Influence of IDT's aperture on the excitation of piezoelectric acoustic waves in $LiNbO_3$ and $KNbO_3$ plates

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Abstract. The results of a study of the influence of the geometric parameters of interdigital transducers (IDT) on their resonance characteristics for YX plates of lithium niobate and potassium niobate are presented in the paper. It is shown that a decrease in the IDT aperture from 6 mm to 2 mm leads to a twofold increase in the intensity of the acoustic signal. The obtained results can be useful in miniaturization of the developed acoustoelectronic sensors.

1 Introduction

Currently, backward acoustic waves are of great interest to researchers around the world [1, 2]. The study of their properties is of fundamental and practical interest. Recently, the possibility of creating a new type of resonator based on such waves has been shown [3]. A new method for detecting these waves in piezoelectric plates using a set of interdigital transducers (IDT) with different spatial periods was proposed in [4]. Obviously, for the development of devices based on backward acoustic waves, it is important to optimize the parameters of the resonators, such as the substrate material, IDT aperture, and the number of pairs of transducers. Optimization can be carried out using the finite element method (FEM), in particular Comsol Multiphysics. Comsol allows you to simulate tasks of this type without the need for real experiments.

2 Investigation objects and experimental technique

For research, 9 resonator models were created with a different number of IDT pairs (2, 4, and 6 pairs) and an aperture of IDTs (2, 4, and 6 mm). For example, Fig. 1 shows the geometry (a) for a resonator with 4 IDT pairs and a 4 mm aperture. The Y cuts of $KNbO_3$ and $LiNbO_3$ plates were used as a substrate. The thickness of the plates in both cases was 375 μm, the width of the strip was 0.25 mm. Tables 1 and 2 show the material constants used for these crystals.

IDTs were placed perpendicular to the direction of X propagation. At the substrate boundaries, the PML condition was applied to prevent re-reflection of the excited waves

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(Fig. 1 b). The use of PML at the boundaries allowed us to avoid the appearance of false peaks in the simulated resonance curve.

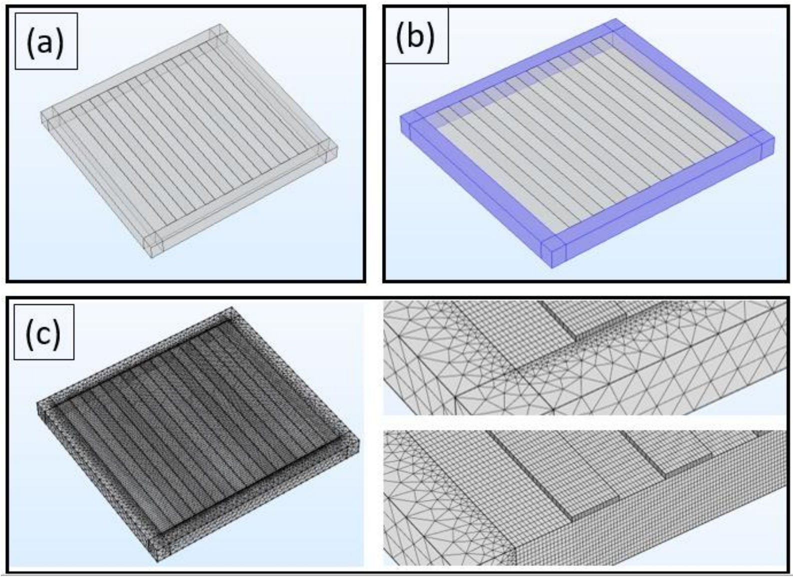

Fig. 1. 3D model (a), place of PML in the model (b), given model grid and enlarged fragment (c).

In the implementation of these absorbing layers, quadratic attenuation functions were used. In the region of the plate free of IDT, mechanical boundary conditions corresponding to free boundaries were used, i.e. mechanical stresses were zero. In the area of contact of the IDT strips with the plate, the continuity of displacements and mechanical stresses between the strip and the plate was used as mechanical boundary conditions.

Acoustic wave excitation was modeled by using periodic changes in the electric potential in the region of IDT strips. Voltage is applied to one strip, and the next one is short-circuited. When compiling the model, a manual grid was generated. In the area under the electrodes, the electrodes and the interelectrode space were divided into parallelepipeds.

In the simulation, a mesh with a linear element size of λ / 50 was used. In the PML field, a free mesh was used, built using the Comsol built-in "Physics controlled mesh" function, which was a set of tetrahedrons of various sizes.

Table 1. The material constants of $LiNbO_3$ crystal [5]

$LiNbO_3$ – Elastic modulii, Ceij,10^{10} [N/m^2]						
C^E_{11}	C^E_{12}	C^E_{13}	C^E_{14}	C^E_{33}	C^E_{44}	C^E_{66}
20.3	5.73	7.52	0.85	24.24	5.95	7.28
Piezoconstants, eij, C/m^2				Dielectric permittivity, $\varepsilon^S_{ij}/\varepsilon_0$		Density, kg/m^3
e_{15}	e_{22}	e_{31}	e_{33}	ε^S_{11}	ε^S_{33}	ρ
3.83	2.37	0.23	1.3	44.3	27.9	4650

Table 2. The material constants of $KNbO_3$ crystal [6]

$KNbO_3$ - Elastic modulii, CEij,10^{10} [N/m^2]						
C^E_{11}	C^E_{12}	C^E_{13}	C^E_{14}	C^E_{33}	C^E_{44}	C^E_{66}
22.6	9.6	6.8	0	18.6	7.43	9.55
Piezoconstants, eij, C/m^2				Dielectric permittivity, $\varepsilon^S_{ij}/\varepsilon_0$		Density, kg/m^3
e_{15}	e_{24}	e_{31}	e_{33}	ε^S_{11}	ε^S_{33}	ρ
5.16	11.7	2.46	-1.1	36.99	24	4630

3 Results and discussion

As a result of the simulation, the frequency dependences of the real part of the IDT electrical impedance for YX lithium niobate and potassium niobate plates were obtained. These dependencies are presented in Figure 2.

