Robust Nanowire Electrodes Array Platform for Biosensing Applications

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ABSTRACT

With recent advancements in the field of nano-biosensing there is an increasing need for highly sensitive multi-analyte detection, requiring only ultra-small volumes of reagents within a robust disposable sensing platforms that are mass-producible using available technologies. Various groups reported different techniques and geometries in order to integrate nanowires into biosensing platrforms. Unfortunately, these techniques offer insufficient reproducibility. They are not practical and time-consuming as they include significant complications in the integration of nanowires with the micron-size contacting points on the same chip, which requires multiple fabrication steps and/or gluing agents. Here, we present the development of a robust testing platform using a disposable chip of Au nanowire array which can be easily inserted in custom designed fixture. The platform has already been successfully tested for a number of biomolecules. Here we present the proof ot concept.

Keywords: biosensing platform, gold nanowires, disposable biochip, elecrode array

1 INTRODUCTION

Nanowires are excellent bio-sensing components in terms of increased sensitivity and low reagents consumption. Different techniques and geometries were used in order to incorporate nanowires into biosensing platrforms. Unfortunately, up to date these techniques signify notable complications, predominantly, in multiple steps fabrication of nanowires and micron-size contacting points on the same chip. Recent studies repoported solution to this problem using micron-scaled chips and nanowires from various materials which were deposited and alighned using dielectrophoresis (DEP), [1]-[3]**.** DEP step was followed by various methods for gluing/soldering nanowires to the fabricated micron-sized contacts which is time consuming and lacks reproducibility. Other techniques included electrochemical growth of horizontal nanowires, [4]-[5], multiple dry/wet etch, lithography and oxidation steps, [6]-[11]. Additional methods of nanowire placement on planar substrates included flow assisted methods, [13], application of Langmuir-Blodgett assembly method, [14], contact printing nanowire transfer, [16]-[17], and roll printing, [18], etc. Nanowires applied in these methods were prefabricated using different techniques, such as laser ablation, [12], chemical vapor deposition (CVD), [15], and electrodeposition in porous anodic aluminum oxide (AAO) templates, [5], [19].

These deposition methods and nanowire fabrication techniques demonstrate the complexity of fabrication, that is augmented by the nescessity to introduce the contact for any type of electrical charachterization of said nanowires, [19]-[20]. Therefore, the bottleneck is to create, with good reproducibility, an easy and fast contact of nano-electrodes with the micro-connectors. This challenge is becoming more significant with the increased use of nanowires and micro-connectors. This work presents a simple way of combining macro connector with pre-fabricated nanowire chips, see Figure 1. The design of the connector socket incorporates the alignment fixture, allowing the precision positioning of the disposable nanowire chip, lower image of Figure 1 .

The upper image of Figure 1 illustrates the cut-out portion of the socket which exposes nanowires to the tested medium. Used chip may be easily removed and replaced by new chip in the slit on the top of the alignment pads.

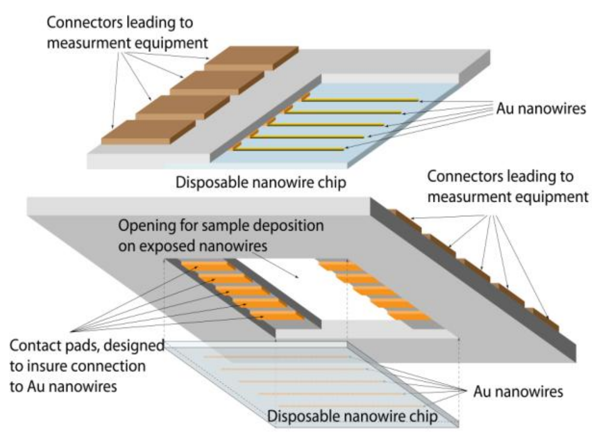


Figure 1: Schematic illustration of the nanowire chip test socket general design; upper image is the top view of the test socket with the disposable nanowire chip positioned for testing, lower image is the view of the alignment features with micron-sized electrodes connected to disposable nanowir chip.

The developed array of nanowiress were tested for sensing performance using a number of biomolecules. In addition, this nanowire array design has the potential of low-volume simultaneous multi-analyte sensing capability. With its high sensitivity and reproducibility, it may lead to a new generation of instant diagnostic and personalized care. Increased sensitivity may be assigned to the fact that nanowire surface exposed to the reagents, is significantly longer (3.5mm of actual exposed wire) then the majority of reported nanowire devices, (predominantly in micrometer range at maximum), [1]-[20]. This unique nanowire-based chip offers ease and rapidity for nanowire connections, without the need for imaging and external aids.

