circular polarisation (in this case, it is known that only the ±1 orders are present (fig. 1)) and LB and CB are induced into the material[6].

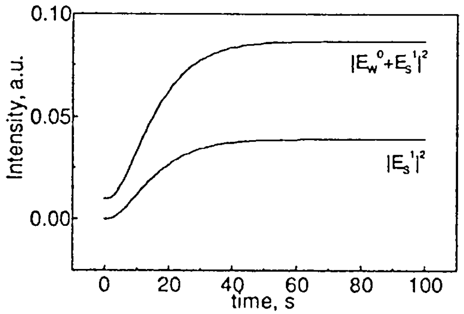

Figure 2: Signal intensity, and the diffraction of the stronger beam (E_S^1)

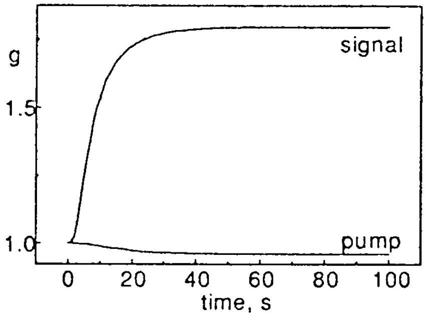

Figure 3: Amplification for the signal and pump respectively

Experimentally one can measure the intensity $|E_W^0+E_S^1|^2$, where E_W^0 and E_S^1 are Jones vectors of the corresponding diffraction orders. In numerical calculations, we assume a pure phase grating recorded in the sample. Thus, the observer could see amplification of the weaker beam due to two mechanisms: the diffraction efficiency of the stronger beam, and non-degenerative mixing between E_W^0 and E_S^1. Different procedures for describing the amplification are known. In papers concerning

photorefractive crystals, they use[7] $g = (|E_W^0+E_S^1|)^2/(E_W^0)^2$, which reflects two mechanisms together. We choose[8]

$$g = (|E_W^0+E_S^1|)^2/((E_W^0)^2 + (E_S^1)^2 \qquad (1)$$

which describes only the non-degenerative mixing, and can have values from 0 to 2, where 1 means no amplification. Here equation (1) is for the weaker (signal) beam, but a corresponding expression could also be written for the other diffraction order.

We introduced a time scale into this virtual experiment, over which LB and CB increase from zero to saturation at "a", following the formula:

$$n = a(1-e^{-\frac{t}{b}}) \qquad (2)$$

In the calculations, we used a wavelength of 633 nm and a thickness of 10μm.

3. Experimental Results

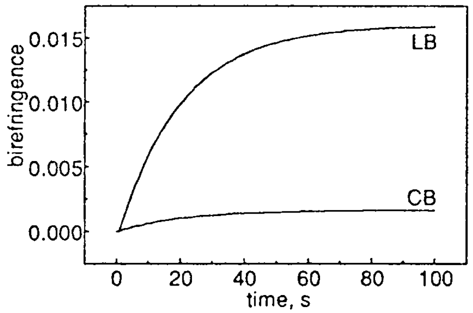

Figure 4: Changes of the linear (a=0.016) and circular (a=0.0016) birefringence (b=20 for both)

When the recording beams have equal intensity, the interference pattern has a linear polarisation with varying azimuth along its period[6]. No circular birefringence could be induced and no energy transfer occurred. When the beam ratio is relatively low (2,4,10) the diffraction efficiency is high, but the amplification g is small. That is why we considered the case when the initial intensity ratio is 1:100. Fig. 2 shows the signal $|E_W^0+E_S^1|^2$ and the diffraction efficiency of the stronger beam $|E_S^1|^2$. The intensity $|E_W^0|^2$ is relatively low here and the difference between the curves is due to amplification (fig. 3.). LB and CB are supposed to have the same behavior in time, and according to (1): a=0.016 and b=20 for both.

If the saturated level of circular birefringence is ten times smaller: a=0.0016 (fig. 4) the diffraction efficiency becomes almost 0.1, but g reaches only 1.09. The conclusion is that the higher the CB, the higher the amplification g and the smaller the diffraction efficiency.