traces of Li as well as Cu may initiate the formation of defects in high resistivity GaAs by heat treatment such as described in ref 1.

The authors are indebted to J. M. Whelan, R. G. Sobers, and W. C. Erdman for supplying crystals, and to A. R. Hutson for comments on the manuscript.

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CONVERSION OF FM LIGHT TO AM LIGHT USING BIREFRINGENT CRYSTALS[1]

S. E. Harris

Stanford Electronics Laboratories
Stanford University, California

(Received 23 November 1962)

Optical polarization interference in birefringent crystals may be used to convert frequency modulated (FM) light to amplitude modulated (AM) light. We report the demodulation of microwave FM light by converting it to microwave AM light using a crystal of calcite between Nicol prisms as shown in Fig. 1.[2] The calcite crystal was five cm long, was cut with its *c*-axis perpendicular to its length, and had end faces flat to a 1/20 of a wave and parallel to about 10 sec. The transmission axes of the Nicol polarizer and analyzer were parallel and at forty-five degrees to the principal axis of the calcite. The crystal was mounted on a turntable to allow rotation about the vertical axis BB' such that the angle between the light and the normal to the crystal face could be varied by small amounts.

The transmission characteristic for the optical E field through the device may be written:

$$E_{\text{out}} = \cos(K_1\alpha + K_2 f)E_{\text{in}} , \qquad (1)$$

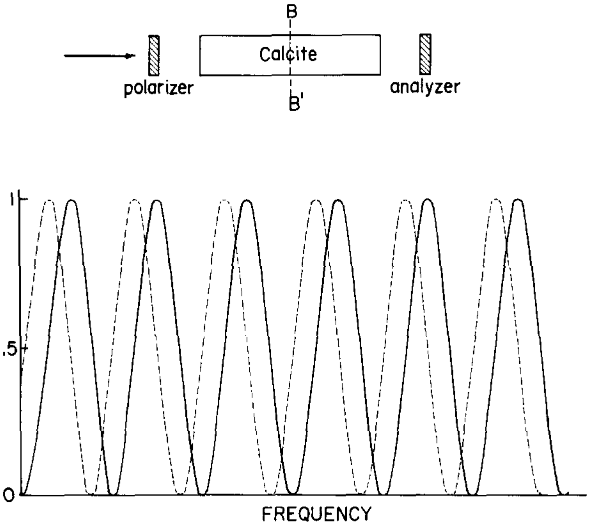

Fig. 1. Intensity vs frequency for two different biases.

where nonessential phase factors have been omitted. Here α is the angle between the incident light and the crystal surface normal and is varied to correctly bias the discriminator curve. This ability to mechanically bias the discriminator curve results in part from the fact that the index of refraction of the extraordinary wave depends on the angle between the light and the *c*-axis and in part from path-length changes caused by double refraction. With the *c*-axis horizontal, K_1 is about π rad/degree which is convenient for operation.

INDEXING CATEGORIES

A. birefringent crystals	E
B. FM to AM microwave light conversion	
C. optical polarization interference	

The sensitivity of the discriminator to changes in frequency depends on K_2 which is given by:

$$K_2 = \frac{\pi L \Delta n}{c} + \frac{\pi L f}{c}\frac{d}{df}(\Delta n)\,, \qquad (2)$$

where $\Delta n = n_e - n_o = 0.17$ for calcite. For calcite the first term of K_2 is about 10 times the second and of the same sign. For our discriminator at 6328 Å, K_2 is equal to π rad/31.6 G.

The operation of the discriminator may be understood physically by considering the intensity transmission as a function of frequency, which is shown for two different values of bias in Fig. 1. To demodulate FM light, the bias is adjusted such that I/I_0 equals 50% at the carrier frequency, and as the frequency swings about this point, amplitude variations result.

The FM to AM conversion is analyzed by starting with an FM light signal of the form

$$E_{\text{in}} = \exp j(2\pi f_c t + \delta \sin 2\pi f_m t)$$

$$= \exp (j2\pi f_c t) \sum_{n-\infty}^{\infty} J_n(\delta) \exp (j2\pi n f_m t) \qquad (3)$$

and multiplying it by the optical transmission characteristic (Eq. 1). The above series is then multiplied by its complex conjugate, and the resultant doubly infinite series attacked with appropriate Bessel identities to yield the result:

$$I_{\text{out}} = 1/2 + \cos 2\theta \left[\frac{J_0(2\delta \sin K_2 f_m)}{2} + \sum_{n=1}^{\infty} (-1)^n J_{2n}(2\delta \sin K_2 f_m) \cos 4\pi n f_m t\right]$$

$$+ \sin 2\theta \sum_{n=0}^{\infty} (-1)^{n+1} J_{2n+1}(2\delta \sin K_2 f_m) \cos 2\pi(2n+1) f_m t, \qquad (4)$$

where $\theta = K_1\alpha + K_2 f_c$, and is therefore the bias.

One important result of this analysis is that to detect FM light signals with small modulation index δ, then for optimum conversion, the crystal length should be chosen such that $K_2 f_m = \pi/2$.

