A Comprehensive Review on Fabrication of Nanowire Biosensors and Applications

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Abstract: Silicon nanowires have been studied and used as high-sensitivity, restricted labelling, and high detection sensors in the last decade. The development of SiNW biosensors and their diagnostic applications are discussed here. Biomarkers related to cancer, coronary diseases, infectious diseases, and other diseases are analysed. SiNW biochemistry is a great promising tool for encouraging the creation andapplication of POC instruments for disease diagnosis. It investigates the use of nanomaterials in biomedical sensors, such as carbon nanotubes, nanoparticles, quantum points and nanowires. For sensitivity and durability, a large area-to-volume ratio is necessary. We assess the working principle of nanowire structures and comprehensive manufacturing processes. Moreover, experiments have beenchecked on the use of the sample for the detection of biomarkers, viruses and DNA, and the finding of drugs. Recent breakthroughs are investigated in self-power, reusability, sensitivity, and long-term stability in high ionic strength solutions. Due to their high conductivity, Nanowire can improve the sensitivity of biomedical sensors.

Keywords: Nanowire Biosensors, Nano-Fiber Biosensors, DNA & RNA and Viruses.

INTRODUCTION

Tiny, sensitive biomedical sensors could detect various diseases early on, raising dramatically the probability of possible interference. If the early diagnosis of breast cancer and latest therapies are

followed, the five-year survival rate is more than 90%, while at a late stage it declines by around 20%. Early detection of cancer requires highly sensitive biosensors [2,3]. , 5 As a result of biomedical sensing science, the most promising developments of biomedical sensing are recent advancements in nanotechnology. Nanoscale research and technology studies applications with less than 100 nanometers of materials and devices. The physical and chemical properties of the nanometer scale are dependent on the volume-to-surface ratios and the quantum effects. This results in very different characteristics than themacroscale [7].

Since the volume-to-area ratio at nanoscale is extremely broad, it modifies the surface of the nano-structure and makes the device sensitive to surface changes. The movement of the electron of the nanostructure is constrained by how quantify causes the energy levels of the system to depend on thescale of the chip. The excited power of low-level semiconductors and the capacity of the volume- normalized oscillator are both improved by decreasing scales [8] which allow for a high efficiency of energy transfer and a comparatively low temperature level of noise for the nanostructures [9]. Sensor manufacturing will gain the size of the biomolecules (~10 to ~100 nanometres), which are in the same range as the nanostructures for medication sensing.

Biomedical sensors are involved in identification and definition of chemical and biological cells, from diagnostics to development of drugs. A host of biomedical activities can be carried out easily by the use of nanomaterials with distinct mechanical, magnetic and optical properties. An example is the use for the imagery and magnetic resonance of semiconductor crystalline nanoparticles marking molecules and colloidal gold. This method enables the electrical and unmarked recognition of various species. The wires are made of semiconductor materials and can be selectively electrical. Carbon nanotubes, also suitable formedical sensor applications, are created by mixing semiconductors and metals, which require more purification. In addition to the protocols of the nanotubes in the literature, the literature often has disadvantages. As generated by nanostructures, they are the best option for high accuracy, uniformity, reproductively and scalability detection of biomedical events.

This analysis addresses the concepts and their integration into a variety of biological and medical applications of nanowire-based biomedical sensors, analysing past research [24,25]. We will address emerging weaknesses in nanowire-based biomedical sensors by long-term stability, ionicity, reusability and self-powering in solvents.

Production and Manufacture of Pseudo Harnesses

Basic Step of the Field Effect Transistors Directional Nanowire

The Field-Effect Transistors of Nanowire are a class of sensor that is derived from the conventional planar FET from the gate, source and drain (Figure 1A). The source and drain are generated in the size of the micron or nanometer by using metallic components. The gate, a thin layer of isolating material, is linked to the source and drains and plays a part in the system's electrical properties. As the voltage is applied, changes in electrical potential generally occur. The number of charged species in an electrolyte solution will affect this solution's conductivity. This detection mechanism was proposed about 30 years earlier by the accumulation of charged species. However, because of its low sensitivity, which makes this planar gate fet sensor inefficient to many application types, a number of detection samples are needed.

On the FETs and in the molecular gates of nanometres, respectively (Figure 1A). Through the differing electrical structure of the FET, the principle of operation remains the same as the usual FET, with the conductivity altered by loaded species of the nanowires. Silicium and silica nanowires are more common among the different semi-conductor nanowires which can be generated by semiconductors like silicon andsilicon due to their high compatibility with CMOS technology. Other benefits of silicon and silica nanowires are the intrinsically high surface ruggedness of the oxide layer as separating layer on the silicon surface and the simplicity with which the silicon and silica nanowires are modified. The bio- molecular accumulation on the substrate does not affect the conductance of the silicone and silica core, since biomolecules do not disrupt them. It is therefore necessary to identify and identify the substrate exposed to specific charged organisms (e.g., DNA, RNA, viruses, etc.). The chemical interactions between nanowire surface and molecules can be rendered with covering nanowires by insulating materials(Figure 1B). Receptors bind load-bearing molecules and alter nanowires' conductivity. When we see the species as an input signal, the receptors act as a barrier, transforming the input signal into improvementsin the system's overall conductance. Figure 1B defines the normal binding mechanism with 3-AMI (APTES), kind of DNA receiver, peptide nucleic acid (PNA) and anticörper. Figure 1B is a standard

