A few words more about resonant acoustooptical interaction

V.Petrov

Saratov State University,

410026, Moscovskaya St., 155, Saratov, Russia

PetrovVV@info.sgu.ru

ABSTRACT

There is considered theoretically the competition near the resonant acoustooptical (AO) conditions of two mechanisms which influence to the diffraction efficiency η_d variation, when the thickness L of the sample (the length of interaction) is changed : 1) the enhancement of η_d due to increase of L, and 2) degradation of η_d due to the increase of optical absorption α_L in crystal.

It is shown that: 1) when changing the length of interaction L the maximum diffraction efficiency η_d is changed and shifted in wave length's scale, reaching the maximum value at defined L which depend on the particular interaction geometry; 2) for particular considered in present work crystals the variation of L is more critical to the wave length λ change for GaAs as compared to InP; 3) when realizing the optimized geometry of AO interaction closed to resonant condition at frequency 2.5 GHz, the diffraction efficiency in GaAs crystals can reach 8% and in InP 3.5 % per 1 mW of conducted electromagnetic power (correspondingly 8000 and 3500 % per 1 W of RF power) when the thickness of samples is about 4 mm .

Keywords: Acoustooptical resonant conditions, band gap, AO modulators, deflectors.

1. INTRODUCTION

The resonant acoustooptical condition's interaction (also "resonant Brillouin scattering") is known effect for more then 30 years [1-8]. But last years interest to it is increased due to the possibility to apply it for many telecommunication's tasks [9-13]. The possibility of application of this effect in high frequency bulk acoustooptics become obvious after the measurement of a whole set of photoelastic constants for crystals GaAs and InP (p_{11}, p_{12}, p_{44}) [6,8]. In [8] was offered to characterize the acoustooptical property of crystals near the resonant conditions with modified figure of merit M_{eff} .

$$M_{eff} = M_2 \exp(-\alpha_L e), \tag{1}$$

where M_2 - figure of merit, α_L - optical absorption in crystal, e - crystal's thickness. For particular investigated crystals GaAs and InP in that work ([8]) were calculated the dependencies of M_{eff} as a function of the light wave length λ. On the basis of these set of dependencies there made fair inference that to reach the maximum value of modified figure of merit M_{eff} near resonant condition is possible when using very thin plates of crystals (200 - 400 μm). But choosing the thickness of crystal's sample when creating the real acoustooptical device it is necessary to take into account not just the effect of degradation of diffraction efficiency when increasing the thickness of crystal e due to increasing the optical absorption α_L but also the effect of enhancement of diffraction efficiency η_d with enlarging of the interaction length L. The very aim of present work is to estimate the influence of both these competitive effects to the efficiency of acoustooptical interaction η_d.

2. BRAGG DIFFRACTION EFFICIENCY CALCULAION NEAR THE SEMICONDUCTOR'S BANDGAP

Diffraction efficiency is a function of several characteristics of crystal - figure of Merit M_2, light refraction n and absorption α_L indexes, which become variable when approaching to the band gap of semiconductor crystal. Besides the diffraction efficiency depends on sound absorption α_S in crystal and on the geometrical sizes of sound's and light's beams apertures.

Let us consider the geometry of AO interaction in which sound beam is propagated along y-axis of rectangular coordinate system. This sound beam is excited by the transducer with sizes L and b. Let us admit that the length of transducer L is equal to the thickness of the crystal e along the light wave propagation (x - coordinate). The sound attenuation index is α_S.

The light beam having the width D is directed to the sound wave front under the angle θ_o which is equal to the Bragg angle θ_b at the central frequency f_o. The light absorption in crystal is defined by light attenuation index α_L.

The angular spectrum of diffracted field E_d can be found using as the product of interacted fields angular spectrums - the light's one E_L and the sound's one E_s. So

$$E_d = A_c E_L E_s, \qquad (2)$$

where A_c - the index which contains the constants and phase members which don't put some adds to the intensity. To calculation convenience and not violet the strictness of approach concerning the diffraction efficiency searching, let us assume that the light field amplitude E_o exponentially decreases in it's cross section along y coordinate due to sound attenuation α_s, and sound field exponentially decreases along the coordinate x due to light wave attenuation α_L.

