

ACCELEROMETER SENSING ELEMENT BASED ON
NANOSTRUCTURED SILICONAnatoliy Druzhynin¹, Igor Kogut², Yuriy Khoverko¹, Viktor Golota²¹Lviv Polytechnic National University, Ukraine²V. Stefanyk Precarpathian National University, Ukraine

druzh@polynet.lviv.ua

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Abstract: In this work we consider sensing elements of an accelerometer which is made using the combined technologies of silicon-on-insulator (SOI) structures and silicon nanocrystals whiskers manufacturing. On their basis a quick-response, high sensitive to acceleration and displacement device with submicrometer and nanometer typological sizes has been designed. This enabled us to create, on its basis, both a discrete device and an element of integrated nanoelectromechanical element silicon-on-insulator structures, which provides control of displacement up to 200 nm.

Keywords: accelerometer, polysilicon, structure silicon-on-insulator, etching, nanoelectromechanical system.

1. Introduction

One of the promising areas of modern solid-state electronics is developing and using nanoelectromechanical systems (NEMS) emerged as a result of combining technologies and constructions of sensitive, actuator elements and plans of transforming information from them on one or few crystals with electrical, optical and radio communications [1-4], the so-called devices – “More than Moore”. The devices “More than Moore” are the complex of systems (devices) on a crystal with the following integrated elements: CMOS-logik, built-in RAM, analog interfaces, nonvolatile memory (NVM), processor (CPU) cores, MEMS, NEMS, sensors. This type of integrated systems opens new prospects for security systems (motion sensors, alarm systems) and communications (wireless communication systems, mobile systems), medical equipment, instrumentality for “smart houses” (intelligent control systems: climate control, control of lighting and electricity, infrastructure of the house) and energetics (alternative sources of energy), etc. In this case, progress of More than Moore direction seems to be important that is motivated by new technological possibilities and unlimited potential of practical experience focused on creating a large number of micro- and nanoelectronic systems. At the same time, development of microelectronics and prospects of nanoelectronics, significantly increased the possibilities of modern microprocessor technology and features of its using in highly informative (intelligent) systems, require implementation of new approaches to the creation of primary measuring transducers, which provide

conversion of controlled values into an easily used signal. Nowadays layers of polycrystalline silicon on the surface of oxidized silicon wafer (SOI structure) are widely used in micro- and nanoelectronics. Such wafers are usually formed by chemical vapor deposition (CVD) [5]. Using the SOI structures opens great opportunities of creating highly sensitive devices of microelectronics, and in combination with methods and techniques of nanotechnology; it enables to create a new class of devices with enhanced functionalities, which, by their characteristics, exceed the existing analogues [6-9]. Appropriately, there are many methods for growing nanostructures, namely molecular beam epitaxy, catalytic growth using a laser, and growth from a supercritical phase of liquid solution, laser ablation or simple evaporation [10-13]. However, these methods are energy-consuming and expensive. That is why using cheap technologies to create Si nanostructures is one of the important problems in the development of nanotechnologies for their subsequent use in nanoelectromechanical devices. One of such technologies is the use of chemical etching and chemical vapor deposition, which has been compatible with technology manufacturing micro- and nanoelectronic devices for a long time [14-22].

The main purpose is to create a sensing element of an accelerometer, using modern resource-saving methods in manufacturing silicon micro- and nanostructures.

2. Experimental procedure

Processes specific for the technology of integrated circuits (diffusion or ion doping, oxidation, photolithography, vacuum metallization, cleaning and heat treatment, etc.) make a foundation for the technological process of creating a sensing element of the accelerometer based on silicon nanostructures. However, there are also processes that are not typical in the semiconductor technology. First of all, anisotropic and isotropic chemical profiling, growth of silicon nanoobjects by the method of chemical transport reactions must refer to such processes.

Fig. 1 shows a schematic representation of the accelerometer based on silicon nanostructures.

The basic processes for the formation of an accelerometer sensor are as follows:

- forming silicon nanoobjects (sensing tip of stationary electrode, which serves like emission electrode) by chemical vapor deposition;
- pyrolytic oxidation (stop-layer for anisotropic and isotropic etching cavities);
- forming original structure SOI by micro zone laser crystallization of polysilicon.
- ion implantation of boron in the polysilicon layer (for creating the required level of concentration of a polycrystalline movable electrode);
- forming an accelerometer cavity, and metallization of electrodes .