binding mechanism. APTES conversions silicon-oxygen connections to siloxane simultaneously, where Xmay be more modified or connected with those receptors.
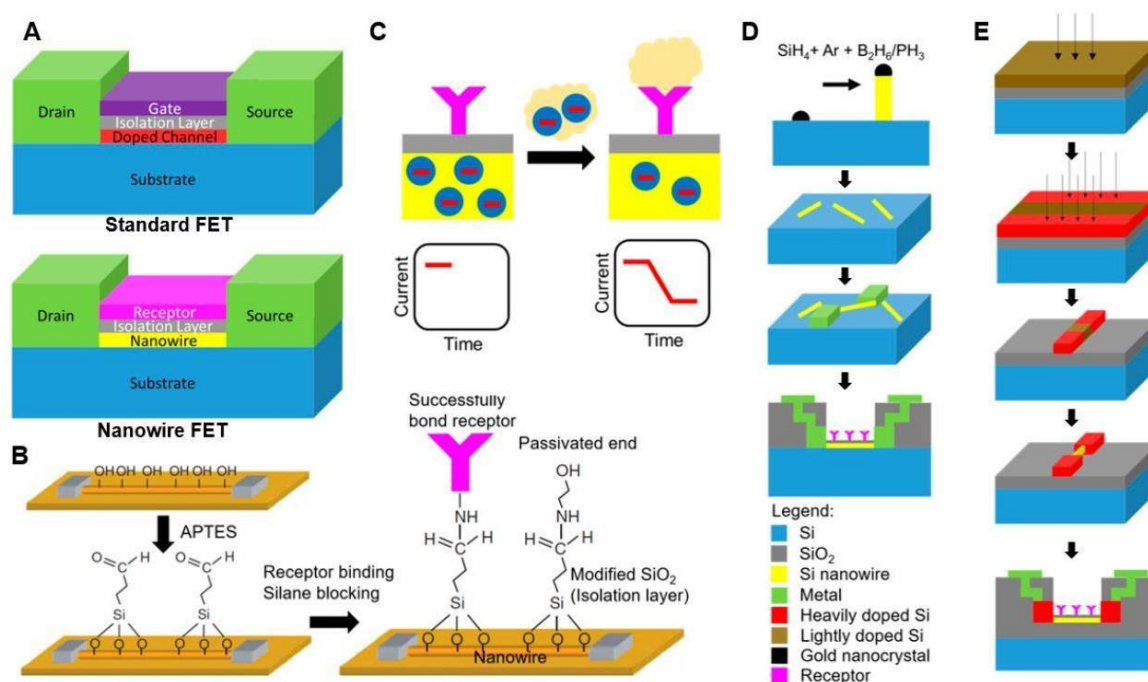
Figure 1: Conceptual overview of field effect transistors (FET) (adopted with permission from [24]). (A)Schematics illustrating the differences between standard and nanowire field-effect transistors. (B) An overview of the functionalization process of the nanowire [31]). (C) Illustrates the operating principles of nanowire sensors. The nanowire sensors fabricated using (D) the bottom-up approach and (E) the top- down approach.

The method by which the sensor works is shown in Figure 1C. The protons are directed through the metallic substrate of Si nanowire FET while the negatively charged species is linked to the receiver. Positive charges result in electron loss or the presence of holes, thus altering the conductivity from sourceto drain. Electrons can be less conductive than holes in the n-type si nanowire that leads to less conductivity. Unlike the traditional vision, the existing carriers in p nanowires will be holes. The real timeelectrical parameters for the Si Nanowire transistors are tested using a semiconductor parameter analyzer. The nano-fire FET is normally on, according to the regular FETs used in electronic circuits. (i.e., often crosses the currents of the DC). Though averaged nanowires are usually more likely to accumulate and have lower statistical noise, a range of nanowires in a single sensing device are widely used.

Another variable is that the insulation layer differentiates the surface load that influences the nanowires conductivity. Surface chemical charges have an effect on nanowires' properties and thereby enhance their behaviour. As the pH gets smaller, the surface that ends with the –NH2 group uses the negative hole fromthe wire surface as seen in Figure 1B to become -NH3+. At

high pH, the nanowire surface is attacked by–OH and becomes –O–. The net effect of these pathways is electron transport in nanowires. The pH of thenano-wire sensors is especially important since the effects of the same solutions depend on the pH of the sensors.

The condensation of the counterparts causes the nanowires to be highly conductive. For example, as the molecules are negatively charged in the solvent, the electrostatic interactions result in positively charged counteractions. Charged counterbalances interact in an enticing bond with negative charged biomollecules. The charges have now been deleted from the targets. This is Debye length (αd). This is Debye length. The debye length measures the amount of an electrostatic charge in a sample from a charged particle. For that reason, the Debye time is necessary to distinguish between molecules in a neutral environment by precise sensors. Since positive charges resulting from the electrostatic action of analytes replace effects of negative charges, there will be no difference in the conductivity of the nanowire. Thus, the conductivity change is only supported by molecules above Debye duration. In contrast, the sensitivity to negative detection in the Debye limit decreases. [35] [35] [35] Long sufficient debye time for charged molecules is operating with high sensitivity. An optimal Debye length is essential to consider when developing sensor based systems. Long debye duration is marginal for the effect of counterfeits. For any approximation the period of Debye of the nanowire sensors can be assessed. μd varies linearly with I as it is mobile phase ionic strength. The Debye time also changes in this equation as the ionic strength increases. Thus, with less conductive fluid, the less sensitive sensor is better used. In diluted PBS samples, the duration of Debye was increased compared to diluted water.

