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Modified silicon nanowires biosensor: Synthesis methods, & early cancer diagnosis!

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Abstract:

In this paper, we present ultrasensitive silicon nanowire (SiNW)-based biosensor devices fordetection of disease biomarkers. The electrochemically induced functionalization method has was used to transplant antibodies targeted against a prostate cancer risk biomarker 8- of hydroxydeoxyguanosine (8-OHdG) onto SiNW surfaces. Antibody functionalized SiNWsensor was used to detect the binding of the biomarker 8-OHdG to the SiNW surface inside seconds of exposure. Detection of 8-OHdG concentrations as low as 1 ng/ml (3.5 nM) was proven. The active device has been connected to a disposable printed circuit board that can be inserted into the electronic reading system as part of an integrated Point of Care (POC) diagnostic. The speed, sensitivity, and ease of biomarker detection using SiNW sensors are depicted they are ideal for eventual POC diagnostics. A huge amount of research and development has been done in the field of nanotechnology and many nanomaterials have been used to detect cancer in its early stages. Nanomaterials have unique physical, optical and electrical properties that have been proven very useful for scanning. Quantum dots, gold nanoparticles, magnetic nanoparticles, carbon over the years, nanotubes, gold nanowires, and many other materials have been developed, along with the discovery of a wide range of biomarkers to lower the detection limit of cancer biomarkers. The basis is proteins, antibody fragments, DNA fragments and RNA fragments cancer biomarkers and have been used as targets in cancer detection and monitoring. It is highly anticipated that in the near future we might be able to detect cancer very early stage, providing a much higher chance of treatment.

Keywords: Silicon nanowire, Biosensor, Surface functionalization , Electron lithography, 8-hydroxydeoxyguanosine(8-OHdG), electronic readout, cancer biomarkers, gold nanoparticles, quantum dots, carbon nanotubes, nanowires, micro consoles

Introduction:

Cancer diagnosis and treatment are of great interest due to its widespread occurrence disease, high mortality and recurrence after treatment. According to National Vital Statistics News, 2002 to 2006 incidence rate (per 100,000 people) of cancer in white people was 470.6, blacks 493.6, Asians 311.1, and Hispanics 350.6, indicating that cancer is widely spread among all races. Lung cancer, breast cancer and prostate cancer were the three leading causes of death in the US, claiming over 227,900 lives in 2007 alone, according to National Cancer Institute. Cancer is also very feared because of recurrences, because even if it is treatable, they can come back after it for a period of time, including after chemotherapy, surgery or radiotherapy. The survival of a cancer patient largely depends on early detection and thus on the development of technologies applicable to sensitive and specific methods to detect cancer is an inevitable task for cancer researchers. Existing cancer screening methods include:

1.Pap test for women for detection cervical cancer and mammography to detect breast cancer, prostate specific antigen (PSA) level.

2.Detection in a blood sample in men to detect prostate cancer.

3.Detection of occult blood in the colon cancers and endoscopy, CT scans, X-ray, ultrasound imaging and MRI to detect various types of cancer.

However, these traditional diagnostic methods are not very effective methods when it comes to cancer detection in very early stages. Some screening methods are also quite expensive and do not available to many people. Therefore, the development of technology that is specific and reliable for early stage cancer detection and is readily available so it can act as a first-line guide is absolutely important. Biomarkers and nanotechnology, two main areas in the development of powerful diagnostics methods, are intensively studied these days. This review will focus on the development of cancer diagnostic methods using biomarkers and nanotechnology with an emphasis on the focus of study mainly on nanomaterials produced in the last three years.

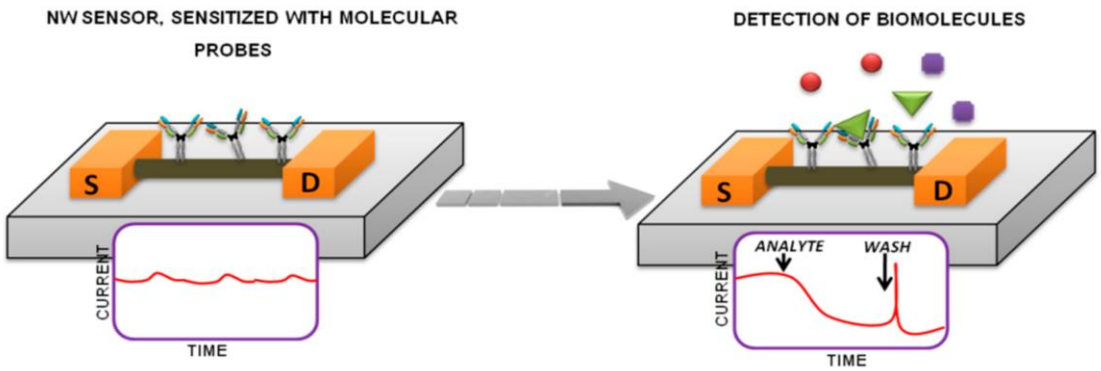

Fig1: The Si-NW-sensors circuit and its working principle

The operation of such devices is based on using the surface of the sensor as a virtual one gate: upon adsorption of charged target molecules on the sensor surface, concn of charge carrier changes in the subsurface layer of the semiconductor (sensor) and its the conductivity changes accordingly. Ensure bio specific detection of target bio molecules in the analyte solution, the surface of the Si-NW-sensors is normally functionalized with a metal provided the immobilization of molecular probes on their surface. Si-NW-sensors are often used as the bottom

