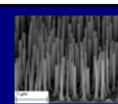
Characterization of heterostructured III-V nanowires grown by molecular beam epitaxy



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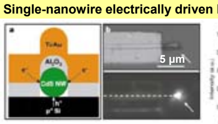
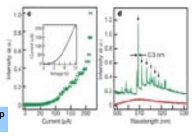
Introduction: Semiconductor nanowires (NWs) have attracted a great attention in various fields of technology due to their size and hence enhanced properties. III-V NWs have proven their potential in fabrication and property improvement of various devices such as nano-sized laser diodes, light emitting diodes, high electron mobility devices, single photon source, solar cells and biological sensors.[1,2,3] Growth of radial and axial heterostructured III-V NWs by molecular beam epitaxy (MBE) using the Au-assisted vapor-liquid-solid mechanism has been reported.[4] However, MBE-grown III-V NWs normally assume a wurtzite (WZ) crystalline structure often suffered by stacking faults compared to that of zinc blende (ZB) crystalline structure in its bulk form.[5] These stacking faults may be a detrimental problem for optical device applications using NWs. In this study, we show a method of controlling the stacking faults in the GaAs NWs.

1. Nanowire based devices:

1. Single-nanowire electrically driven lasers[2]

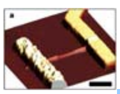


Electrically injected with CdS nanowire on top of a p+ doped Si wafer.



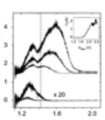
- Very crude design (not heterostructured, no in built p-n junction).
- Very poor performance.

2. Single quantum dot Light emitting diodes[3]



AFM image of LED device. Contacts to NWs made by using electron beam lithography.

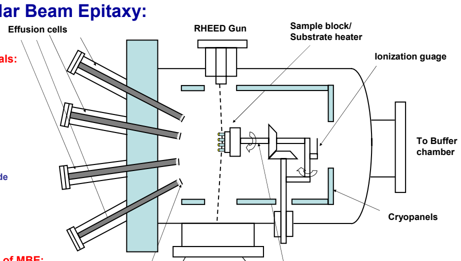
TEM image of an n-InP/i-$InAs_{0.6}P_{0.4}$/p-InP NW. Rotational stacking defects are seen in the InP segments, with a higher density of stacking defects in n-InP.



Electroluminescence spectrum at 10 K from an InP NW LED with a 12 nm InAsP active region.

- High density of stacking faults.
- No radial heterostructures.

2. Molecular Beam Epitaxy:



Source Materials:

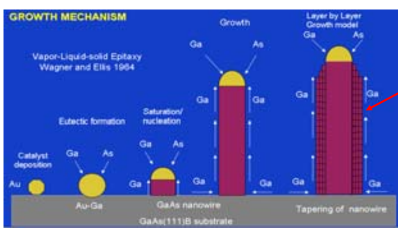
- Gallium
- Indium
- Aluminium
- Arsenic
- Antimony
- Silicon
- Beryllium
- Gallium Telluride

Special features of MBE:

- Ultra high vacuum > ultra high purity.
- Heterostructures with abrupt interfaces.
- Growth rate can be accurately controlled.
- In situ characterization.

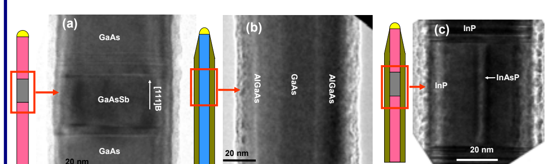
RHEED image captured during the NW growth

3. Nanowire growth mechanism:



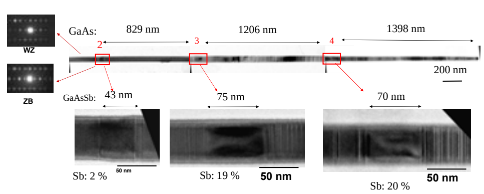
Diffusion length of group III adatoms can be altered by changing the growth conditions and hence possible to grow radial heterostructured NWs.

4. Heterostructured nanowires:



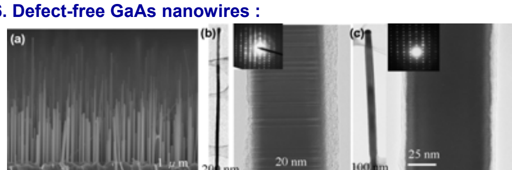
TEM image of (a) GaAs/GaAsSb/GaAs axial heterostructured NW, (b) GaAs/AlGaAs radial heterostructured NW, and (c) InP/InAsP/InP axial heterostructured NW enclosed by InP, with their corresponding schematic diagrams on their left side.

5. GaAs/GaAsSb axial heterostructured nanowires:



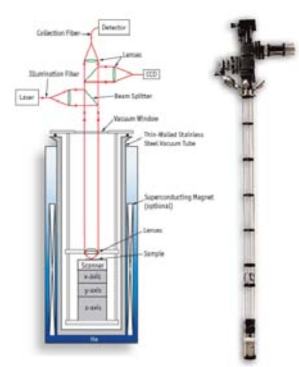
High resolution TEM image of a GaAs NWs with GaAsSb inserts. The growth rate of NW and density of stacking faults is observed to vary along the length of the GaAs NW. We attribute the formation of stacking faults to the faster growth rate of NWs.

6. Defect-free GaAs nanowires :



(a) Cross sectional view SEM image of GaAs NWs showing long and short NWs, (b) Overview image of long NW (b) and short NW (c) with their corresponding high resolution TEM images and SAED patterns in the insets. This indicates that stacking faults can be controlled by decreasing the growth rate of NWs.

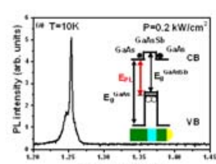
7. . Our new approach : Low temp. (2K) scanning confocal microscope with magnet :



A schematic diagram of the confocal setup in attoCFM I is shown to the left.

Special features :

- Max optical resolution λ/2.
- Spectral range ~600 nm to 1.55 µm.
- Superconducting magnet 11 T.
- Imaging and spectroscopy with positioning down to 10 nm.



Low temperature (10 K) µ-PL emission spectrum from a single GaAs/GaAsSb heterostructured NW at a power density of 0.2 kW/cm². Inset shows the schematic diagram to present the band gap alignment and PL transition in a staggered type II GaAs/GaAsSb heterojunction. Filled and open dots indicate electrons and holes, respectively.

8. Results & Conclusions:

1. We could grow axial and radial heterostructured NWs successfully.
2. We demonstrate the technique to grow defect-free WZ GaAs NWs by MBE.

References:

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