THE LIMITING RESOLUTION IN COLLINEAR ACOUSTOOPTIC LIGHT FILTRATION

V. B. Voloshinov and V. N. Parygin

Vestnik Moskovskogo Universiteta. Fizika,
Vol. 35, No. 1, pp. 90-93, 1980

UDC 535.853.22:534.29

Collinear acoustooptic filtration in a long crystal is considered, where the acoustic power density varies on account of damping and divergence. An estimate is made of the limiting passband for such a filter in the visible range. It is shown for a quartz crystal that a length of about 20 cm may be taken as optimal, while the realistically attainable passband is 0.1 nm.

Collinear acoustooptic interaction in an optically anisotropic medium can be used in light filtration [1-3]. The basic parameters of such a filter are the passband $\Delta\lambda$ and the diffraction performance I_1. These quantities are calculated from a system of linear differential equations for the collinear interaction [1]:

$$\frac{dC_0}{dx} = -\frac{q}{2} C_1 e^{j\eta x}; \quad \frac{dC_1}{dx} = \frac{q}{2} C_0 e^{-j\eta x}; \qquad (1)$$
$$C_0(0) = 1, \quad C_1(0) = 0,$$

where C_0 and C_1 are the amplitudes of the incident and diffracted light waves, x is coordinate, q characterizes the amplitude of the elastic wave and the photoelastic properties of the medium, and η is the synchronism coefficient for the wave vectors of the light and ultrasound, which is defined by the difference of the projections of the speeds on the x axis.

The intensity I_1 of the diffracted light can be derived by integrating (1):

$$I_1 = C_1 C_1^* = \frac{q^2}{q^2+\eta^2} \sin^2 \sqrt{\left(\frac{ql}{2}\right)^2 + \left(\frac{\eta l}{2}\right)^2}, \qquad (2)$$

where l is the length of the acoustic column, which implies that the maximum intensity $I_1 = 1$ is attained for $ql = \pi$ and $\eta l = 0$. The passband $\Delta\lambda$ is defined by $|\eta l| = 0{,}8\pi$ for $ql = \pi$, where I_1 is halved. As

$$|\eta l| \simeq \frac{2\pi \Delta n l}{\lambda^2} \Delta\lambda + \frac{\pi \Delta n \Delta\varphi^2 l}{4\lambda}, \qquad (3)$$

where Δn is the difference in refractive indices of the material, λ is wavelength of the light, and $\Delta\varphi$ is the divergence of the light or ultrasound [1], we get

© 1980 by Allerton Press, Inc.

the passband as

$$\Delta\lambda \simeq \frac{0{,}8\,\lambda^2}{\Delta n l} + \frac{\lambda\,\Delta\varphi^2}{4}. \qquad (4)$$

Expressions (2) and (4) show that high resolution $k=\lambda/\Delta\lambda$ and high efficiency are obtained by increasing the interaction length l and the aperture of the beams and ultrasound d. It follows from (4) that it is necessary to use a crystal with a long interaction region (over 10 cm) on operating with highly colimated beams. When the length is

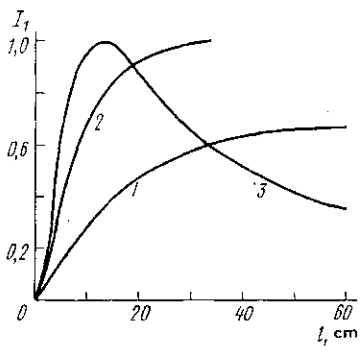

Fig. 1

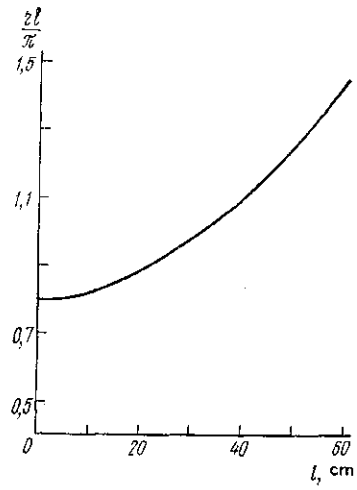

Fig. 2

Fig. 1. Diffracted light intensity in relation to length of interaction region for q of: 1) 0.2; 2) 0.34; 3) 0.5.

Fig. 2. Filter passband calculation.

of this order, one has to consider effects such as the absorption of the acoustic and optical waves, the reduction in the ultrasonic power density on account of divergence in the acoustic beam, heating of the medium by the light and ultrasound, and so on. Acoustooptic filters have been built with resolution $R>10^3$ that employ collinear diffraction in quartz crystals of length over 10 cm [4]. It is therefore necessary to calculate the transmission band on the basis of the fall in the control acoustic power [4].