of the measuring cell, where the analyte solution is placed , or inside microfluidic system . In this case, the process of bio specific fishing occurs and biospecific probe/target bio macromolecule complexes are formed on the surface positive elements. Because the target molecules are charged in the biological fluid, the change in v the conductance of the Si-NW-sensors is recorded at a set gate voltage (Vg), similar to the field nano transistors. Si-NW-sensors can be produced in both n- and p-type lines, and both of these types can be used for protein and nucleic acid detection. theoretical after adsorption of negatively charged protein or nucleic acid on n-type Si-NW-sensors molecules, the conductivity of the sensors decreases and increases during adsorption p-type Si-NW-sensors.

In CMOS technology, a top-down manufacturing method is used (CMOS is an add-on metal-oxide-semiconductor tare structure and standard industrial micro technology schema production) . Although other methods are used for production silicon nanowire structures that have a high development potential, e.g edge and corner lithography , these methods will not be discussed as a goal in the paper the work is to use these structures for biomedical purposes, not to create them. Although there are different ways to fabricate Si-NW-sensors based on the field effect transistors, it should be noted that compatibility between SOI (silicon-on-insulator) their great advantage is the method of manufacturing nanofiber sensors and CMOS technology compared to nanowires made from other materials and self-grown nanowires because ensure the possibility of organizing the industrial production of equipment, their relative low cost and small size.The advantage of this method is the possibility of using Si-NW-sensors in medicine diagnosis perform direct (unlabeled) highly sensitive multiplex analysis involving small volume (~5 µl) of biological fluid. In biomedical research nanotubes, graphene films or nanowires are often used as sensitive elements in nano biosensor .The use of Si-NW-sensors made by CMOS technology seems to be suitable most, because in the long run it will ensure: the possibility of relatively cheap mass production; low concentration detection limit (down to one molecular level); possibility of multiplex analysis in real time (~10 min per bio sample); high detection accuracy of target molecules.

Synthesis of SiNWs techniques : In general, there are currently two procedures were developed for nanofabrication processes SiNWs and include a top-down approach and bottom-up approach . Efficient performance A SiNW biosensor can be determined by various factors such as diameters, carrier densities, and surface chemistry. An an in-depth discussion of bottom-up synthesis SiNW was reported by Ramanujam et al. . The the bottom-up approach includes processes such as vapor-liquid- solid (VLS) and oxide-assisted growth (OAG) and photo- lithography or electron lithography . VLS technology has was reported to have adopted to synthesize SiNWs along with their applications as biosensors. Bottom up method involves the synthesis of SiNWs from bulk metal-catalyzed reaction silicon wafer, while the top-down technique starts from a large amount of silicon wafers and trims to preferred and desired size and shape of SiNWs through a lithographic mechanism anism.

VLS :