Let us now assume that exponentially decreased light wave is restricted in the cross section by rectangular aperture from 0 to D. In such an approach it can be written the expression for incident light wave angular spectrum

$$E_L(\gamma) = \int_0^D E_o \exp(-\alpha_s y)\exp(-i2\pi \frac{\sin(\gamma)}{\lambda_o} y)dy \qquad (3)$$

The expression for sound field angular spectrum can be written as

$$E_s(\gamma) = \frac{\xi}{2}\int_0^L \exp(i\beta x)\exp(-\alpha_L x)dx \qquad (4)$$

where

$$\beta = -\frac{2\pi f_o}{V}\sin(\gamma); \qquad \xi = -\frac{\pi}{\lambda_o \cos(\Theta_o)}\sqrt{\frac{2P_{ac}M_2}{Lb}}.$$

γ - variable angle; $sin(\gamma) = sin(\theta_b)$- $sin(\theta_o)$, P_{ac} - the power of sound wave.

Then the diffraction efficiency η_d (when acoustical power P_{ac} is given) can be found as the relation of intensities of diffracted I_d and incident I^o light when $\theta_b = \theta_o$.

$$\eta_d = I_d/I^o = (|E_d|)^2 \qquad (5)$$

The dependencies of refractive n and absorption α_L indexes as well as the figure of merit M_2 on the light wave length for GaAs and InP crystals are given from the papers [28,191].

When calculating there where used following data: acoustical power P_{ac}=1mW; the width of sound beam b=0.05 mm; aperture of light beam D=0.5 мм; sound velocity for correspondingly GaAs and InP, V = 4.73 10^3 m/s and 4.596 10^3 m/s; central frequency f_o=2.5 GHz.

On Figures 1 and 2 are given the calculated curves of the diffraction efficiency in percents per 1 mW of acoustical power as a function of the wave length of incident light λ_o for different meanings of transducer's length L which is equal to the length of AO interaction and equal to the thickness of a crystal e.

As it can be seen from the graphs there exists the optimum meaning of the light wave length λ_{opt} when the diffraction efficiency reaches the maximum. Besides it is necessary to note that is depend on the length of AO interaction L. When changing L the maximum meaning of the diffraction efficiency is also changed and shifted along the light wave length λ. The diffraction efficiency is reached the maximum for the particular geometry of AO interaction. It is interesting to take note that the optimum light wave length λ_{opt} which is characterized the maximum diffraction efficiency is differ from the meaning of λ which corresponds to the maximum of M_{eff} in work [8].

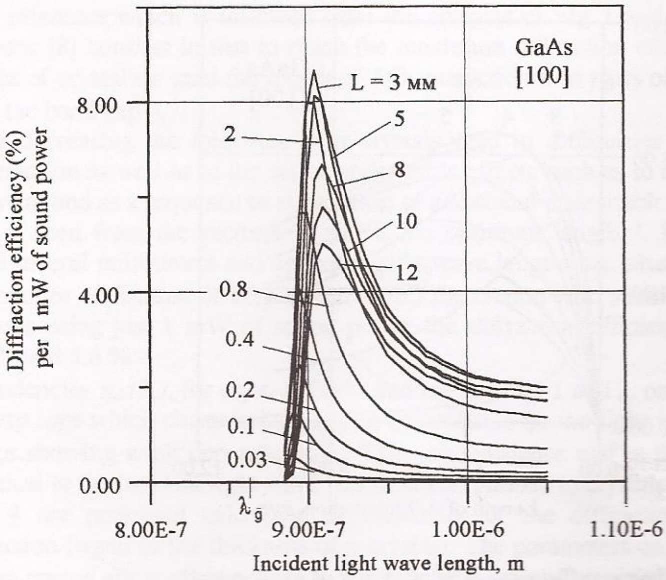

Fig. 1. Dependencies of diffraction efficiency on incident light wave length (%) per 1 mW of sound power for crystal of GaAs closed to a resonant condition. Central frequency is equal to 2.5 GHz. The transducer's length was varied from: L= 0.03 to 12 mm. The maximum of diffraction efficiency = 8.66 % corresponds to L = 3 mm at light wave length = 905 nm.

