Understanding the regrowth mechanism of multi-walled carbon nanotube forests.

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Multi-walled carbon nanotube (MWCNT) sheets and yarns show promise for applications in many areas of advanced materials science [1-4]. Much of the research effort has been focused on the factors which enable the growth of MWCNT forests that can be spun into yarns or pulled into sheets. As reported in previous studies [5-7], the MWCNT forests show spin-capability when they are grown on substrates with a high density of catalyst nanoparticles. It is thus important to form and preserve a high density of suitably-sized Fe nanoparticles in order to grow such spin-capable MWCNT forests. Recently, Iwasaki et al. [8] demonstrated that the diameter and chirality of a CNT forest are preserved when a second single-walled CNT forest is grown on the same substrate in a regrowth process. This allows one to reproduce, by regrowth of the CNTs, the same quality that the initial forest gains from the properties of the active catalyst nanoparticles.

Here we show how MWCNT forests grow on the spin-capable forest substrate in a regrowth process. Fig. 1 shows MWCNT forests grown by sequential pulsed injections of acetylene for 1 min with a 1 min break between two injections. The spin-capable top forest which was grown first on the highly dense Fe nanoparticles was peeled off by the regrowth of the curled bottom forest. This means that the quality of the forest is not preserved by the MWCNT regrowth process. This results from the deactivation of the catalyst nanoparticles on which the top forest (first forest) grows. As shown in Fig 1d, the bottom forest (second forest) grows in only a portion of the holes left on the substrate surface after removing the top forest, indicating that the second forests do not grow in all of the holes that include Fe catalysts. Interestingly, the spin-capable first forest stands upright on the top of the second forest, with entangled together with the neighboring CNT bundles at the bottom of the first forest. This supports the yarn- and sheet-pulling mechanism in which the end-to-end connections result from the top and bottom of the forests, where a fraction of the nanotubes form loops or join end to end [2].

[1] M. Zhang, K. R. Atkinson, and R. H. Baughman, Science **306**, 1358 (2004).
[2] X. Zhang et al., Adv. Mater. **18**, 1505 (2006).
[3] M. Zhang et al., Science **309**, 1215 (2005).
[4] A. E. Aliev AE et al., Science **323**, 1575 (2009).
[5] J.-H. Kim et al., Carbon **48**, 538 (2010).
[6] G. D. Nessim et al., Nano Lett. **8**, 3587 (2008).
[7] P. B. Amama et al., Nano Lett. **9**, 44 (2009).
[8] T. Iwasaki, J. Robertson, and H. Kawarada, Nano Lett. **8**,886 (2008).

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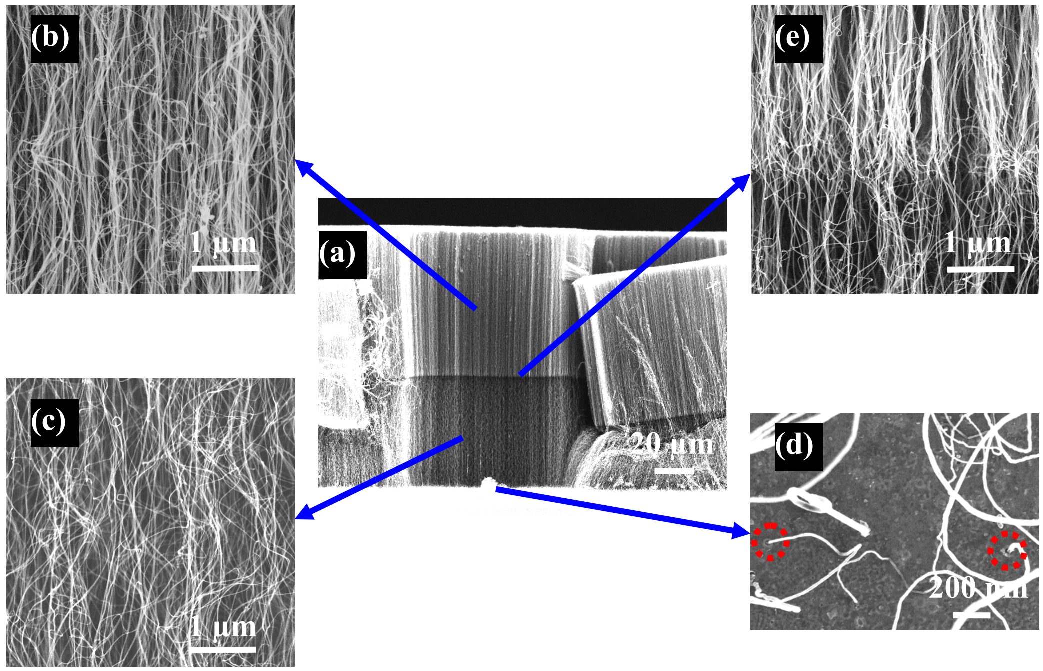

Figure 1: The regrowth process of spin-capable MWCNT forests. : SEM images of (a) double-layered MWCNT forests, (b) the top forest (first forest), (c) the bottom forest (second forest), (d) the surface showing the initial growth of the second forest, (e) the interface between the top forest and the bottom forest.