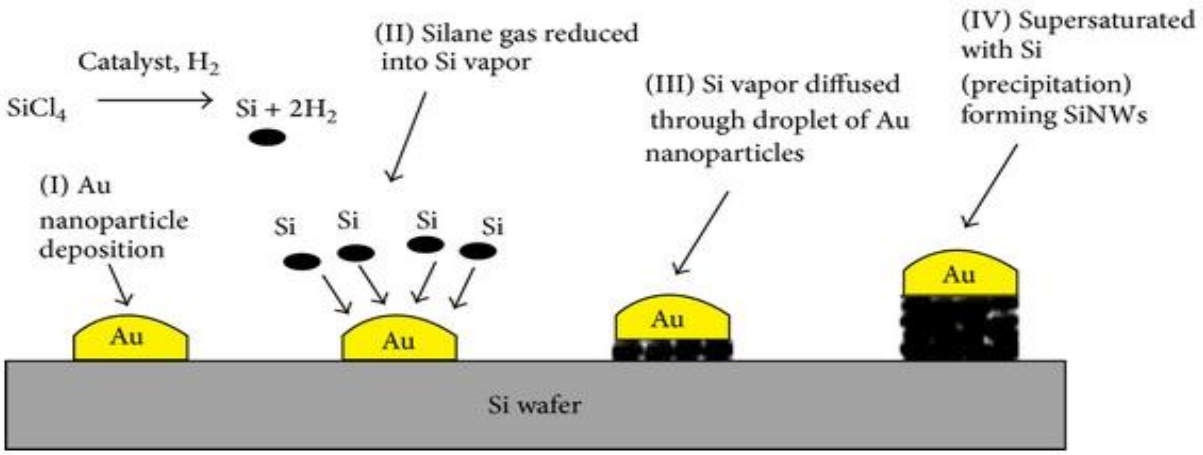

Fig2:ThesiliconnanowirebiosensorsynthesisusingVLSmethodviaCVDmethod:Step(i)Goldnanoparticledeposition.Step(ii)Reductionofsilanegastosiliconvapor.Step(iii)Diffusionofsiliconvaporviagoldnanoparticles.Step(iv)FormationofSiNWsviasuper-saturationwithsilicon.

The synthesis of silicon nanowires via VLS was first described in 1964 using a silicon substrate integrated with liquid Au droplet. Metal-catalyzed deposition occurs in VLS (Au, Fe, Pt, Al, etc.) on the silicon wafer and then SiNW growth is enhanced either by chemical vapors deposition (CVD) technique. In fact, silicon wafers coated with metal

catalysts are placed in the middle of the tube furnace and the siband (SiH4) or tetrachlorosilane (SiCl4) and passed above the metal catalyst accumulated on the Si wafer in the slot ber at a higher eutectic temperature. SiH4 gas serving as a silicon gas source would be converted to silicon vapor and dispersed through a metal catalyst to produce metal-silicon alloy droplets. How Silicon Diffuses Through Catalytic Metal Nanoparticles list leading to a saturated state of the state, silicon is precipitated from the metal-Si droplets form silicon nanowire.

OAG via thermal evaporation:

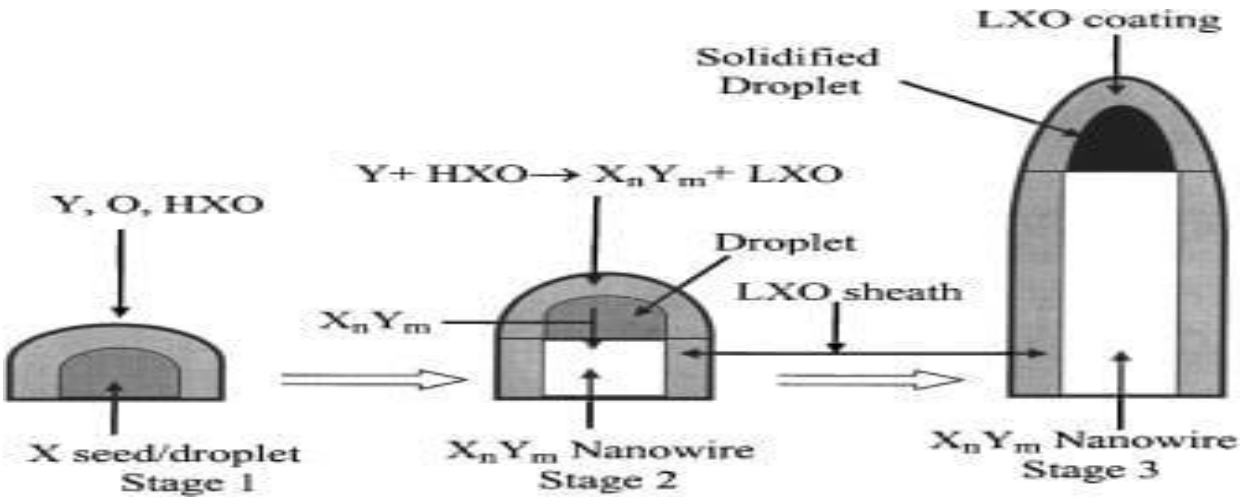

Fig3: oxide assisted growth mechanism for nanowire

Recently, many researchers have effectively synthesized SiNWs via a bottom-up approach called OAG via thermal evaporation due to its creation enormous amount of SiNW . Using the OAG method to grow SiNWs were significantly improved by using SiO as a starter material for nucleation and growth stimulation SiNWs without the use of metal-catalyzed generation SiNWs with high purity and without metal impurities. The development of SiNWs using the OAG method has reported by Shao et al. Briefly, they reported that an alumina boat holding a mixture of SiO powder (10 g) and Si powder (0.05 g) was placed on aluminum oxide tube, inside the tube furnace. At special pressure sure, Argon was introduced as a carrier gas and for 10 h the furnace was heated to a temperature of 1250–1300 °C. The resulting SiNWs have a diameter of 85 nm and were collected around an alumina tube surface. One of the properties produced SiNWs through the OAG method has on its outer side layer, an oxide layer that is chemically inert. On effectively improve electrical and optical properties of fabricated SiNWs, the outer layer coated the oxide layer should be removed by oxide treatment layer with hydrofluoric acid (HF). It should be noted that this method is more convenient do VLS as enables the production of SiNWs with various morphology in chains, rods, wires, ribbons and coaxial structures and the use of silicon sources such as silane (SiH_4) or $SiCl_4$ can be bypassed.