In the case of lithium niobate, two piezoelectric waves excited in the frequency range of 6-9 MHz were considered. The first peak corresponds to the SH_1 wave, and the second one corresponds to the A_1 wave, which is characterized by the presence of a frequency range with an backward group velocity. It can be seen from the Figure 2 that a change in the IDT aperture practically does not affect the value of the impedance of the signal corresponding to the SH_1 wave. An increase in the number of strip pairs from 2 to 6, as one would expect, leads to a significant narrowing the IDT passband for the SH_1 wave.

As for the backward A_1 wave, a decrease in the IDT aperture from 6 mm to 2 mm leads to an increase in the intensity of the acoustic signal by a factor of two. Moreover, for effective excitation of a given wave, 2 pairs of electrodes are sufficient. This, apparently, is associated with achieving the optimal ratio between the number of pairs of strips and their length, leading to a more complete electrical matching of IDT at a given frequency with the internal resistance of the generator.

In the case of potassium niobate, two piezoelectric waves SH_0 and S_1 are excited in the considered frequency range 3-11 MHz. As is known, this material is characterized by a very strong piezoelectric effect [7], and the electromechanical coupling coefficient for zero-order waves with shear-horizontal polarization (SH0) can reach 98% [8]. For the considered geometry (hf = 1687 m/s), the SH_0 wave has an electromechanical coupling coefficient of

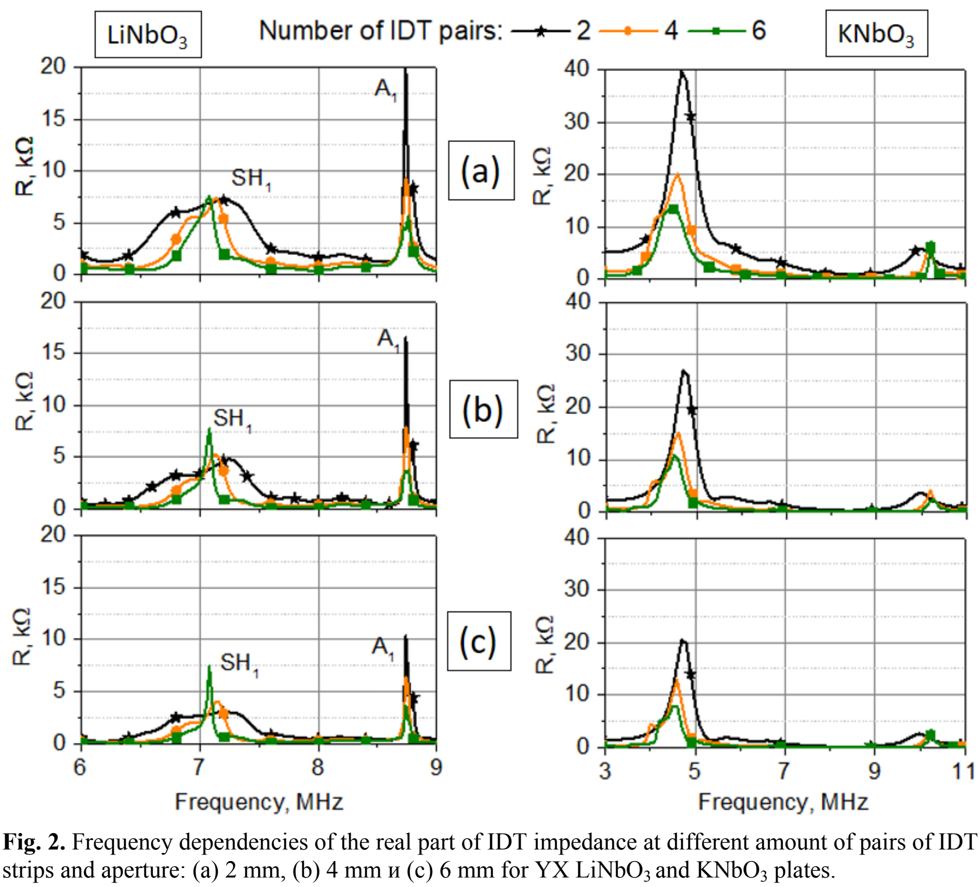

Fig. 2. Frequency dependencies of the real part of IDT impedance at different amount of pairs of IDT strips and aperture: (a) 2 mm, (b) 4 mm и (c) 6 mm for YX $LiNbO_3$ and $KNbO_3$ plates.

42%. The analysis shows that in this case, an increase in the number of pairs of strips also leads to a decrease in the passband of the IDT, but not as much as in the case of lithium niobate. A decrease in the IDT aperture from 6 mm to 2 mm, as in the case of lithium niobate, leads to an increase in the intensity of the acoustic signal by a factor of two.

Thus, we can conclude that if the array of sensor elements is placed on the surface of the piezoelectric plate, significantly lower IDT apertures can be used to effectively excite the corresponding acoustic waves. This will allow either to place a larger number of sensor elements on one substrate, or to ensure miniaturization of the developed sensors.

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