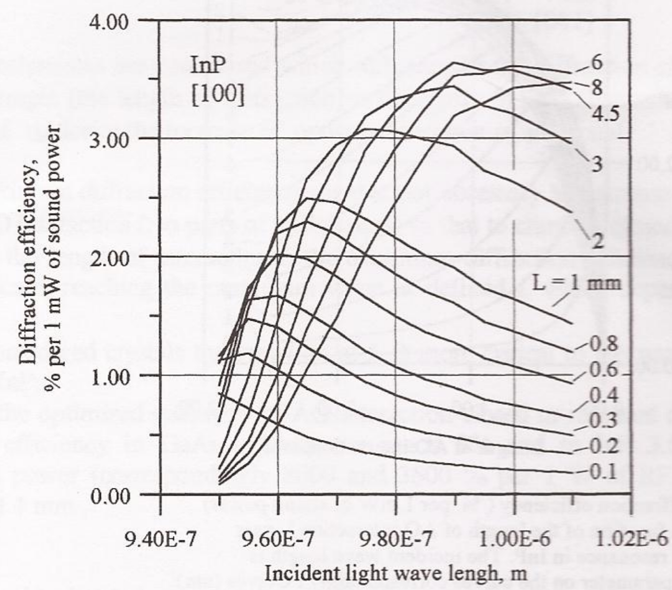

Fig. 2. Dependencies of diffraction efficiency (% per 1 mW os sound power) on the incident light wave length near the band gap in crystal InP . The length of AO interaction L is the parameter on the curves. Central frequency is equal to 2.5 GHz. Maximum diffraction efficiency = 3.64 % when L = 4.5 mm and light wave length = 990 nm.

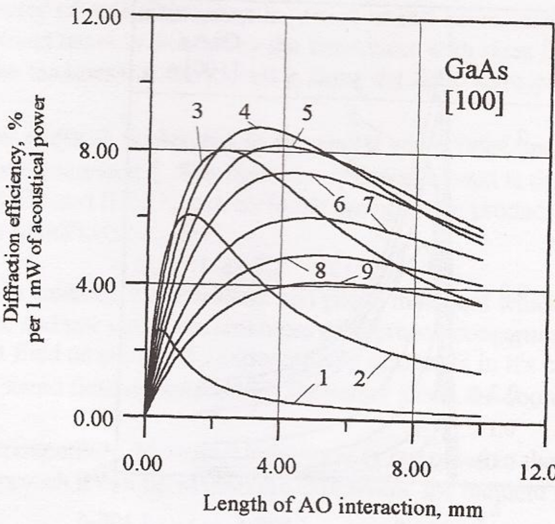

Fig.3. Diffraction efficiency (% per 1 mW of sound power) as a function of the length of AO interaction L closed to the band gap in GaAs. Parameter at the curves is the incident light wave length correspondingly: Curves (nm): 1 - 890nm; 2- 895; 3 - 900; 4 - 905; 5 - 910; 6 - 915; 7 - 925; 8 - 935; 9 - 945 nm. Central frequency =2.5 GHz; Maximum meaning of diffraction efficiency = 8.66 % when L = 3 mm and light wave length = 905 nm.