Metal assisted chemical etching:

This is the cheapest and simplest method of synthesis SiNM . This method involves two main stages which are non-current metals (silver, nickel, platinum, gold) deposition on a silicon wafer followed by chemical etching in a solution based on fluoride ions . Real-time response electroless deposition and chemical etching has reported by Brahiti and co-workers and it means dipping a cleaned silicon wafer into NH_4HF_2 and $AgNO_3$ solution. In this method, the silver ions attract electrons from the siliconcon substrate that came from silver deposition nanoparticles on the silicon surface . The silicon under the silver nanoparticles is oxidized and holes are formed exposure to HF; the holes created serve as a descending route for the rest of the Ag nanoparticles, forming a longitudinal and transverse suspension of silicon forming formation of an arrangement of SiNWs. Zhang a co-workers also reported that when parameters like temperature, concentration and time of deposition and doping. level, different morphologies of SiNWs are manipulated fields could be produced.

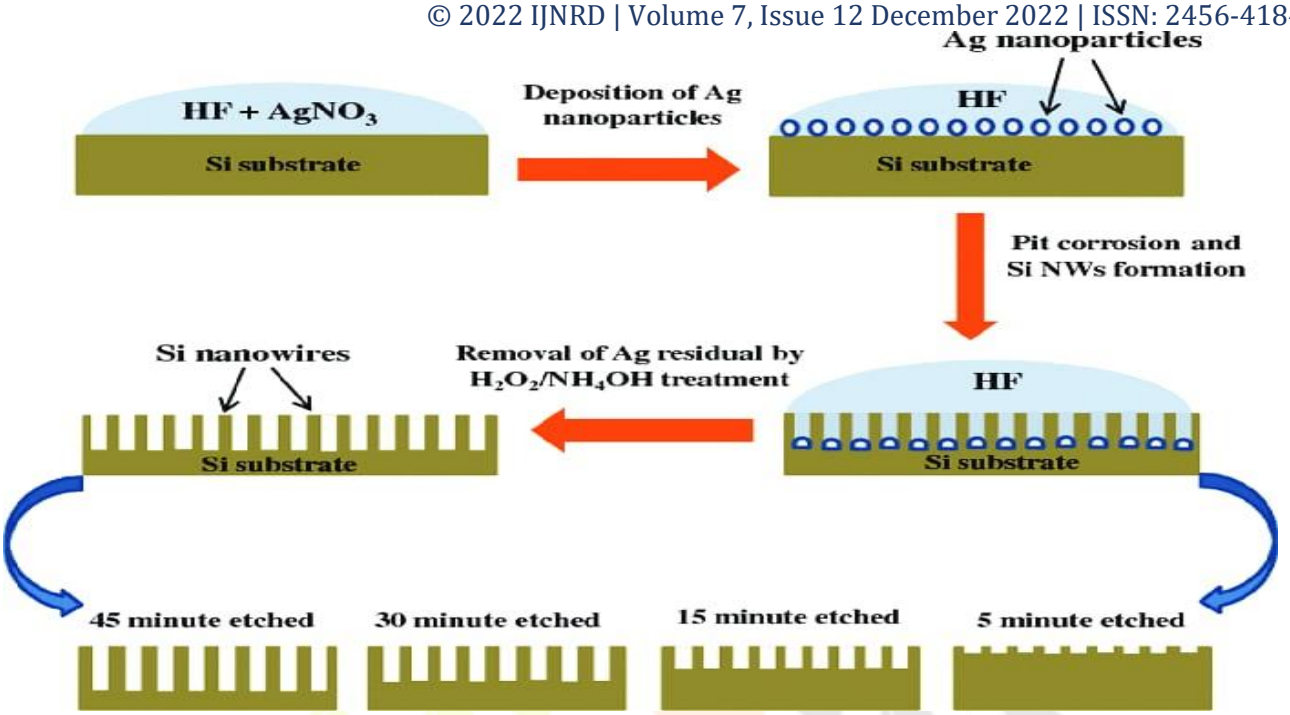

Fig4: metal assisted chemical etching mechanism i.deposition of Ag nanoparticales ii.pit corrosion & SiNWs formation iii.Removal of Ag residual by H2O2/NH4OH treatment

Detecting protein marker with use of SiNW nanosensors:

