compared to the periodicity of the modulation field, small-signal analysis of the laser output from the end mirrors gives

$$I_1 = I_0\left\{1 - \phi^2\left[\frac{1}{|\phi_m|^2} + \frac{(1+\sin^2\theta_B)}{\alpha}\frac{c}{L}\right]\right\}$$

where $\phi = VBl \sin \omega_m t$ is the Faraday rotation in radians, ϕ_m is the magnitude of the maximum tolerable rotation before laser quenching occurs, I_0 is the laser output intensity at zero modulation field, θ_B is the Brewster angle, α is the dissipation loss factor in fractional photon loss per second due to all causes other than Faraday rotation, L is the effective length of the cavity, l is the physical length of glass rod, V is the Verdet constant, B is the amplitude of the modulation magnetic field at a frequency ω_m, and c is the vacuum velocity of light. The intensity of the laser beam reflected off the plasma tube Brewster window facing the glass rod is

$$I_2 = I_i\delta^2(1 - \sin^4 2\theta_B)^2 \cdot\left(1 - 2\frac{\tan 2\theta_B}{\cos 2\theta_B}\frac{\phi}{\delta}\right)$$

where δ is the angular rotation of the glass rod around the laser beam from perfect alignment conditions, and I_i is the beam intensity inside the laser cavity, and is related to I_0 by $I_0 = I_i(1 - r)$, r being the reflectivity of the end mirror. These analytical results indicate the following.

1) When the system is well aligned ($\delta = 0$), I_1 and I_2 are both modulated at second harmonic of the modulating frequency. Linear modulation requires a dc magnetic field superimposed on the modulating field.
2) By making $\delta > |\phi|$, I_1 can be modulated linearly with large modulating index without a dc magnetic field.
3) Knowing the magnitude of the ac modulation field and δ, the Verdet constant of the modulating rod can be accurately obtained from measuring the modulation index of I_2.

Experimental measurements confirm all these predictions. Amplitude modulation up to 6.7 mc/s has been observed. Using a phase-sensitive detection system, Faraday rotation as small as 0.01 second of arc per path was measurable from I_2. The same detection system can measure a polarization rotation no less than 10 seconds of arc with the Faraday cell outside the laser cavity. This enchancement on the measurement sensitivity by intracavity loss perturbation technique is in accord with our analysis.

5C-2 High-Frequency Electrooptic Effect in Ferroelectric Barium Titanate, I. P. Kaminow, *Bell Telephone Laboratories, Inc., Crawford Hill Laboratory, Holmdel, N. J.*

Electrooptic coefficients in small (typically $0.010 \times 0.010 \times 0.150$ inch) single domain barium titanate bars have been measured between 5 and 250 Mc/s using a 6328Å optical heterodyne technique. Piezoelectric resonances have an unexpectedly strong influence on the measurements, even at high harmonics. However, the coefficients approach the following values at high frequencies: $r_{33} = (2.8 \pm 0.5) \times 10^{-9}$ cm/V, $r_{13}/r_{33} = +0.3 \pm 0.1$, where the relative sign is also measured by the heterodyne method. The high frequency value for $r_c = r_{33} - (n_a/n_c)^3 r_{13}$ is then 1.9×10^{-9} cm/V, which agrees, within experimental error, with the strain-free value found by Johnston[1] using an entirely different method.

The value for r_{33} given above is less than the value measured earlier[2] on a plate-like sample over a narrow band near 70 Mc/s. The error in these earlier measurements is attributed to third harmonic resonances in the measuring band. The bar-shaped samples, though more difficult to fabricate than the electroded plates, have the advantages of smaller capacitance, because of the absence of fringing fields, and higher electrical Q (about 10).