We performed two types of experiments with the discriminator. In both microwave FM light was obtained using the electro-optic effect in a *z*-cut crystal of KDP.[3] The KDP crystal was placed in a microwave cavity and the light polarized along one of the electrically induced principle axes. The modulator was operated cw with a phase deviation $\delta = .05$ at 2.4 G, and also, by utilizing proper high order cavity modes, at 7.1 and 10.8 G.

To detect the presence of microwave FM light without a microwave phototube, the discriminator may be biased to either a peak or a null of the intensity transmission characteristic; *i. e.*, θ may be set to 0 or $\pi/2$ respectively. The presence of the FM will then be evidenced by a decrease or increase of the average transmitted intensity as shown by Eq. (4). The ratio of the change in average intensity when the modulator is run in the FM position and the discriminator is employed (ΔI_{FM}), to the change in average intensity when the modulator is run in the AM position (ΔI_{AM}), should be $\sin^2 K_2 f_m$ for small δ. Microwave FM light at 6328 Å was allowed to travel through the discriminator, which was biased for minimum transmission, and was then incident on a Dumont 6911 photomultiplier. The experiment was performed at 2.4 G, 7.1 G, and 10.8 G and $\Delta I_{(AM)}/\Delta I_{(FM)}$ was 11 dB, 5 dB, and 2 dB respectively, which checks well with analysis.

In the second experiment, demonstrating direct demodulation of frequency modulated light, the output of a pulsed ruby laser was frequency modulated at 2.4 G. After passing through the discriminator, the light was incident on a Sylvania SY-4302A microwave phototube.[4] With about 100 μA of photocurrent the detected signal out of the microwave phototube was about −50 dBm with a signal/noise ratio of at least 20 dB. When the discriminator was removed, the light transmission and hence the photocurrent approximately doubled, but no microwave signal was observed. In this experiment the bias of the discriminator was of almost no consequence. This is expected since the ruby laser oscillates almost randomly in a number of modes[5] and in addition suffers frequency changes due to temperature effects, and thus the bias is continually varying during the course of one laser pulse.

The author wishes to thank A. E. Siegman, B. J. McMurty, and R. J. Morris for helpful discussions. Thanks are also due to Ben Yoshizumi for help in performing the experiments and Leonard Dague for skilled construction of equipment.

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[1] This work was supported by the Aeronautical Systems Division of the United States Air Force at Wright-Patterson Air Force Base, Ohio.

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DOUBLE REFRACTION OF WATER AND SOME OTHER LIQUIDS IN STRONG SHOCK WAVES

A. H. Ewald[1] and S. D. Hamann
Australian Commonwealth Scientific and Industrial Research Organization
Division of Physical Chemistry, Melbourne, Australia

(Received 15 October 1962)

In the course of some investigations of the optical properties of liquids compressed by shock waves from explosions, we have observed that a number of pure liquids become anisotropic in the stressed region behind a shock front.

The method consisted, essentially, in photographing a shocked liquid between crossed polarizers, using uniform back illumination from a short-duration argon flash. Any region of optical anisotropy in the liquid appeared in the photograph as a bright area on a dark ground. In detail, the technique was an adaptation of one used earlier[2] to photograph shock waves by unpolarized light. The original arrangement was modified by inverting the explosive assembly (so that the shock wave moved into the liquid through the aluminum bottom of the cell) and by covering the two windows of the cell with pieces of Polaroid sheet cut in such a way that their directions of polarization were mutually at right angles and at 45° to the direction of travel of the shock front (see Fig. 1). Figure 2 shows a shock wave in water, photographed by this method. The double-refracting region appears as a bright area immediately above the advancing bottom of the cell. The diffuse appearance of the advancing front edge of the area is probably due to the curvature and unevenness of the shock front caused by the smallness of the driving charge and by inhomogeneities in the explosive (*cf.* ref 1). An independent measurement of the shock velocity, combined with Rice and Walsh's[3] equation of state for water, indicated that the conditions at the shock front at the time of the photograph were: pressure, 70 kbar; density,

INDEXING CATEGORIES
A. shock waves (in liquid)
B. optical anisotropy
C. crossed polarizers
E

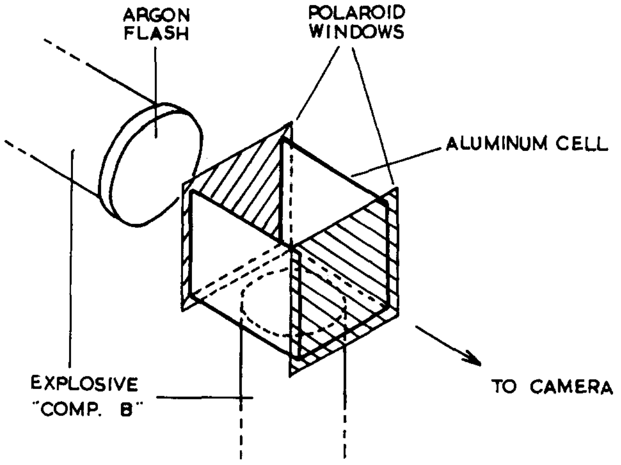

Fig. 1. A schematic diagram of the experimental arrangement. The hatching indicates the directions of polarization of the POLAROID windows. Light emitted by the products of explosion was shielded from the camera by steel masks (not shown).