Determination of protein markers associated with oncological diseases listed in the literature can be roughly divided into two stages. The first stage is connected with determination of DL detectors based on Si-NW sensors in a model solution for the purpose to determine their potential in earlier detection of diseases. It should be noted that for earlier detection of the disease, it is essential that the detection limit be below femtomolar concentration threshold. Almost all of the works listed below, with rare exceptions, made it possible to achieve such low detection limits using silicon nanowire detectors. This indicates the high potential of this technology for earlier disease detection. The the second phase of research involves adapting these technologies to protein identification markers in the patient's biological fluid, which usually include serum and to a lesser extent urine and other biomaterials. More detailed analyzes of the use of Si-NWs for detection protein markers in clear solutions and in biological material are listed below.Antibodies or aptamers can be used as sensitive elements of SI-NW sensors for biospecific detection of proteins. First, antibody-based biospecific Si-NW sensors to consider Lieber C.M. et al. were the first to detect protein and individual virus particles using this method Si-NW-sensor: multiplex analysis of prostate specific antigen (PSA) was performed, carcinoembryonic antigen (CEA) and mucin-1, a transmembrane glycoprotein assocd with bladder cancer . Aldehyde propyltrimethoxysilane (APTMS) was used in this study. serves to modify the surface of the sensor, while the respective monoclonal antibodies (mAb) were used to functionalize its surface. Detectable concentration range for PSA, CEA and mucin-1 in buffer solutions was between 50 and 100 fg/ml. The detection limits of low concentrations, achievable with Si-NW-sensors, are determined increased surface to volume ratio. Moreover, according to data from the literature while reducing the silicon nanowire (Si-NW) diameter from 200 to 50 nm the concentration detection limit achievable with the Si-NW-sensor will be 206 times lower. However, decreasing the Si-NW diameter brings about an increase in the low frequency flickering noise that prevents detection of a valid signal. Another approach, which makes it possible to lower the concentration detection limit achievable with the Si-NW-sensor use of electromagnetic fields. In the concentration limit of hepatitis core antigen The detection of virus C (HCVcoreAg), achievable with the Si-NW-sensor, was shifted down to 10–17 M using a microwave generator that allowed the Debye radius to be increased up to 14nm Low CEA detection limits (1 fg/ml and 10 fg/ml) after application of Si-NW- sensor, made by standard CMOS technology, were demonstrated in. in another paper , low detection limits were achieved using an integrated Si-NW sensor polydimethylsiloxane (PDMS) microfluidic device using a junctionless nanowire transistor. Protein α-fucosidase associated with hepatocellular carcinoma was detected at concentration of ~1.3 pM using a Si-NW-sensor with PDMS microfluidic channel, functionalized by fuconojirimycin receptor (α-fucosidase inhibitor). The integration of the Si-NW-sensor with two PDMS channels made it possible to reduce the detection limit for PSA and marker of non-small cell lung cancer – 19 CYFRA21-1 (cytokeratin fragment) to 1 fg/ml . Cheng et al. used a standard Si-NW-sensor to detect CYFRA21-1 at a given concentration at least 1 fg/ml. The same detection limit was demonstrated for neuron-specific ones enolase, an enzyme associated

with lung cancer.Using a Si-NW-sensor, Pham et al. detected liver-associated α-fetoprotein carcinoma, ovarian carcinoma and testicular carcinoma at a concentration >10 ng/ml . Cervical cancer-associated protein p16INK4a was detected in concn 100 fg/ml using polycrystalline Si-NW-sensors. For the purpose of biospecific detection of target molecules as molecular probes, not only antibodies but also aptamers can be used . We know that aptamers have a number of advantages compared to antibodies . Their main advantage is the temperature resistance, high binding constant, possibility of chemical modification of end groups, simplicity of the synthesis process, short development time, possibility to arrange suitable in vitro sequence and their low price . Thanks to these advantages, you can tamers are an attractive object for use in biomedical research, medical diagnostics and therapy .In our study, we showed the possibility of using aptamers as molecular probes to detect D-NFATc1 (nuclear factor of activated T-cells), whose expression in increased in cancer cells, lung tissues, as well as in the hepatitis C virus marker HCVcoreAg concentration of 2.5 × 10−15 M [7]. Using DNA aptamers, we also detected protein-vascular endothelial growth factor associated with breast cancer and gastric cancer concentration 2.59 nM 2.59 nM. Application of spectral ellipsometry near surface plasma observation conditions nance to experimentally determine the differences between the rate constants of spec interaction of tumor M2 pyruvate kinase (Tumor M2-PK) in blood serum patients suffering from colorectal cancer in different stages and with different metastatic foci and highly specific monoclonal antibodies located in layers on the surface of the SOI-biochip. In this study after M2-PK tumor detection, the Si-NW-sensor showed a low concentration detection limit (10−15 M to 10−13 M) and high specificity. The results obtained can offer the possibility of creating methods for early diagnosis of colorectal cancer, detection metastases in different areas and identification of disease recurrence . Colorectal-associated activated leukocyte cell adhesion molecule (ALCAM).cancer, pancreatic cancer, melanoma, breast cancer and ovarian cancer have been observed in serum with a detection limit of 15.5 pg/ml .NFAT has recently been shown to be a transcription factor that is highly expressed in tumor cells . Two types of fabricated Si-NW chips: those with narrow NW (w = 90 nm) and those with wide NW (w = 3 µm) were compared for their multiple uses, i.e. the possibility of repeated cycles of detection-regeneration of the surface of Si-NW chips at detection of D-NFATc1 in serum. Analysis showed that he received the signal from the wide NW was much more stable than that obtained from the narrow NW. This confirms that Si-NW nanosensor chips containing a wide NW are far more suitable for the analysis of proteins in biological fluids. We have also shown that the use of Si-NW chips with a narrow NW allows lower detection limits to be achieved.