In an idealized resonant circuit in which no fringing or circuit capacity is added in parallel with the crystal, the modulating power per unit bandwidth per (modulation index)[2] is proportional to the ratio of cross-sectional area to the length of the crystal along the optical beam. For a fundamental Gaussian optical maser beam and a crystal of given length, it is readily shown that this ratio is a minimum when the beam inside the crystal is characterized by a confocal length equal to the crystal length. Depending on the safety factor, $S^2 \geq 1$, allowed for the beam cross section, the minimum area/length ratio is $S^2\,(4\lambda/n\pi)$ where λ is the optical wavelength and n the refractive index. Hence, the dimensions may be increased while keeping the ratio fixed in order to simplify fabrication without sacrificing efficiency. However, the transit time differential between optical and modulating waves is increased in proportion to the length and the maximum operating frequency reduced accordingly.

Other problems connected with the use of $BaTiO_3$ for light modulation will be discussed and comparisons will be made with related perovskite-type materials.

[1] A. R. Johnston, *Appl. Phys. Lett.*, vol. 7, p. 195, 1965.
[2] I. P. Kaminow, *Appl. Phys. Lett.*, vol. 7, p. 123, 1965.

5C-3 Semiconductors as Electrooptic Modulators for Infrared Radiation,[1] A. Yariv and C. A. Mead, *California Institute of Technology, Pasadena, Calif.*

The electrooptic properties of a number of semiconductors were investigated. We were particularly interested in the possibility of using these materials for modulation of infrared radiation ($\lambda > 3\mu$), since many of the efficient modulation materials for the shorter wavelengths, such as KTN and KDP, are opaque in this region. Most semiconductors, on the other hand, have a region of transparency extending from the fundamental absorption wavelength to well into the infrared, where the lattice absorption becomes important. We have investigated experimentally the modulation potential of a number of semiconducting materials. These include ZnS and GaAs of the noncentrosymmetric 43m class where a linear electrooptic effect exists, Si and Ge which have a cubic (diamond) structure and hence possess only a quadratic effect, and Te of the D_3 (32) class. The electrooptic coefficients were determined by using a He-Ne 3.39 μm laser as the radiation source and measuring the transmission fraction between crossed polarizers as a function of the applied electric field. In cases where the conductivity precluded dc measurements, pulse techniques were employed. Based on our experiments, GaAs appears as the most suitable material for infrared modulation. Its electrooptic characteristics will be discussed in some detail.

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5C-4 Synthesis of Electrooptic Shutters Having a Prescribed Transmission vs. Voltage Characteristic,[1] E. O. Ammann, *Sylvania Electronic Systems—West, Mountain View, Calif.*

A procedure is described for the synthesis of electrooptic shutters having arbitrarily prescribed transmission vs. voltage characteristics. The procedure is an adaptation of the birefringent network synthesis procedure of Harris et al.[2] The synthesized shutter consists of n identical cascaded cells between an input and output polarizer. The synthesis procedure prescribes the angles to which the cells should be rotated and the angle of the output polarizer. Although it is assumed in this paper that each cell contains a Kerr-effect material, the synthesis procedure is equally applicable if each cell utilizes the Pockels effect. The technique of this paper is of possible use in many situations where standard Kerr-cell (or Pockels-cell) shutters are now employed. By controlling the shutter's transmission vs. voltage characteristic, we are able to control the shape and duration of the transmitted optical pulse independently of the form of the applied voltage pulse. Thus by this procedure, one can reduce the duration of the optical pulse resulting from a given applied voltage pulse. Possible applications are briefly discussed in the areas of high-speed photography and Q-switching of lasers.

[1] This work was supported by the Sylvania Independent Research Program.
[2] S. E. Harris, E. O. Ammann, and I. C. Chang, "Optical network synthesis using birefringent crystals, I: Synthesis of lossless networks of equal-length crystals," *J. Opt. Soc. Am.*, vol. 54, pp. 1267–1279, October 1964.

5C-5 An Internally Scanned Laser, E. S. Kohn and V. J. Fowler, *General Telephone and Electronics Laboratories, Inc., Bayside, N. Y.*

A method for producing a scanned beam of light from a laser has been devised and tested in our laboratories. The method appears to be applicable to a high deflection rate scanner for use in display.

Scanning is accomplished by transmitting sonic pulses down an optical delay line situated within a special four-mirror laser