Compound Semiconductor Nanowires: An Overview

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Outline

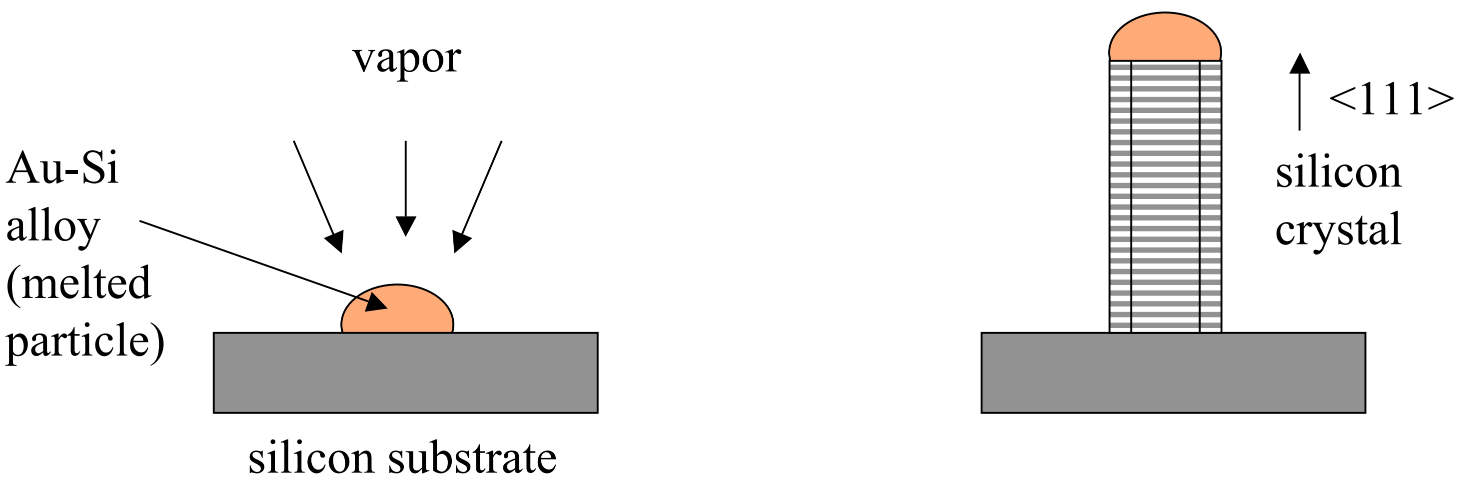
- Introduction
- Fabrication
  - The Vapor-Liquid-Solid growth mechanism
- One-dimensional phenomena
- Devices

Introduction

- Nanowires: solid 1-dimensional structures
  - Longitudinal dimension > 1 μm
  - Lateral dimensions < 100 nm
- Embedded vs. Self-supported

Fabrication

VLS Mechanism



Nanowires by the Vapor Liquid Solid (VLS) method

Laser ablation overcomes thermodynamic equilibrium constraints, and enables liquid nanocluster formation.

a) FESEM image of GaP nanowires. Inset: TEM image of the end of one of these wires.
b) SEM image of Si nanowires, with Au-Si catalyst nanoparticles.

Crystallinity

Si Nanowire

- (100), (111) crystal axis along growth direction
- Thick amorphous oxide (~5nm) cladding a crystalline core.

Crystallinity

GaN Nanowire

- (100) crystal axis along growth direction
- Continuity of the lattice up to the surface (~1nm oxide)

VLS Semiconductor Nanowire Repertoire

GaN
GaAs

InP
InAs

ZnS
ZnSe

CdS
CdSe

Ternary SC

Si
Ge

SiC
TiC

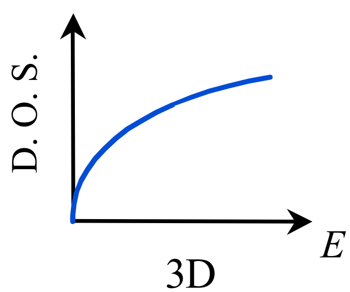
ZnO and other oxides

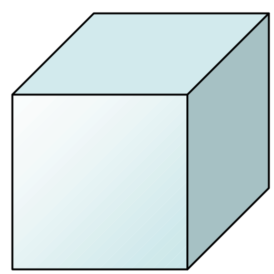
Electronic Structure in a 1D System

Electronic Density of States

3D (bulk):

$$E = \frac{\hbar^2}{2m}\left(k_x^2 + k_y^2 + k_z^2\right)$$



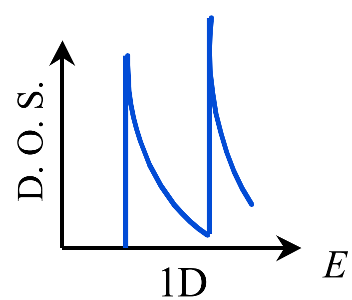


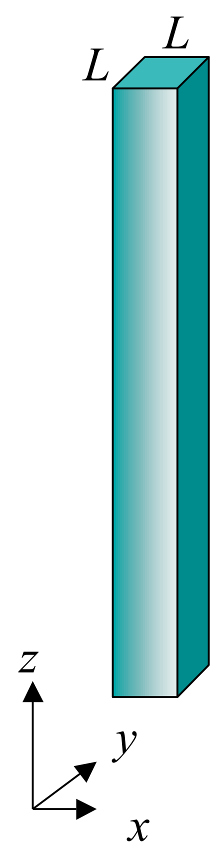
1D (nanowire):

$$E = \frac{\hbar^2}{2m}\left(k_x^2 + k_y^2 + k_z^2\right)$$

$$k_x = p\frac{\pi}{L},\quad p = 1,2,3,\ldots$$

$$k_y = q\frac{\pi}{L},\quad q = 1,2,3,\ldots$$





Quantum Confinement in Si Nanowires

Scanning tunneling microscopy & spectroscopy (STM/STS) studies on small-diameter (1.3-7 nm) Si nanowires.

- Growth along (110) and (112) directions.

- The bandgap of the SiNW, deduced from STS tunneling conductances, shows wire diameter dependence.

Ma et al., Science 299, 1874 (2003)

Tunable Bandgap in InP Nanowires

diameter	□
exciton energy	↑
PL energy	↑

Luminescence spectrum is controlled by **size** and **geometry**, not by **composition**.

M. S. Gudiksen et al., J. Phys. Chem B 106, 4036 (2002)

Surface Effects

$$\text{Surface} = 2\pi rL$$
$$\text{Volume} = \pi r^2 L$$
$$\downarrow$$
$$\text{Surface/Volume} \propto r^{-1}$$

- A large fraction of the atoms is on the surface.
- The carriers are at most several nanometers away from the surface.

Nanowire Sensor
Surface effects

- Chemical gating of the nanowire.
- Reversible changes in conductance.
- Enhanced sensitivity due to small size of conduction channel.
- Multiplexing : 1 mm^2 can fit 1 million chemically-modified nanowires.

Conclusions

- Nanowires with controlled, uniform diameter can be prepared by the VLS method from a large variety of SCs.
- Devices of various types have been demonstrated, being advantageous mainly for their small sizes.
- One-dimensional systems show interesting physical phenomena (quantum confinement, 1D DOS, surface effects, strain relaxation) that are not present in the bulk. These have not yet been creatively utilized in applied devices.