Flow of Manufacturing

The nano-fiber-inspired bio-sensors are both based on bottom-up and top-down approaches. Bottom-up approaches were particularly effective in increasing high-grade nanowires on silicon wafers as shown in Figure 1. While most nanowires are cylindrical, contemporary bottom-up technology enables a wide range of forms to be produced. The manufacturing process normally starts with the production of silicon nanowires by chemical vapour deposition. In the presence of degrading gases, Si nanowires can be catalysed by CVD. And Si nanowire is dissolved into ethanol, which is atomically thin, and attached to a silicone substrate. A photoresist is then sprayed on a metal electrode substratum with Si-nanowires and spin-coated. The metal electrodes are modelled by a technique of etching. The nanostructure is passivatedand adjusted for receptor binding after bottom-up manufacture. The nanowire surface is easily exposed to oxygen-rich air or atmosphere. The bottom-up

process for producing high quality nanowire sensors has a drawback when using randomly controlled nanowires, which leads to lower uniformity and lower yields. Further alignment measures such as Langmuir-Blodgett, blown-bubble, microfluidic flow, touch printing and electric field are needed during production to optimise orientation. However, the normal CMOS manufacturing procedure is incompatible with some alignment methods and makes it difficult to produce significant numbers of matched nanopires. The high-down methods are used to build matchable nano- wire products compatible with standard CMOS technology, based on the processes used for micro production of a silicone-on-insulator (Sioi) wafer or single crystalline silicone (SiC). The method starts with doping boron or phosphorus on the top layer of an SOI wafer, as shown in Figure 1E. The patterned area is then treated for source and drain doping in order to distinguish the source and drain leads, and ion sputterings form the source and drain electrodes (RIE). Then Si nanowire lithography is generated for metal contacts by E-beam and is made with thermal evaporation. In addition to the bottom-up procedure, the build endoskeleton is surface-modified and passivated. The top-down approach is compatible with theCMOS methods, but the bottom-up nanowires produced are thicker. Irrespective of the physical differences between drain and source, they share the same architecture.

Figure 2 also shows another way of manufacturing silicon nanowire with bulk SCS. The production methods include photolithography, silicone dry gradation, anisotropic wet etching and thermal oxidation. It is made by a number of different processes. The width of the silicon nanowires is regulated by a method of thermal oxidation. The effect is crystallised nanowires of silicon. Figures 2A and 2B show the architectural schemes of the manufacturing processes for SCS wafers of specific guidance (100) and (111). A dense film of silicone dioxide is grown on a silicone substitute for the fabrication of silicone- based electronics. The Dielectric grading technique is used to remove silicone dioxide in the top layer after the photolithographic deposition and the definition of the room and line. Cleaning approaches are applied after the photoresist has been removed. The silicon nanowires are then fabricated in a certain position inside the pillars after the silicon-deep RIE etching phase. The bare silicone is subsequently etched in an anisotropic wet etching process (different directions) till {111} the silicon surface plane is disclosed. As seen in Figure 2A, {111} surfaces are shown as the hourglass-shaped silicon structures. The nanowire silicone arrays consist of a phase of thermal oxidation, in which the top layers of the hourglass constructions have the silicone nano films, while the lower layer contains the thermal oxide isolated from the upper and lower layers by the thermal oxide. The nanowire size is dependent on the SCS wafer's pattern width potential.

The lowest one-dimensional method for manufacturing silicone-nanowire (111) requires an oxide stage of development. A range of methods are often used to classify the suitable patterns through photolithographing and etching. The main method of deep vacuum development includesproducing nanowires on a silicone substratum. Different structures such as wires and ribbons may be created by their distinct vertical and horizon extent (111) silicon nanowires. On the sidewalls thermal oxidation is then used to ensure complete passivity. The anisotropic dry grafting process is performed on the bottom surface of the structure and a secondary, deep silicon RIE process is used to produce the sacrificial layer. TMAH solution is used to etch {111} planes after the addition of SiO2 sensitisation. Finally, the procedure of thermal oxidation is performed for the manufacture of rectangular nanowire structures.