If we assume that the acoustic wave propogates along the x axis of the crystal, then the coefficient q appearing in (1) decreases in proportion to the square of d and is also dependent on x. The coordinate dependence of q is due to the reduction in the acoustic power density, because the cross section of the acoustic column is not constant in a real device but varies with the length on account of divergence. If the aperture is dependent on the acoustic divergence $\Delta\varphi$ and the path length x in accordance with $a'(x)=d_0+\Delta\varphi x$, then we get the following coordinate dependence of q on the basis of the damping:

$$q(x) = q\frac{e^{-\alpha x}}{(1+\beta x)^2}, \qquad (5)$$

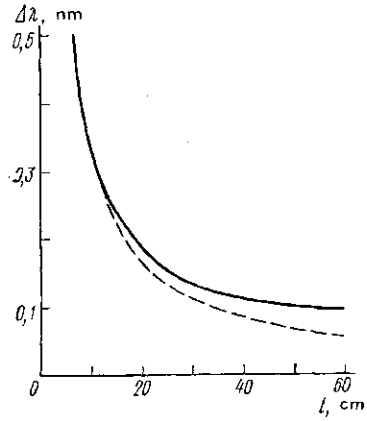

Fig. 3. Passband in relation to length of interaction region.

where $\beta = \Delta\varphi/d_0$ and α is the ultrasound attenuation coefficient. System (1) cannot be solved on the basis of (5) in a general form, but it can be solved numerically for specified values of α, β and q, so $\Delta\lambda$ can be calculated as a function of l.

Here we consider an example of the passband of a visible-region filter employing a quartz crystal and a longitudinal acoustic wave propagating along the x axis. The dimensions of the transducer are taken as d_0 = 0.3 cm, with the ultrasound damping α = 0.02 dB/cm and λ = 600 nm.

Figure 1 shows the calculated efficiency in relation to interaction length for η = 0 (α=0,003 cm^{-1} and β=0,008 cm^{-1} for several values of q; (1) with (5) and q = 0.34 shows that the condition $|\eta l|=0{,}8\pi$, for which I_1 is halved from the maximum value, alters as l increases. Figure 2 shows the increase in $|\eta l|$ with distance, which determines the passband.

The relation between $|\eta l|$ and $\Delta\lambda$ of (3) allows one to calculate the variation of the passband with distance (Fig. 3). The calculation has been performed for λ=600 nm and α=0,003 and β=0,08 cm^{-1}. For comparison, the dashed line of Fig. 3 shows the variation in $\Delta\lambda$ without allowance for the divergence and damping, i.e., for α = 0 and β = 0. It is clear that one is not justified in using quartz crystals with l in excess of 20 cm for the purpose. If l>20 cm the resolving power begins to be affected by the reduction in the control power density, and as a result the passband alters little as l increases. Also, $\Delta\lambda$ is inversely proportional to the length for any l if α = β = 0. If q = 0.34 and l>20 cm, Fig. 1 shows that there is no major increase in the performance. Therefore, a length of about 20 cm may be taken as optimal, while the realistically attainable passband is $\Delta\lambda \simeq 0{,}1$ nm.

Similar calculations have been performed for collinear filtration in lithium niobate crystals. The birefringence of lithium niobate is larger by about an order of magnitude than that for α - SiO_2 and $CaMoO_4$. Therefore, the working ultrasonic frequencies in an $LiNbO_3$ crystal are substantially higher [2]. A major contribution to widening the passband is the reduction in the acoustic power due to damping. However, even at frequencies of the order of 10^9 Hz there is relatively low damping in lithium niobate. Therefore, the broadening of the passband in $LiNbO_3$ sets in at interaction lengths that considerably exceed the real dimensions of the crystals. In principle, $LiNbO_3$ can give higher resolution that does quartz. The limiting resolution is determined in the main by the size of the specimen, the optical quality, and the heating of the crystal due to loss in the piezoelectric transducer.

Here we have used a scheme for collinear filtration in which the light beam and the ultrasound pass only once through the crystal, i.e., without reflection [1]. If a double-pass system is used for the light [2] it is possible to double the resolution by comparison with a single pass. Therefore, a passband of 0.05 nm can be obtained with the optimum interaction length.

REFERENCES

1. S. E. Harris and S. T. K. Neih, J. Opt. Soc. Amer., vol. 62, no. 5, p. 672, 1972.

2. S. E. Harris, S. T. K. Neih, and D. K. Winslow, Appl. Phys. Lett., vol. 15, no. 19, p. 325, 1969.

3. N. A. Esepkina, A. A. Lipovskii, V. Yu. Petrun'kin, and A. S. Shcherbakov, in collection: Acoustooptic Methods of Data Processing [in Russian], Leningrad, p. 22, 1978.

4. V. B. Voloshinov, Abstracts for the First All-Union Conference on Laser Radiation Parameter Control, Part 2 [in Russian], Tashkent, p. 182, 1978.

2 February 1979