Environment-favorable applications for carbon nanotubes

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Carbon nanotubes serve as building blocks for lead-free, conductive polymer composites and oil/water-separation membrane filters.

Polymer-based conductive pastes have been actively investigated as possible replacements for lead-based solders in electronic circuits. However, potential for increasing the electrical conductivity of polymer composites reinforced by metallic fillers is limited because of the generally poor contacts.\(^1,2\) Although metallic fillers generate electrical paths in the polymer matrix, poor contacts prevent the electrical conductivity of metal/polymer composites from reaching the levels usually achieved for bulk metals.\(^2\) Therefore, the efficiency of the electrical network (a key parameter for increasing its conductivity) is largely dependent on network morphology and junction quality.

We have significantly improved the electrical conductivity of silver (Ag)/polymer composites by incorporating multiwalled carbon nanotubes (MWNTs) decorated with self-assembled nano-Ag particles with an average size of 5nm.\(^2\) We functionalized the nano-Ag particles with phenyl rings—see Figure 1(a)—which can lead to homogeneous dispersion and attachment to MWNTs through the \(\pi-\pi\) interaction (‘stacking’) without detrimental effects on the MWNTs’ electrical and mechanical properties.\(^3-6\) We additionally functionalized the nano-Ag particles on MWNTs with glutaric acid (g-Ag-MWNTs) to prevent oxidation.\(^2\) Figure 1(b) shows that MWNTs coated with such particles form an effective electrical network based on micrometer-sized silver powders. We employed the tubes as 1D scaffolds and improved the contact interface by attaching nano-Ag particles. The conductivity achieved for the composite \((2.5 \times 10^5\text{S/cm})\) was even higher than that of bulk tungsten \((1.9 \times 10^5\text{S/cm})\), and we successfully screen printed electrical interconnects: see Figure 1(c).\(^2\) This novel composite might find immediate, practical applications in the fields of interconnects and micropackaging systems in electrical devices.\(^1,2\)

Oil/water-separation technology has drawn much attention because of its potential in wastewater treatment, oil/water

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refining, and oil-spill cleanup. However, conventional technologies such as coagulation flocculation, skimming, centrifugation, and gravity separation have disadvantages, including low separation efficiency, high operation costs, large size, and generation of secondary pollutants. To overcome these problems, we have been working on a new membrane filter that demonstrates both superhydrophobicity and superoleophilicity (i.e., characterized by an extremely strong affinity for oils combined with very strong water repellency) for oil/water separation.

We fabricated such a filter by synthesizing vertically aligned MWNTs on a stainless-steel mesh. The dual-scale structure—nanoscale needle-like tubes on the mesh with microscale pores—combined with the low surface energy of carbon amplified both hydrophobicity and oleophilicity. The contact angles for diesel and water were 0 and 163°, respectively: see Figure 2(a) and (b). The intrusion pressure for water was almost 50 times greater than that for diesel: see Figure 2(c). The nanotube filter could successfully separate oil and water layers, as well as surfactant-stabilized emulsions. The inset in Figure 2(d) shows the test emulsion before and after filtering. The separated phase of red diesel could be clearly observed after the first filtering pass on top of the blue-violet layer where diesel and water are mixed. The permeate solution was re-shaken and immediately passed through the filter multiple times, thus increasing the volumetric fraction of the phase-separated diesel. Pure diesel or lubricating oil could be separated after three to five iterations: see Figure 2(d).

This new membrane filter is a promising candidate for simple oil/water separation because of its high efficiency. The mechanism can be readily expanded to a variety of hydrophobic-oleophilic mixtures. This represents our next development step.

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