substituting into (7) and evaluating the difference of beats for $\xi = \pm\eta$, we calculated the peak-to-peak shift of beat frequency. This was 7 kHz at a beam power difference for which we measure 9 kHz.

CONCLUSION

In the use of ring lasers as rotation sensors, the magnitude of nonreciprocal dispersion effects we observe could be a source of major error. For example, in the ring we used, the nonreciprocity of transmittance would need to be maintained less than 10^{-7} to cause an error of less than 1 earth's rotation rate anywhere in the Doppler line. Our experiment showed that there were environmental disturbances of nonreciprocal transmission much larger than this. It appears, therefore, that the performance of ring lasers as rotation sensors will be affected by how well errors caused by nonreciprocal dispersion can be controlled in practice.

In these experiments, we had only rough control over the total cold Q of the ring resonator. We did not measure it accurately. The results suggest, however, that if accurate cold Q measurements were made, and the laser were protected from dust and misalignment to maintain the Q constant from run to run, the method described here could be used for measuring the dipole moment of laser transitions.

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5C3—GaAs as an Electrooptic Modulator at 10.6 Microns

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***Abstract*—The electrooptic properties of a number of semiconductors were investigated. Of particular interest was the possibility of using these materials for modulation of infrared radiation, since many of the efficient modulation materials for the shorter wavelengths, such as KTN and KDP, are opaque in this region. We have investigated experimentally the modulation potential of a number of semiconducting materials. These include ZnS and GaAs of the noncentrosymmetric 43m class. The electrooptic coefficients were determined by using a Co_2, 10.6μ and a He-Ne 3.39 μ laser as the radiation source. Based on our experiments, GaAs appears as a suitable material for infrared modulation at $\lambda > 10\mu$.**

THE ADVENT OF efficient and high power infrared lasers, such as the CO_2 10.6μ laser, reemphasizes the need for modulation materials and techniques in the medium infrared range. Since the conventional electrooptic modulation materials such as KDP, KTN [1], and L_iNbO_3 [2] become opaque in the near infrared (L_iNbO_3, the best in this respect, transmits from 0.4 to 5 microns), we have decided to investigate the suitability of semiconducting crystals for this purpose.

The criteria for choosing an electrooptic semiconductor are as follows.

1) Eg (energy gap) $> \hbar\omega$. ω is the radian frequency of the light to be modulated. This insures freedom from interband transitions that render the material opaque.

2) Restrahlen absorption frequencies sufficiently below that of the optical signal so that lattice absorption is not significant.

3) High resistivity so that the losses due to the modulation currents can be tolerated at the high field strengths ($E > 10^3$ volt/cm) typically used.

4) Small free carrier absorption. The optical absorption by free carriers (electrons and holes) is given by

$$I = I_0 e^{-\alpha z}$$

where

$$\alpha = \sqrt{\mu/\epsilon}(1/\rho)\left(\frac{1}{\omega^2\tau^2}\right), \qquad \omega\tau \gg 1. \tag{1}$$

ρ = the bulk resistivity and τ is the mean carrier lifetime. The free carrier absorption which increases as λ^2 in the infrared range of interest can lead in the case of high power CW lasers, not only to an attenuation of the optical signal, but to an additional source of heating. As a matter of practical interest, it turns out that for the range of resistivities which is necessary to satisfy Condition 3, say $\rho > 10^7$ ohm/cm, the free carrier absorption at $\lambda < 15\mu$ is negligible.

5) The obvious requirement of a large electrooptical coefficient.

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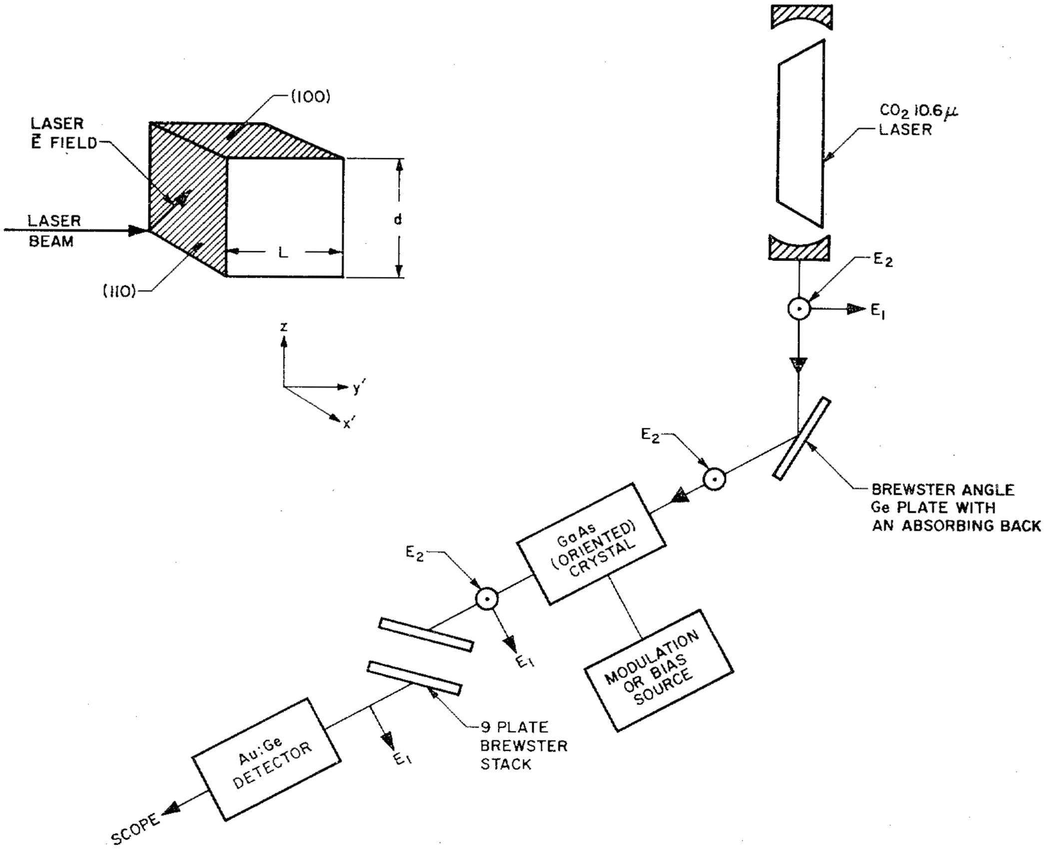