Fig: diagram of sol-gel preparation and process for fluorescent

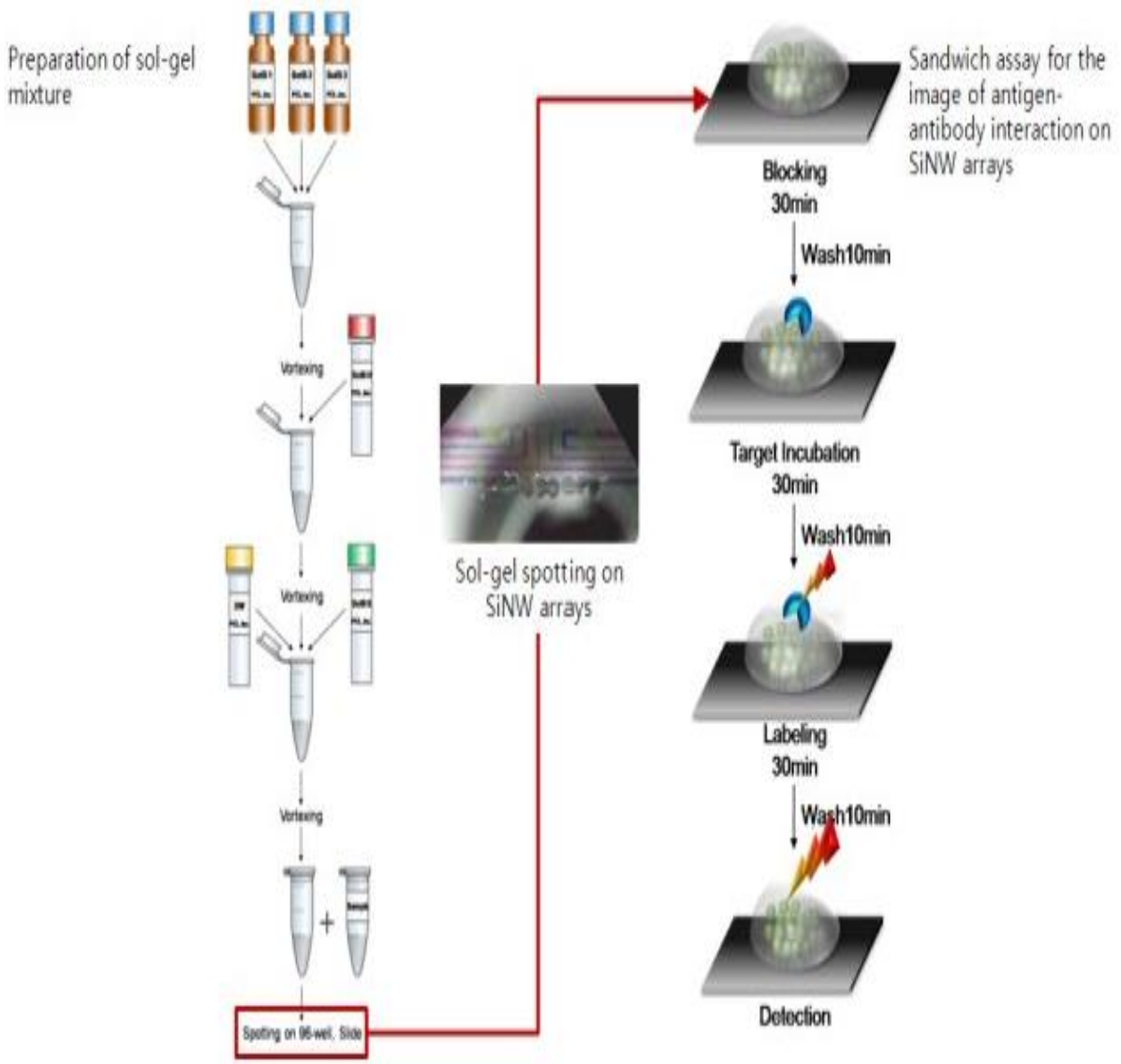

Table1:Detection of proteins associated with different types of oncopathology using silicon nanowires biosensors.