The continual reflow of fresh fluid is one of the essential elements of these nanowire sensors. The bulk of nanowires on the sensor surface are fed or taped with a solvent. For electrophoresis-based sensor systems polydimethylsiloxane (PDMS) analytical instruments are widely used. PDMS is useful in bio-sensing systems because it is fundamentally "biocompatible." Certain disadvantages exist in the above-mentioned microfluidic fluid exchange process. The sensors will penetrate the nanowires surface due to the laminar fluid flow in nano channels. In addition, with the advent of biomolecules [54], the sensor performance would be reduced. A model based on acrylic was designed to overcome the disadvantages of PDMS microfluidic channels [56].
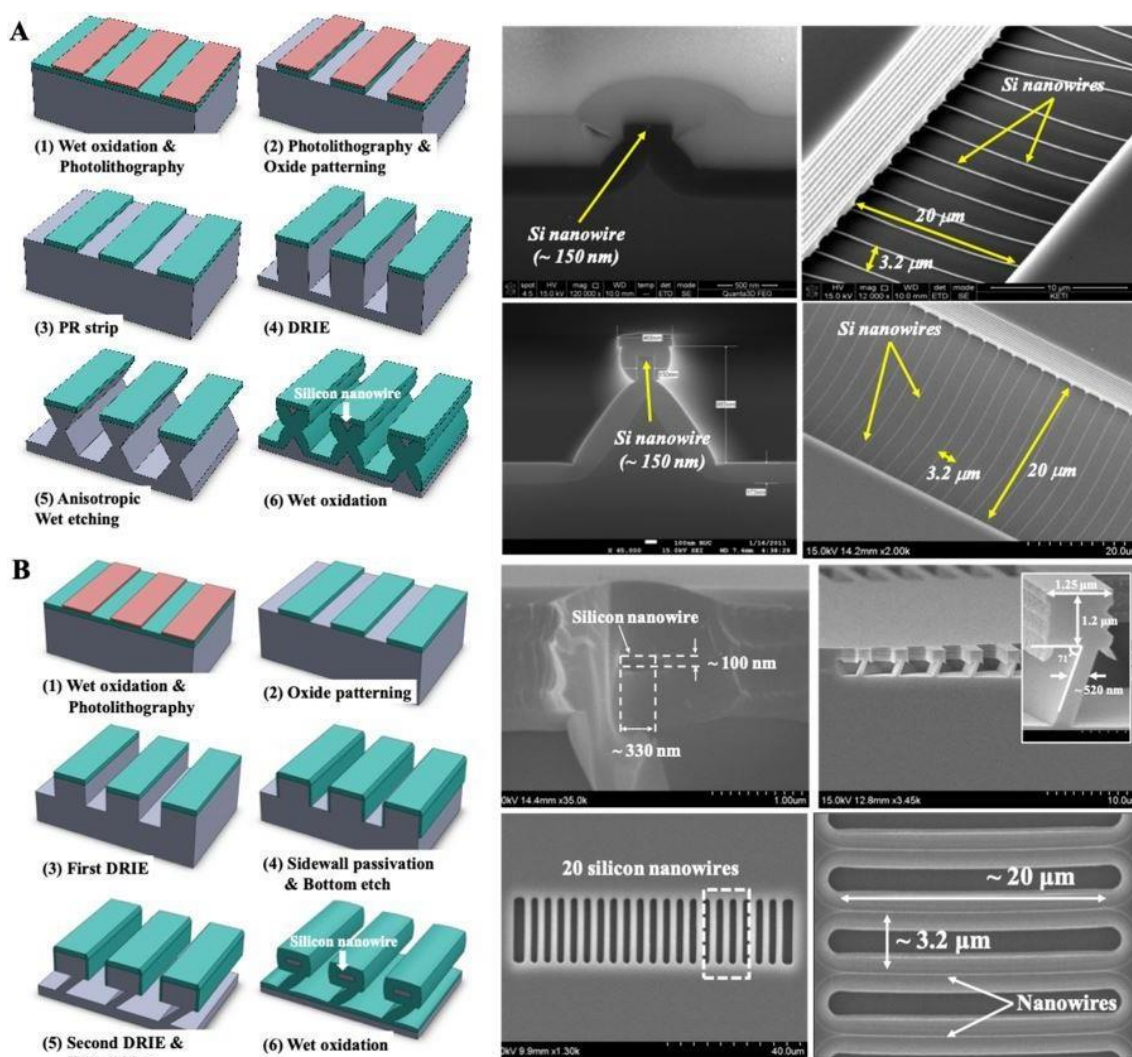
Figure 2: Top-down fabrication process and results using single-crystalline silicon (SCS) wafer. (A)(100)- silicon (adopted with permission from [51,52]). (B) (111)-silicon (adopted with permission from [53]).

Detection by Different Biological

AgentsProteins

Many new biomarkers were identified by the research and may be used for diagnosing diseases technically. Single marker trials do not provide sufficient diagnosis to diagnose complex diseases such as cancer [3]. Many biomarkers in a clinical trial should be identified. Once multiple biomarkers in cancer patients are detected, doctors are going to determine the status of cancer. The first use of silicone nanowires p-type for protein detection was to locate proteins in solution with the nanowires [16]. Since then, multiple nanowires and nanowire arrays have been established to identify several disease markers simultaneously in

one chip.

Many contemporary studies have shown that these markers are both detectable from the entire blood in real time. Various biomarkers like cardiac biomarkers found in blood can now be identified. Most recent research shows that nanostructured sensing platforms are used to track various proteins so that diseases such as diabetes, Parkinson's disease, atherothrombosis, and auto inflammatory diseases can be found. In addition, nanowire on a chip device was designed to identify biomolecules in depth, where nanowires are preconcentred, insulated and filtered for quick and practical clinical use.

Janissen et al. suggested proposals to improve the efficiency of pathogens biomarkers for surface functionality and covalent immobilisation. The surface functionalization of APTES, ethanolamine, was compared with the passivation of PEG in the study via poly (ethylene glycol) (PEG) (Figure 3A). The useof ethanolamine has led to a significant increase in receptor density and coating homogeneity (Figure 3B,C). PEG increased the sensitivity and the reaction of the receptor to the ligand in addition to its binding to the receptor. (3) Additional mobility for antimicrobial immobilisation to a substrate, resultingin better binding; and (4) reduction in Debye sensing time. The functions used to find the IBMP8-1 biomarker have also been adapted. In serum 49 fM and 38 fM are measured in the measurement limit (LOD) and the minimally detectable concentrations (MDC) (Figure 3D). This test tests the linear ranges between 90 and 500 fM. This study employs a number of techniques to produce stable protein biosensors in a multiplexing format using nanowires.
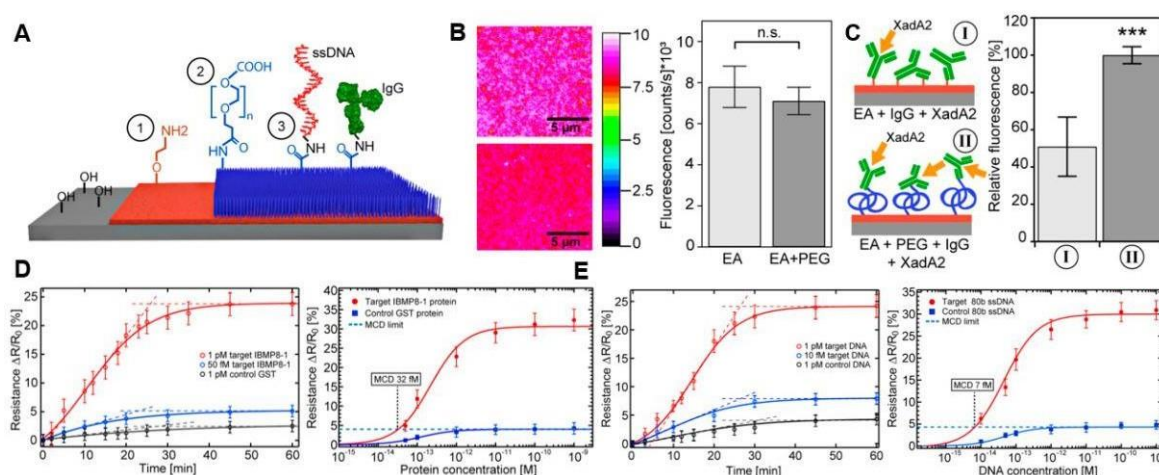

