Breakthrough in the Synthesis of Interconnected NW/NT and NT/NW/NT Heterojunctions with Branched Topology

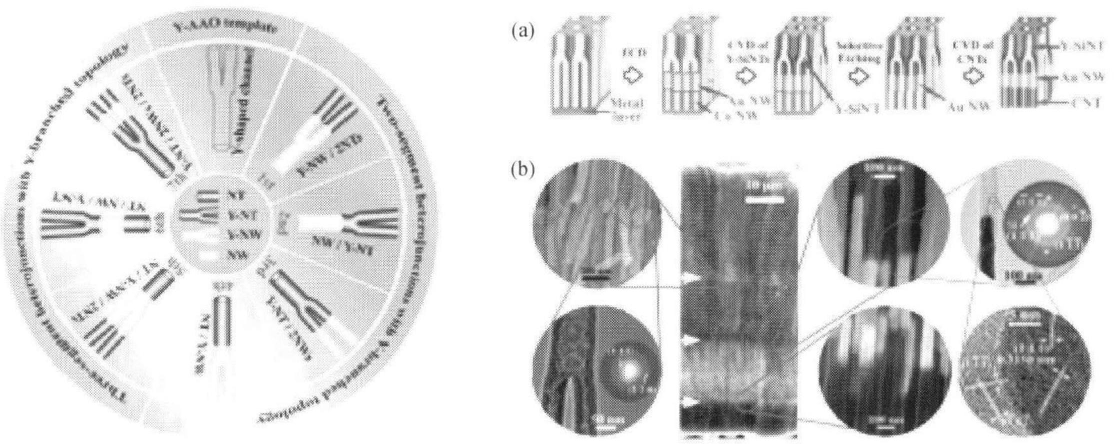

Fig (Left) Schematics of the NT/NW and NT/NW/NT hybrid architectures with Y-branched topology. (Right) One of the heterostructures: Y-SiNT/2AuNWs/2CNTs architecture. (a) The fabrication procedure; (b) structural characterization.

Recent researches on one-dimensional (1D) nanostructures show that segmented hybrid structures of nanotube (NT) and nanowire (NW) could provide novel building blocks for fabricating nanoscale electronics and photonics devices, and have a wide variety of other applications in barcodes, optical readout, biology, catalysis, self-assembly and magnetic manipulation. A wide variety of segmented nanoscale heterojunctions, such as segmented NWs of metal/polymer, semiconductor/semiconductor, metal/semiconductor and metal/metal, hybrid NTs of metal/metal, carbon NT/NW, and tree-like nano-heterojunctions, etc., have been reported. However, all these studies have exhibited limited control over the geometry and complexity of 1D nanoscale heterojunctions that can be ultimately essential for building nanodevices. It has been a very challenging and significant task to develop a generic approach for precisely controlled fabrication of high yield interconnected two-segment nanotube/nanowire (NT/NW) and three-segment nanotube/nanowire/nanotube (NT/NW/NT) hybrid architectures with branched topology.

By using Y-shaped nanochannels of anodic aluminum oxide (Y-AAO) template, breakthrough on NT/NW/NT heterojunctions with branched topology has been achieved in Guowen Meng's group at the Institute of Solid State Physics, Chinese Academy of Sciences.

Two-segment NT/NW heterostructures with Y-branched topology

By simply sequential electrodepositing metal NW (MNW) and chemical vapor depositing (CVD) Carbon NT (CNT) in different portions of Y-shaped nanochannels of anodic aluminum oxide (Y-AAO) template, the following four types of Y-branched two-segment CNT/MNW heterojunctions with different functionalities have been achieved: (i) Y-MNW/2CNTs, i. e. one Y-shaped MNW connects with two CNTs in the branches of the Y-shaped construct; (ii) MNW/Y-CNT, i. e. one MNW connects with a Y-shaped CNT; (iii) Y-CNT/2MNWs, i. e. one Y-shaped CNT connects with two MNWs in the Y-branches; (iv) CNT/Y-MNW, i. e. one CNT connects with a Y-shaped MNW.

Three-segment NT/NW/NT heterostructures with Y-branched topology

Based on the above four types of two-segment CNT/MNW heterojunctions with Y-shaped topology, researchers tried to insert one more segment of NT on the other end of the NWs, to achieve complex three-segment NT/NW/NT hybrid nanostructures with Y-shaped topology. For this purpose, they utilized a combinatorial sequence of electrodeposition of MWs, selectively etching part of the deposited NWs, and CVD growth of CNTs on both ends of the NWs inside the Y-shaped nanochannels. The resultant three types of three-segment CNT/NW/CNT heterojunctions with distinctive functionalities are as the following: (i) CNT/Y-MNW/2CNTs, i. e. one CNT connects with a Y-shaped MNW, and then with two CNTs in the Y branches; (ii) CNT/MNW/Y-CNT, i. e. one CNT connects with a MNW, and then with a Y-shaped CNT in sequence; (iii) Y-CNT/2MNWs/2CNTs, i. e. one Y-shaped CNT connects with two MNWs in the branches, and then with another two CNTs in the branches in sequence.

About the NW segment materials

The NW segment in the above seven types of hybrid nanostructures with Y-shaped topology can consist of not only metals of magnetic (e. g. nickel) and nonmagnetic (e. g. aurum, copper), but also a wide range of other materials that can be achieved via electrodeposition, selectively etched and are stable in the growth of NTs as well. They have already constructed compound semiconductor CdS, magnetic alloys of CoPt and NiCo, as the NW segment in the hybrid structures. Even very stable noble metals (e. g. Au, very difficulty to etch) can also be built as the NW segments in the middle of the NT/NW/NT hybrid architectures via additional electrodepositing a sacrificial segment of metals (e. g. Co, easy to etch) before electrodepositing the desired noble metal Au NW segment in the fabrication process. Additionally, the NW segment itself in the hybrid nanostructures could also consist of two or more sub-segments of NWs consisting of different materials with distinct properties. For example, they have constructed two sub-nanowires consisting of magnetic metal Ni and nonmagnetic metal Ag as a whole NW segment in the hybrid structures of Y-CNT/2AgNWs/2NiNWs /2CNTs.

About the NT segment materials

The NT segments in the hybrid architectures can consist of not only Carbon NTs, but also other materials that could be built into NTs inside the nanochannels of AAO via other techniques. For example, they have successfully replaced CNTs with semiconducting silicon NTs (SiNTs) and insulating SiO_2 NTs in the NT/NW and NT/NW/NT hybrid architectures. Additionally, the NTs on the two ends of the three-segment NT/NW/NT hybrid structures with Y-branched topology not only can consist of the same material of carbon, silicon and silica, but also can be constructed with different materials with distinct properties. They have built a hybrid architecture of Y-SiNT/2AuNWs/2CNTs, with one end consisting of a Y-shaped NT of silicon (Y-SiNT) and the other of two CNTs.

Heterostructures with more complex topology

The Y-branched topology can be extended to multi-generation Y-branches and multi-branches from one stem if AAO template with corresponding shaped channels is used, as an example, they have built a three-segment hybrid nanostructure with three-branches: three-branched-CNT/3NiNWs/3CNTs, i. e. one three-branched-CNT connects with three NiNWs in the branches and then connects with three CNTs in the branches in sequence.

The above breakthrough has been published in Angew. Chem. Int. Ed. 48 (39), 7166—7170 (2009), and has been highlighted in the frontispiece at the beginning of the journal. Additionally, the breakthrough has been featured on Nature China after being published.

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