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HOW TO CREATE 3 GHZ BANDWIDTH AO BRAGG CELL

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Normally we assume that the frequency band of acoustooptical (AO) devices can not exceed one octave or 2/3 of central frequency f_o otherwise the influence of the next higher diffraction order is violet the output signal. But it still seems very attractive to increase more and more the absolute frequency band of AO cells because of the wish to process of large value of information in real time. For this aim we try to increase central frequency before it is possible. Between today known AO materials, perhaps just lithium niobate allows to reach several Gigahertz central frequency for AO device. The real sound attenuation of about 1 dB/(cm GHz^2) [1], restricts the practical application of this crystal by frequencies about 5 or 6 GHz. When talking about the acoustooptics of GHz region we can note then the level of higher diffraction orders is neglectable and there is no more reason to wary about their influence to the output signal. Why not to try now to realize the frequency band, say, from 1 to 4 GHz ? Of course there remains the question how to do this.

Let us consider one of possible variants of the realization of 3 GHz bandwidth AO deflector with the use of multielement phased transducer for acoustical beam steering. We assume that multielement structure has the length L and the periodicity l , so the number of elements is n. This structure can be represented as the filter-type wave guide system. Following to the approach suggested in [2] we will consider the electrical field in the multielement system as the infinite sum of spatial harmonics each (m-th) of which has the wave number β_m. If in general case the phase shift between the neighboring elements is φ_o then the phase shift per period for m-th harmonic is $\varphi_m = \varphi_o + 2\pi m$, or $\varphi_m = \beta_m l$. Each m-th harmonic of the electrical field will excite the plane acoustical wave moving in the direction of wave vector K_m the module of which is equal to $K = 2\pi/\Lambda = 2\pi f/V$, where Λ - is the acoustical wave length, V - sound velocity. Then the angle of m-th acoustical plane wave front inclination can be written as $\alpha_m = \arcsin(\varphi_m V/ 2\pi fl)$ when the Bragg angle is equal to $\Theta_b = \arcsin(\lambda_o f / 2n_o V)$ where λ_o is the light wave length in vacuum and n_o - the refraction index of interaction medium. So that to satisfy the bragg condition in whole chosen frequency band Δf it is necessary to provide such a frequency law of sound beam steering ($\alpha_m(f)$) that the angle of light incidence $\Theta_{oi} = \alpha_m(f) - (-1)^i \Theta_b$, (where i = 1 for anomalous dispersion; i=2 for normal dispersion of multielement filter type waveguide system), is remain constant. Now let us analyze the obtained equation for Θ_o:

$$\Theta_{oi} = \arcsin \{ [V/2\pi] [\varphi_m(f)/ lf] \} - (-1)^i \arcsin [(\lambda_o/2n_o V) f] \qquad (1)$$

In this formula f is variable value, $V/2\pi$ and $\lambda_o/2n_o$ - are constants. To build the necessary law of $\alpha_m(f)$ we just can change l and $\varphi_m(f)$. If to leave l =const then we can find the ideal law of the phase shift $\varphi_m(f)_{id}$ per period l when the bragg conditions is fulfilled exactly in the band Δf:

$$\varphi_m(f)_{id} = (2\pi fl/V) \sin[\Theta_{oi} + (-1)^i \arcsin(\lambda_o f/2n_o V)]$$

Calculations show that to obtain the dependence $\varphi_m(f)_{id}$, which is not ecceed the region $(0 \div 1\ \pi)$ in wide frequency band (say, more then 1 GHz) using lower number of harmonics m, it is need to choose very small period l (several micrometers in frequency region about 3 GHz) of multielement system in whole band Δf. From the other hand if Δf is big enough (say from 1 to 4 GHz), the length B of the electrode (of separate element) which is responsible for the inductance, on lower frequencies must be very large (about $\lambda_w/4$, where λ_w - the electro magnetic wave length in wave guide. At f=1 GHz λ_w is equal to about several centimeters. It is obviously that the active loss in the wave guide conductor of 3 μm width and, say, 3 cm length is so large that the whole energy can be lost at first several elements.

This problem can be solved by the use of the change of the other value in equation (1) - the period l . We can divide the multielement system to several (k) parts with different periods ($l_1 \div l_k$) . Each part of the transducer has own optimized: period l_n ; the length L_n; the length of separate electrode B_n and the thickness of the piezoelectric h_i, and is responsible for it's own part of frequency region $\Delta f_n = f_{n,max} - f_{n,min}$. For such a case the ideal dependence of phase shift $\varphi_m(f)_{id}$ can be build when the following boundary conditions are fulfilled: $\varphi_m(f_{n-1,max}) = \varphi_m(f_{n,min})$.

It is also possible to consider the situation when the multielement system has constant phase shift per cell and variable period l along the length of the transducer L. From the equation (1) we can get the formula for the ideal frequency dependence of the period to provide the fulfillment of the bragg condition in the band Δf.

$$l = \varphi_m V / 2\pi f \sin\{\Theta_{oi} + (-1)^i \arcsin(\lambda_o f / 2n_o V)\}$$

Then we have to find the tuning mechanism to switch on for each frequency the necessary part of the transducer's length with the period corresponding to this frequency. For such an aim can be used the wedge shaped piezoelectric layer. The region which excites the sound waves is move along the transducer's length when the frequency is change. This region reminds the moving window which opens the working part of the transducer: necessary thickness and the period for each frequency.

Let us, for the example, consider the Anti-phase array when Δf=3GHz; m=0 and $\varphi_o = \pi$ ($\varphi_o \neq \varphi_o(f)$). In the case i=1 to provide the band from 1 GHz to 4 GHz the period must be changed from 40 μm to about 400 μ m . In this case the whole length of the transducer can be made as large as the coincidence of ideal and real frequency dependence of the period allows.

From the practical point of view, as it seems to us, the best way for the creation of AO cells with very big frequency band is to optimize the two possibilities of beam steering realization: the division of the transducer for several parts with different periods and the provision inside of each part of ideal smooth frequency dependence of the phase shift per period.

Calculations show that before mentioned method allows to extend significantly the frequency band of AO bragg cells providing simultaneously very high diffraction efficiency. We can expect several percent of diffraction efficiency with 3 GHz bandwidth of acoustooptical interaction.

REFERENCES

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