Figure 3: Generalized strategy for ultrasensitive detection of protein and DNA using nanowires (adopted with permission from [62]). (A) Schematic representing the functionalization process to allow high sensitivity. (B) False-colored image of fluorophore antibodies bound to the ethanolamine and PEGylated surfaces. (C) PEGylated surface has higher relative fluorescence.

(D,E) Detection of protein antigen (D) and ssDNA (E) using the developed devices.

DNA and RNA

A single DNA and RNA sequence can be identified by using nanowire sensors [63]. Silicon nanowires consist of PNA single beam sequences serving as DNA receptors [64]. It has been shown that DNA can be detected at the femtoliter stage[65], but not in silicones. In contrast to quartz crystal, surface plasm resonance and nanoparticle improved resonance device it is much more efficient for DNA detection. This is also far more accurate. Janissen et al. approaches can be employed to further improve the efficiency of nanowire sensors. First results showed that the maximal ssDNA detection was approximately 1 femtomolar [62] stage. (Table 3E). Nanowires can also be used to classify nucleic acid-based proteins and protein-protein bonds in addition to the detection of individual strands of DNA

Nanometer devices may be transformed into sensors for the RNA by PNA or DNA to operate. For example, Lu et al. suggested the use of tetramethylammonium hydroxide to manufacturing a Silicon Nanowire Biosensor using anisotropic Wet Etching. Uniformity and decreased production costs have been supported by the self-limitation of machines. A quick detection of the carcinogenic miRNAs (miR- 21 and mirR-205) with the low LOD down to 1 zeptomol has been demonstrated by this low cost biosensor. It was shown that the miRNA aim and single-nucleotide misplaced sequences can be differentiated, and that serum spikes are also detected. Nanowire biosensors have also been modified for use for virus identification in the biotechnology industry. Then Huang et al. and the exonuclease III- assisted target recycling system announced a method of amplifying the observed signal, reaching a detection limit of pm 3.6.

A host of new possibilities for diagnosis and treatment, including the use of nano-wire-based DNA sensors, open up the possibility to screen cancer biomarkers such as telomerase and carcinoembryonic antigen. In addition to Urinary Tract disorders (e.g. Bladder and prostate) but also other kinds of cancers,a variety of cancer-related urinary microRNA candidates were recently reported by Yasui et al (lung, pancreas, and liver). This study provides the basis for the possible work of building a urine-based cancer

treatment clinic[74]. In contrast with the needs of clinical medicine, multiplexing is however still too limited. The ability to distinguish a range of analytes from the same sample at the same time keeps the key of unlocking vital data and making useful diagnoses. When combined with natural language processes, the need for high-performance multiplexing and machine-

based learning diagnostics continues to be even greater.

Virus

One of the crucial activities of nano-fire sensors is the effective detection of smallpox as smallpox is a very fatal disease which can be used as biological weapons. A number of dangerous viruses, including Dengou, influenza A H3N2, H1N1, and HIV, are identified by nanoelectronic systems as well. The surface of the nanowire includes anticuerpos that only adhere to the target viruses. In addition, these anticorps affect the nanowire's electrical conductivity. For example, a Si nanowire-based biosensor has been developed by Shen et al. that can track up to 29 influenza viruses a mL of expired air. The use of nanowires for Ebola detection was recently published by Ibarlucea et al.[82]. After 30 minutes of incubation, the LOD of 6.25 nM was estimated, which was by 6 orders much better than the ELISA result. In real time point-of-care diagnostics for emerging and epidemic diseases, nanoelectronics will play an increasingly important role.

Recent Advances in Nanowire Sensors

This section presents important recent advances in addressing intrinsic problems of traditional nanowire- based biosensors, including the incorporation of in vivo sensing, low-cost hand-held devices, and novel approaches in the processing of measured signals. New, more practical and applicable biomedical instruments have been created with the help of current nanotechnology-based biosensors.

