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Characterization, Functionalization, and Assembly of
Silicon Based Nanowires and their Applications
in FETs and Sensor Devices
硅納米線表徵，功能化，組裝及其在場效應
晶體管與傳感器中的應用

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CHARACTERIZATION, FUNCTIONALIZATION,
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Abstract

Electronic devices are being in small sizes and of better performance. Yet, challenges come along since further miniaturization of devices require even higher precision technology and the traditional planar fabrication technology will soon reach its limit. One dimensional (1-D) nano-scale materials have brought possibilities for overcoming the difficulties and their potential to be applied in the electronic industry has created excitement all over the world. In this project, p-type and n-type silicon nanowires (SiNWs) were synthesized by electroless template method and thermal evaporation method respectively. To align the disordered nanowires, micro-fluidic system was used to assemble them to fabricate field effect transistors (FETs) based on SiNWs and silicon nanotubes (SiNTs), and gas sensor devices based on palladium (Pd) functionalized SiNWs.

Micro-channels with widths of 500 μ m, 200 μ m and 100 μ m were used in the micro-fluidic system. Micro-channels of smaller widths were observed to lead to better nanowire alignment. More than 90% nanowires and nanoribbons can be aligned to the same direction within $\pm 5\%$ degree when the channel width is down to 100 μ m. With this kind of technique, 2,5,8 11-tetra-(t-butyl)-perylene (TBP) nanowires, 9,10-Diphenyl anthracene (DPA) nanoribbons, SiNWs, SiNTs and zinc oxide (ZnO) nanowires were aligned successfully.

In order to investigate the properties of the SiNWs based FETs, template method was used to synthesis the p-type SiNWs by etching boron doped silicon wafers. The SiNW FETs shows an increase in the conductivity and higher saturation voltage with a more negative gate voltage. The P-type SiNWs have a hole mobility of 8.5 $\text{cm}^2/\text{V}\cdot\text{s}$, and

an on-off ratio about 10^4 in air. The hole mobility increases one order to $76 \text{ cm}^2/\text{V}\cdot\text{s}$ in vacuum, with an on-off ratio larger than 10^4 .

SiNWs decorated by Pd nano-particles were used for hydrogen detection. The SiNWs were fabricated via a thermal evaporation method using Tin (Sn) catalyst. The as-grown SiNWs were chemically treated to remove surface oxide and then coated with a thin layer of Pd nano-particles. A gas sensor was fabricated with the Pd-functionalized SiNWs. The sensor showed better sensitivity to hydrogen and faster responding time than the macroscopic Pd metal wire hydrogen sensor.

Single-crystalline ZnS/Si core-shell nanowires have been synthesized via a two-step thermal evaporation method. The nanowires have uniform diameters of 80-200 nm with lengths range from several to several tens of micrometers. Single crystalline Si nanotubes can be obtained by chemical etching away the ZnS core from ZnS/Si structure. Investigation on FETs fabricated from the Si nanotube suggests that the non-doped Si tube shows weak n-type semiconductor properties, induced by point defects and surface states.

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Table 4.1: Work function of different materials.

List of Symbols and Abbreviations

Ag	silver
AgNO ₃	silver nitride
APTES	3-aminopropyltriethoxysilane
Ar	Argon
Au	gold
BF	bright field
Ca	calcium
CL	cathodoluminescence
Cu	copper
CVD	chemical vapor deposition
DC	direct current
DF	dark field
DPA	9,10-Diphenylanthracene
EDS	energy dispersive spectrometer
EELS	electron Energy Loss Spectroscopy
FET	field effect transistor
FCC	face center cubic
FeCl ₃	iron chloride
GaAs	gallium arsenide
GaN	gallium nitride
GaP	gallium phosphide
Ge	germanium

H ₂	hydrogen
H ₂ O ₂	hydrogen peroxide
H ₂ SO ₄	sulfuric acid
HF	hydrofluoric acid
HRTEM	high resolution Transmission Electron Microscopy
InAs	indium arsenide
InP	indium phosphide
LB	Langmuir-Blodgett
MOS	metal-oxide-semiconductor
MPTMs	3-mercaptopropyltrimethoxysilane
N ₂ O	nitrous oxide
NH ₃	ammonia
Ni	nickel
OAG	oxide-assisted growth
OM	optical microscopy
PCB	printed circuit board
Pd	palladium
PdCl ₂	palladium chlorid
PDMS	polydimethylsiloxane
PNA	peptide nucleic acid
Pt	platinum
Re	reynolds number
SAED	selected area electron diffraction

SEM	scanning electron microscope
Si	silicon
SiC	silicon carbide
SiGe	silicon-germanium
SiNT	silicon nanotube
SiNW	silicon nanowire
SiO	silicon monoxide
Sn	tin
SnO ₂	tin oxide
STM	scanning tunneling microscope
STEM	scanning Transmission Electron Microscopy
TBP	2,5,8,11-tetra-(t-butyl)-perylene
TEM	transmission electron microscopy
UV	ultraviolet
VLS	vapor-liquid-solid
WO ₃	tungsten oxide
XRD	X-ray diffraction
ZnO	zinc oxide
ZnS	zinc sulfide
ZnSe	zinc selenide
Ag	silver
AgNO ₃	silver nitride
APTES	3-aminopropyltriethoxysilane

Ar	argon
Au	gold
BF	bright field
Ca	calcium
CL	cathodoluminescence
Cu	copper
CVD	chemical vapor deposition
DC	direct current
DF	dark field
DPA	9,10-Diphenylanthracene
EELS	electron energy loss spectroscopy
FET	field effect transistor
FCC	face center cubic
FeCl ₃	iron chloride
GaAs	gallium arsenide
GaN	gallium nitride
GaP	gallium phosphide
Ge	germanium
H ₂	hydrogen
H ₂ O ₂	hydrogen peroxide
H ₂ SO ₄	sulfuric acid
HF	hydrofluoric acid
HRTEM	high resolution transmission electron microscopy

InAs	indium arsenide
InP	indium phosphide
MOS	metal-oxide-semiconductor
MPTMs	3-mercaptopropyltrimethoxysilane
N ₂ O	nitrous oxide
NH ₃	ammonia
Ni	nickel
OAG	oxide-assisted growth
OM	optical microscopy
PCB	printed circuit board
Pd	palladium
PdCl ₂	palladium chloride
PDMS	polydimethylsiloxane