Characterization of Si nanowires produced by PE-CVD method

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Abstract

In this poster we describe concept, technology and results of a novel electrochemical biosensor based on Si nanowires (NWs) grown at low temperatures (320 °C) using gold seeds on thin oxide grown on thick gold electrode deposited on Si or Polyimide (PI).

Flexible biosensors based on SiNWs are attractive for example for implantable or wearable devices due to their low cost manufacturing, their ability to bend to accommodate almost any shape and they can be used on almost any material.

The NWs have a tapered shape with diameter at the base of 30-100 nm and a length in the order of few microns. The SiNWs were functionalized using deposition of 3-aminopropyl-trimethoxysilane (APTMS) in ethanol. Much of the interest in APTMS lies in their potential as inexpensive and versatile surface coatings for applications including control of wetting and adhesion, chemical resistance, biocompatibility, molecular recognition for sensor applications and many others.

Here we focus on impedance spectroscopy of samples dipped onto biological solution, e.g. phosphate buffer saline (PBS) that may contain the analyte to be tested. The detection mechanism is based on the chemical interaction between the functionalized NWs and the analyte.

The impedance changes are described taking into account the NW resistance and the NW/electrolyte impedance assuming a combination of lumped and distributed transmission line models. The model takes also into account the interfacial resistance between the Si-NWs and the electrolyte, the double layer capacitance and the ion-transport in the solution.

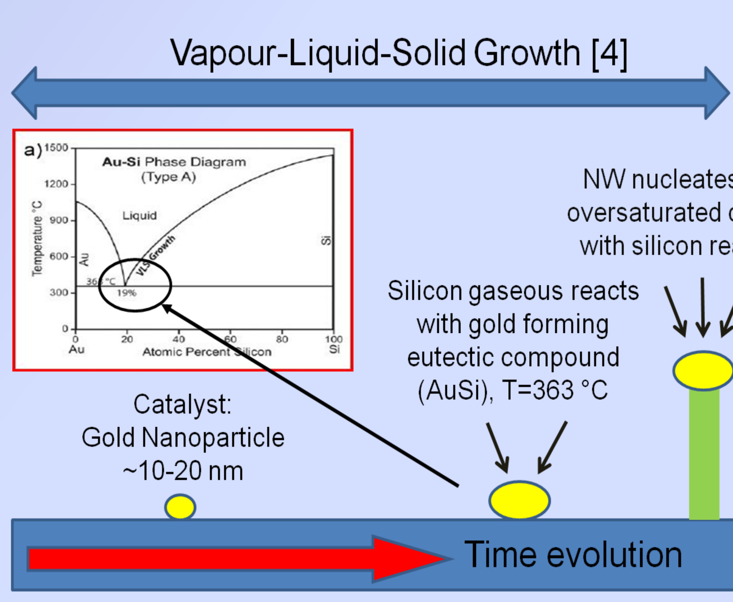
Functionalized Silicon-Nano-Wire (SiNW)

Silicon nanowire growth by Vapour Liquid Solid (VLS) mechanism

VLS mechanism is one of the most widely used technique for the growth of NW, due to its simplicity.

In this mechanism, the metal catalyst forms liquid alloy droplets at the eutectic point by adsorbing vapor components. The alloy is supersaturated, and 1D crystal growth begins, and it continues as long as the vapor components are supplied.

The mechanism works at relatively high temperature (metal catalyst must form a liquid alloy). Therefore, chemical processes that occur at high temperatures, such as chemical vapor deposition (CVD) is generally used in combination with that mechanism.



[4] R. S. Wagner, W. C. Ellis, Applied Physics Letters Volume 4 No. 5 1964

Au-catalyzed SiNWs by Plasma Enhanced Chemical Vapor Deposition (PECVD)

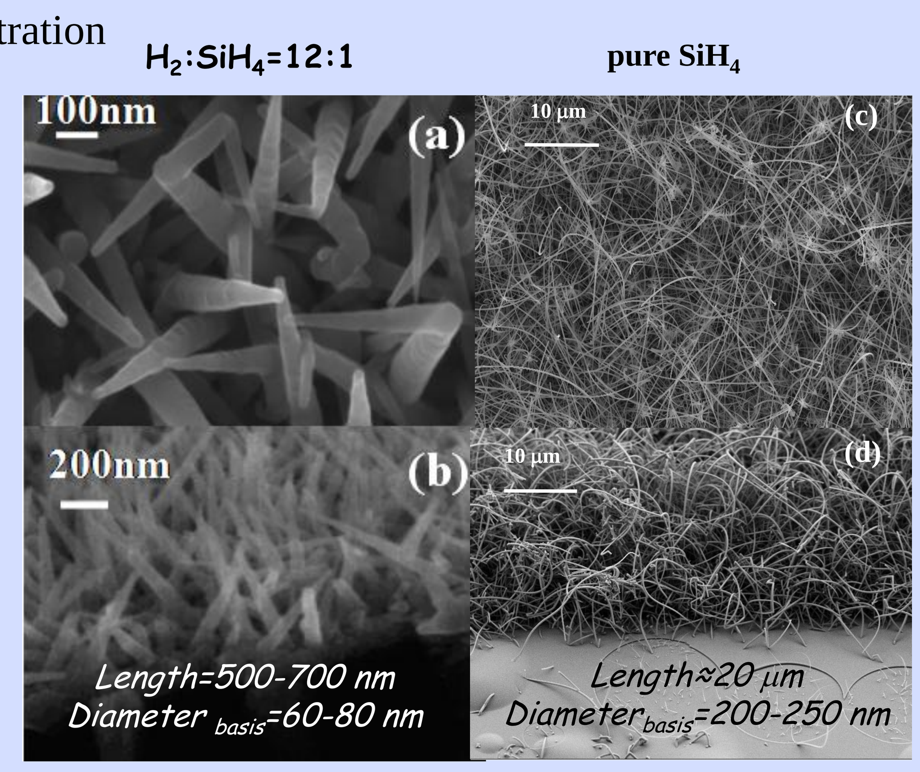
CVD allows epitaxial growth of silicon wires.