Sense in Vivo

The traditional nanowire solutions are available in the lab. Further research is therefore done in the creation of biosensors which monitor the biological condition of one's life constantly. The group of the Lieber group has shown that nanowire sensors can be inserted in the human body in order to detect bioelectric signals like the neurons in the brain for long periods. It is the in vivo world that faces many challenges in our nanowires. The in vivo microenvironment of ions, onthe one hand, will promote silicone nanowires oxidation [85,86]. Investigators have found earlier that the use of nanowires with cells has been fragile[88]. Zhou et al. showed a multifunctional nanowire coating approach to improve their longevity[89]. In an analysis of the 10 nm Al2O3 shell, it was determined that for at least 100 days in 1 to37 −C in 1 PBS, the nanowire's diameter remained almost the same (Figure 4A). The technique applies to many nanostructures, among which Si–Ge, Si–In and InAs. However, the sensitivity of nanowires

declined as shell thickness increased. The engineer must also balance performance with long-term reliability. Nanowire will nevertheless significantly improve the long-term trust in nanowire as an electronic medium for injection. This will open up further study to the use of nanowires like an electronic injectable platform. In the other hand, cells are capable of detecting the existence of nanowires, contributing to possible questions regarding the toxicity and side effects of nanowires on cell activity. Cells have not yet been thoroughly investigated in their reaction to nanomaterials. The effect of nanowires on cell viability and proliferation is conflicting literature. Instead, scant literature provides evidence for the impact on cell viability, elongation and differentiation of 1D nano-structure. Figure 4B provides an example of a SiC toxicity analysis which also includes SiC's effect on human mesenchymic stem cell and cancer cells. Another example is the toxicity of SiC to humans. Factors that have been analysed: growth, viability, proliferation, migration and differentiation. Silicon carbide nanowires have been shown to be toxic not to the MCF-7 line of human mesenchymal stain cells. The nanowires were shown to significantly reduce stem cell adherence, proliferation and differentiation against osteoblasts and adipocytes. (Photo 4D). Tension from the modified morphical properties that allow cytokines to shift is the cause of the toxicity of the nanowires. Likewise, Alaraby et al. found, but the authors could not clearly associate such adverse effects with cytotoxicity and transmutagenesis, with Ni nanovires which can cause DNA damage, gene alteration, and oxidative stress in the cells. The study indicates that the interactions between cells and nanowires are both highly dynamic and complex. As this subject is poorly known, further studies are needed to determine the potential toxicity of nanowires in humans.
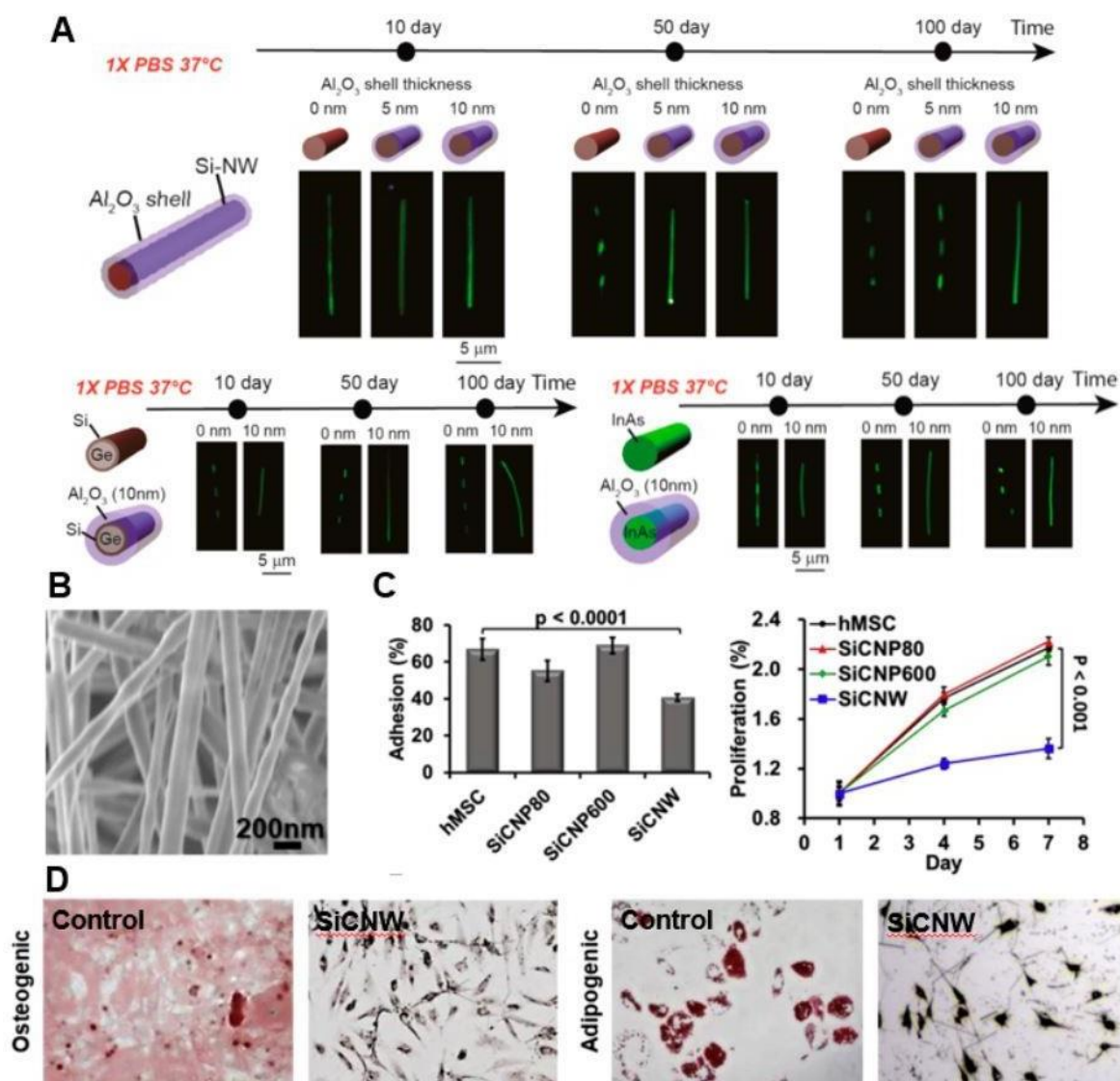
Figure 4: Design nanowires for in vivo sensing. (A) Improving long-term stability by Al2O3 shell coating[89]. (B–D) Cytotoxic effects of SiC nanowires to cell behavior and differentiation (B) SEM pictures of SiC nanowires. (C)Quantification of adhesion and proliferation of hMSCs on nanowires and nanoparticles. (D)Quantification of differentiation potency of hMSCs on SiC nanowires.

