Development of technology for producing nanowires on $LiNbO_3$ piezoelectric plate surface

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Abstract. Integration of nanostructures with acoustic delay lines within planar technologies give the chance of development the acousto-nanoelectronic sensors with high sensitivity and selectivity. An initial step in this direction is investigation of interaction of tunnel nanostructures with acoustic piezoactive waves propagating in piezoelectric substrates. In this work the technology of nanowire production on the surface of lithium niobate plate has been developed. This technology is based on using electronic lithography method with help an electronic beam in a raster electronic microscope. The nanostructure consisting of nanowire with size 20nm x 180nm was placed in the center between IDTs of acoustic delay line. The volt-ampere characteristics of this nanowire in presence and at the absence of the acoustic wave were meazured by picoampermeter. The analysis has shown that presence of piezoactive acoustic wave is influenced on electric current in a nanowire.

1 Introduction

In spite of long period investigation of interaction between acoustic waves with semiconductor materials the achievements in nanotechnology are allowed now to produce electrically controlled barriers structures on the new technological level and with new materials. For example, p-n transition, barrier Shottki, jump of chemical potential on the intermediate layer between two materials. In this case it is necessary to conduct new investigations in the field of interaction of different acoustic wave types with such new structures. At present time this scientific direction is very actual and interesting [1, 2].

It should be noted that the technology of electronic devices is now moving on the nanoscale level. Now the process allows you to produce active elements with up to 32 nm in size and in the future, it will be possible go to 10 nm. This is due to the ever-increasing demands on the basic parameters of semiconductor devices such as power consumption and the maximum operating frequency. An important task is development a modern nanoelectronic and learning active components of modern measuring devices of several nanometers. One promising approach to build such devices is to use a single molecule as

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the active element. This approach is implemented in the new field of molecular electronics physicists, where is the element based on a single molecule transistor. This class of devices will allow to transfer to new size limits, functionality, and is of fundamental physical interest in connection with the ability to operate the energy spectrum of individual molecular components [3, 4].

It is necessary to note that integration of nanostructures with acoustic delay lines within planar technologies give the chance of development the acousto-nanoelectronic sensors with high sensitivity and selectivity. An initial step in this direction is investigation of interaction of various nanostructures with acoustic piezoactive waves propagating in piezoelectric substrates. This is possible due to mechanical displacement of piezoelectric media particles during acoustic wave propagation and accompanying electric field [5]. The value of such displacement is about 10 nm which is comparable with nanostructure dimensions.

In this work the technology of nanowire production on the surface of lithium niobate piezoelectric plate has developed.

2 Experimental

The acoustic delay line and the system of electrodes supplied to the nanostructure were produced by the next way (Figure 1).

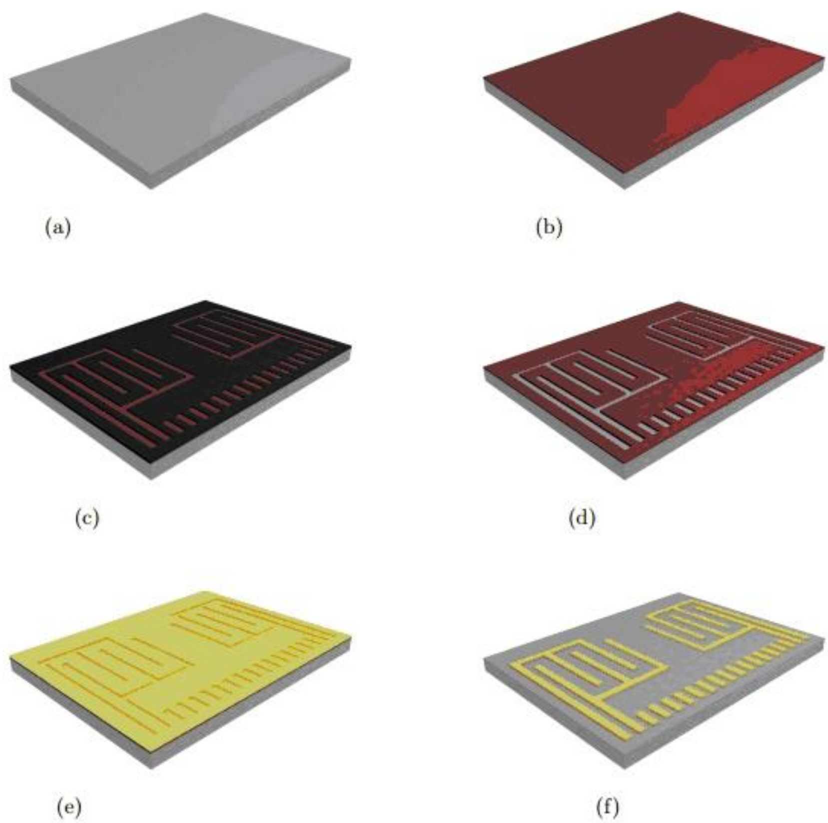

Fig. 1. Technology for production of acoustic delay line: a) sample prepearing, b) resist applying, c) exposition, d) developer procesing, e) metal sputtering, f) lift-off procedure.