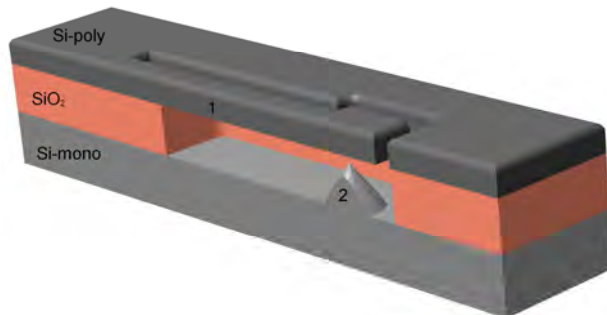


Fig. 1. Schematic representation of sensing accelerometer element based on silicon nanostructures: 1- movable electrode; 2- stationary electrode.

All these processes are important and, to a great extent, determine the metrological characteristics of fabricated devices. We will note the basic processes that were used in manufacturing the accelerometer sensor based on silicon nanostructures.

2.1. Forming a stationary electrode

To develop a real electrode, the processes of growth of silicon nano-objects on Si-substrate with (111) orientation have been studied. For this purpose, gold films of different thickness - from 4 to 10 nm were deposited. To obtain a uniform distribution of gold in crystals, 30 min's annealing of the samples was carried out at the temperature of 600 °C, followed by cooling at a rate of about 3 °C / min.

The substrates having been treated thermally, coagulation of the gold in drops took place. The average diameter of the droplets Si-Au depends strongly on the thickness of the deposited film, and decreases from 100 to 40 nm with film thickness decreasing from 10 to 4 nm. After high-temperature annealing of the plate, and coagulation of the deposited layer in drops, we obtain a plate for further growth of edges of stationary electrodes by chemical vapor deposition. Si growing was performed on silicon substrates with different thickness of the gold film - 10 nm and 4 nm. The analysis of the growth experiments was carried out using the methods of electron and atomic-force microscopy. To ensure regularity of the formed nano-objects [17,18] using

pattern there was formed gold cells (Fig. 2), with an array of pedestals (nuclear centers) obtained on each of them, which were subsequently used to form a fixed electrode tip Si.

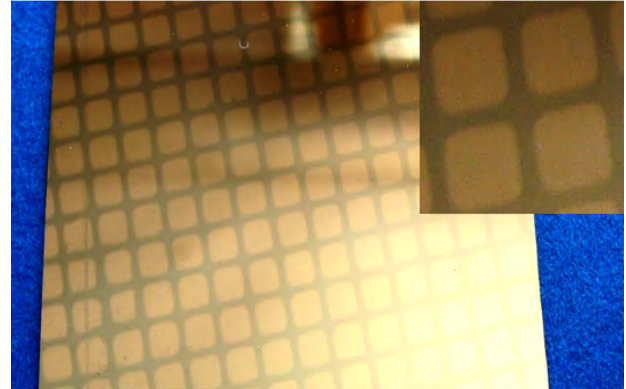


Fig. 2. Plate with deposited film and formed cells.

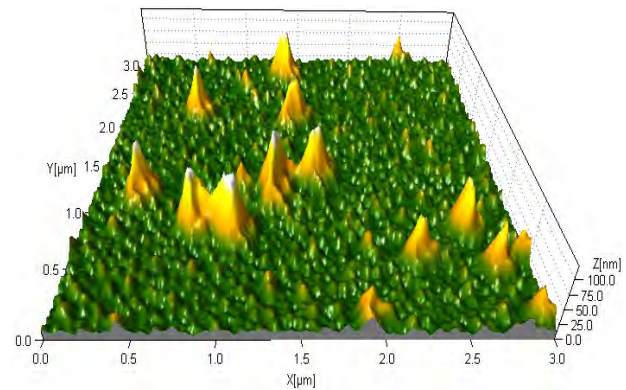


Fig. 3. AFM image midsize of pedestals on Si substrate with a gold film thickness of 10 nm.

As a result of the experiments [19-22] an array of pedestals Si, the average size of which is shown in (Fig. 3) has been formed on the silicon wafer. Sizes of the emission electrodes according to which the calculation of autoemission was performed were ~ 1.8 m (Fig. 5).

2.2. Formation of cavities in an accelerometer.

To create a sealed cavity, movable consoles, electrodes, beams, etc., and given the trend of reducing elements to the nanometer sizes there has been conducted a pyrolytic oxidation of the formed nanostructures (silicon substrate with the grown silicon pedestal) to a thickness that provided the complete protection to the sensitive emission electrodes during subsequent technological processes and amounted to 2-3 microns.