In CVD a volatile gaseous silicon precursor such as SiH_4 serves as a silicon source. The precursor react on the surface and cracked into his constituents. Contaminations e.g. gold particles are critical factor to the anisotropic growth of silicon.

The condition for the growth of the SiNWs were:

- T_g=330-400 °C
- SiH_4 diluited in different H_2 concentration
- P=1 Torr
- t=10 min @ P=50 mW/cm^2
- Plasma 13.56 MHz

By changing the SiH_4/H_2 dilution, it is possible to tune the NW size



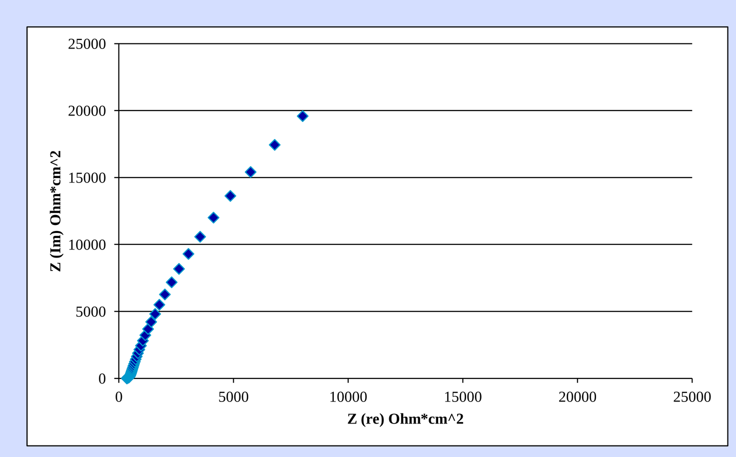
SEM images SiNW (a) and (c) top view (b) and (d) cross section

Results

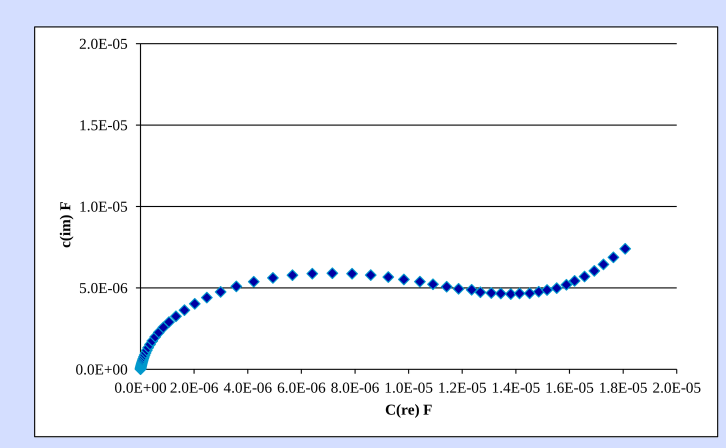
Impedance spectroscopy measurements

The nanowires are immersed in an electrolyte (PBS) as well as the gold electrode. Therefore can assume that the electrochemical impedance of the structure is composed of the impedance of the:

- The gold/electrolyte electrochemical capacitance and
- The nano silicon nanowire capacitance connected in parallel to the gold electrode
- The gold electrode can be simply modeled using the Randle's model



impedance are measured from 0.1 Hz to 1M HZ by a Bio Logic SP-200 potentiostat - Nyquist plot at 0V



complex capacitance extract from impedance measurement

Charge/discharge of SiNWs anode

The electrolyte solution was DMC:FEC 4:1 1M $LiPF_6$

- Electrodes D Si 5+6 the current was given according to the theoretical capacity of Si (4,200 mAh/g) and was aimed for C/5
- Electrodes D Si 7+8 the current was given according to capacity of 2,150 mAh/g (as was seen in similar electrodes) and was also aimed for C/5

Electrode	First Discharge	First charge	Irreversible capacity	2nd cycle (Charge/ Discharge)	3rd cycle (Charge/ Discharge)
D Si 5	2,731	2,327	404	2,301/2,224	2,185/2,238
D Si 6	2,802	2,338	464	2,272/2,361	2,278/2,337
D Si 7	2,721	2,280	441	--	--
D Si 8	2,791	2,347	444	--	--

Conclusions

- **SiNWs were grown by Vapour Liquid Solid (VLS) mechanism**
- **Au-catalyzed SiNWs were grown by PECVD in different concentrations of the silicon precursor**
- **SiNWs were deposited on Si, Au and stainless steel**
- **The measured capacitance was significant higher than the standard electrolyte/insulator/semiconductor structure**
- **SiNWs anode capacity measured to be around 2300 mAh/g after the first cycle, and decreased to be around 2250 mAh/g after the second cycle**

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