2E1-2

Investigation of the electro-induced 2D domain structures in LiTaO₃ crystal

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1. Introduction

The research interests in acoustic metamaterials and phononic cristals have been currently increased in last two decades. Acoustic metamaterials (AMs) are even more novel than their electromagnetic counterparts. AMs provide a new tool for developing the advanced, controllable, and high performance devices. The possibilities of application of the acoustic wave signal processing are determined on their interaction in the crystals with each other (phonon-phonon interaction), or with the waves, which has another physical properties: electromagnetic, spin, free electrons and etc. All these interactions can be determined by nonlinear properties of the crystals [1,2]. Hovewer, the nonlinear properties of the crystals have ability to control. The most usfull and applicable to electronic industry are the method of electroinduced anisotropy [3,4].

In this research we discuss the method and physical properties of the 2D domain structure formation in $LiTaO_3$ single crystal for advanced electronic device applications.

2. Theoretical investigation of 2D domain structure formation in a volume of the $LiTaO_3$ crystal

The 2D domain array in a 36° rotated Y-cut, X-propagating $LiTaO_3$ single crystal was induced by electrodes fabricated on the top and bottom surfaces (see **Fig. 1**). The electrodes of E1 and E2 were arranged on the top surface, and E3 and E4 on the bottom surface of the crystal. Two pairs of the electrodes on the both sides of waveguide were mutually perpendicular. Device included two inter digital transducers (IDT) 1, IDT2, and electrode structure, which was arranged between IDTs. All surface structures were made from aluminum using a conventional lithography method. The crystal thickness was 350μm. The domain structure was induced by applying different electric potentials to electrodes and had a great potential to controlling by changing the applied voltage. The surface acoustic wave (SAW) propagates along the X-direction, and the electric field was applied in a volume of the Y-direction. Due to electrostatic effects, the periodic acoustic impedance array was induced in the volume of the waveguide. We investigated the shear-horizontal (SH) wave interaction with the induced structures.

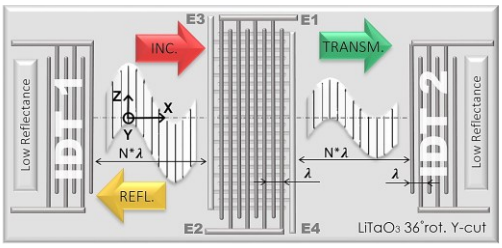

Fig. 1 Structure and principle of the SAW device.

Acoustic wave propagation in the periodically polled anisotropic ferroelectric media is shown in **Fig. 2(a).** The periodical structure represents the periodic acoustic impedance array Z_{in}^{n} (see **Fig. 2(b)**). That structure had been characterized by areas with different ultrasound velocity V1 and V2, and width h1 and h2 respectively.

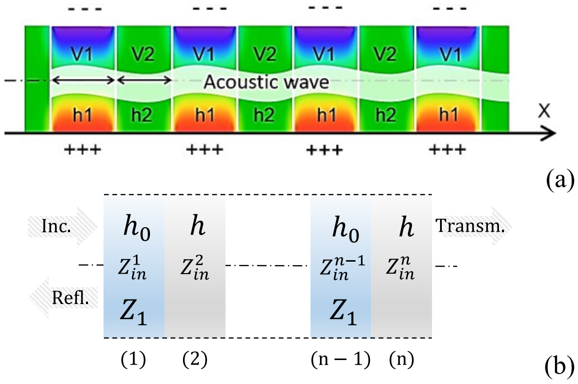

Fig. 2 (a) Electro-induced periodical acoustic impedance structure, (b) model of the acoustic wave propagation in the periodical structure.

The equations of the acoustic wave propagation in anisotropic ferroelectric media as follows [5]:

$$C_{ijmn}\frac{\partial^2 U_m}{\partial x_i x_n} + e_{mij}\frac{\partial^2 \varphi}{\partial x_i x_m} = \rho\frac{\partial^2 U_j}{\partial t^2}$$

$$e_{ijm}\frac{\partial^2 U_j}{\partial x_i x_m} - e_{ij}\frac{\partial^2 \varphi}{\partial x_i x_j} = 0,$$

where $U_{m,j}$ is the mechanical displacement, ρ is the density, φ is the electric potential, and e_{ijm} is the piezoelectric tensor coupled with the tensor h_{ijm} as