Analyte	Medium	Detection Limit *	Method
PSA	buffer	1.7×10^{-15} M	Si-NW
	serum	3.13×10^{-14} M	
	buffer	3.48×10^{-17} M	Si-NW PDMS
	serum	3.48×10^{-16} M	
	buffer	3.48×10^{-17} M	
	serum	3.48×10^{-16} M	
CEA	buffer	6.51×10^{-16} M	Si-NW
	serum	1.17×10^{-14} M	
	serum	6.51×10^{-16} M	Si-NW PDMS
	serum	1.3×10^{-16} M	Si-NW
	buffer	1.3×10^{-17} M	
	serum	1.3×10^{-16} M	
	buffer	1.3×10^{-17} M	JNT
MUC1	buffer	4.09×10^{-16} M	Si-NW
	serum	7.37×10^{-15} M	
APOA2	urina	3.8×10^{-13} M	Poly-Si-NW
D-NFATc1	buffer	2.5×10^{-15} M	Si-NW
	serum	2.5×10^{-14} M	
CYFRA21-1	buffer	3.33×10^{-17} M	Si-NW PDMS
	serum	3.33×10^{-16} M	
	buffer	3.33×10^{-17} M	Si-NW
	serum	3.33×10^{-16} M	
AFP	buffer	1.46×10^{-13} M	Si-NW
	serum	7.28×10^{-15} M	Si-NW PDMS
α-fucosidase	buffer	1.3×10^{-12} M	Si-NW PDMS
VEGF	buffer	2.59×10^{-9} M	Si-NW
	tissue	5.0×10^{-15} M	
Tumor M2-PK	buffer	10^{-13}–10^{-15} M	Si-NW
ALCAM	serum	2.38×10^{-13} M	Si-NW
$p16^{INK4a}$	buffer	6.48×10^{-15} M	Poly-Si-NW

Detection of specific nucleic acid with use of SiNW_Nanosensors:

According to the National Institutes of Health (NIH), the main characteristic of a biomarker is the possibility of objective measurement and assessment as an indicator of normality biological processes, pathogenic processes or pharmacological response to therapy.Discovery of new biological markers of cancer in order to obtain diagnostic, prognostic or therapeutic data represent one of the key tasks of modern biomedical reSearch. Many tests commonly used in clinical practice that use such known cancer-related biomarkers such as PSA (prostate cancer marker), CEA (colorectal cancer). marker), α-fetoprotein (liver cancer marker), CA 125 (ovarian cancer marker) and CA 19-9(pancreatic cancer marker), have been reported to lack sensitivity and specificity. That

appears to be why, in July 2012, the US Preventive Services Task Force does not recommend a PSA-based test for prostate cancer screening. Accordingly, the new cancer associated biological markers are required to provide better test accuracy be found to detect tumor progression and changes at the cellular level, and patient response to therapy. In recent years, a new group of potential epigenetic tumor markers have been distinguished: microRNAs (miRNAs), which are non-coding RNA between 21 and 25 nucleotides long. The use of miRNAs as diagnostic and prognostic markers have a number of advantages. Most miRNAs are conserved . further tumors have unique miRNA expression profiles already at an early stage of carcinogenesis.

Involvement of miRNAs in key cellular processes including proliferation and cell death because the control of oncoprotein expression makes them quite promising tumor biomarkers, they know that cancer-specific miRNAs are detected in the blood already in the early stages of the tumor growth, while their number increases with the progression of the disease. In contrast with other types of biomarkers are miRNAs extremely stable in the bloodstream, making them the most reliable for use in oncology practice [58]. Additionally, miRNAs specific to each cancer type is already formed in the early stages of carcinogenesis. Current miRNA detection methods are mainly divided into two groups: those based on amplification and hybridization. An example of the former is real-time quantitytive PCR (qPCR). This includes Northern blotting, in situ hybridization, microarray and deep sequencing [60]. In fact, these methods also require pre-amplification of the sample its hybridization, and do not fully meet the requirements of clinical diagnosis, which are based on simplicity of application, speed of expression, their low price, high sensitivity and specificity. Today, qPCR is the benchmark for quantitative evaluation of miRNAs .

However, amplification procedures are very time-consuming and qPCR results depend on them fluorescent markers. High concentration detection limit and complex labeling procedures complicate the use of Northern blotting and in situ hybridization as routine methods miRNA detection . Limitations arising from the use of microarrays and deep sequencing are their high price, long reaction time and sophisticated data analysis. other methods such as surface plasmon resonance and Raman spectroscopy are complicated because of expensive tools. The use of electrochemical biosensors is limited by their detection speed and the probe knotting effect. Si-NW based sensors have such advantages such as label-free detection, low concentration limits of detection, fast response and good selectivity.

