DEVELOPMENT OF NANOBIOSENSORS BASED ON ACOUSTOELECTRONIC TECHNOLOGIES

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Integration of nanobiosensors with acoustic delay lines within planar technologies gives a chance to develop the acousto-nanoelectronic sensors with high sensitivity and selectivity. This type of sensors can be used to register biospecific interactions, to detect various biological objects, to monitor sensitivity of bioobjects towards various antibiotics, etc. In present paper the acoustoelectronic chip sensor implemented on lithium niobate plate with a system of interdigital transducers (IDTs) for exciting proper acoustic wave is developed. The sensor is inserted into the chip holder of the standard socket of knife type. Acoustoelectronic devices is calculated for anti-symmetric (A0) and symmetric (S0) Lamb waves as well as shear-horizontal wave (SH0) of the zero order. The area, 80x80 μm^2 in square, is located in the centre of the chip for formation of a nanostructure. The sensing properties of the nanostructure are modified by its vibration produced by proper acoustic wave, propagating through bio-active area. Fabrication of the integrated sensor is accomplished by standard lithography, various photo-resist, and reactive ion etching. The as-developed device is considered as a prototype of a nanoelectronic transducer, where nanostructures or nanogaps for realization of molecular transistors on the basis of proteins-enzymes are created.
Keywords: nano-biosensors, nano-structures, acousto-electronic sensors, piezoelectric plates, electron lithography

1. Introduction

Efficient and fast biological analysis is required in many fields of science and technology, such as security systems, ecology, industry, medicine, etc. It stimulates research and development of new mutually-supplemented sensing methods and devices. The usefulness of the devices becomes higher when analysis is accomplished in real time and just in a place, as well as when it is fast, reliably, stable, and does not need large volumes of the test analytes. Usually, biosensors consist of two main blocks – bio-selective element made of proper biological membrane or structure and of physical transductor (transducer) converting the response of the structure to electric signal detected by common instruments [1]. Improvements of the sensor performance are possible through developing more sensitive and selective biological structures (e.g. protein-based ferments [2]) and more advanced transducers or both.

Another approach is to integrate facilities of different techniques, e.g. biosensing and acouso-electronics. This approach has already been demonstrated for advanced express-analysis of microliter liquid samples containing low concentrations of microbes, nano-particles, antibiotics, and other bio-objects [3]. Nanoelectronic approach has already been applied for development of conductometric bionanosensor detecting biochemical reactions [4].

The goal of the present paper is research and development of a novel hybrid sensor integrating an acoustic delay line and a biological structure on same substrate. The sensing properties of the structure are modified by its vibration produced by proper acoustic wave, propagating through bio-active area. The waves concentrated near the surface, distributed through thin plate, and/or propagating in the bulk are compared with each other. The sensor is tested towards kinetics of nano-particles formation in liquid bio-solutions, dynamics of the microbe-antibiotics interaction, and specific bio-reactions.

2. Development of inter-digital transducers for an acoustoelectronic chip-sensor

At 1st step, the phase velocities of the appropriate acoustic waves were calculated using well-known method described in [5]. Lithium niobate plates with two free faces were considered. For the plates the motion, Laplace, and material equations were solved. For vacuum the electric induction the Laplace equation was satisfied. Moreover, the acoustic wave satisfied mechanical and electrical boundary conditions: the normal components of mechanical stress was zero at the boundary with vacuum; the potential and electric induction was continuous at the boundary.

As a result, the phase velocities V for anti-symmetric (A0) and symmetric (S0) Lamb modes as well shear-horizontal wave of the zero order (SH0) were determined for 128YX, Y-Z+50 and YX crystallographic orientations of lithium niobate as offering very high values of the electromechanical coupling coefficient (k^2) [6].

At the 2nd step, using the as-calculated velocities relevant photomasks and IDTs for acoustoelectronic chip-sensor were developed. The values of wavelength λ and the strip length of IDTs were calculated. The thickness of plate was h = 350 μm.

The results are presented in the Table 1.

