DEVELOPMENT OF TUNNEL NANOSTRUCTURES ON A PIEZOELECTRIC SUBSTRATE

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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 piezactive waves propagating in piezoelectric substrates.
This is possible due to mechanical displacement of piezoelectric media particles during
acoustic wave propagation and accompanying electric field. The value of such dis-
placement is about 10 nm which is comparable with tunnel nanostructure dimensions. In
this work the technology of tunnel nanostructure production on the surface of lithium
niobate plate has been developed. This technology is based on a standard lithography,
various photoresist and reactive ion etching. The area of 100x100 microns in size served
in the center between two interdigital transducers placed on the piezoelectric surface as
a prototype of a nanoelectronic sensor. The production of tunneling nanostructures in
this area was carried out by electronic lithography method with help an electronic beam
in a raster electronic microscope.

Keywords: acoustic delay line, lithium niobate, acousto-nanoelectronic sensor, tunnel nano-
structure

1. Introduction

In spite of long period investigation of interaction between acoustic waves with semiconduc-
tor materials the achievements in nanotechnology are allowed now to produce electrically con-
trolled 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 materi-
als. 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 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 tunnel nanostructures with acoustic piezoelectric 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 tunnel nanostructure dimensions.

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

2. Development of tunnel nanostructure production technology on a piezoelectric material

The investigated submicron structure was placed in a square 100×100 µm² located in the centre of the YX lithium niobate plate with the size of 12×13 mm² (Fig. 1). The sample centre was connected with 20 pads with the size of 1×1 mm² of each one.

Figure 1: Acousto-electronic delay line with tunnel nanostructures in the central part of a chip 100×100 µm².

For production of the samples the technology of the rigid suspended mask and a method of two-shadow dusting were used. Use of a three-layer mask allowed to make various systems of nearby tunnel contacts of the submicron sizes with the reproduced parameters. The mask for sputtering represented three-layer thin-film system consisting of actually masking layer (Ge, 20 nm) and a soluble in acetone polymeric layer (~ 500 nm) intended for deduction of the masking layer and for carrying out an explosive lithograph. For the purpose of achievement of the maximum resolution, formation of the image was made by carrying out an electron beam lithography on PMMA layer which is previously applied on Ge layer with the subsequent transfer of the image in underlying layers by the method of anisotropic jet ionic etching which is the most precisely transferring the geometrical sizes of a mask.
The essence of a method of two-shadow sputtering consists in application of consecutive stages of sedimentation of the conducting film from the directed beam of metal atoms at various hades of the beam on a substrate through specially created lithographic mask.

The technology of the samples production consisted of several stages.

In the beginning in the Z-400 setup a layer of $\text{Al}_2\text{O}_3$ with thickness 250 nm deposited on a lithium niobate plate by the method of magnetron dispersion. Before sputtering the set up was pumped out up to the pressure $(4-6) \times 10^{-6} \text{ mbar}$.

Then PMMA/MMA copolymer was deposited by using the centrifuge at a speed of rotation of 5000 rpm during 60 s. The thickness of copolymer was 0.54 microns. After that the samples dried on a hot tile at a temperature of 180 °C within 30 minutes.

Then in the Z-400 setup the Ge layer was sputtered by the method of resistive and thermal evaporation with a speed of 0.9 Å/s with thickness of 20 nm. After that the PMMA electronic resist layer of the 0.27 microns thick was drawn on. The time and speed of drawing was 30 s and 5000 rpm, respectively. Samples were dried on a hot tile at a temperature of 160 °C within 10 minutes.

Further the large drawing was formed. For this purpose PMMA layer was lit through a quartz photo mask with 20 contact pads in the short-wave ultra-violet range within 2 min at the radiation power $25\pm 27 \text{ mW/cm}^2$ on wavelength $\lambda = 310 \text{ nm}$ and developed in mix of toluene and isopropanol in the ratio 1:3 within 20 seconds (Fig.2). After developing the sample was washed out during 5 s in isopropanol and dried up by clean air.

![Figure 2: The schematic image of a sample after ultra-violet flare and development.](image)

At the following stage a submicron part of structure was formed. For this purpose not lit earlier central region was lit by an electronic beam in the scanning electronic microscope "Stereoscan-240" (SEM). Control of a beam of a microscope was exercised by means of the computer. The template for an electronic lithograph (Fig. 3) was formed in the graphical environment "Lasi".