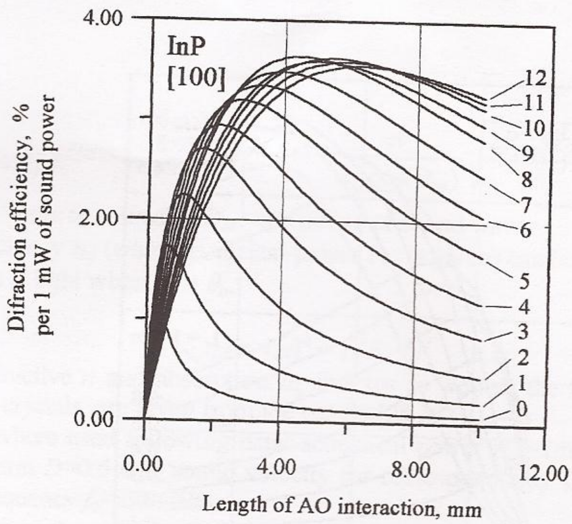

Fig.4. Diffraction efficiency (% per 1 mW of sound power) as a function of the length of AO interaction L near AO resonance in InP. The incident wave length is the parameter on the curves correspondigly : Curves (nm): 0 - 950 nm; 1 - 955 nm; 2 - 960 nm; 3 - 965 nm; 4 - 965 nm; 5 - 975 nm; 6- 980 nm; 7- 985 nm; 8 - 990 nm; 9 - 995 nm; 10 - 1000 nm; 11 - 1005 nm; 12 - 1010 nm. Central frequency = 2.5 GHz. Maximum meaning of the diffraction efficiency = 3.64 % when L = 4.5 mm and light wave length = 990 nm.

The other important inference which is followed from the analysis of Fig 1 and 2 which is also differ from the inference made in work [8] consists in that to reach the maximum diffraction efficiency there is not necessary to decrease the thickness of crystal's e (and the length of AO interaction L to parts of millimeters) so that to climb as closed as possible to the band gap λ_g.
The requirements of decreasing the thickness of a crystals lead to difficulties in the realization of necessary geometry of AO interaction as well as to the set of undesirable effects such as to multiple reflections of light from plan surfaces of a crystal and as a sequence to appearance of additional undesirable diffracted spots.
On the contrary as it seen from the pictures 1 and 2 the optimum length L for considered geometry of AO interaction is formed several millimeters and optimum light wave lengths are situated rather far from the band gap λ_g. That allows to hope for realization of very effective AO interaction with small acoustical powers. For example to the considered cases using just 1 mW of sound power the diffraction efficiency can reach in GaAs and InP, correspondingly 8.6% and 3.6 %.
Comparing the dependencies $\eta_d(\lambda_o)$, for crystals GaAs and InP , at Fig. 1 and 2, one can see that curves for crystals GaAs have more sharp tops which characterized strong dependence on the light wave length, when the curves for InP have smooth tops showing weak dependence λ_o. This circumstance makes the optimization of AO geometry with GaAs more crytical to the incident light wave length in comparison to crystals InP.
On Figures 3 and 4 are presented calculated dependencies of the diffraction efficiency on the length of acoustooptical interaction (equal to the thickness of a crystal). The parameters on the curves are the incident light wave length λ_o. These curves allow more exactly to define the meanings of optimum length L when the diffraction efficiency η_d reaches maximum. So for Gallium Arsenide the diffraction efficiency maximum η_d =8.66% when the sound power is 1 mW and the length of interaction at λ_o = 905nm is equal to L= 3 mm. For Indium Phosfide η_{dmax} =3.64 % is realized at the same acoustic power when L= 4.5 mm at λ_o = 990 nm.
The differences of present work results in comparison to ones given in [8] can be easily explained. When finding the diffraction efficiency near AO resonance there are two mechanisms are in competition : from one hand the increasing η_d due to enlarging of the length of AO interaction and from the other hand - the decreasing η_d due to increasing optical absorption in crystal. This competition is defined the existence of optimum L when η_d has maximum. When defining the effective figure of merit in[8] such competition absents.