Table 1: The calculated parameters of acoustoelectronic delay lines for the chip-sensors based on lithium niobare plate

Wave type, propagation direction.	f, MHz	V, m/s	h/λ	k^2, %	λ, mm	d, mm
SH0, Y-X	3.7	4438	0.3	21	1.214	0.286
A0, 128YX	3.0	2811	0.37	4	0.937	0.234
S0, Y-X+50^0	4.3	6700	0.24	11	1.638	0.4
A0, Y-Z	2.1	2525	0.3	5	1.21	0.3
S0, Y-Z+50^0	4.2	6808	0.22	10	1.638	0.4

As an example, the topologies of the photomasks for acoustoelectronic chip-sensors based on SH0 wave and YX lithium niobate plate are shown on Fig.1.

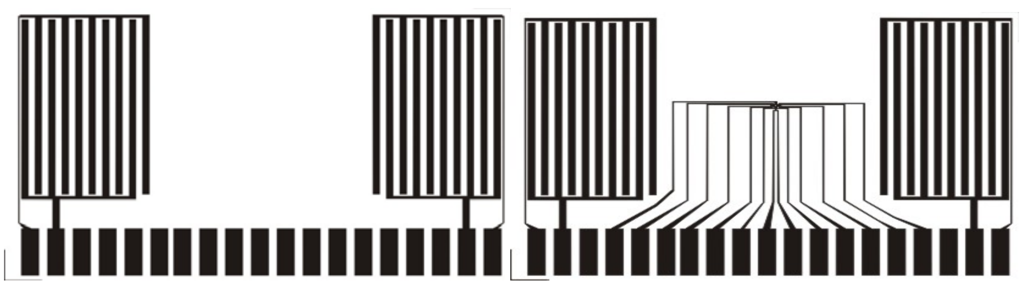

Figure 1: The photomask for an acoustoelectronic chip-sensor with dimensions 18mm x 12mm.

3. Development and testing the integrated sensor

Acousto-electronic part of the integrated sensor consisted of a plate of piezoelectric lithium niobate crystal, 0.35 mm thick, a system of interdigital transducers (IDTs) for generation proper acoustic wave, an active zone between transducers (80 x 80 μm^2), and a system of output electrodes compatible with common holder. The sensor has 2 modifications:

- in 1st one a test object is located directly in active zone and probed by an acoustic wave. This sensor may be immersed in a test liquid totally;
- in 2nd one a nano-biosensor is fabricated in the active zone and an acoustic wave probes the sensor.

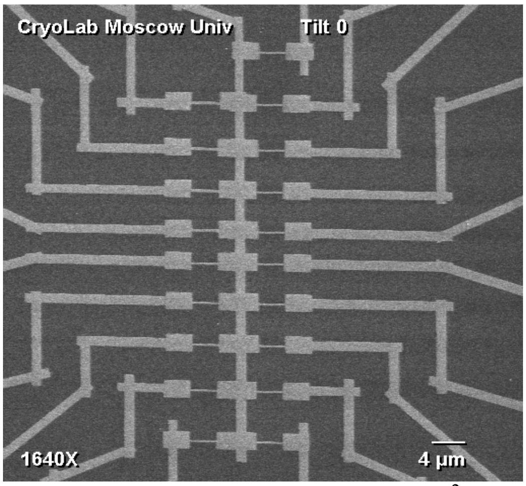

Figure 2: The photo of central (active) sub-micron zone (80 x 80 μm^2) of the sensor with nano-electrodes made by electron microscope.

Fig.3 shows transfer function of the acoustic delay implemented on $LiNbO_3$ plate with two different propagation directions – along Z-axis (a) and 50^0 of the axis Z (b). The different picks presented on the Fig.3 are attributed to different acoustic plate modes propagating in the plate. Since the modes have various velocities, piezoelectric fields, and elastic displacements each of them affects a bio-structure (bio-sensors) in particular manner.

