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ON SPURIOUS BULK WAVE EXCITATION IN SAW GRATING REFLECTORS ON GaAs (001) (110)

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Reflection of SAW from groove gratings on cubic crystal is analyzed numerically on the basis of perturbation theory. It is shown that for certain angles of incidence, the conversion of SAW into bulk waves vanishes. This reduces the SAW reflection loss from grating.

1. Introduction

As known, GaAs is a piezoelectric cubic crystal that posesses also interesting semiconducting properties. This makes possible to place both surface (SAW) devices like SAW resonators, filters and delay lines, and electronic circuitry to drive them (switches, amplifiers and other active elements) on the same chip.

In some applications, for example in filter banks, it is necesary to reflect SAW in perpendicular direction. It happens however, that the reflection losses are high for SAW propagating along (110) direction on (001) cut GaAs, which orientation is prefered in applications. This is because of part conversion of SAW into bulk waves that takes place in such oriented cubic crystal with grooves in it. In this particular direction of SAW propagation, and in its vicinity (and in direction 90^0 degrees from these, due to the crystal symmetry), SAW wave-number is lower than cut-off wave-number of shear wave polarized horizontally. Thus any surface perturbation that results in horizontal surface traction matched to these bulk waves will excite them in expense of the SAW power, thus resulting in the reflection loss.

The idea is to find such reflection angle, that is to determine the groove grating orientation on the crystal, that minimizes the induced surface horizontal traction. In fact this is required for all groove gratings necessary to make SAW circulating on the crystal as discussed above, however with the reflection angles not necessarily being right angles.

This is analyzed in next section, where we propose appyling three subsequent Bragg reflections, as depiced in Fig.1 presenting the SAW propagation path on the

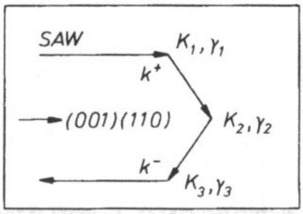

Fig.1. SAW path in the set of three grating reflectors with different grating periods and orientations on the crystal.

crystal. The symetric pattern includes one parameter, angles of the first and the last reflection θ that will be optimized with respect to bulk wave excitation. The Bragg reflective gratings will be characterized by their wave-numbers $K_1 = K_3$ and K_2, and relative reflection coefficients from strip $\gamma_1 = \gamma_3$ and γ_2.

2. Theory of groove-grating reflector

Below, the perturbation theory is applied presented in [1,2]. In the theory, we replace groove grating by sinusoidal corrugation including the lowest Fourier components of the surface profile, that is $(\mathbf{x} = (x_1, x_2), z = x_3)$

$$z = z_S = h\exp(-j\mathbf{K}\mathbf{x}) + cc., \; K = 2\pi/\Lambda.$$

If grooves width is halft their period Λ, and they are H deep, $h = H/\pi$.

The wave-field on the medium plane $z=0$ is expanded into

$$[\mathbf{u}, \mathbf{T}]^T(\mathbf{x}) = [u_i^+, T_{3j}^+]^T \exp(-j\mathbf{k}^+\mathbf{x}) + [u_i^-, T_{3j}^-]^T \exp(-j\mathbf{k}^-\mathbf{x}),$$

where time-dependence exp $(j\omega t)$ has been dropped, and

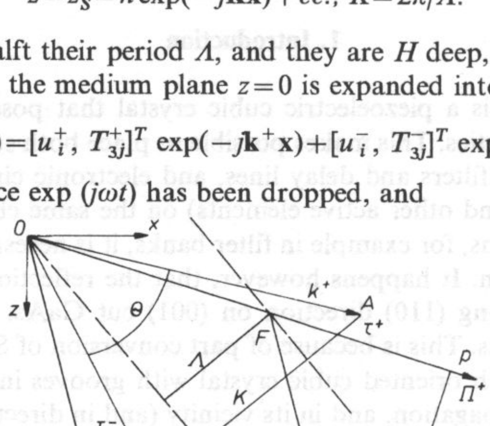

Fig.2. Geometrical relationships between SAW and grating wave vectors, Poynting vectors and SAW beam-widths.