Paper-based Device Integration

Its low material and manufacturing costs and biodegradability have the main advantages of PADs. Li et al. conducted a pioneering report on the use of ZnO nanowires in Glucose detection PADs by researchers.They printed the complete PAD with a leading ink, and used the ZnO nanoparticles to produce ZnO

nanowire as seed crystals (Figure 5A). Hydrothermal processing at 70°C created ZnO

nanowires. For large-scale growth, the hydrothermal process can be expanded without losing physical properties or control over the size of ZnO nanowires. Others in many ways will help. In a glucose-measuring procedure, the authors then used the sensor. The sensor data showed that the detection was maximum of 94.7µM and that the linear range was up to 15 mM. (Figure 5C,D). Even if this sensor is not constructed to reach a 0.5 µM LOD, it has huge biosensor ability. While several barriers lie ahead, they can be implemented successfully. Owing to the presence of enzymes, certain proteins are found in living systems. For the use of nanoparticles in drug delivery, the longer term safety of enzymes at room temperature is a key issue. Secondly, the high surface roughness which greatly obstructs the detection mechanism must be addressed to ensure accurate PAD detection at low concentrations (Figure 5B). Recently, nanofibrillated cellulose (NFC) paper has been developed to provide a solution that enhances the surface roughness of ZnO-PADs on a Nanometer scale, theoretically. Finally, a wireless and power- free device is needed to meet the need for remote sensing. A section listed will fulfil the requirement for self-powering technology.
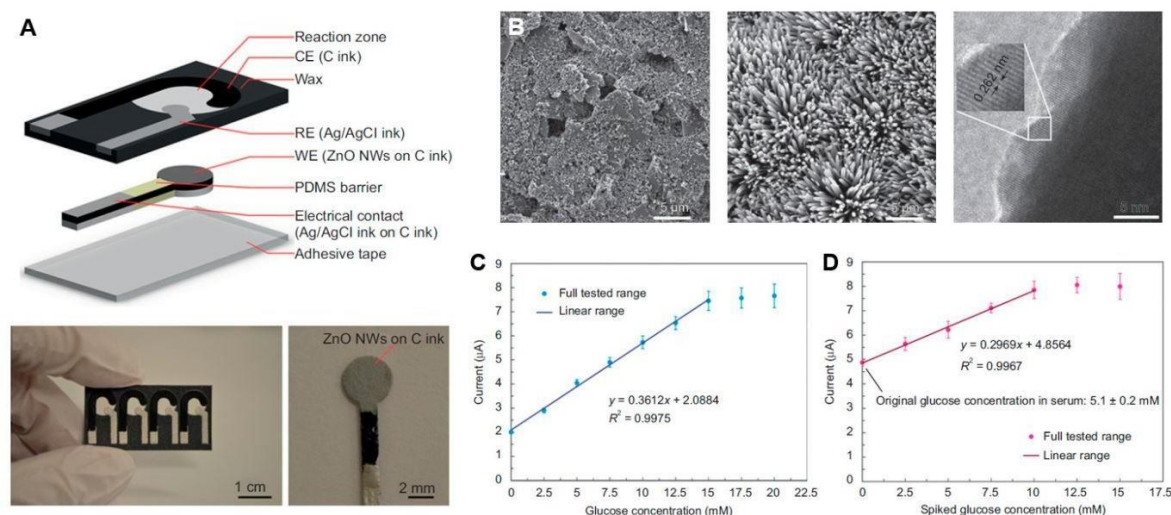

Figure 5: Integrate nanowires with disposable devices (adopted with permission from [97]). (A) Schematic and photograph of paper-based analytical devices (PADs) with ZnO nanowires. (B) Characterization of ZnO nanowires. From left to right: (1) SEM image of rough carbon surface before the growth of nanowire; (2) SEM image of nanostructured carbon surface with deposited ZnO nanowires;(3) TEM image for quantification of nanowires. (C) Calibration of sensor in buffer. (D) Quantification of detected limits and linear range of the PADs in serum.

Self-operated

Two ways of producing energy exist: the use of triboelectric and biofuel nanogenerators.

These propertieshave been widely used in modern industrial or household appliances since the piezoelectric effect of ZnO nanowires was found in 2006[100]. In order to power the nanowire-based pH sensor and the wireless datatransmission mechanism, a 1,26-volt output voltage is achieved while the ZnO nanowire array is serial. Most of the mechanical energy produced by significant bodily activity is, however, derived from the body's muscle and heart tissue. Biofuels are used in vivo as a more frequent energy source. The in vivo powering option has been examined both as oxygen and as oxygen-based approaches. H. Hansen et al. therefore demonstrated that piezoelectric effects and biofuels could be used in vivo to produce a self- powered computer. A nanofiber poly(vinylidenes fluoride), which was then converted into biochemical energy that was then deposited in a flexible enzyme bio-fluoride cell, was used for the extraction of mechanical energy from the heart and lung (i.e. breathing motion of the lung and the heart beating). Combining these techniques leads to improved performance and time usage.

