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High Efficiency Single Wall Carbon Nanotube Synthesis Using Single- and Multi-layered Porous Substrates

Abstract
Over the past 25 years since the discovery of the single-wall carbon nanotube (SWCNT), the field has taken great strides in the development of SWCNT-based applications. However, the SWCNT cost is one of the primary bottlenecks for establishing a SWCNT-based industry. Therefore, the research and development of SWCNT mass production technologies (high growth efficiency synthetic technology) to achieve low production cost, are essential for realizing the practical use of "SWCNT products". Super-growth (Water-assisted) CVD affords a method of high growth rate, high efficiency synthesis, and high purity of millimeter-tall SWCNTs [1]. For further improvements of the SWCNT growth efficiency have been reported by a number of researchers using various approaches. In this study, we focused on the substrate designs as a new approach for high efficiency SWCNT growth. Specifically, we investigated the use of using porous substrates composed of wire meshes on increasing SWCNT growth rates as well as real growth yield.
Here we show an exceptionally high-efficiency synthesis of long SWCNT forests using porous substrates (metal meshes) in place of nonporous flat substrates. This study examined the dependence of the growth efficiency on various mesh structures, including wire diameter, aperture size, and total surface area. We demonstrated that the synthesis of SWCNT forests is highly dependent on the initial porosity as well as maintaining the open pores throughout the duration of the growth; we achieved the high efficiency synthesis of SWCNT forests (height: >3.47 mm, average growth rate: 301 mm min^{-1}, and yield: 12.7 mg cm^2 in 10 min growth time). Furthermore, we showed that the initial growth rates exceeded 1 millimeter per minute (1,000 mm/min) [2]. Based on these results, we also implemented the high yield SWCNTs using a multi-layer, three-dimensional (3-D) metal mesh porous substrate consisting of eight parallel and evenly spaced mesh substrates. SWCNT yield in this synthesis improved 78-times compared to that of a single flat nonporous substrate. In addition, the total SWCNT yield was greater than eight-fold (mesh layered number). This yield improvement caused from the two reasons. First, mesh substrate provided a higher surface area substrates than that of a flat nonporous substrate. Second, the individual substrate layers acts as heating elements for subsequent catalyst layers proving the uniform delivery of the reacted source gases. CNTs grown possessed identical single-walled structure from the first layer to the final (8th) layer [3]. This architecture led to the achievement of the total carbon conversion efficiency of above 80% with single-walled structure (average: 1.2 number of walls). We believe this represents an interesting alternative approach for highly efficient synthesis and the cost reduction of SWCNTs, resulting in the acceleration of SWCNT application developments in our future life.

References
[1] K. Hata, D. N. Futaba, K. Mizuno, T. Namai, M. Yumura, S. Iijima, Science, 306, 1362 (2004).
[2] N. Matsumoto, A. Oshima, S. Ishizawa, G. Chen, K. Hata, Don N. Futaba, RSC Adv., 8, 7810 (2018).
[3] N. Matsumoto, S. Ishizawa, K. Hata, Don N. Futaba, e-J. Surf. Sci. Nanotech., 16, 279 (2018).