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TEMPLATE-FREE FABRICATION OF CARBON NANOTUBE-POLYMER ULTRA POROUS NANOSTRUCTURES

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Introduction

Low-density assemblies of conductive nanomaterials are usually unstable under successive dynamic loading conditions. In most real-world applications, deformation and failure of the structure not only cause malfunctioning but also nanomaterials can be released from the assembly and contaminate the environment and/or user. To prevent this, many have looked at hybridizing nanomaterials with a polymer matrix to increase the stability of the overall structure. Due to their unique superior properties carbon nanotubes (CNTs) have been used as conductive nano-fillers within different polymer matrixes and porous design approached have been introduced to achieve a range of low-density materials. Typically, CNTs are first dispersed in a solution using ultrasonication or emulsification using surfactants to increase the CNT loading and prevent agglomeration of CNTs within the polymer matrix and then foaming is done by template-based[1] or freeze-drying methods[2]. These approaches require multiple complex steps, the overall CNT fraction tends to be low and predicting the conductive percolation threshold in 3D random network is more complicated[3]. In our research, we address this problem, for the first time, with an inverse approach of fabrication. We prepare free-standing, stable 3D conductive anisotropic structures by dry spinning of CNT sheets. The CNT structure was coated by pyrolytic carbon (PyC) to produce stable junctions at CNT interconnections resulting in an ultra-porous (porosity ~99.9%) foam structure (density ~ 6.0 mg/cm^3). In a final single step, the hybrids are produced by infiltration of polymer solutions into the CNT structures with subsequent removal of the solvent. The multifunctional properties of our CNT-polymer nano-hybrid foams can be tuned over a wide range easily by changing the polymer solution concentration, providing resulting densities from ~8.8 mg/cm^3 to ~107 mg/cm^3. The dynamic cyclic compression result showed the structural stability and reversibility under high (80 %) compressive strain in over 150 successive compression cycles without hysteresis. Utilizing the advantages of ultralow density, super porosity and anisotropic structural robustness, diverse multifunctionality of the CNT-polymer hybrids is successfully demonstrated in piezoresistive sensing for human motion detection, oil absorption from water, and electromagnetic interference (EMI) shielding applications.

Materials and Methods

Multiwalled carbon nanotubes (CNTs) were grown in a chemical vapor deposition (CVD) method using acetylene precursor, polydimethyl siloxane, PDMS (Sylgard® 182). The morphology was studied using scanning electron microscopy (SEM), cyclic compression behaviour was tested using an Instron machine and the real-time piezoresistive response were measured. Electromagnetic interference shielding effectiveness (EMI SE) of the samples was measured in the X-band frequency range (8.2–12.4 GHz) using a Vector Network Analyzer. The selective organic liquid and oil absorption from water surface and the one-spot oil clean-up ability of the samples were tested.

Results and Discussion

SEM images revealed the homogeneity of the ultra-thin PDMS PDMS coating all around the CNTs which secure the CNT-CNT junctions. The real-time piezoresistive response under dynamic loading condition with 40 % and 80 % cyclic compressive strains were recorded, and results showed the resistance decreases with increasing compression in both the longitudinal and transverse CNT alignment directions. The best piezoresistive performance was shown by low PDMS containing sample CP-5. Oil and organic liquids are efficiently removed from water surface by CP-5 with reusability. The EMI shielding performance of CP-5 showed, with thickness 1 mm S_{21} is 63.4 dB meaning around 99.999926 % X-band electromagnetic interference of the total power is shielded by the sample.

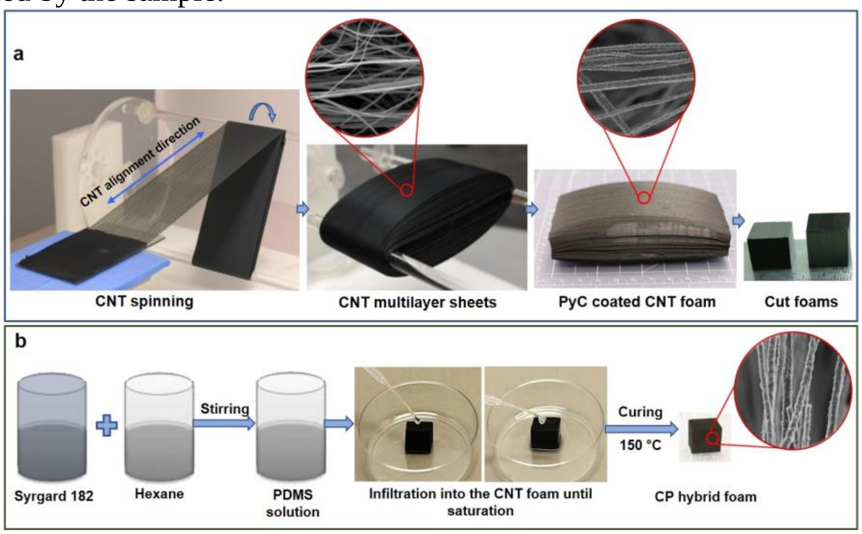

Figure 1. Schematic of (a) CNT/C (C-100) foam fabrication and (b) CNT/C-PDMS (CP) hybrid foam preparation process

Conclusions

The template-free technique can be easily adopted and extend to different CNT-polymer systems and this anisotropic design approach of CP hybrid foams showed multifunctionals potential use in several diverse application fields with superior performance. These results showed the promise and possibilities offered by the anisotropic CNT-polymer hybrids, to harness the multifunctionality of the CNTs to their fullest.

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