RESONANT MODAL ANALYSIS OF THE TWO-DIMENSIONAL PHONONIC CRYSALS TRANSDUCERS

Hong-lang LI[1*], Wen-jia TIAN[1], Ya-hui TIAN[1], Xiao-xi Li[2], Yong-qiang Bai[2] , Shi-tang HE[1]

[1] Institute of Acoustics, Chinese Academy of Sciences, Beijing, P.R. China, 100190
[2] The Beijing Municipal Institute of Labour Protection Beijing 100054
[3] Beijing Gas Co., Ltd. Beijing 100035
*Corresponding author, E-mail: lhl@mail.ioa.ac.cn; Tel.: 010-82547805

A three-dimensional (3D) finite element method (FEM) model was proposed to analyze the resonant modal of the transducers based on two-dimensional (2D) phononic crystals (PnCs). Using this model two modals existed with symmetric modal and anti-symmetric modal can be extracted, and then reflectivity of the transducers was derived. An example of transducer based on 2D PnCs composed of IDTs of aluminum strips and tungsten stubs on top of IDTs was analyzed. The calculated reflectivity with different thickness of the stubs shows that a optimal thickness of tungsten stubs exists for a specified IDTs. This modal analysis offer a useful tool for the optimal designing 2D PnCs on the surface acoustic waves devices.

Keywords: Surface acoustic wave; Transducers; Resonant modal; Frequency response; Phononic crystal

1. INTRODUCTION

Phononic crystals [1] (PnCs) composed of periodic elastic materials have been obtained much attention in recent years due to its particular characteristic. With the unique properties, PnCs have been widely used in many fields such as elastic resonators [2], couplers [3], filters [4] and waveguides [5].

Interdigital transducers (IDTs), as one-dimensional (1D) PnCs, were used many years to excite and receive surface acoustic waves (SAWs) in applications of resonators, filters and sensors. In recent years, two-dimensional (2D) PnCs obtain more attention as they have richer properties of band gaps than 1D PnCs. Many researchers are working on the study of using 2D PCs on the SAWs devices. Marc [6] has proposed a SAW resonator with 2D reflectors which improved the Q of SAW resonator a lot. He analyzed the model of SAW resonator based on 2D reflectors with approximating the dots by a uniform metallic layer adopting finite element method (FEM)/boundary element method (BEM) used in 1D IDTs [7]. However the results of this method were not enough accuracy due to dots' shape is ignored. In recent years, more accurate calculation methods need to be explored.

In this paper, for the new transducers structure based on 2D PnCs, a three-dimensional (3D) FEM model was used to analyze the resonant modal of the transducer. Also the height of the PnCs on the effect of resonant modal and reflectivity of electrode was studied..

2. MODEL OF ANALYSIS

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2.1. Model for analysis of transducers based on 2D PnCs

As shown in the Figure 1, the new transducers structure based on 2D PnCs is composed of traditional 1D IDTs and the 2D PCs with metal dots on the top of the IDTs.

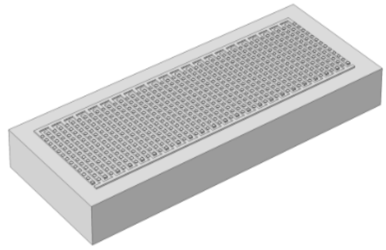

Figure 1.Transducers structure with 2D PCs

To analyze the resonant modal of the transducers, a 3D FEM analysis model was built as shown in the Figure 2. With a Cartesian coordinate system the z axis is perpendicular to the substrate surface and the x axis is perpendicular to the IDTs. To reduce the time and memory cost of the model, only one period of the transducers was built. In the model, period boundary conditions (PBC) were used both in the x direction and the y direction to simulate the countless pairs of the transducers. On the bottom of the substrate the fixed constraint condition was used. On the upper of the substrate the free surface condition was adopted. Electric potential was applied on the electrode.

The commercial software COMSOL Multiphysics was adopted to analyze the 3D FEM model above.

Through the analysis of the eigen frequencies, resonant modals including symmetric modal and anti-symmetric modal can be obtained. And then the reflectivity and velocity of the transducers can be obtained as the formula [8] (1):

$$\begin{cases} v = p(f_{sc+} + f_{sc-}) \\ \kappa p = \pi \dfrac{f_{sc+} - f_{sc-}}{f_{sc+} + f_{sc-}} \end{cases} \tag{1}$$

Where f_{sc+} and f_{sc-} are the symmetric modal and anti-symmetric modal frequencies, p is the period of the electrode.

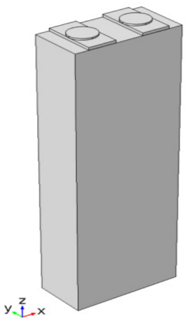

Figure 2. 3D FEM model for analysis.

2.2 Results of the resonant modal of transducers based on 2D PnCs

As an example, a transducers structure based on 2-D PCs was adopted. This transducers consists of 128°YX Lithium Niobate ($LiNbO_3$)substrate, aluminum strips with a period of 6μm and a thickness of 0.7μmon the substrate surface and tungsten cylinder stubs with the radium of 3μm and a thickness of 0.4μm on the aluminum strips as shown in the figure 3.

Using the method above, the 3D FEM model was built and the COMSOL Multiphysics was used to analyze the resonant modals of this structure. And then resonant modals of symmetric modal and anti-symmetric modal of SAW were extracted according to the deformation field. As resonant modals in IDTs, there existed two modals of SAW in the 2D PnCs transducers structure with the symmetric modal and anti-symmetric modal. To the new transducers structure, as shown in Figure 3, there are also two modals existed with symmetric modal and anti-symmetric modal.

