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Effects of nanotube size and roof-layer coating on viscoelastic properties of hybrid diamond-like carbon and carbon nanotube composites

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ABSTRACT

Hybrid carbon nanobuffers are developed by exploiting the ultra-hardness and wear-resistant properties of diamond-like carbon (DLC) coatings and the inherent viscoelasticity properties of vertically aligned carbon nanotubes (VACNTs). The viscoelastic properties of carbon nanobuffers incorporating thin-walled and thick-walled CNTs, respectively, are characterized by means of nanoindentation dynamic mechanical analysis tests. It is shown that the thin-walled nanobuffer has a better damping performance than the thick-walled nanobuffer due to its buckling-driven friction and post-buckling behaviors; particularly under large displacements. In addition, it is shown that under large indenter displacements, the VACNT arrays with DLC coatings display the improved stress distributions and enhanced strain energy dissipation performances due to the load transfer on the top of VACNTs. Molecular dynamics (MD) simulations are performed to investigate the roof-layer effect on damping behavior and structural deformation of the coated and uncoated VACNTs under nanoindentation. The results confirm that the VACNT with a DLC coating exhibits the significantly damping characterizations than the non-coated VACNT. Overall, the results presented in this study reveal the potential for tuning the damping performance of CNT-based nanobuffers through a careful control of the CNT size.

1. Introduction

Minimizing the effects of inertial impacts and oscillating forces is a fundamental design problem in all dynamic mechanical systems, including those at the nano-scale [1–3]. In systems characterized by reciprocating motion, effective energy absorbers are essential in improving their efficiency and prolonging their service lives. Recent advances in foam-like materials such as carbon nanotube (CNT)-polymer composites [4–6] and vertically aligned carbon nanotube (VACNT) films [7–9] provide an unprecedented opportunity to efficiently and reliably inject damping characteristics into load-bearing applications. However, while CNT-polymer composites have a promising viscoelastic damping performance, the suffer a number of important disadvantages, including poor dispersibility [10,11], self-agglomeration weakness [12,13] and inevitable sliding interactions [14,15]. Notably, CNT-metallic matrix composites suffer similar disadvantages [16–18]. In contrast to CNT-based composites, pure CNT films transfer impact responses by means of a direct folding/

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buckling of the CNTs and frictional movements among the neighboring CNTs [7,19–21]. However, the viscoelastic properties of such CNT films are limited by the weak interactions among the tubes, which cause the CNT films to split easily under the effects of the impact response [22,23]. Furthermore, the wetting behavior of CNT arrays prompts a transition of the CNT film behavior from a viscoelastic response to an elastic response when exposed to a humid atmosphere and/or a chemically functionalized environment [24–26]. The viscoelastic behavior of CNT films under mechanical compression has been extensively examined in recent years [19–21]. However, relatively few investigations have examined the role played by buckling-driven interactions in mitigating the effects of impact or possible strategies for optimizing the damping performance of CNT films. Thus, the mechanisms responsible for impact resistance and energy absorption in CNT films during compression merit further investigation.

The present study develops a hybrid nanobuffer material, in which the inherent viscoelastic properties of VACNTs are combined with the high-hardness and high-wear resistance properties of diamond-like coatings. The mechanical behavior of the nanobuffer material is investigated by means of a nanoindentation dynamic mechanical analysis (nano-DMA) technique given the use of CNTs with both thin (~3 nm) and thick (~9 nm) wall thicknesses. Molecular dynamics (MD) simulations are then performed to further examine the effects of the diamond-like carbon (DLC) coating on the structural deformation and damping behavior of the hybrid carbon composites.

2. Experimental

2.1. *Fabrication of hybrid carbon nanobuffers*

As shown in Fig. 1(a), in preparing the VACNTs, a tantalum nitride (TaN) coating and a nickel (Ni) catalyst were deposited in turn on a Si (100) substrate using a physical vapor deposition (PVD) system with a sputtering power of 800 W and a chamber pressure of 6.4×10^{-3} Torr. The Ni layer was heated from 350 °C to 800 °C over a period of 5 min in a N_2/H_2 (10/90 sccm) plasma gas; causing it to ball up into nanoclusters in order to serve as catalyst particles for a subsequent growth of VACNTs (note that the presence of the TaN coating diminishes the surface mobility of the Ni catalyst particles;

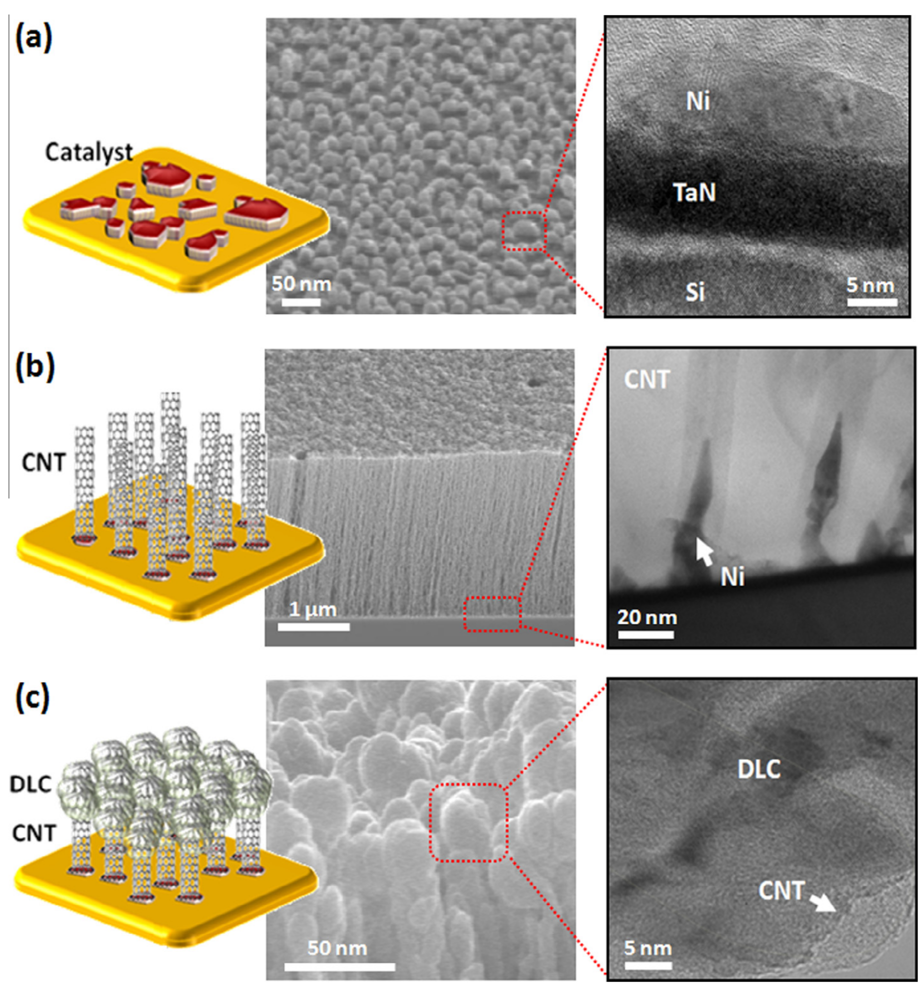

Fig. 1 – The schematic illustrations and their corresponding SEM and HRTEM images acquired at various stages of sample synthesis process: (a) Ni catalyst nucleation on silicon substrate, (b) VACNT growth, and (c) DLC coating on VACNTs. (A color version of this figure can be viewed online.)