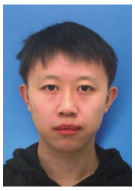
Growth of long, aligned carbon nanotubes using nanodiamond as a growth seed

Department of Applied Physics, Graduate School of Engineering

Ph.D Student Yuanjia Liu

Assistant Professor Taiki Inoue Researchmap https://researchmap.jp/inoue_t?lang=en

Professor Yoshihiro Kobayashi Researchmap https://researchmap.jp/koba_ap_eng_ou?lang=en



Abstract

In this study, we developed a method to synthesize long and aligned carbon nanotubes (CNTs) using nanodiamonds as growth seeds. By patterning nanodiamond particles on a silicon substrate and controlling the growth temperature and precursor gas flow rate in chemical vapor deposition, we found that CNTs could grow along the direction of gas flow. Through the combined analysis of secondary electron yield mapping and atomic force microscopy, we distinguished between impurity metal particles and nanodiamond particles, demonstrating that CNTs were indeed growing from the nanodiamond particles.

Background & Results

Carbon nanotubes (CNTs) are anticipated as versatile nanomaterials for various fields due to their excellent electrical, optical, mechanical, and thermal properties. Especially, long and directionally aligned CNTs are suitable for electronic devices, and methods for efficiently growing such CNTs are in high demand. In chemical vapor deposition, the most common method for growing CNTs, metal nanoparticles are commonly used as catalysts; however, this approach leaves metal impurities around the CNTs. These impurities can negatively impact CNT properties and potentially degrade device performance, making the development of impurity-free CNT growth methods highly desirable. In this study, we explored a method to grow long and aligned CNTs using nanodiamond particles, a nonmetallic material, as the growth seeds to address this issue. Nanodiamonds are stable at high temperatures and can potentially produce low-defect CNTs without residual metal impurities. Experimental results demonstrated successful growth of over 100 μm-long aligned CNTs by precisely controlling the growth temperature and precursor gas flow rate. Additionally, we developed a novel analysis method using secondary electron (SE) yield in electron microscopy to distinguish if metal impurities were involved in CNT growth. This approach confirmed the absence of metal particles at the CNT tips, and combined with atomic force microscopy analysis, indicated that CNT growth was initiated by particles derived from nanodiamonds. Furthermore, structural analysis revealed that the grown CNTs possessed high crystallinity and relatively small diameters. This study is the first to demonstrate the successful long, aligned growth of CNTs using nonmetallic seeds, showing that metal-impurity-free CNT growth is achievable. This method could eliminate the need for metal removal steps, potentially leading to the future development of high-performance CNT-based electronic devices.

Significance of the research and Future perspective

To apply carbon nanotubes (CNTs) in high-performance electronic devices, it is essential to form long and aligned CNTs on a substrate. While techniques for growing long, aligned CNTs using gas flow in chemical vapor deposition were known, they have relied on metal particles as growth seeds. These metal particles posed a problem by remaining as impurities. The achievement of long, aligned CNTs free from metal impurities, as realized in this study, is expected to lead to applications in next-generation electronic devices.

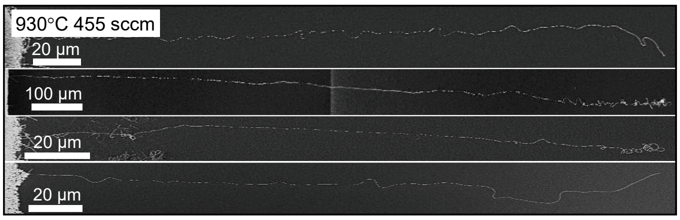


Figure 1 Scanning electron microscopy images of aligned CNTs grown from nanodiamond.

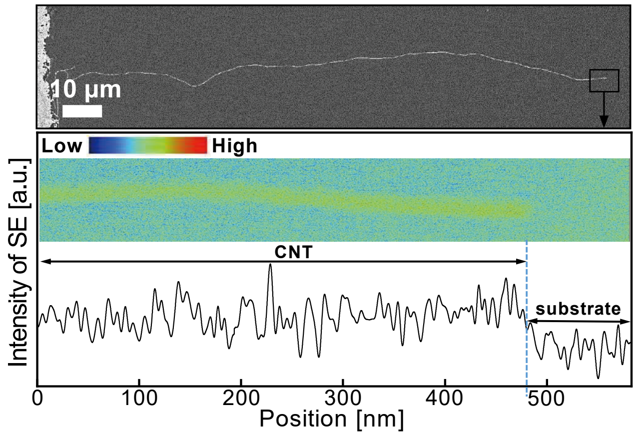


Figure 2 Scanning electron microscopy image and secondary electron yield map of an aligned CNT grown from nanodiamond.

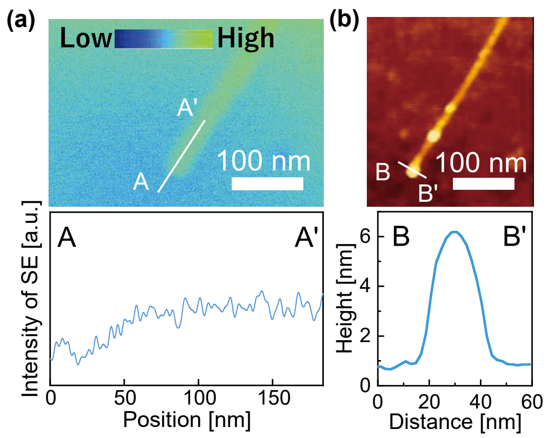


Figure 3 (a) Secondary electron yield map and (b) atomic force microscopy image of an aligned CNT tip.

Patent

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Keyword nanocarbon materials, carbon nanotubes, chemical vapor deposition