2.3. Forming a movable electrode

The formation of a movable electrode of the accelerometer was based on laser polysilicon recrystallization as a method of obtaining advanced semiconductor layers in silicon-on-insulator structures, which was used to create a variety of sensors of physical quantities [23, 24]. For this purpose, an appropriate preconditioning of the

initial samples was carried out. On the formed oxidized silicon wafers from the gas phase in the reduced-pressure reactor, polysilicon 0.5 micron layers were deposited at the temperature of 625 °C. To control the processes of nucleation and growth of the grains during the micro-zone recrystallization at the formation stage of KNI-structures, we envisaged application of the method of selective heating of materials to create a given temperature profile in the heat-affected zone of emission [24].

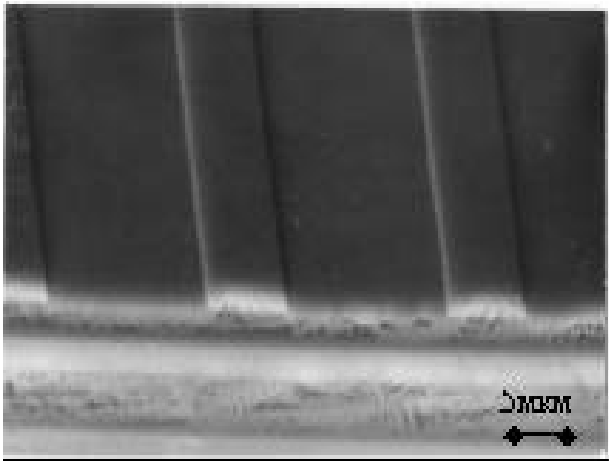


Fig. 4. Photo of section of SOI structure.

For this purpose, a SiO₂ 0.75 microns film was additionally additionally deposited onto the polysilicon layer. Besides, Si₃N₄ strips with a width of 5 microns and increments of 30 mm were created as shown in Pic.4. As a result of the laser recrystallization we have obtained monocrystal blocks with an average crystallite size of 20 × 500 microns which will be used in the future as moving parts of accelerometer.

The final stage of the formation of the accelerometer sensor is the creation of a topological figure on the surface of the SOI structure with the subsequent processes of microprofiling using anisotropic and isotropic etching, which can be described as:

- isotropic plasma - chemical etching of unmasked areas of a SOI structure at a depth of 1.5 microns;
- re-deposition of a Si₃N₄ layer with a thickness of 0.02 microns, deposition of SiO₂ layer with a thickness of 0.1 microns and the formation of plasma-chemical etching and photolithography masking areas on the horizontal surface of the SOI structure;
- anisotropic plasma-chemical etching of pyrolytic SiO₂ at the bottom of etched holes in the SOI structure;
- anisotropic plasma-chemical etching of SiO₂ to increase the height of etched holes in a silicon wafer by 0.5 microns;
- isotropic etching of silicon at a depth of 0.5 microns for creating three-dimensional depth cavities under the surface of SOI structures.

Thus, during the formation of a movable electrode of an accelerometer, the basic technological processes are used as those underlying the production of integrated circuits.

3. Experimental results

A sensing element of the accelerometer operates as follows. When a potential difference between movable and fixed electrodes, initial emission current is induced (Fig. 5a). With the moving mass of the electrode displacing (Fig. 5b), the distance between the edges increases. This leads to reducing intensity of the electric field in the cavity, as well as emission current, which is registered with a gauge or fixing scheme.

Table 1 represents the values of the intensity of electric field and autoemission current calculated for a given displacement of a movable element when a potential difference between the electrodes is 1000 V; radius of curvature at the tip of electrode equals 5 nm.

Table 1

Autoemission current with displacements of a movable electrode

Displacement, μm	Electric field intensity, V/sm	Autoemission current, A
0	$4,6 \times 10^7$	$1,5 \times 10^{-6}$
0,2	$4,2 \times 10^7$	$3,2 \times 10^{-7}$
0,4	$3,8 \times 10^7$	$7,2 \times 10^{-8}$