$$\mathbf{k}^{+}+\mathbf{k}^{-}=\mathbf{K} \tag{2.1}$$

is the Bragg condition. Other wave-files components are neglected [1]. The discussed wave-components are shown in Fig. 2, where the beam-steering effects is accounted for (angles $\tau^{\pm}$ between wave-vectors $\mathbf{k}^{\pm}$ and corresponding Poynting vectors $\Pi^{\pm}$); $W^{\pm}$ are the SAW beam-widths.

The theory results in following relations for a tracting arrising on the medium crystal surface when SAW propagates under periodic shallow grooves ($n, m=1, 2$)

$$T_{3n}=-\rho\omega^2(z_S u_n)-(z_S T_{nm})_{,m},\ T_{33}=-\rho\omega^2 z_S u_3.$$

Expilicitly, for grooved grating reflectors we get

$$T^{-}_{3n}=-\rho\omega^2 h u^{+}_{n}-h(-jk^{-}_{nm})T^{+}_{nm},$$

$$T^{+}_{3n}=-\rho\omega^2 h^{*} u^{-}_{n}-h^{*}(-jk^{+}_{m})T^{-}_{nm}, \tag{2.2}$$

$$T^{-}_{33}=-\rho\omega^2 h u^{+}_{3},\ T^{+}_{33}=-\rho\omega^2 h^{*} u^{-}_{3},$$

where ρ is the mass density of the substrate and h characterizes the perturbation introduced by shallow grooves into the system. In the above relations, the left-hand sides represents the response of the grating which is the first-order quantity with respect to h, to the incident wave-field characterized by $\mathbf{u}$ and $\mathbf{T}$ appearing in the right-hand sides (the zero-order quantities, $\mathbf{T}$ can be evaluated as depedent on $\mathbf{u}$ [3]). The perturbation traction is responsible for synchronous generation of SAW in the new direction satisfying the Bragg condition, Eq. (2.1), that is for reflection. As shown in [1], the reflection coefficient can be evaluated with help of reciprocity relationship [4].

3. Bragg reflection at arbitrary angle

Let us consider the case of incident wave having wave-number $\mathbf{k}_1$ (Fig.3), its wave-field includes all particle displacement components, u^{-}_{i} on the substrate surface. Let the Bragg reflection structure is chosen with such a wave-vector $\mathbf{K}_1$, that the

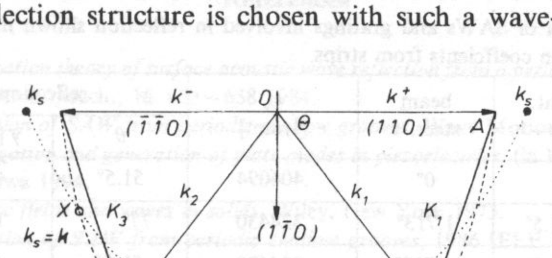

Fig.3. Wave-vectors of SAWs involved in subsequent reflections from gratings, and their relation to cut-off wave-numbers od bulk waves.

reflected SAW wave-number $\mathbf{k}^+ = (k, 0)$. Thus the reflected SAW propagates in $x_1 = (110)$ direction, and its surface wave-motion includes u_3^+ and u_1^+ [4].

One easily notices from Eqs. (2.2) that the traction T_{3i}^+ resulting from the incident SAW includes all three components, which will eventually excite SAW in $\mathbf{k}^+$ direction. But the traction T_{32}^+ is not involved in this SAW excitation because there is not u_2^+ component in the wave-motion of this wave.

The stress T_{32}^+ however, will excite a bulk wave, which cut-off wave vector is higher than k^+. There indeed is the horizontally polarized shear bulk wave with wave-motion u_2 on the crystal surface, which is in synchronism with the traction T_{32}^+. As known [5], the power delivered to this wave by the traction is $\frac{1}{2}\,\mathrm{Re}\{(j\omega u_2)^* T_{32}\}$, the lack of which power in the reflected SAW amounts to the SAW reflection loss.