First, the lithium niobate substrate was washed in a centrifuge with a stream of isopropyl alcohol and acetone, and then wiped with dimethylformamide (a). Then, a Shipley S1813 resist was applied by the centrifuge, after that it was dried for 5 minutes on HotPlate at a temperature of 115^0C (b). The corresponding photomask was superimposed on the sample in the MA-750 combining unit and the structure was exposed to UV radiation at a wavelength of 400 nm for 75 seconds at an intensity of 50 mW /cm^2 (c). Next, the sample was placed for 1 minute in a KOH-based developer with a concentration of 0.01 mg/ml (d). After that, thermal evaporation of 100 nm of titanium and 30 nm of gold on top of it was sputtered through the obtained photoresist mask (e). Then, using the lift-off method, the sample was freed from the remnants of the undeveloped photoresist, and the result was a structure of IDT and supply electrodes for the nanostructure (f). The geometry size of obtained delay line was 11mm x 13mm with substrate thickness 0.35mm.

After production of the delay line, the corresponding nanostructure was placed between the IDT. To produce it, we used an electron lithography method with a two-layer overhanging resistive mask. This approach allows to avoid low-quality edges due to the contact of the sprayed metal with the walls of the photoresist and to obtain rather sharp boundaries of metal nanostructures [6]. The technology used has the next steps:

- PMMAA4 resist was applied to the centrifuge, dried on HotPlate for 10 minutes at 180^0C. Then, on top of it, a conductive polymer AR-PC 5090.02 was applied in a centrifuge and dried on HotPlate for 2 minutes at 90^0C.
- Illumination was produced by an electron beam with a dose of about 400 μC/cm^2 for accelerating voltage of 20 kV at aperture of 30 μm.
- The conductive polymer was removed in deionized water for 1 minute. Then, PMMAA4 resist manifested itself for 2.5 min in a 93% solution of isopropyl alcohol and deionized water.
- Next, 1 nm of titanium through the resulting mask as a sublayer for adhesion and 15 nm of gold were thermally sprayed.
- Lift-off structures in boiling acetone were carried out.

In result of this modified method we obtained central nanostructure with geometry size 80x80 μm^2 (Figure 2).

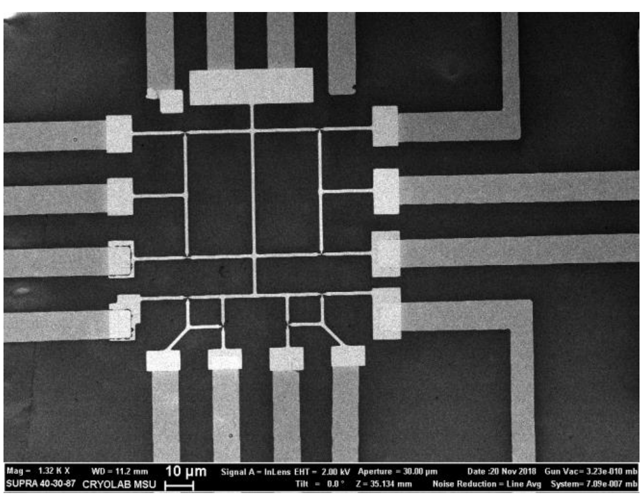

Fig. 2. SEM image of the obtained nanostructure placed between IDTs of acoustic delay line.

This structure consisted of eight nanowires. Each nanowire was 180nm in length, 20nm in width and with thickness about 77nm (chromium -7nm, gold-50 nm, and titanium- 20 nm).

The SEM image of obtained nanowire is presented in Figure 3.

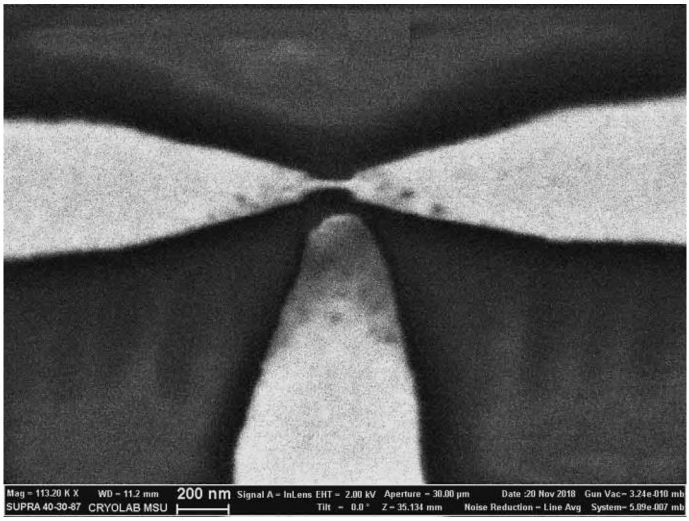

Fig. 3. SEM image of the obtained nanowire of the nanostructure placed between IDTs of acoustic delay line.