3. CONCLUSION

Two competitive mechanisms are considered which influence to the diffraction efficiency η_d variation, when the thickness L of the sample (the length of interaction) is changed : a) the enhancement of η_d due to increase of L, and b) degradation of η_d due to the increase of optical absorption α_L in crystal.
Main inferences are:

1) to reach the maximum diffraction efficiency there is not necessary to decrease the thickness of crystal's e (and the length of AO interaction L to parts of millimeters) so that to climb as closed as possible to the band gap λ_g.
2) when changing the length of interaction L the maximum diffraction efficiency η_d is changed and shifted in wave length's scale, reaching the maximum value at defined L which depend on the particular interaction geometry;
3) for particular considered crystals the variation of L is more critical to the wave length λ change for GaAs as compared with InP;
4) when realizing the optimized geometry of AO interaction closed to resonant condition at frequency 2.5 GHz, the diffraction efficiency in GaAs crystals can reach 8% and in InP 3.5 % per 1 mW of conducted electromagnetic power (correspondingly 8000 and 3500 % per 1 W of RF power) when the thickness of samples is about 4 mm .

To J.Sapriel my friend is devoted.

REFERECES

1. *R.Loudon*. Theory of the first-order Raman effect in crystals. // Proc.Roy.Soc. (London). V.A275. 218. 1963.
2. *D.K.Garrod and R.Bray*. Resonant brillouin scattering in GaAs. // Physical Review B, V. 6. No 4. August 1972.
3. *R.Berkowicz and D.H.R.Price*. Resonant scattering from ZnO and CdS. // Solid State Communications. V. 14. 1974.
4. *V.M.Levin, R.G.Maev, Z.I.Filatova*. "New mechanizm of acoustooptical interaction in piezosemiconductor crystals", Pisma v ZH E T F, v.17, № 2, p.127-130, 1973 г.
5. *V.V.Proklov and V.N.Chesnokov*. "AO Intermodulation Effects in Resonant Photoelastic Materials". SPIE-Proc. Vol. 2643, p.253-256, 1995.
6. *P.Renosi and J.Sapriel*. Acousto-optics of semiconductor crystals and superlattices in resonance conditions. // Ultrasonics. V. 31. No 5. 1993. p.327-332.
7. *V.Petrov, J.Sapriel*. Quality jump of super high frequency Acousto- Optics. Bragg cells on the base of the use of some properties of GasAs and InP. // International Symposium on Surface waves in solids and layered structures and National conference on Acoustoelectronics. 17-23 May 1994. Moscow-St.Petersburg. p.207-211.
8. *P.Renosi and J.Sapriel*. Near-resonance acousto-optical interactions in GaAs and InP. // Appl.Phys.Lett. V.64. No. 21. 23 May 1994.
9. *V.V.Petrov, B .Gur'ev V.Kolosov S.Kuryshov S.Lapin, J.Sapriel*. High Efficiency 2 GHz bandwidth Bragg Cells on the Basis of Acousto-Optical Resonant Conditions in GasAs and InP. // World Symp. On Ultrasonics. Berlin. Sept. 1995.p.31-37.
10. *P.Renosi*. Etude des effets acousto-optiques resonants dans GaAs et InP et dispositifs assicies. // Thesis Orsay France. 1995.
11. *V.Petrov, B.Gur'ev, V.Kolosov, S.Kuryshov, S.Lapin, J. Sapriel*. On acoustooptical resonant conditions in GaAs and InP for the creation of high efficiency 2 GHz bandwidth Bragg cell. // Photonics and Optoelectronics N 3. New York – Moscow. October 1995. p. 12-18.
12. *J.Sapriel, P.Renosi and P.Le.Berre*. New development of resonant acousto-optics in semiconductors. // Proc. SPIE. V.2643. May 1995.
13. *S.Gosselin, J.Sapriel*. Fast Multiple 8x8 Acousto-Optical Crossbar Switching Architecture for Telecommunication Wavelengths. // Advances in Acoustooptics AA-O'97. European Acousto-Optical Club. St.Petersburg. Russia June 24-25. 1997. p. 96.
14. *R.Berkowicz and D.H.R.Price*. Resonant scattering from ZnO and CdS. // Solid State Communications. V. 14. 1974.