# Effect of thickness of the catalyst film and the hydrogen gas on the spin-capability of a MWCNT forest

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Multi-walled carbon nanotube (MWCNT) sheets that can be spun directly from a spin-capable MWCNT forest promise novel applications that utilize the unique and outstanding characteristics of the material.[1, 2] The growth of spin-capable MWCNT forests will be achieved through the understanding of the important factors affecting the forest growth, since the precise conditions necessary for effective spin-capability are extremely sensitive. In this paper, we discuss the initial catalyst thickness and the roles of the hydrogen. These factors were investigated in order to assess and understand these critical parameters and thereby develop a repeatable and reliable spin-capable MWCNT growth process.

Figure 1 shows the MWCNT sheet produced by spin-capable MWCNT forest. The spin-capable MWCNT forests were grown from Fe films deposited by electron-beam evaporation on Si substrates having a thermal 400 nm $SiO_2$ layer using chemical vapor deposition (CVD). In order to investigate how the thickness of Fe films affects CNT growth, the thickness of the Fe films was varied in the range of 3-7 nm and was monitored by a quartz-crystal sensor fixed inside the e-beam evaporation chamber. The average height of the CNT forests reduced from 430 to 280 μm as the thickness of the Fe film increased from 3 to 7 nm. More importantly, the areal density and tube diameter of the CNTs highly depend on the thickness of Fe catalyst. We have observed that the CNTs grown on Fe films with range of 4-6 nm are able to produce spin-capable forest.

A further factor in controlling the characteristics of the forest is the use of a reducing agent, $H_2$, during the growth periods. In order to examine the effect of $H_2$ on CNT forest growth, experiments were carried out at the same growth conditions with/without flow of $H_2$ gas. Figure 2 shows that alignment of CNTs grown in He-$H_2$ mixture are better straight than those in He. We also found that height of CNTs grown in He-$H_2$ mixture is higher than that in He and the spin-capable CNT forest can be produced in He-$H_2$ mixture.

[1] M. Zhang, K. R. Atkinson, and R. H. Baughman, Science **306**, 1358 (2004).
[2] J.-H. Kim et al., Carbon **48**, 538 (2010).

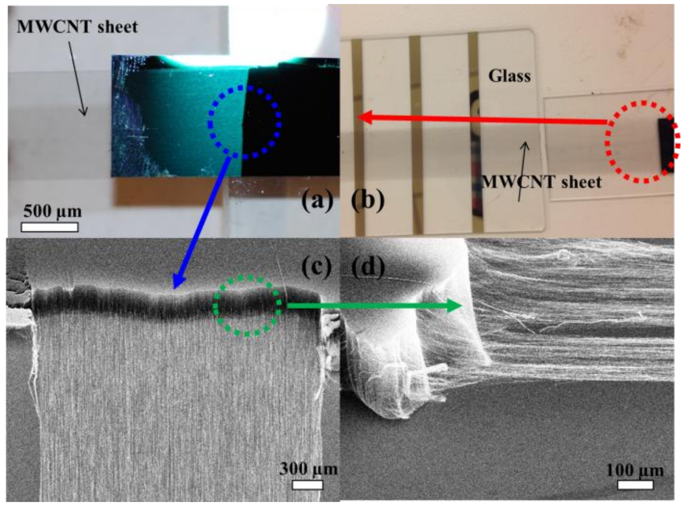


*Figure 1:* The high resolution SEM images and photographs of (a-b) ribbons pulling from Si substrate and (c-d) the MWCNT sheet pulling from the CNTs forest.

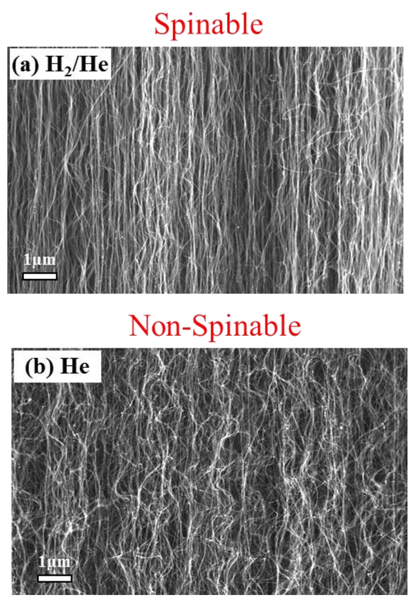


*Figure 2:* As grown CNT forests with/without $H_2$.