Fig. 1. The experimental setup and the crystal orientation for the 10.6μ modulation.

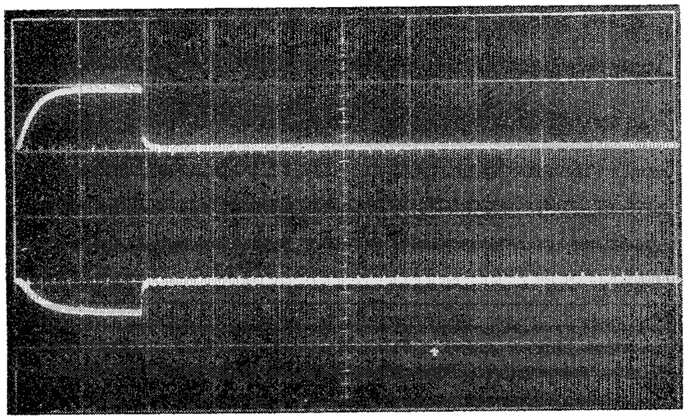

Fig. 2. Upper trace: the voltage pulse applied to the GaAs crystal. (Vertical scale = 1000 V/division.) Lower trace: the optical pulse at 10.6μ as transmitted by the crossed polarizers. (Horizonal scale = 1 μs/division.)

Semi-insulating GaAs satisfies all of these requirements and is, as far as we could determine, the best electrooptic modulation material of all the materials investigated to date. Its electrooptic properties at $1\mu < \lambda < 1.7\mu$ have been investigated by Ho and Buhrer [3]. We have measured the electrooptic properties at 3.39μ and 10.6μ using, respectively, a He–Ne and a CO_2 laser.

The experimental setup and the crystal orientation with respect to the optical beam are shown in Fig. 1. With the bias applied normal to a (001) face and the light incident, as shown, normal to a (110) face along y', the differential phase retardation is [4]

$$\Gamma = \Gamma_{x'} - \Gamma_z = \frac{\pi L n_0^3}{\lambda} r_{41} E_z$$

where y' and x' are rotated 45° with respect to the x and y axes and where $n_0 = 3.34$ is the index of refraction throughout the region of interest. r_{41} is the only independent electro-optic coefficient in $\bar{4}3m$ crystals. The retardation Γ was measured by means of cross polarizers which cause the transmission ratio to be

$$\frac{I}{I_0} = \sin^2 \frac{\Gamma}{2}. \tag{3}$$

Working with values of I/I_0 of up to 30 percent we obtained

$$n_0^3 r_{41} = 5.9 \times 10^{-9} \frac{\text{cm}}{\text{volt}}, \qquad r_{41} = 1.6 \times 10^{-10} \frac{\text{cm}}{\text{volt}}$$

at $\lambda_0 = 3.39\mu$. At $\lambda_0 = 10.6\mu$ the values are the same, subject to an error of ±20 percent. By way of comparison, we have for KH_2PO_4(KDP)

$$n_0^3 r_{63} = 3.3 \times 10^{-9} \frac{\text{cm}}{\text{volt}}, \qquad r_{63} = 9.7 \times 10^{-10} \frac{\text{cm}}{\text{volt}}$$

so that the retardation, under similar conditions in GaAs exceeds that of KDP.

As an illustration of a modulation setup, we show in Fig. 2 the optical pulses at 10.6μ obtained in transmission with microsecond voltage pulses.

Since the low-frequency dielectric constant is $\epsilon = 11.5$, which is very near the optical value $\epsilon = n_0^2 = 11.15$, it should be possible to design long traveling-wave modulators.[1] In this connection it is important to note that for the sample used, no absorption at 10.6μ could be detected in path lengths up to one cm.

As a final instrumental note we draw attention, in Fig. 1, to the use of Brewster's reflectors and transmission stack for the cross polarizers. The reflector, using Ge, yielded a beam with polarization higher than 99 percent. With the nine-plate stack, using silver chloride, a polarization of 95 percent was achieved. The GaAs sample used had a resistivity of 4×10^8 ohm/cm obtained by Fe and Ni doping.

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[1] This possibility was suggested in a post-talk comment by Dr. E. I. Gordon.