Numerical evaluation of T_{32}^+ for different incident wave propagation direction θ (Fig.3) shows, that there are two cases where $T_{32}^+ = 0$: for $\theta \simeq 51.5^0$, and for $\theta \simeq 160^0$, thus there are not bulk wave excitation when SAW is reflected from grooves. The second case however ($\theta \simeq 160^0$), is not convenient for applications because the SAW wave-vector is close to bulk-wave cut-off wave-vector (the point marked by X in Fig.3), and slight missorientation of the substrate can disturb the reflector performance.

4. Properties of a set of Bragg reflectors

To obtain the SAW propagation path shown in Fig.1, another reflections are necessary, involving the grating wave-vector $\mathbf{K}_n$ shown in Fig.3. The reflections $\mathbf{k}^+ \Leftrightarrow \mathbf{k}_1$, and an analogous $\mathbf{k}^- \Leftrightarrow \mathbf{k}_2$ have been discussed above that helped us to evaluate θ.

What concern the reflection $\mathbf{k}_1 \Leftrightarrow \mathbf{k}_2$ involving the grating with wave-vector $\mathbf{K}_2$, this is an ordinary SAW reflection, in which case the corresponding bulk-wave cut-off wave-number k_s' is smaller than the Rayleigh wave-number, and the grating does not excite bulk waves.

In Table 1, one can find parameters describing all three grating reflectors and corresponding SAWs involved in Bragg reflections (the last rows concern the case of

Table 1. Characterization of SAWs and gratings involved in reflection shown in Fig. 3, and resulting relative reflection coeffcients from strips.

k[1/mm]	orient. (110)+	beam steer. τ	k_s [1/mm]	reflection parameters		
				θ	γ [H/Λ]	Λ [mm]
$k^+ = .349407$	0^o	0^o	.404094	51.5°	4.21	20.161
$k_1 = .367020$	51.5°	1.713°	.324430	77°	1.19	13.750
$k_2 = .367020$	128.5°	−1.713°	.324430	51.5°	4.21	20.161
$k^- = .349707$	180°	0°	.404094	160°	.55	8.953
$k_2' = .363252$	20°	8.513°	.356637	140°	.51	9.204
$k_1' = .363252$	160°	−8.513°	.356637	$\omega = 10^6 s^{-1}$		

$\theta \simeq 160^0$). Note that some SAWs are subjected to beam steering. Each grating reflector should have shape of parallelogram *OFPE* shown in Fig.2, with grooves in direction *OP* and period Λ, Because of different velocities of incident and reflected SAWs, the incident and the reflected SAW beam-widths ($W^{\pm}$) are generally different.

The SAW reflection per strip evaluated by interpretation of SAW decaying coefficient κ on the path $D^{\pm}$ along the propagation direction between subsequent grooves, the decaying taking place doe to the reflection from grooves [1, 2]. The relative reflection coefficient γ (relative to H/Λ, here we consider case of groove width $\Lambda/2$), is evaluated as square-root of the ratio of the reflected SAW transmitted through aperture width W^-, to the input SAW power flowing through W^+.

5. Conclusion

Let us stress that we applied perturbation theory that neglects higher field harmonics induced in the gratings. This can bring certain discrepancies in evalution of optimal θ. Experimental investigations are recommended to get its correct value, and lowest SAW reflection loss possible in the proposed tripple grating reflector structure.

It should also be noted that the reflected SAW is no langer plane SAW, even if the incident SAW is plane [6, 7], and the subsequently reflected SAWs will also be nonplanar. In conclusion, we must not attempt to obtain full reflection to avoid seriously nonplaner SAW at the output of the set of reflectors discussed above. That is, some reflection losses are not avoidable, depending on admitted loss of uniformity of the SAW beam, SAW diffraction etc.

Acknowledgments

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