Development of Carbon Nanotube Yarn without Binder and that In-situ TEM Observation during Voltage Applying

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Previous research has shown that carbon nanotubes (CNTs) have a number of unique and superior properties, including electrical conductivity, thermal conductivity, and mechanical strength. The combination of these properties along with their nanoscale structure has led to the applicability of CNTs in diverse areas. While the scope of previous studies was limited to thin films of CNTs, recent studies have also explored the bundling of CNTs into yarns and their electrical and mechanical properties. CNT yarns are fabricated using a parallel drawing and spinning method. Twisted CNT yarns are produced directly from substrates with vertically aligned CNTs. However, this method results in a lot of impurities, which originate from the binder-like resin used for obtaining thick and long yarn. Therefore, there is a need to develop a CNF yarn fabrication method that does not use binder. Moreover, our study investigates the effect of applying a voltage to the yarn. Theoretically, the conductivity of a CNT yarn can be reduced to that of a single CNT, which enables the yarn to be used as a conducting wire [1]. However, the physical phenomena responsible for current flow in CNT yarns have not yet been investigated. It is crucial to develop an understanding of these phenomena to increase the applicability of CNT yarns, including their use as conducting wires. In this study, CNT yarns with and without current flow were observed and analyzed using transmission electron microscopy (TEM).

For the current flow analysis, CNT yarns were fabricated by a combined drawing and spinning method from a dense, tall, and highly vertically aligned CNT forest grown on a substrate. First, the CNTs were grown using thermal chemical vapor deposition. A section of the grown CNTs near the edge of the substrate was taken and drawn in parallel to the substrate surface while spinning. We determined the proper drawing speed and spinning rate required for successful CNT yarn fabrication (FIG. 1). Then the yarn structure was observed via in situ TEM analysis. Based on TEM observations, it was concluded that the CNT yarn had a diameter of 5 μm and some individual CNTs protruded from the surface of the yarn (FIG. 2). These results suggest that the yarn was not perfectly spun. Moreover, a closer examination of the edges of the yarn revealed spaces between the CNTs.

Current was applied to the fabricated CNT yarn. Low-magnification TEM images were taken during a 5 mA current flow through the CNT yarn containing FeO particles (FIG. 3). The centers of the TEM images show thin, long contrast areas in which black, small catalyst particles are clearly seen. Only particles with diameters
greater than ~250 nm were observed in the TEM images. During current flow, the large particles repeatedly moved left or right on the yarn. In addition, it was observed that both the imperfectly spun CNTs and the larger particles on the CNT yarn rotated around the center axis of the yarn. This confirmed that the CNT yarn rotates during current flow. The rotation was not continuous; after the completion of one cycle, the rotation almost stopped. When a current of 5 mA was applied to the yarn, the rotation became negligible. As a conductive paste fixes both ends of the CNT yarn in place, the sole driving force for the rotational phenomena was the current flow.

When a 5 mA current was applied to the CNT yarn, the CNT yarn could no longer be observed by TEM. TEM analysis showed that the CNT yarn was cut from the holder. The diameter of the cut end of the yarn was smaller than the diameter of the remaining CNT yarn. The cut end was very small, consisting of only a few CNTs (Fig. 5(b)). Furthermore, regions of the cut CNT yarn exhibited some amorphous carbon, indicating that the CNT yarn had sublimed as a result of the resistive heating due to the large current flow.

The above results show current flow through CNT yarns can give rise to various phenomena. It is assumed that these can be related to the method for yarn fabrication and the thermal property of CNTs.

References