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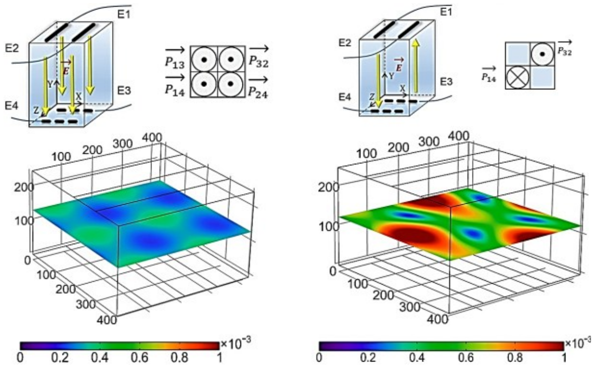
follows $e_{ijm} = \varepsilon_0(\varepsilon_{ij} - 1)h_{ijm}$. Solution of the wave propagation equation with taken into account the dependence of the elastic, piezoelectric and the dielectric coefficients on the electric field can be sought in form of the independent simple wave's form of $\boldsymbol{U} = \boldsymbol{A}e^{ikx}$. The results reflected and propagated waves in frequency domain have been characterized by spectra consists of periodically repeated principal Bragg peaks and racks of secondary maximums alternating with zeros of reflection. Using FEM, the piezoelectric polarization and domain formation process in the finite unit of the domain structure were investigated. In **Figs. 3 (a)** and **3(b)** was shown results of the static displacement for two different electroinduced domain structures. It is clearly found the volume induced periodical domain structure, which represents the regions with the impressed value of the total static displacement. The structure of the domain array and its intensity depends on the applied electric potential.

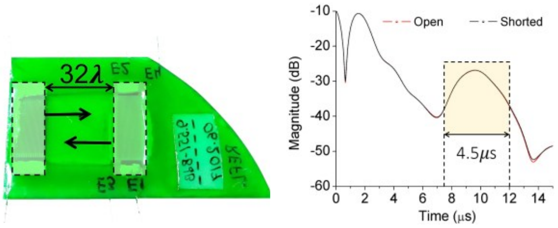


(a) (b)

Fig. 3 Induced domain structure in a crystal.
(a) and (b) are the total displacement in a $LiTaO_3$ crystal for different domain structures.

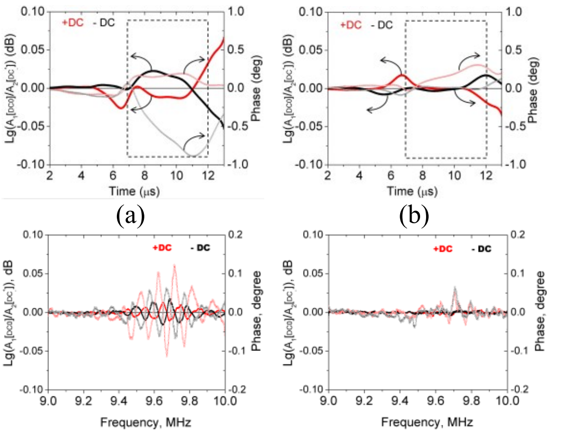
3. Experimental results of the controllable acoustic wave interaction

On the base results of calculation, the optimal SAW devices structure was proposed and fabricated. The photograph and time response of the 10 MHz SAW device are respectively shown in **Figs. 4 (a)** and **4(b)**. The distance between transducer and domain structures was 32λ. The experimental results of the magnitude relative deviation and phase absolute deviation for discussed domain configurations are shown in **Figs. 5(a)** and **5(b).** The dependences of the reflected signal on a frequency are shown in **Figs**. **5(c)** and **5(d).** Parameters of the reflected signal were measured for SAW devices with domain structure with pitch between electrodes is equal 0.5. The DC value is 500V. Reflected signal was measured for two different DC polarities.



(a) (b)

Fig. 4 (a) Photograph of fabricated experimental sample of 10 MHz SAW device, (b) measured time response magnitude of reflected signal for open and shorted electrodes.



(a) (b)

(c) (d)

Fig. 5 (a) and (b) the experimental results of the reflected signal magnitude and phase deviation for two different domain configurations. (c) and (d) frequency response of the Brag reflection for magnitude and phase and different domain configurations.

4. Conclusion

We investigated the principle and features of the electroinduced 2D domain structure in ferroelectric material with crossed on the surface electrodes structure. Theoretical and experimental results shows the existence of the periodical domain structure and controllable potential (see in **Fig. 5**). Obtained results can be used for developing of the advanced signal processing device in electronics industry.

References

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