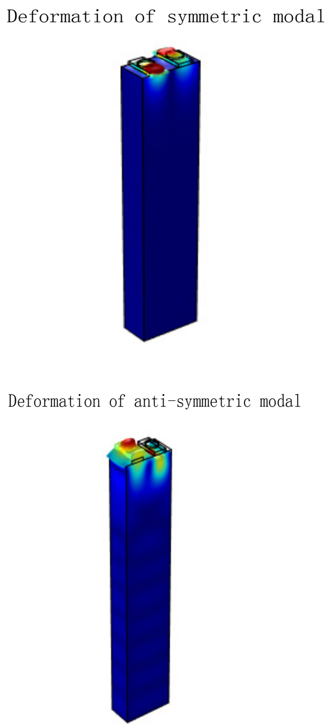

Figure 3. Deformation field of two SAW resonant modals.

2.3 Analysis of the influence of the height of PnCs on the reflectivity of transducers

With analysis of the resonant modal, the velocity and the reflectivity of per electrode can be obtained by the formula (1).

Table1. Reflectivity of different height.

Height (um)	Symmetric modal (MHz)	anti-symmetric modal (MHz)	Reflectivity (%)
0.00	314.46	320.63	0.97
0.10	302.10	315.78	2.22
0.20	291.13	312.18	3.49
0.30	265.72	306.85	7.18
0.40	274.16	298.58	4.26
0.50	254.40	291.39	6.78
0.60	237.05	282.54	8.76
0.70	221.17	273.00	10.49
0.80	207.07	265.20	12.31
0.90	194.54	258.21	14.06
1.00	227.39	248.64	4.46
1.10	225.34	241.76	3.52
1.20	224.25	234.68	2.27

In order to verify the efficiency of the method, the height of tungsten as zero was first calculated, which showed exactly close to the results of the FEM/BEM model. Further in order to analyze the influence of the height of the tungsten dots on the reflectivity of the transducers, the resonant modals of different height of tungsten were analyzed. When the thickness of the aluminum was specified as 0.7μm, the reflectivity of different height of tungsten dots was calculated. Results of the height from zero to 1.2μm are listed as the table 1.

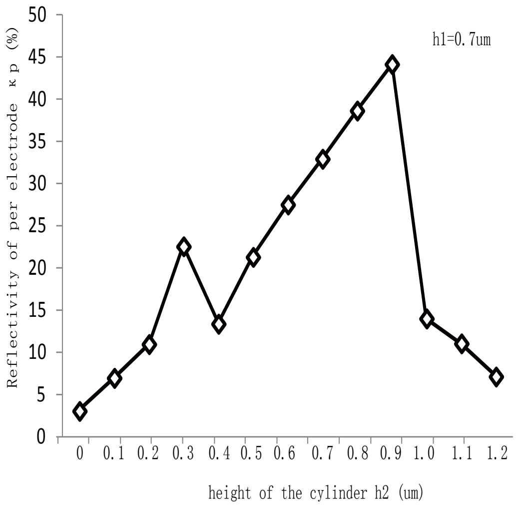

Figure 4. Reflectivity of transducers based on 2DPnCs

Results from the table 1 were also displayed in the Figure 4. From the figure, it can be seen that the reflectivity became larger as the height of the dots became larger and then it became smaller as the dots became higher. Obviously, while the height of the cylinder is 0.9μm, the reflectivity of per electrode is highest among those different heights.

3. DISCUSSION AND CONCLUSIONS

A 3D FEM model was proposed to analyze the resonant modals of the new transducers structure with 2D PnCs. The analysis results shows that the 2D PnCs transducers have symmetric modal and anti-symmetric modal of SAW as the IDTs. Moreover the influence of the height of dots on the reflectivity of per electrode was extracted, which showed that with the increasing height of tungsten, the reflectivity per electrode increased firstly and then decreased. Thus an optimized height of dots exists for one structure with a specific 1D IDT structure to obtain high reflectivity. This method can be used to analyze other more 2D piezoelectric PnCs to make full use of the PnCs in SAW devices.

As the new transducers structure showed better character than the traditional transducers, it may bring more applications of the 2D PnCs to the SAW devices. More work are waited to be done.

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REFERENCES

[1] EEN Sigalas MM. Elastic and acoustic wave band structure. *Journal of Sound and Vibration* 158, pp. 377-382 1992.

[2] Sun JH, Lan CW, et al. A ZnO/silicon Lamb wave filter using phononic crystals. In: *Proc. IEEE Frequency Control Symp.*,pp: 1-4, 2012.

[3] R.H.Olsson III, James G. Fleming, et al. Micromachined bulk wave acoustic band gap deices. *Transducers &Equrosensors*.PP.317-321, 2007.

[4] Wu TT, Hsu CH, et al. Design of a highly magnified directional acoustic source based on the resonant cavity of two-dimensional phononic crystals. *Applied Physics Letters* 89:171912, 2006.

[5] Sun JH, Wu TT. Analyses of surface acoustic wave propagation in phononic crystal waveguides using FDTD method. In: *Proc. IEEE Ultrasoncis Symp.,* pp.73-76, 2005.

[6] Solal, M. Gratier, et al. A SAW Resonator With Two-Dimensional Reflectors. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* 57:1, pp.30-37 2010.

[7] Ken-ya Hashimoto. Surface acoustic wave divices in telecommunications modelling and simulation. National defence industry Press, Beijing, 2002.

[8] Plessky P and Koskela J. Coupling-of-Modes Analysis of SAW Devices. International Journal of High Speed Elecronics and Systems, 2000, 10(4):867-947.