2 EXPERIMENTAL

2.1 Nanowire chip fabrication

Nanowire fabrication was conducted using well developed CMOS fabrication techniques. Starting material for our disposable bio-sensing platform is a single side polished 4' Si(100) wafer, P-type (B), with thermally grown 100 nm thick layer of SiO_2. E-beam lithography was used to transfer pattern forming 1 x 1 cm^2 nanowire chips, (Ebeam Writer VB6 UHR EWF from Vistec Lithography). Two layers of metal, 5 nm Ti as an adhesive layer and 95 nm of Au, were deposited at the room temperature via E-beam evaporation (E-beam Evaporator AXXIS from Kurt J. Lesker). Nanowires. 100 nm wide and 7 mm long, were formed by lift-off technique. Prepared samples were diced with the diamond saw (dicing precision of ± 25 µm) and cleaned. The integrity of nanowires' arrys was evaluated by optical microscopy and confirmed by SEM imaging, Figure 2.

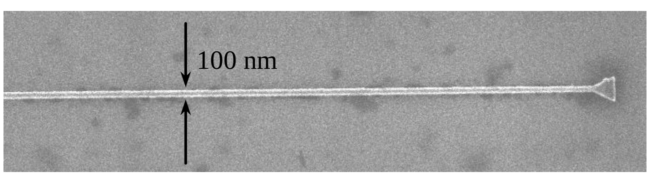


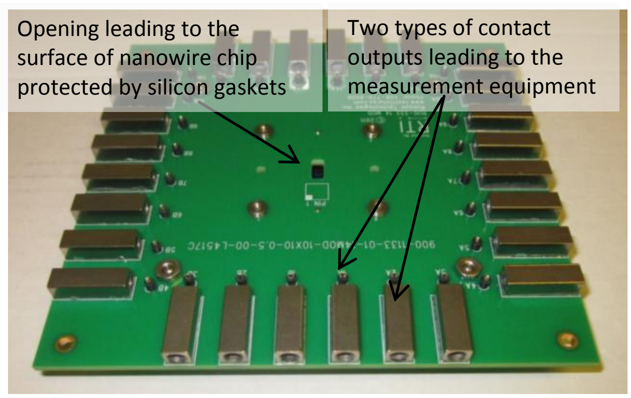
Figure 2: SEM image of the single gold nanowire form the nanowire array fabricated by lift-off technique on 1 x 1 cm^2 Si/SiO_2 chip.

2.2 Nanowire chip test socket fabrication

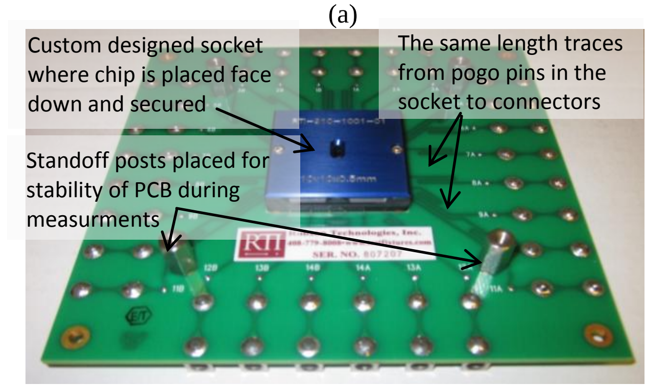
The fixture, as an intermidiate step between the nanowire electrode array and the testing equipment, required great degree of consideration. The challenges, among others, involved the precision alignment feature, to ensure the proper positioning of every nanowire with respect to the micro-sized contact pad; appropirate choice of the micron sized contact pad shape and material; protection of the contact pads from the liquid testing medium; minimization of the test socket contribution to the individual nanowire measuremetns. These challenges were addressed in the final device.

The alignement feature is a cavity in high performance plastic with the alignement precision of ±40µm in both *x*- and *y*-directions. Contact pads are the custom flat tipped Beryllium Copper base with the gold-on-nikel plating pogo pins, dimensioned and positioned in such way that even with the maximum misalignment in either (*x* or *y*) direction, alignment of the pogo pin contact with every nanowire is ensured. Custom laser cut silicon gaskets were introduced as a mean to protect the pogo pins from any liquid test samples which are deposited onto the surface of our nanowire chip placed in the testing socket, see Figure 3. The material used for these gaskets is a super-soft electrically resistant silicon rubber from McMaster-Carr with the durometer hardness tolerance of ±5 and the working temperature range form -60°C to +200°C.

The traces from the pogo pins in the test socket to the connectors are adjusted to be of the sampe length, thereby each pair has identical contribution to the final measuremets, simplifying the calibration process, Figure 3(b). These traces are coated for their protection with the materials used as in typical printed circuit board (PCB) design.



(a)



(b)

Figure 3: Image of PCB with the nanowire chip test socket: (a) view of the top/testing side of the socket, and (b) view of the inverse of the test socket with the area where nanowire bio-chip is placed and secured.

