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Carbon Nanotube – Substrate Interface Characteristics Studied via TEM

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The unique properties of carbon nanotubes (CNTs), including their high current density, ballistic conductance, and high thermal conductivity, make them extremely attractive materials for electronic applications such as field emitters, sensors and nanoelectronic devices, and for thermal management structures [1]. Knowledge of the CNT/substrate interfacial characteristics is important in order to achieve controllable growth and the desired application-specific properties.

Si and SiC substrate effects on the CNT formation mechanisms have been studied via transmission electron microscopy (TEM) and energy dispersive spectroscopy (EDS). Multi-walled carbon nanotubes (MWCNT) have been synthesized using a thermal chemical vapor deposition (CVD) technique by exposing Si and 6H-SiC substrates to a mixture of xylene (carbon source) and ferrocene (catalyst) vapors at 770 ^{o}C for thirty minutes, as previously reported [2].

TEM studies reveal high density growth of vertically aligned MWCNTs, 100-200 μm in length, on both the Si and 6H-SiC substrates. The growth of CNTs on a Si substrate is a somewhat unexpected result, expanding previous observations for inhibition of such growth under similar growth conditions, due to catalyst deactivation via the formation of stable iron silicide ($FeSi_2$) and iron silicate (Fe_2SiO_4) phases [2]. These encouraging results for uninhibited CNT synthesis suggest that high density CNT growth on Si is achievable using hydrogen-mediated growth conditions. In addition, high-resolution TEM reveals an interfacial amorphous layer, most likely SiO_2 formed after CNT growth, as shown in Figure 1. The surface of the (001) Si substrate is free of iron-containing phases known to hinder the growth of CNTs on Si. In addition, EDS analysis reveals that there are insignificant numbers of Fe catalyst particles observed at the near interface region, suggesting a predominantly tip-based growth mechanism [3].

TEM studies of the CNT/6H-SiC interface reveal high-density growth of multi-walled carbon nanotubes, Figure 2 (a). In contrast to the CNT/Si interface, Fe catalyst nanoparticles form a nearly continuous interfacial layer on the SiC substrate, as found by TEM (Figure 2 (b)), and EDS analysis. This suggests a root-based formation mechanism for the CNT growth on the 6H-SiC substrate [3].

Additional studies with TEM revealed that while MWCNT growth was achieved on both Si and 6H-SiC substrates, different growth templates provided different growth mechanisms for CNT growth at equivalent growth conditions. Further studies are underway to explain in detail the underlying growth mechanisms.

References

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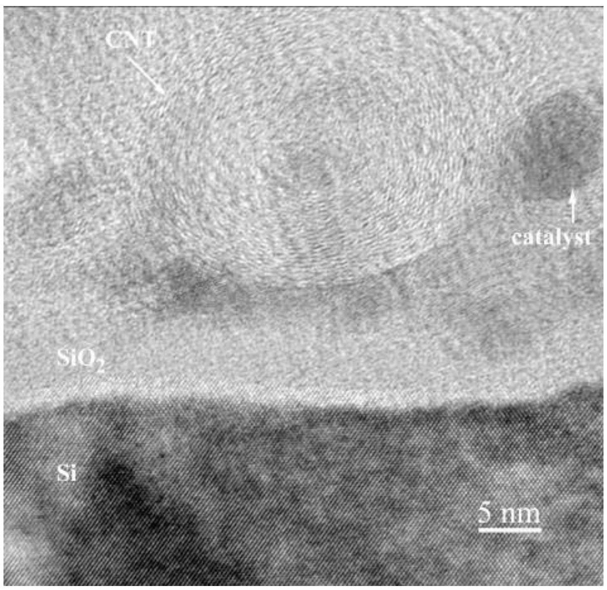
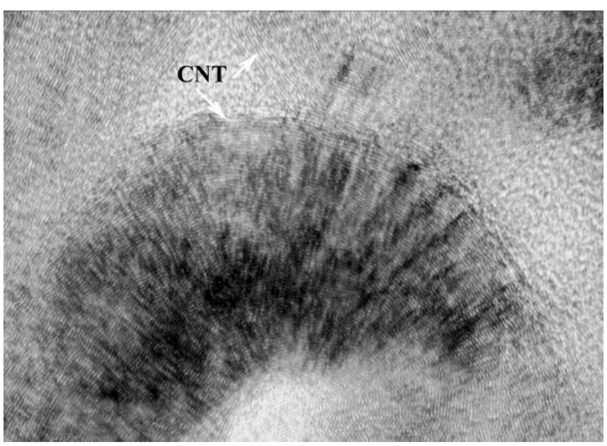


Fig.1 Cross-sectional TEM from the CNT/Si interface, revealing SiO_2 interfacial layer, catalyst particle and HRTEM of a multi-walled carbon nanotube.



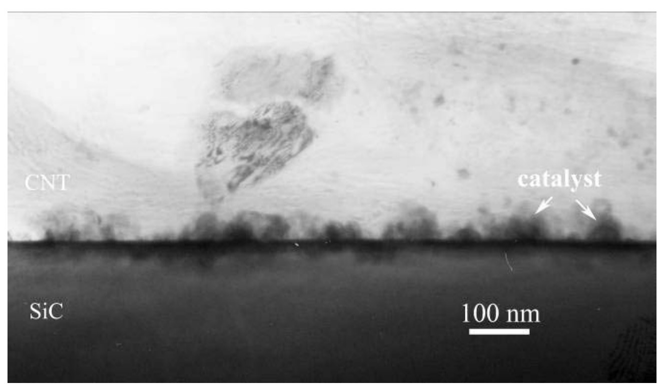


Fig.2 (a) HRTEM of MWCNT composed of ~ 80 graphene sheets and (b) cross-sectional TEM of the CNT/6H-SiC interface. The dark features at the interface are an almost continuous layer of catalyst.

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