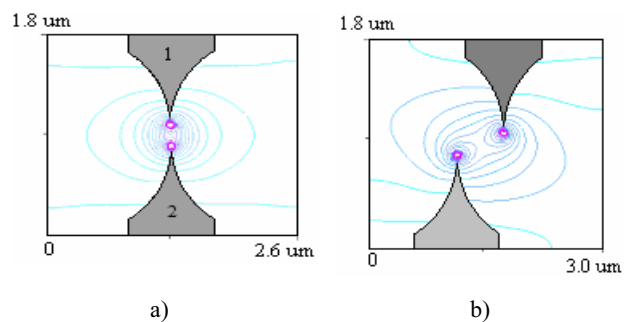


Fig. 5. Principle of the accelerometer based on silicon nanostructures

Considering strong dependence of the autoemission current on the value of movement, as evidenced by the results shown in Table 1, and very little inertia of the movable electrode, the proposed elements can be the basis for creating supersensitive accelerometers with registration of changes of emission currents both in discrete performing and for the creation of accelerometer elements within nanoelectromechanical systems [25].

It should be noted that the constructive insulating layer of SiO₂ the autoemission sensing element of the accelerometer withstands the intensity of an electric field up to 1000 V/ μm , so is appropriate for high-voltage application in devices and in integrated nanoelectromechanical systems.

4. Conclusion

As a result of the complex research we have designed a sensitive element of accelerometer based on silicon nanostructures and proposed a construction which improves sensitivity parameters, resistance to external

influences of electromagnetic fields, provides its low inertness. The device is appropriate for creating both a discrete and nanoelectromechanical systems. Based on the experimental research it has been found that offset between the electrodes of accelerometer leads to two order change of the autoemission current. The sensitive element of the accelerometer can be used in both industry and scientific research, particularly for the creation and exploitation of devices intended to register acceleration under high vacuum, for example in aerospace applications.

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ЧУТЛИВИЙ ЕЛЕМЕНТ АКСЕЛЕРОМЕТРА НА ОСНОВІ НАНОСТРУКТУР КРЕМНІЮ

Анатолій Дружинін, Ігор Когут, Юрій Ховерко,
Віктор Голота

У роботі розглянуто чутливий елемент акселерометра, виконаний з використанням суміщеної технології створення структур кремній-на-ізоляторі та ниткоподібних нанокристалів кремнію. На його основі розроблено малоінерційний, швидкодіючий, високочутливий до прискорення і переміщень пристрій із субмікрометровими та нанометровими топологічними розмірами. Це дало можливість реалізувати як дискретний прилад, так і елемент зінтегрованих наноелектромеханічних систем зі структурою кремній-на-ізоляторі, який за безпечує контроль переміщення з точністю до 200 нм.



Anatoliy Druzhynin – D.Sc., professor, Head of the Department of Semiconductor Electronics at the Institute of Telecommunications, Radio-electronics and Electronic Engineering, Lviv Polytechnic National University, Ukraine.

He is also the winner of Ukrainian State Prize in Science and Technology (2011). The main scientific activities of prof. A. Druzhynin include: theoretical and experimental study of strain-induced effects in silicon, germanium and their solid solutions whiskers. Prof. Druzhynin is the Director of the Scientific Research Center “Crystal” at the Department of Semiconductor Electronics and the supervisor of Sensor Electronics Research Laboratory. Prof. Druzhynin has authored more than 450 scientific papers including more than 40 inventor's certificates and patents.

Under his supervision three Doctor of Engineering and ten Ph.D. dissertations in engineering science have been defended.



Ihor Kogut – D.Sc., professor, Head of the Department of Computational Engineering and Electronics of V. Stefanyk Precarpathian National University, Ukraine. The main scientific activities of prof. I. Kogut relate to design of perspective element base including 3-dimensional architectures for systems-on-crystal

on the basis of silicon-on-insulator structures.

Prof. Kogut has authored over 350 scientific papers including more than 40 inventor's certificates and patents. Prof. Kogut leads a scientific work of postgraduate students and has supervised Ph.D. dissertation thesis.



Yuriy Khoverko – Ph.D., senior researcher, doctorate student at the Department of Semiconductor Electronics of Lviv Polytechnic National University, Ukraine.

Research interests cover physics and technology of semiconductor devices, micro-and nanoelectronic structures and sensor electronics.

Research findings have been published in more than 150 scientific papers, and 7 patents have been granted by Ukraine.



Viktor Golota – Ph.D., associate-professor of the Department of Computational Engineering and Electronics of V. Stefanyk Precarpathian National University, Ukraine.

The researcher has authored 55 publications, including 40 scientific publications and 15 patents for utility models. His research interests relate to

the development of and research into promising micro-and nanoelectronic components for the creation of specialized computer systems, such as systems-on-chip, including sensory, using programmable logic integrated circuits.