DEVELOPMENT OF SILICON NANOWIRE LAB-ON-CHIP MICROFLUIDICS INTEGRATED BIOSENSOR FOR LOW CONCENTRATION BIO-MOLECULES DETECTION

By

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LIST OF ABBREVIATIONS

AFM	Atomic force microscope
2-ME	2-methoxyethanol
Ag/AgCl	Silver/silver chloride
APCVD	Atmospheric pressure chemical vapor deposition
APTE	(3-Aminopropyl)triethoxysilane
BioFET	Biomolecular field effect transistor
BOE	Buffer oxides etch
CHIT	Chitosan
CNTs	Carbon nanotubes
CO	Carbon monoxide
CO_2	Carbon dioxide
C-V	Cyclic voltammetry
CVD	Chemical vapor deposition
DC	Direct current
DIW	Deionized water
DNA	Deoxyribonucleic acid
DNAFET	DNA field effect transistor
DPV	Differential pulse voltammetry
dsDNA	Double-strain DNA
EDX	Energy-dispersive X-ray
EtOH	Ethanol
FESEM	Field emission scanning electron microscope
FET	Field effect transistor
FTIR	Fourier transform infrared spectroscopy
IPA	Isopropyl alcohol

ISFET	Ion-sensitive field-effect transistor
ITO	Indium tin oxide
IUPAC	International Union of Pure and Applied Chemistry
LOC	Lab-on-a-chip
LPCVD	Low-pressure chemical vapor deposition
MEA	Monoethanolamine
MEMS	Micro-electro-mechanical system
MeOH	Methanol
MOCVD	Metal-organic chemical vapor deposition
MOSFET	Metal–oxide–semiconductor field-effect transistor
MWNTs	Multi-walled carbon nanotubes
NaOH	Sodium hydroxide
NWs	Nanowires
O_2	Oxygen gas
PBS	Phosphate buffer saline
PDMS	Poly(dimethysiloxane)
PECVD	Plasma-Enhanced chemical vapor deposition
PL	Photoluminescence
PVD	Physical vapor deposition
PMMA	Poly(methyl methacrylate)
RT	Room temperature
Si_3N_4	Silicon nitride
SiI_2	Silicon diiodide
SiO_2	Silicon dioxide
SPR	Surface plasmon resonance
ssDNA	Single-strain DNA

TiO_2	Titanium oxide
UV	Ultraviolet
UV-Vis-NIR	Ultraviolet-visible-near infrared
VLS	Vapor-liquid-solid
V	Vapour
XRD	X-ray diffraction

LIST OF SYMBOLS

Al	Aluminium
Ar	Argon
Au	Aurum
C	Carbon
Cu	Copper
E_g	Energy band gap
ε_∞	Optical dielectric constant
F	Farad
Fe	Iron
h	Channel's height
Hz	Hertz
L	length
Mg	Magnesium
mg	milligrams
mm	milimeter
n	Refractive index
nm	nanometer
O	Oxide
P	Density of solution (g/cm^3)
rpm	Revolution per minute
R	resistance
Zn	Zinc
α	Absorption coefficient
λ	Absorption band edge

Ω	Ohm
°C	Degree Celsius
µm	Micrometer
Si	Silicon

Pembangunan Silikon Nanowayar Makmal-atas-Cip Microfluidics Bersepadu Biosensor untuk Kepekatan Rendah Pengesanan Bio-molekul