The block scheme of the measurement setup is shown in Figure 4. To excite an acoustic wave with a frequency of 2.77 MHz in a YX $LiNbO_3$ plate, the input IDT was supplied with voltage from an alternating signal generator G6-34. The second IDT was used to receive and monitor the parameters of the transmitted acoustic wave. To measure the current-voltage characteristics of the nanowire, a picoammeter and a voltage source based on a digital analogous transducer (DAT) were used. The obtained current-voltage characteristics are shown in Figure.5.

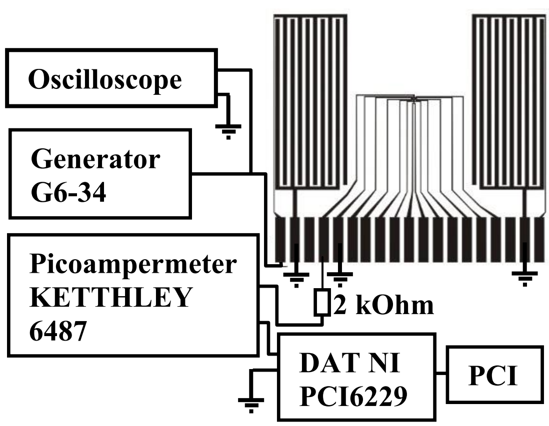

Fig. 4. Experimental setup.

3 Results and discussion

An analysis of the obtained results has shown that metallic conductivity (Ohm's law) is realized in the nanowire. The black curve in Figure 5 corresponds to the voltage-current characteristic of the nanowire in the absence of an acoustic wave in the substrate. The current-voltage characteristic of the nanowire shifts downward at the appearance of an acoustic wave in the substrate due to the appearance of an additional acoustoelectronic electromotive force (EMF). This effect is associated with entrainment of conduction electrons in the nanowire with electric field of the acoustic wave propagating along the nanowire in the piezoelectric substrate.

In the experiment, the dependence of the acoustoelectronic EMF on the amplitude of the excited acoustic wave is observed. The red and green curves in Figure 5 correspond to the amplitude of the voltage at IDT 2.5V and 7V, respectively.

In summary, we modified a method to fabrication of a nanostructure on the surface of piezoelectric plate. In result, we fabricated nanowires with geometrical sizes 180nm in length, 20nm in width and with thickness 100nm. The current-voltage dependencies of this nanowire was measured at various value of the amplitude of the excited acoustic wave. It was found that the current-voltage characteristic of the nanowire shifts downward at the appearance of an acoustic wave in the substrate due to the appearance of an additional acoustoelectronic electromotive force (EMF). This effect is associated with entrainment of conduction electrons in the nanowire with electric field of the acoustic wave propagating along the nanowire in the piezoelectric substrate. This effect could be useful for development of more sensitive hybrid acousto-nano-biosensors.

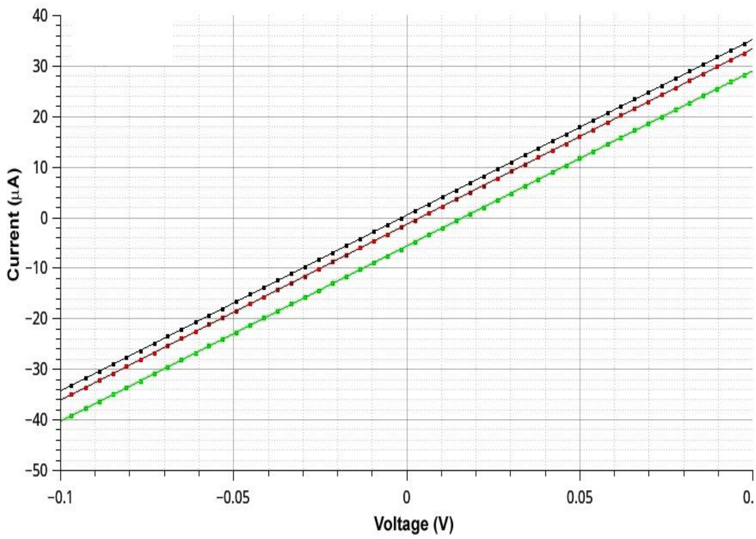

Fig. 5. The current-voltage characteristics of the nanowire at various values of the amplitude of the voltage at input IDT: 0.7V (black), 2.3V (red), 7.5V (green).

This work was partially supported by Russian Science Foundation grant #18-49-08005 in frame of development of hybrid acoustonanosensor and by Russian Foundation of Basic Research grants #19-07-01091-a and 18-29-23042-mk in frame of development of technology for production of nanostructures.

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