Data Processing and Computer Technology

Diagnosis of disease typically requires multiple markers being examined. The vast majority of the future biosensors are still being proved by devices with spiking tests, where gold is already standard for characterisation. Signal analysis methods must be extended to applications to consider the full advantagesof multivariate and multiplexing schemes. The idea to use signal processing to collect information more efficiently from nanowire sensor arrays came from the fact that gas sensors are based on signal processing. Cho et al, for example, use a nano-fire sensor array of platinum, copper, indium, and nickel for the detection of explosive potential vapours from chemicals. The decision tree was also used for the evaluation of sensor array signal to estimate explosive precursor concentrations and access to explosive probabilities with an accuracy of over 90 per cent and an error rate below 1 per 100. Shehada et al suggestions of using Si nanowires to track breath prints for diagnosing applications [112]. Shehada et al. (Figure 6A). (Figure 6A). They also modified the nanoparticles with one or two steps. The array was distinguished by a mixture of eleven disease markers linked to various cancer types (AC). Research has led to the creation of an artificial neural network (ANN) where the sensing characteristics are classes and the sample classification is the performance. The input data of different sensors and a current diagnosis

conditioned the AI. We also used a deep neural network, along with a range of nanowire biosensors to analyse the breath of patients. It was shown that nearly all binary diseases could

be identified with a precision of at least 80% by the same neural network. However, the latest study does not fully understand machine learning techniques as the sample size is already too limited and results in a poor precision rate (i.e. ~ 60%) for some diseases with minimal samples. Following this study, 1404 subjects evaluated by Nanobiosensor produced a widespread array of clinical data on the Exhaled Molecules. (Show 6B). In thisstudy 13 new chemicals appearing to be linked to certain diseases were found. The promising results of these clinical studies demonstrate a successful transformation of nanobiosensors from proof of principle into operational clinical diagnostics. In addition, more information with recent advances in uncontrolled deep learning can be obtained from the arrayed data.
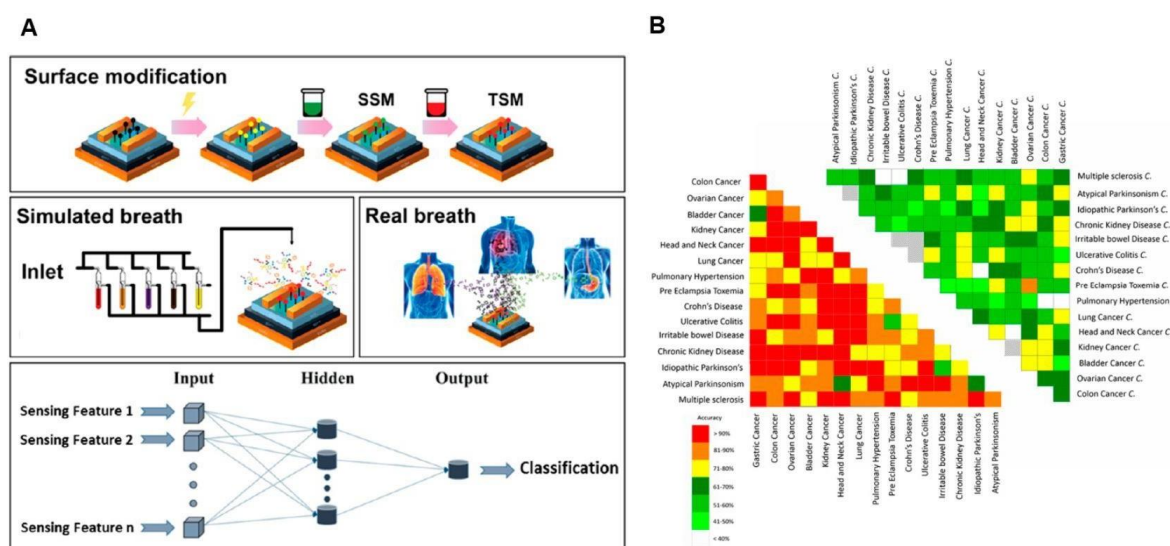

Figure 6: Signal processing strategy for multivariable nanowire biosensors. (A) Disease diagnostics based on machine learning [112]. (B) Big data strategy to correlate exhaled molecules detection by nanowire sensors with specific disease [113].

Summary and Perspective

Features	Application	Reference
Top-down fabrication process using SCS wafer	Photodiode and FET for the retinalprosthetics system	[52,53]
High sensitivityusing PEG cross-linker	Detection of proteinand DNA	[62]

Long-term stability using Al2O3 shell coating	In vivo sensing	[89]
Integrating nanowires with disposable device	Glucose detection	[97]
Multivariable detection using machine learning	Multiple disease diagnosis	[112,113]

Conclusion

Nanowire sensors have shown enormous promise in practical sensing markets with specialised biological receptors. These tools have many advantages, including real-time electrical signal transduction with high sensitivity and label-free detection viability. Further changes will be needed for marketing despite its positive aspects. Although the sensitivity of the CAS is extremely high, it is too low for ambient noise, particularly in vivo environments. Improvements in the receptor binding method could solve this issue and improve the simplicity of the final product In addition; a higher return ratio with the latest top-down manufacturing processes makes commercial goods more competitive. Nonetheless, a nano-wire sensor's performance will depend on its ability to achieve the same efficiency as gold standards like PCR and ELISA. Nanowire-based biosensors in particular can deliver exciting and useful sensor technology.

CONFLICTS OF INTEREST

There are no financial issues or interest of conflicts to declare.

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