Multijunction carbon nanotube network

Jyh-Ming Ting and Chi-Chih Chang

Micro- and Nano-Materials Laboratory, Department of Materials Science and Engineering, National Cheng Kung University, Tainan, Taiwan

(Received 6 September 2001; accepted for publication 30 October 2001)

Branching structure in carbon nanotubes (CNT) are of great importance in developing CNT-based mechanical or electrical applications. For this purpose, CNTs exhibiting two-dimensional and three-dimensional junctions are being sought. Among them, only two-dimensional branching structures of Y-junction and T-junction CNT have been synthesized. In this letter, we have grown CNT branching webs having two-dimensional H-junction and multiple Y-junctions, and three-dimensional multiple junctions using a thermal chemical vapor deposition method without the use of a template. The result not only shows the possibility of creating three-dimensional complex CNT structures but also provides the nanotechnology community with new base materials for the development of nanoscale mechanical or electrical devices. © 2002 American Institute of Physics. [DOI: 10.1063/1.1432442]

Due to their excellent properties, the use of CNTs in molecular-scale or nanoscale devices is being extensively explored. This inevitably involves the creation of two-dimensional (2D) and three-dimensional (3D) junctions, which have been considered as the building blocks of nanodevices. For the creation of such junctions, an approach is to place CNTs across patterned metals, which requires sophisticated manipulations.1 Another approach is through the formation of branching nanotube during the growth. The first observation of branching CNTs demonstrates the formation of L-junction, Y-junction, and T-junction CNTs in an arc-discharge method.2 The nanotube diameters are in the order of 10 nm. However, the formation of these different junctions was totally random. A single branching pattern of Y-junction CNTs can be obtained using either hot filament CVD method3 or pyrolysis of nickelocene along with thiophene.4 Theses methods give CNTs with diameters range from 15 to 100 nm. The so-called nanochannel alumina (NCA) method was also been used to grow Y-junction CNTs and the electronic transport in such Y-junction CNTs was determined.5,6 The tube diameters range from 35 to 60 nm. Furthermore, a CVD method was used to grow Y-junction CNTs.7 However, this method requires the use of a template.

All the above junctions are limited to 2D structure or involve at most three-way junctions. For future mechanical or electrical applications, multiple-way junctions or 3D junctions may be required.8 In the letter, we report the growth of H-junction CNTs and three-dimensionally connected CNTs using a simple thermal CVD method without the use of any template. Single crystal silicon wafers were used as the substrate for the growth of CNTs. Substrate was first scratched using a 600-grit sand paper, cleaned ultrasonically, and then placed in a horizontal tube of a thermal CVD furnace. A ceramic boat carrying iron powders as the catalyst source was positioned at a distance of 5 cm away from the substrate upstream. The arrangement allows evaporation-deposition of the iron powders to occur at desired temperatures such that nanosize iron catalysts were seeded on the Si substrate. CNTs were then grown through the pyrolysis of methane on the catalysts at a temperature of 1100 °C. Figure 1 is a micrograph of a typical substrate with CNTs. Webs of CNTs are seen. In addition to previously reported Y-junction CNTs, there are H-junction CNTs and 3D CNT webs. Figure 2 is a montage of two micrographs. The figure shows a H-junction CNTs. The branching CNTs have a uniform diameter of 38 nm. It is seen that the CNT running up and down at the left-hand side bend only slightly at the junction, while the one at the right-hand side bends at an angle near 90 degs. No catalyst was observed throughout the H-junctions when the specimens were examined using transmission electron microscopy (TEM). It is believed that the Nanotube 1 is the nanotube representing the parent stem that grows out of the catalyst. Nanotube 1 then splits into a Y-junction, and one branch (Nanotube 2) of which becomes a stem and further splits into another Y-junction or a nearly T-junction. Furthermore, as seen at the left-lower corner of the left-hand side micrograph. Nanotube 3 of the second Y-junction also becomes a stem and splits into another Y-junction nanotube.

Such a continuous splitting or branching nanotubes is

FIG. 1. CNTs grown on Si substrate. In addition to previously reported Y-junction CNTs, there are also H-junction CNTs and 3D CNT webs.

Present address: NSC Southern Region MEMS Research Center, National Cheng Kung University, Tainan, Taiwan.

© 2002 American Institute of Physics.
not limited to the creation of 2D structures. Figure 3 shows a 3D CNT web consisting of CNTs with a uniform diameter of 47 nm. At the center point A, there are five CNTs connected together. Moving away from point A, branching of Nanotubes α and β to become Y-junction CNTs is seen. One of the branches in the upper Y-junction (α) further becomes another Y-junction. The mechanism of CNT branching is currently unknown. However, it is believed that structural variations must take place at the growing tips which then lead to the branching of CNTs. Such variation to form Y-junction CNTs have been explained from topological point of view and the formation of defects.9,10 It is thought in general that local stresses generated at the tips during the complex growth of CNTs may provide a favorable condition for CNT branching.

Using a simple thermal CVD method, new 2D and 3D branching structures of CNTs with the branching nanotubes exhibiting uniform diameters were obtained. The synthesis of connections between two or more CNTs is a critical step in the development of CNT-based circuits. Basic nanodevice elements including p–n junction in diodes, heterojunction in transistors, and metal-oxide-semiconductor junction all need such connections. The formation of 2D H-junction and multiple Y-junctions, and 3D web of CNTs not only shows the possibility of creating three-dimensional complex CNT structures but also provides the nanotechnology community with new base materials for the development of nanoscale mechanical or electrical devices, such as various fundamental nanoscale junctions and quantum wires.

This work was supported by the National Science Council in Taiwan under Grand No. NSC 89-2216-E-006-073 and NSC 90-2218-E-006-050.

FIG. 2. H-junction or multiple Y-junction CNTs. Nanotube 1 is the nanotube representing the parent stem that produces continuous branching CNTs such that Nanotube 2 and Nanotube 3 later also become stems of Y-junction CNTs. All the branching CNTs exhibit a uniform diameter of 38 nm. The branching structure consists of 2 Y-junction CNTs, each of which has different angles of bending.

FIG. 3. 3D CNT web consisting of CNTs with a uniform diameter of 47 nm. Five CNTs connect together at the center point A. Moving away from point A, continuous branching of nanotubes α and β to become Y-junction CNTs is seen.