Based on the analysis of research papers, we have identified large number of miRNAsstudies using nanosensors. So in the article a chip for a Si-NW-sensor produced with CMOS compatible technology using gas phase regeneration and lithography methods, was used to detect oncological diseases in patients based on the analysis miRNA rate in blood plasma. It was shown that the Si-NW-sensor enables the detection of an increased miRNA level in breast cancer patients compared to healthy controls control group and ovarian cancer patients. Lu et al. developed a complementary metal oxide semiconductor (CMOS)-compatible Si-NW sensor made by anisotropic wet etching technology with its own limitation that provides much lower production costs and ultra-low concentration detection limit. This nanosensor enabled rapid (<1 min) detection miR-21 and miR-205 with a low detection limit of 1 zmol (~600 copies), as well as excellent discrimination of tumor-associated single-nucleotide mismatched miRNA sequences. In addition, the researchers succeeded using the fabricated Si-NW sensor detect miRNAs in whole RNA extracted from lung cancer cells, as well as in humans blood serum samples, which proves the possibility of their use for the identification of clinical samples for early cancer diagnosis. In another paper label-free and direct hybridization analysis for ultrasensitive The detection of miRNA was established using Si-NW devices. Measured resistance change before and after hybridization directly correlates with the concentrations of the hybridized target miRNAs. At the same time, the detection

limit of 1fM was shown. This method allows to identify fully identical and non-identical miRNA sequences. Moreover, Si-NW devices is able to detect miRNAs in total RNA extracted from Hela cells. Researchers suggest that this approach will enable label-free detection of miRNAs early diagnosis of cancer with ultra-high sensitivity and good specificity (Table 2). The multiplexity of sensor elements on one chip can ensure the detection of different ones markers in one biofluid sample. Gao et al. presented a CMOS-compatible Si-NW sensor integrated with PDMS microcircuits for real-time label-free and multiplexed miRNAs high selectivity detection that allows low concentration limits of detection to be achieved. This nano sensor has been shown to identify the lungs in a fast and sensitive manner cancer biomarker miRNA-126 with the lowest possible level of 0.1 fM and CEA with good specificity up to 1 fg/ml. Detection power was defined for both ideal and clinically relevant samples using miRNA analysis in whole RNA and CEA in blood serum The table below shows the results of nucleic acid detection studieswith a Si-NW sensor.

The table shows that the studies were mainly devoted to the identification of individuals microRNA types associated with different types of oncopathologies. To increase diagnostic reliability, the use of these technologies for spectrum identification seems promising microRNAs, rather than individual types, in the analysis of biological materials of patients with oncopathologies as noted in the case of protein profiles.

Table 2. Detection of nucleic acids, using nanowire silicon biosensors.

Analyte	Medium	Detection Limit *	Method
DNA	buffer	1.0×10^{-15} M	Si-NW-FET
	buffer	1.0×10^{-15} M	
	buffer	1.0×10^{-15} M	
miRNA	buffer	1.0×10^{-17} M	Si-NW
U6 snRNA	cells	~2.2×10^{-5} M *	poly-Si-NW FET
miRNA	buffer	1.0×10^{-15} M	
miRNA-363	buffer	1.0×10^{-17} M	Si-NW
	plasma	no data	

Conclusion:

In this paper, we have discussed the importance of using array-based Si-NW sensors effect transistors and their applications in biomedicine. Using silicon field effect transistors developing sensors offers the advantage of their low signal-to-noise ratio and high temperature stability, resistance to changing response depending on the environment, low concentration detection limits and reliability, high response repeatability, small response change over time, speed of expression and the possibility of their mass production. Additionally, the integration of Si-NW sensors into microfluidic systems is increasing popularity because it allows very low (on the order of nanoliters) volumes to be used samples in the analysis, which provides short response times. Despite the aforementioned advantages of Si-NW sensors based on transsistors, still have several limitations:

(1) well-shaped NW structures with drivenatomic composition and heterojunctions are necessary to fabricate devices withgood reproducibility;

(2) can be the integration of NW sensors into microfluidic systems problematic due to the small size of the device;

(3) non-specificity is difficult to avoid interactions when using NW sensors in whole blood or serum analysis.

This was made possible by silicon nanowire detectors based on field effect transistors low concentration limits of protein and nucleic acid detection in sample solutions femtomolar and subfemtomolar concentration level. So they can be customized for the purposes of early medical detection of oncological and infectious diseases overcoming existing problems of non-specific detection and improving stability properties of nanowires in the biological environment. It should be noted that the prospects the use of these detectors in the earlier detection of oncological diseases will be determined by adapting them to identify the spectrum of proteins and nucleic acids associated with oncopathology, rather than individual types of proteins and nucleic acids.

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