The connectors, two types for flexebility in the measurement techiques, are placed in such way as to ensure the maximum stablity of PCB during measurements (i.e.

banana plugs are positioned on their side), Figure 3(a). For the same reason, four standoff posts are placed on the bottom part of the PCB, Figure 3(b). The PCB with the custom socket was fabricated by Robson Technologies Inc.

2.3 Nanowire chip testing

A number of proof-of-concept tests were conducted in order to ensure proper functioning of the fixture/bio-chip. The test confirmed the actual connection of the pogo pins to nanowire electrodes, see Figure 4.

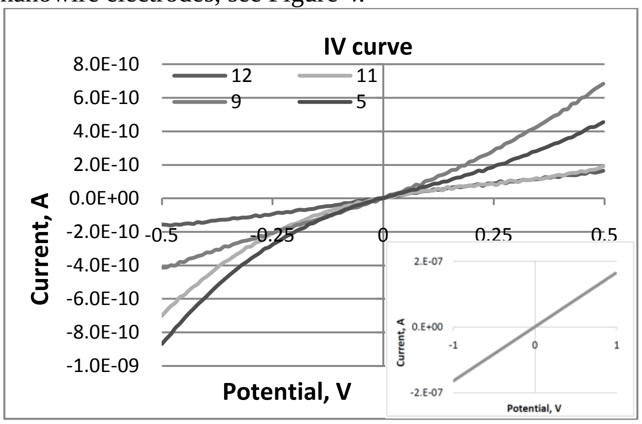


Figure 4: Typical current vs. voltage comparative measurement for four selected nanowires on the same biochip measured using customized PCB. (Numbers indicate different nanowires on the same chip. Insert is the IV measurement in case if optimal alignment of nanowires with macro pogo pin contacts)

Although a slight difference in current values is observed, its value is within 0.6nA from minimum detected current value to the maximum. These slight differences may be assigned to a number of factors, including the variations of the pressure applied by pogo pin to different nanowire, slight deviations of nanowires dimensions, etc. However, the most notable result of this test is the succesful connection achieved between the nanofabricated device and the macro-manufactured test socket. Inlet of Figure 4 is the best *I-V* measurement achived with our structure, thus setting the experimental resistance of individual nanowire to 5 MΩ. The aligment and connection between the nanowire and pogo pin contact may be further optimized with appropriate ajustment to nanowire design.

We have tested the performance of our nanowire arrays by monitoring their response to biomolecule binding. As shown in Figure 3a, the 3.5mm x 8mm opening on the top of the fixture allows easy access to the planar nanowires. 0.01, 0.05 and 0.1% BSA in 20mM phosphate buffer at pH 7.4 were applied onto the sensor array, followed by monitoring of nanowire resistance. Binding (adsorption) of BSA to the nanowire surface caused a significant change in nanowire resistance (Figure 5). Sensor response is clearly dose dependent with a clear saturation plateau at 0.05% BSA.

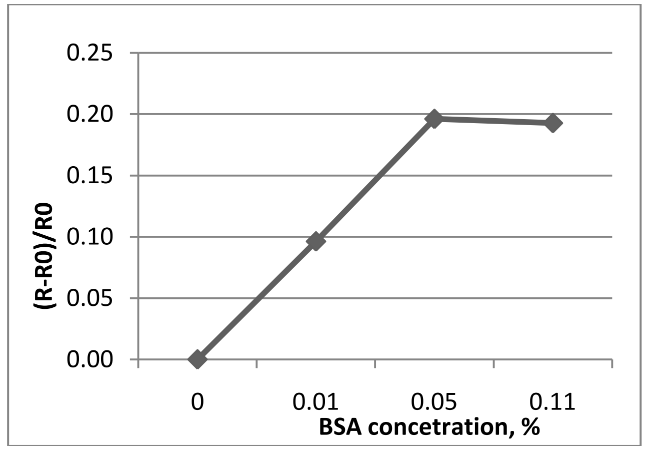


Figure 5: Nanowire chip response calibration in phosphate buffer.

Similar procedures were reported using pure titanium, but scanning force microscopy (SFM) confirmed that BSA adsorption was inhibited at high pH, [22], [23]. Here, our proof-of-concept experiment shows that protein molecules can be efficiently adsorbed onto Au nanowires, which in turn elicit significant sensor response, allowing us to detect binding.

3 SUMMARY AND CONCLUSION

This study demonstrated a facile approach for the connection of nanowires to macro-connectors. We show that protein can be efficiently adsorbed on to the nanowires, elicit significant does-dependent response. We have sucessfully constructed a robust platform suitable for simultaneous multi-analyte detection with high sensitivity and reproducibility using low reagents consumption. Our ongoing work is to adsorb antibodies onto the nanowire surface to detect specific antibody-antigen complex formation. We are also working on the functionalization of the nanowire surface with self-assembling monolayer (SAM). This will provide a more efficient way of biomolecules immobilization, making our nanowire array a more versatile in detecting biomolecular binding events.

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