Wurtzite/Zinc-Blende 'K'-shape InAs Nanowires with Embedded Two-Dimensional Wurtzite Plates

Jung-Hyun Kang[1], Marta Galicka[2], Perla Kacman[2], Hadas Shtrikman[1]

1 Dept. of Condensed Matter Physics, Braun Center for Submicron Research, Weizmann Institute of Science, Rehovot, Israel;

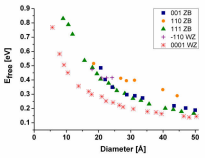
[2] *Institute of Physics, Polish Academy of Sciences, Warsaw, Poland.*

Introduction

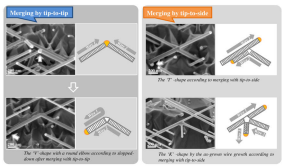
III−V semiconductor nanowires (NWs) have been suggested as a promising platform for the emergence of Majorana Fermions. Due to strong spin−orbit coupling and Zeeman splitting InAs NWs have become key ingredients of hybrid semiconductor/superconductor devices used in the quest of Majorana Fermions. The prediction that Majorana Fermions obey nonabelian exchange statistics can only be tested by interchanging such carriers in "Y'- or 'X'- (or 'K'-) shaped nanowire (NW) networks. We present the results of growth of 'K'-shaped InAs nanowires consisting of two interconnected wurtzite (WZ) wires with an additional zinc-blende (ZB) wire in between and results of modeling the crystal structure which explain the transformation from wurtzite to zinc-blende and the coexistence of both crystallographic phases in such nanowire structures.

Interconnected InAs nanowires

Nanowire growth

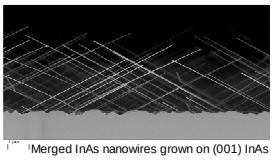


Dependence of the wire free energy on the nanowire diameter. The most energetically favorable InAs NWs are WZ structure along [0001] axis.



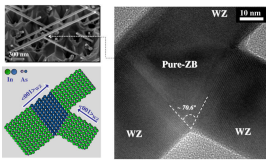
Possible ways of merging of two NWs leading to 'V'-, 'T'- or 'K'- shape InAs NWs.

'T'-shape nanowires



Merged InAs nanowires grown on (001) InAs

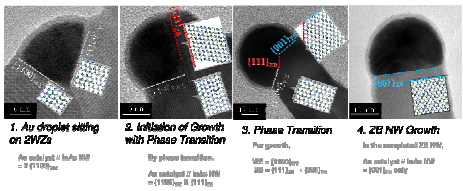
When the droplet of the hitting WZ wire barely touches the surface of another WZ wire growing along a symmetrical direction, the droplet slightly etches the hit wire and slips down along its lateral surface.



The interconnection of two merged WZ NWs has pure ZB structure and trapezoid shape.

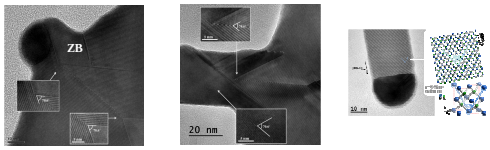
'K'-shape nanowires

Schema and SEM image of 'K' shape nanowire.



Au droplets driving phase transition:
When the droplet of the hitting wire turns to the [001̄] orientation a new ZB wire grows in the [001̄] direction from the intersection.

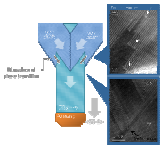
The morphology of the intersection during the formation of the 'K'-shape interconnected InAs NWs – A trapezoid-shaped crystallite with pure ZB structure, similar to these reported in T-shaped wires.

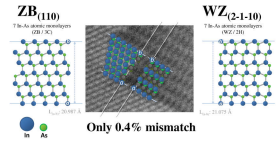


The angle of ~ 70.6° corresponds to the angle of symmetrically crossed two In-lattices of ZB structure heading toward the "−z" direction, which strongly supports the [001̄] growth direction of the ZB NW.