![Figure 3: The topology of the test scheme of nanoelectrodes system.](image)
At that the current of a beam was 20 pA, accelerating voltage was 30kV and diameter of a beam was equal ~ 80 Å. For the best focusing of a beam the opened earlier layer of Ge was scratched by a thin tungsten needle by means of the special manipulator so that the edge of scratch was at distance ~ 60µm from the place of the forthcoming flare.

After an electronic flare the PMMA was developed in mix of toluene and isopropanol in the ratio 1:10 within 60 s at T= 20°C maintained in the thermostat. After developing the sample was washed out in isopropanol during 5 s and then blown by clean air.

Thus, after a two-level lithograph in the top layer of a three-layer mask the drawing of structure with tracing and contact pads was formed (Fig.4).

![Figure 4: The schematic image of a sample after an electronic lithograph and development.](image)

The drawing created in an electronic resist in the lithography process by selective etching was transferred to beneath layers. Anisotropic etching of Ge in CF₄ was the first step. At that the electronic resist played a mask role, and the drawing was transferred to Ge layer. Then copolymer was anisotropically etched through a Ge mask in O₂ before achievement of a layer of Al₂O₃. After that at isotropic etching of copolymer in O₂ (change of the mode was reached by change of pressure of O₂) it was formed "subetching" behind a mask of (size the "subetching" was 250 nm) and, thus, overhang of a film of Ge over a copolymer layer was provided, as has given the name of a method - a method of the rigid suspended mask (Fig. 5).

![Figure 5: The schematic image of a sample after etching.](image)

All three stages occurred without rupture of a vacuum in jet ionic etching setup "RDE-300" and were controlled by laser interferometry method by means diagnostic Multisem-440 complex.

At the following stage the structure of electrodes was formed. Sputtering of gold with a subsputtering of chrome which is necessary for adhesion of gold was carried out for this purpose. Chrome and gold sputtering was carried out in the high-vacuum sputtering setup L-560. Chrome was sputtered by method of electron beam evaporation, and gold by means of a method of resistive and thermal evaporation. Samples were located on the special rotary table allowing sputtering under various hades of atoms on a substrate. Sputtering was carried out in several steps.
At first at an angle $155^\circ$ to a surface normal sputtered a layer of chrome with 7 nm thick. Rate of chrome sputtering was 0.7 Å/s. Then under the same corner a layer of gold with 15 nm thick was sputtered. The sputtering rate of gold was 1.1 Å/s. At this stage the crossing point between electrodes of electrodes is formed.

At the following stage the electrodes sputtering was carried out. For this purpose at an angle $294^\circ$ to a surface normal a layers of chrome and gold 7 nm and 40 nm thick, respectively, were sputtered (Fig. 6).

![Figure 6: The schematic image of a sample after two-shadow sputtering.](image)

Thus, at two-shadow sputtering the mask drawing is reproduced twice in a metal film (with shift of 250 nm).

At the following stage removal of a mask was carried out.

The sample was located in acetone where there was a dissolution of copolymer and washing off of the Ge, chrome and gold layers lying on him and on the sites which aren't covered with copolymer there was a ready structure. After "explosion" the sample was washed out in isopropanol and blown by clean air.

The photo of the tunnel nanostructures system obtained as a result of the described above technology located in the central part of the acousto-electronic delay line (Fig. 1) is presented on Fig. 7.

![Figure 7: The tunnel nanostructures system located in the central part of the acousto-electronic delay line.](image)
3. Conclusion

In this work the technology of tunnel nanostructure production on the surface of lithium niobate plate has been developed. This technology is based on a standard lithography, various photoresist and reactive ion etching. The area of 80x80 microns in size served in the center between two interdigital transducers placed on the piezoelectric surface as a prototype of a nanoelectronic sensor. The production of tunneling nanostructures in this area was carried out by electronic lithography method with help an electronic beam in a raster electronic microscope.

In the next steps the experiments concerning to interaction of different types of acoustic waves with developed nanoelectronic structure will be performed.

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REFERENCES