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Investigations of the Actuator Based on Lithium Niobate Diffuse Bonded Bimorph Structure

Uliana Yakhnevych[1], Oleh Buryy[1], Yuriy Suhak[2], Ihor I. Syvorotka[3], Dmytro Sugak[1,3], Sergii Ubizskii[1], Holger Fritze[2]
[1] Lviv Polytechnic National University, 12, Bandera Str.,79013 Lviv, Ukraine
[2] Institute for Energy Research and Physical Technologies, Clausthal University of Technology, 19B Am Stollen, 38640 Goslar, Germany
[3] Scientific Research Company “Electron-Carat”, 202, Stryjska Str., 79031 Lviv, Ukraine
Corresponding Author’s e-mail address: yakhnevych.u@gmail.com

Summary:
The simulation of the actuator based on lithium niobate bimorph (bidomain) structure was carried out by the finite elements method. The calculated value of the displacement of the actuator was about 17.8 μm at the voltage of 300 V. Based on results of simulation, an actuator was manufactured from the oppositely polarized plates of congruent lithium niobate bonded by diffusion of copper from the film placed between the plates. It was found that the displacement of this actuator is equal to 9 nm upon the applied voltage of 1 V, and to 26.5 nm upon 3 V.

Keywords: positioning devices, bidomain structure, lithium niobate, diffusion bonding method, Doppler interferometer

Introduction

The systems of precise positioning are widely used in the areas of science and technique where the small movements should be realized with high precision, linearity, reproducibility and thermal stability. Particularly, such systems are used for precise positioning of the probe in the devices of scanning probe microscopy, precision engineering devices, micro-electromechanical systems, micro-dispensers, micro-motors for surgery, laser gyroscopes, mechanisms of laser resonator adjusting, piezo-drives of regulating systems of car suspensions and lamps, etc. [1]. One of the most frequently used materials for electromechanical actuators is the lead zirconate-titanate ($PbZr_xTi_{1-x}O_3$, PZT) piezo-ceramics. However, in accordance with the decision of EU, the lead containing compounds must be removed from technical devices [2]. Thus the piezoelectric crystals, particularly lithium niobate ($LiNbO_3$, LN) and lithium tantalate (LT) are considered as an alternative to PZT. These crystals almost do not have shortcomings of PZT, however the values of their piezoelectric moduli are significantly (approximately an order) lower than the ones of PZT. To increase the possible deformation under the influence of the electric field the bimorph structures can be used. Such structures are formed by two bonded plates of piezoelectric crystals, at that the vectors of polarization of both parts are anti-parallel and perpendicular to the interface between them. In other words, such a construction is a bidomain structure functioning in accordance with bimorph principle. Thus, the purpose of this work is a simulation, preparation and testing of the actuator of precise positioning based on lithium niobate diffuse bonded bimorph structure.

The actuator simulation

The simulation of an actuator is carried out by the finite elements method. The parameters of LN crystal used in our calculations are indicated in Tab. 1 (in accordance with the data given in Ref. [3]). The orientation of the plates was (Y + 127°) in accordance with data given in [4].

Tab. 1: The parameters of $LiNbO_3$ crystal used in our calculations

Parameter	Value
Density, kg/m^3	4700
Dielectric permittivity	$\varepsilon_{11} = \varepsilon_{22} = 43.6$; $\varepsilon_{33} = 29.16$
Elastic constants, 10^{10} Pa	$C_{11} = C_{22} = 20.3$; $C_{33} = 24.3$; $C_{44} = C_{55} = 6.0$; $C_{66} = 7.5$; $C_{12} = 5.3$; $C_{13} = C_{23} = 7.5$; $C_{14} = -C_{24} = C_{56} = 0.9$
Piezoelectric coefficients, C/m^2	$e_{15} = e_{24} = 3.7$; $e_{22} = -e_{16} = -e_{21} = 2.5$; $e_{31} = e_{32} = 0.2$; $e_{33} = 1.3$

The obtained results are in good agreement in the entire investigated range (–300…300 V) with the experimental data (see [4]). Particularly, in accordance with [4], the displacement of the actuator is about 17 μm at the voltage of 300 V, whereas the calculated value of the displacement is equal to 17.8 μm.

Formation of bidomain structure of $LiNbO_3$ crystal

One option to obtain the bimorph structures from single-crystal materials is the diffusion bonding method, which, for example, has been used to obtain lithium niobate-tantalate plates [5]. In our case, the 0.5 mm thick oppositely polarized LN plates were bonded by copper films of different thickness (700, 600 and 350 nm) deposited on both negatively and positively charged lithium niobate plates.

The XY surfaces of the crystals were mechanically processed till the flatness degree of λ/8 (for the wavelength λ of 633 nm). The deposition was performed by thermal method on the equipment of Torr International, Inc. (USA). The film thickness control was carried out by the sensor based on the quartz microbalance. The plates were connected by annealing in air during 24 hours at 800 °C under the load about 3 kg/cm^2 applied to the connected surfaces. Investigations of the bonding interface between the plates were carried out by polarizing microscope ECLIPSE LV100 POL (Nikon, Japan) in the direction perpendicular to the surface of connection throw the polished XY side. Based on the obtain results, we conclude that the best bonding was obtained for two negatively charged surfaces with 350-nm thick copper film deposited on only one plate.

Testing of the actuator of precise positioning

The active element of the actuator was manufactured from LN plates in accordance with the technological scheme described above. The gold electrodes were deposited on the surfaces of the active element (the area of 5×30 mm^2) by sputter coating. One edge of the actuator was rigidly fastened in the special holder between two copper electrodes used to apply the voltage (Fig. 1). The measurements of the actuator displacements upon applied voltage were performed by laser Doppler interferometer Polytec OFV 505. The interferometer design allows to use the alternating voltages in the range of 1…10 V. This study revealed that applying of the voltage of 1 V leads to the displacement of 9 nm at the actuator length of 23 mm (the distance from the holder to the center of the light spot). At the applied voltage of 3 V the displacement is equal to 26.5 nm.

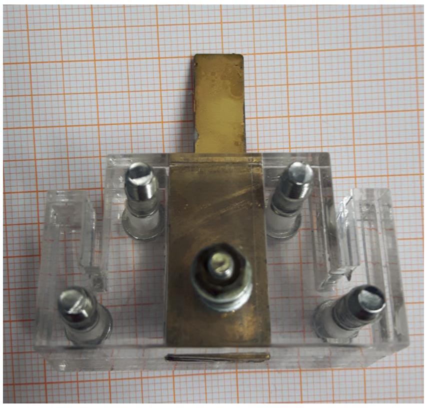

Fig. 1. The actuator of precise positioning based on lithium niobate diffuse bonded bimorph structure.

Conclusions

Based on the results of the simulation, an actuator was manufactured on the basis of oppositely polarized plates of congruent lithium niobate, connected by diffusion of copper from the film placed between the plates. It was found that the displacement of the actuator is equal to 9 nm for the applied voltage of 1 V, and to 26.5 nm at the voltage of 3 V.

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