Silicon nanowire structures as high – sensitive pH - sensors

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Abstract. Sensitive elements for pH-sensors created on silicon nanostructures were researched. Silicon nanostructures have been used as ion-sensitive field effect transistor (ISFET) for the measurement of solution pH. Silicon nanostructures have been fabricated by “top-down” approach and have been studied as pH sensitive elements. Nanowires have the higher sensitivity. It was shown, that sensitive element, which is made of “one-dimensional” silicon nanostructure have bigger pH-sensitivity as compared with “two-dimensional” structure. Integrated element formed from two p- and n-type nanowire ISFET (“inverter”) can be used as high sensitivity sensor for local relative change [H+] concentration in very small volume.

1. Introduction
In recent years, system-on-chip technology has been increasingly used to create complex, integrated systems on a single chip. The development of ISFET sensors, a new generation of analytical devices, is one of today’s most promising directions of investigation in the field of analytical biology and chemistry.

2. ISFET sensors technology
The technologies of pH-sensitive elements on the basis of silicon nanostructure include a combination of two basic stages: formation of silicon structures with nanodimensions and sequence of operations CMOS of process.

SOI and polysilicon layer have been used for formation of nanostructures. Suspended nanowire structures were formed by methods of photolithography and selective etching. Diameter of 1µm-length nanowires was varied from 20-100 nanometers. On the surface of Si nanostructures low temperature ultrathin SiO₂ (thickness ~ 20Å) was formed by plasma oxidation

3. Results and discussion
Two kinds of ISFET: “two-dimensional” nanostructures (silicon films) and “one-dimensional” nanostructures (nanowires) were investigated as pH sensors (figures 1, 2). Both devices respond appropriately to pH changes.

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The Agilent B1500A semiconductor parameter analyzer was used to obtain the pH from 3 to 9 buffer solutions, where the temperature was room temperature (25°C). Threshold voltages were applied using a gold reference electrode. The buffer solutions were used phosphate buffered saline (PBS) 1M.

Threshold voltage of ISFETs ($V_t$) dependences of pH value are presented on figures 3, 4.

ISFET sensors constructed on the basis of “one-dimensional” nanostructures (nanowire) and “two-dimensional” nanostructures (silicon film) have a linear pH sensitivity – 41.8 mV/pH and 39 mV/pH respectively in a concentration range between pH 3 and pH 9. With nanowires greater sensitivity in comparison with films on voltage (7%) and on current (25%) was observed.
For the purpose of creation of the sensors for relative change of value pH with high sensitivity, us have been developed integrated elements formed from two n - and p - type nanowire ISFET (“inverter”), made on structures SOI and polysilicon (figures 5, 6).

Nanowire SOI and polysilicon “inverter” were investigated as high sensitive sensors to pH changes. Transfer characteristics of nanowire SOI and polysilicon “inverter” for different supply voltage are presented on figures 7, 8. The amplification coefficient of SOI and polysilicon “inverter” (K) varied from 30 to 150 and from 5 to 30 respectively.

The gold reference electrode was used for definition of voltage on the input.
Such elements with high sensitivity 5 V/pH could be used as sensors based on local relative pH changes. Amplification coefficient of “inverter” depended on variation supply voltage.

The amplification coefficient depends on molarity of solution (figure 9). Thus “inverter” could be used for determination of molarity.

![Figure 9. Dependence of K vs molarity of solution.](image)

4. Conclusion

Silicon nanostructures were fabricated with standard semiconductor processing techniques. This demonstrates the feasibility of fabricating ISFET’s and associated circuits with a standard CMOS process with minimum modifications.

Recent studies have demonstrated the ability of semiconducting nanowire field-effect transistors to serve as highly sensitive label-free sensors for control of various redox reactions. Research of silicon nanostructures used in case of pH-sensitive elements provided a perspective of its usage in a difficult analytical Microsystems «lab on a chip» [1]. Nanowire pH sensors approach appears to have potential for extension to a fully integrated system, with wide use as sensors in molecular and cellular arrays. High sensitivity sensor of local relative change H+ concentration could be used for control biochemical reactions. Miniaturization of sensors opens a broad possibility for studying pH gradient on the active surface at nanoscale or even inside the microobjects like cells [2, 3]. The formation of nanowire systems on polysilicon dramatically reduces the cost of sensors.

5. Reference

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