ABSTRAK

Makmal-atas cip direka dengan nanowayar satu dimensi menawarkan sifat elektrik yang sangat baik di mana analisis bio molekul pada kepekatan yang sangat rendah menjadi semakin relevan bagi masyarakat perubatan dan penyelidikan. Jumlah baik teknik dan kejayaan awal telah ditubuhkan untuk mengesan kepekatan kecil; Walau bagaimanapun, untuk ukuran tinggi pemprosesan dan pengesanan label bebas masih kawasan penyiasatan segar. Banyak kumpulan penyelidikan telah melaporkan tahap tinggi pengiktirafan bio dengan menggunakan semikonduktor nanowire. The biosensor semikonduktor silikon nanowire menggunakan wayar Nano antara dua bahan menjalankan. Nanowire ini mempunyai atom yang tertumpu di permukaannya. Oleh itu, sebarang perubahan kecil pada caj hadir pada nanowire yang akan menyebabkan perubahan dalam aliran semasa. Dalam tesis ini, kajian simulasi ditambah pula dengan pendekatan eksperimen untuk menerangkan perubahan dalam tingkah laku wayar permukaan sebagai fungsi caj permukaan. Kelakuan linear kekonduksian untuk meningkatkan sensitiviti yang nanowire biosensor semikonduktur ditentukan. Wayar silikon hendaklah antara 5 hingga 20nm untuk membolehkan jarak purata antara atom, oksida harus setipis mungkin untuk integriti permukaan optimum, dan lapisan fungsi harus menjadi kurus dan mempunyai pemalar dielektrik yang tinggi. Kepekatan ion elektrolit hendaklah direndahkan untuk mempunyai panjang pemeriksaan Debye yang besar. Untuk mengesahkan keputusan ini teori, nanowire Silicon 15nm ≈ telah dipalsukan menggunakan fotolitografi konvensional ditambah pula dengan proses punaran kering. Untuk menentukan keupayaan peranti, ia tertakluk kepada pelbagai nilai pH dan untuk mencapainya, peranti itu dikendalikan berdasarkan prinsip Field Kesan Transistor (FET). Permukaan peranti ini adalah lubang dikuasai (p-jenis bahan). Oleh itu, adalah agak mudah untuk tindak balas kepada nilai pH bagi mengukuhkan ia tindak balas kita dirawat lagi permukaan silikon nanowire oleh proses yang dipanggil protonation. Pembawa cas pH adalah disebabkan untuk berinteraksi antara tuduhan nanowire di permukaan luar nanowire dan pembawa mudah alih pada permukaan dalaman nanowire itu. Dengan pendekatan yang sama, permukaan silikon nanowire telah deprotonated dalam pH cecair yang lebih rendah dan pembawa mudah alih habis di permukaan dalaman silikon nanowire. Apabila peranti diuji dengan pH antara 2 hingga 14 dan p-jenis peranti Si nanowire diubahsuai dengan cara ini menunjukkan peningkatan langkah demi langkah dalam kealiran sebagai pH penyelesaian dan bagi mengesahkan peranti ini supaya keupayaan penderiaan, ia telah diubah suai dengan menggunakan (3-aminopropyl) triethoxysilane (APTES) dan tiub nano karbon (CNT) untuk mewujudkan kimia yang mengikat antara sensor dan ssDNA. Silanization tesis ini bertujuan untuk membentuk ikatan di antara muka antara komponen sensor Si-O-Si- dan komponen organik (-OCH2CH3) menggunakan Organofunctionalalkoxysilanes (3-aminopropyl) triethoxysilane (APTES) dan CNT. Penerima ss-DNA berinteraksi dengan platform sensor, menyebabkan peningkatan dalam bidang kerana makhluk semasa diukur diwujudkan di seluruh nanowire silikon dengan caj separa, sensor ini membolehkan pengesanan ss-DNA biomolekul tunggal terkandas. Peranti telah

disahkan menggunakan pencairan siri DNA dan sambutan biosensor yang telah berjaya dipantau menunjukkan tindak balas linear untuk pencairan siri kepekatan DNA. Oleh itu, dengan sambutan elektrik yang sangat baik, ia mempunyai potensi untuk fabrikasi komersial besar-besaran. Oleh itu, ia memudahkan digunakan untuk penyakit diagnostik dalam aplikasi perubatan.

Development of Silicon Nanowire Lab-on-chip Microfluidics Integrated Biosensor for Low Concentration Bio-molecules Detection

ABSTRACT

Lab-on-chip fabricated with one-dimensional nanowires offer excellent electrical properties where bio molecular analysis at very low concentrations is becoming increasingly relevant for medical and research communities. Good number of techniques and promising results has been established for detecting small concentrations; however, for high-throughput measurements and label-free detection are still area of fresh investigation. Many research groups have reported high level of bio recognition by using semiconductor nanowire. The semiconductors silicon nanowire biosensor utilizes a Nano wire between two conducting materials. The nanowire has its atoms concentrated on its surface. Thus, any small changes in the charges present on the nanowire will cause a change in the flow of current. In this thesis, a simulation study coupled with experimental approach to explain the change in wire surface behavior as function of the surface charge. The linear behavior of the conductivity to increase the sensitivity of a semiconducting nanowire biosensor is ascertained. The silicon wire should be between 5 to 20nm to allow mean distance between atoms, the oxide should be as thin as possible for optimum surface integrity, and the functional layer should be thin and have a high dielectric constant. The ionic concentration of the electrolyte should be kept low in order to have a large Debye screening length. To confirm these theoretical results, Silicon nanowire of ≈ 15nm was fabricated using conventional photolithography coupled with dry etching process. To determine the capability of the device, it subjected to various pH values and to achieve this, the device is being operated based on the principle of Field Effect Transistor (FET). The surface of the device is hole dominated (p-type material). Therefore, it is quite convenient to response to the pH values in order to strengthen it response we further treated the surface of silicon nanowire by process called protonation. The pH charge carriers are caused to interact between the charge of nanowire at outer surface of the nanowire and the mobile carriers at inner surface of the nanowire. By the same approach, the surface of silicon nanowire was deprotonated in lower pH liquid and the mobile carriers are depleted at the inner surface of silicon nanowire. When the device is tested with pH between 2 to 14 and p-type Si nanowire devices modified in this way exhibit stepwise increases in conductance as the pH of the solution and in order to validate the device for the sensing capability, it was modified using (3-aminopropyl) triethoxysilane (APTES) and carbon nanotube (CNT) for creating binding chemistry between the sensor and ssDNA. A silanization is conducted to form bonds across the interface between sensor components Si-O-Si- and organic components (-OCH2CH3) using Organo functional alkoxy silanes (3-aminopropyl) triethoxysilane (APTES) and CNT. The receptor ss-DNA interact with the sensor platform, resulting in increase in the current being measured due field created across the silicon nanowire by partial charge, this sensor allows the detection ss-DNA single stranded biomolecule. The device was validated using serial dilution of DNA and the biosensor response was successfully monitored showing a linear response to the serial dilution of DNA concentration. Hence, with its excellent electric response, it has

potential for mass commercial fabrication. Thus, facilitating it use for disease diagnostic in medical application.