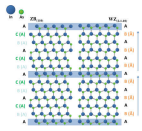
- Symmetrical merging of 2-WZ structures
- The 'V'-shape interface between ZB and merged WZ structures → 70.6°
- ZB structure of the 3rd wire: Phase transition from 2 symmetric WZ structures

Symmetric merging of two WZ structures with 35.3° leads to the growth of wire with the phase transited to ZB, which follows the direction of the two vectors summation.

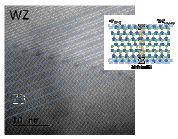




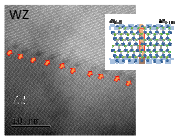
HR-TEM image showing the staircase interface of ZB and WZ structures with a schematic of atomic structure.



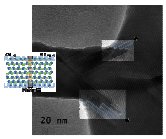
Schematic image of periodically matched In−As atomic layers. Every 7th In-As stacking mono-layers (A) in WZ and ZB structures match each other.



Every 7th In-As stacking mono-layers (A) in WZ and ZB structures match each other.
→ Each 1 interface step consists of 6 In-As mono layers.

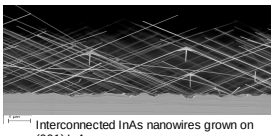


Other unmatched In-As adatoms at the interface make strains due to alignment mismatch.



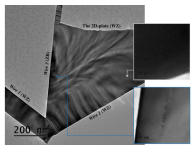
TEM image showing the crystal structures of the ZB wire representing periodically matched In−As monolayers (blue-dotted lines are guides for the eye) between WZ and ZB structures along the crystal structure transition.

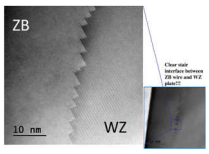
2D InAs plates with WZ structure

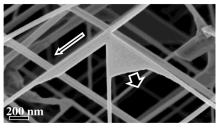


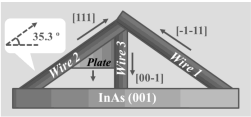
Interconnected InAs nanowires grown on (001) InAs

SEM image of interconnected InAs nanowires with 2D-plates.

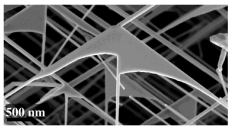






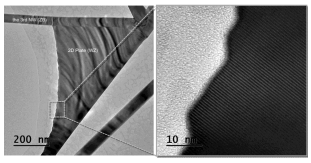


Following the growth of the ZB wire between two merged WZ wires, 2D-plates show up between one of the WZ wires (Wires 1 or 2) and the additional ZB wire, which is perpendicular to the substrate (Wire 3).

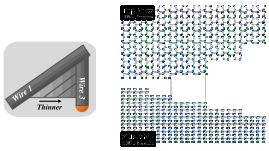


When grown long enough, the plates fill both spaces on the right and left-hand side of Wire 3, which is then observed as a dissector of the angle between the two WZ NWs.

The interface between the 2D-plate and Wire 2 has indubitably pure WZ structure without any interruption → epitaxial growth of the WZ plate from the WZ wire.
The interface between the WZ plate and the [001̄] oriented ZB wire:
the staircase like interface is constructed by In−As adatoms in WZ and ZB structures.



2D-plate surface – staircase like edge. The thickness of the pure WZ crystal structures plate gradually decreases from ~70 nm at Wire 1(2) side to ~10 nm at the Wire 3 side.



Atomic models of the plate crystal structures depict the matching of stair edges with the stair lines of thickness change.

Conclusions

Unique combination of WZ and ZB structures were obtained by MBE growth of inclined InAs NWs on (001) substrate:

- The 'K'-shape NWs are constructed by two merged WZ wires growing in the oblique ⟨111⟩ directions with an additional ZB wire in between, growing along the [001̄] axis.
- Further growth results in the appearance of a WZ 2D-plate between the WZ and ZB wires.
- The plates show a clear boundary with the WZ wires.
- At the interface between ZB wire and the WZ plate a periodic staircase is observed - one stair is constructed of six In−As monolayers with ZB and WZ structures at either side.

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