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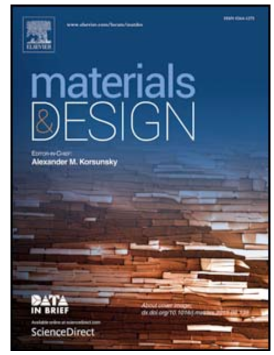

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Damping characteristic of Ni-coated carbon nanotube/copper composite

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Abstract

In this paper, the damping capacity and mechanical strength of Ni-coated carbon nanotube (CNT) reinforced copper-matrix nanocomposites (Ni-coated CNT/CMNc) and single-crystal copper are investigated using molecular dynamics (MD). It is found that the mechanical strength of copper can be significantly improved by the embedded Ni-coated CNT. However, a relatively higher dissipation rate is observed for the Ni-coated CNT/CMNc compared with single-crystal copper. To have a better understanding of the augmented dissipation rate for Ni-coated CNT/CMNc, the effects of oscillation frequency and temperatures on the quality factor (Q factor) are explored. The simulation results show that the Q factor decreases with the increase in angular frequency or temperature for both single-crystal copper and Ni-coated CNT/CMNc. In addition, a weaker frequency and temperature dependence is obtained for the case of Ni-coated CNT/CMNc compared with single-crystal copper. Furthermore, by tracing the source of dissipated energy, we demonstrate that the distorted Cu lattice structure caused by the attraction of Ni is the dominant factor for the high damping rate of Ni-coated CNT/CMNc.

Keywords: Damping, Q factor, Carbon nanotube, Nanocomposite, Molecular dynamics

1 Introduction

The recent advances in nanotechnology have motivated the development of novel nanoscale devices. It is expected that the miniature electronic integrated circuits and nanoelectromechanical systems (NEMS) can be realized using these nanoscale devices [1]. Central to all these possible applications is the mechanical strength and damping capacity of the used nanomaterials. In general, a higher quality factor (Q factor) is critical to improve the nano-scale device reliability and performance as it implies less energy dissipation during each oscillation cycle. Furthermore, for these sensing nano-resonator applications, the detecting resolution is directly related to Q factor.

Over the past decade, carbon nanotubes (CNTs) have received significant interest due to their extraordinary strength, low dissipation rate, and unique electrical properties [2–12]. However, their practical applications in NEMS are hampered by several obstacles such as their manipulation problems (placement, movement, etc.). Incorporating CNTs into matrix materials resulting in the so called 'CNT-reinforced nanocomposites' becomes a much more appropriate way to utilize these unique properties of CNT. Among the CNT-reinforced nanocomposites, CNT-reinforced metal-matrix nanocomposites (CNT/MNc) have several distinct advantages such as inherent stability at elevated temperature and high strength [13–23]. For instance, previous study showed that the yield strength of Al could be enhanced about 27% by CNTs at a low weight fraction of 1.2 wt.% [14]. Deng et al. reported an enhancement of 41.3% in Young's modulus of CNT/Al composites compared to the Al matrix [16]. Chai et al. found that the mechanical strength of CNT/Cu nanocomposites was three times greater than that of pure copper [20]. However, it should be noted that successful studies in this area are very limited and the enhanced mechanical property of reported CNT/metal nanocomposites is still below the theoretical value that can be predicted by Halppin-Tsai model [24, 25]. This phenomenon is mainly caused by inhomogeneous CNT dispersion into matrix and the weak bonding between CNT and metal matrix. Tremendous efforts have been paid to address these drawbacks and, transition metal coating techniques are found to be an effective method in enhancing the interface performance between different materials [26–30]. In particular, nickel-coating technique can significantly improve the interfacial strength between CNT and Cu matrix [31–33]. For instance, for the particular case of CNT-reinforced copper-matrix nanocomposites (CNT/CMNc), the binding energy between CNT and copper matrix is very small without surface treatment due to the poor wettability [34]. After CNT coating with nickel, Lim et al. demonstrated that the interfacial strength between CNTs and copper matrix was significantly improved [34, 35]. In our previous work, we also found that the interfacial performance between CNT and copper matrix could be much improved with nickel-coating [36].

Most of researches on CNT/MNc were focused on obtaining a high strength or hardness. Despite the importance of damping capability, very little attention has been paid to their damping ability and mechanisms. At nanoscale level, the damping

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