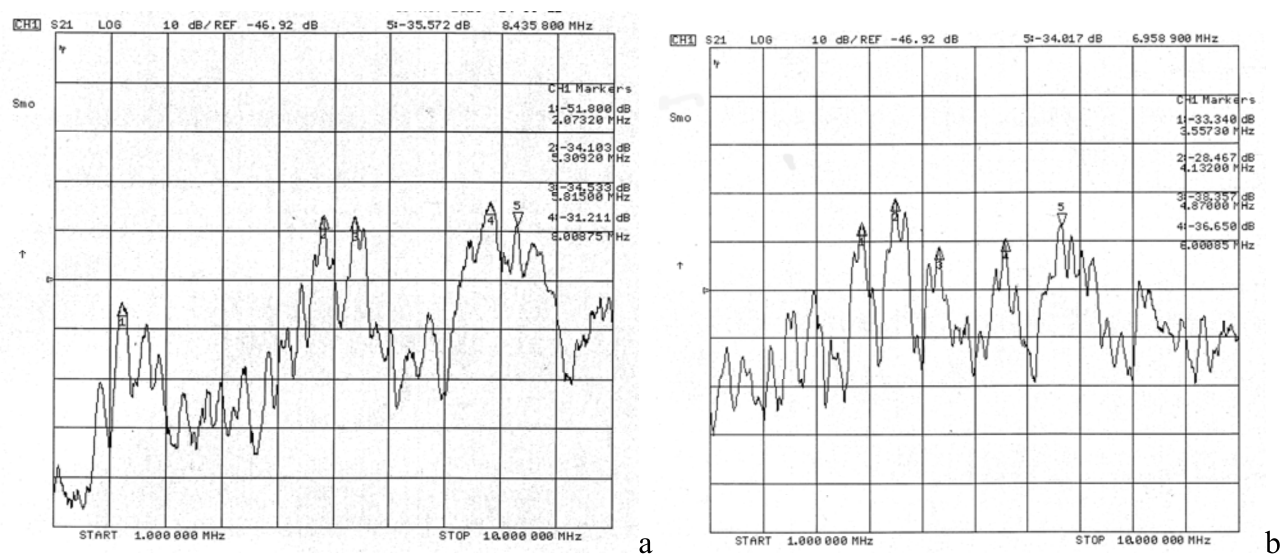

Figure 3: Transfer function of the acoustic delay implemented on $LiNbO_3$ plate propagation direction along Z (a) and $Z+50^0$ (b) direction.

The measured phase velocities of the modes are 2.5±0.2 km/s, 6.4±0 km/s, 7.1±0.1 km/s, 9.7±0.1 km/s, 10.2±0.4 km/s for Fig.2,a and 5.0±0.3 km/s, 5.8±0.3 km/s, 6.9±0.3 km/s, 9.5±0.2 km/s 10.8±0 km/s for Fig.2,b.

The nano-electronic transducer was fabricated by common technologies such as E-beam lithography with various photo-resists, magnetron sputtering (Leybold Heraus Z-400), and reactive ion-bean etching (Alcatel RDE-300, Multisem-400). Exposure of the photo-resists was accomplished by Carl Zeiss SUPRA 40 and lithograph system Raith ElphyQuantum. When selective molecular biosensors are developed [7] some nano-gates for immobilizing protein-ferment-based molecules from ambient may be fabricated in the same structure.

Future activity in the field will be devoted to i) improvement of the transfer function of the acoustic delay lines. For this it will be use splitted IDT's electrodes and special cover at plate boundaries in order to prevent wave reflection and reduce spurious signals, ii) increase in amplitude of acoustic vibrations affecting the bio-sensors. For this, an acoustic beam will be focused just to the place of the biosensor location; iii) reducing acoustic attenuation produced by nano-structures by comparing different probing waves. The improvements may result to further optimization of the integrated sensor.

4. Conclusions

The first sensor prototype integrating facilities of bio-sensing and acouso-electronics is developed using $LiNbO_3$ piezoelectric plate as a substrate. Fabrication of the device is accomplished by standard micro-electronic techniques (E-beam lithography, magnetron sputtering, ion-bean etching). The types of the acoustic waves (A0, S0, SH0) and propagation directions (along Z-axis and 50^0 of the axis Z) are optimized as providing highest coupling constant (lowest loss on electro-mechanical transduction) and single wave propagation (largest rejection of unwanted signals) through a bio-active zone (biosensor or bio-membrane). Further improvements of the integrated devices are discussed.

Acknowledgements

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