Highly aligned carbon nanotube/polymer composites with much improved electrical conductivities

Xuemei Sun, Huisheng Peng

Department of Macromolecular Science and Laboratory of Advanced Materials, Fudan University, Shanghai 200438, China

Introduction

Carbon nanotube (CNT)/polymer composites have been extensively investigated due to their superior combined properties from both CNTs and polymers [1–2]. For example, CNTs impart good mechanical, electrical, and chemical performance into the composites, while polymers make the composite low-cost and easy to fabricate: a combined set of desired properties cannot be found in the individual constituents, thus making these composite materials very useful in many applications [3]. CNT/polymer composites are generally synthesized by a solution process where three key steps are involved: dispersing CNTs in solvents, mixing CNTs with polymers, and casting mixtures into films or powders. One of the main challenges using such an approach is that CNTs are randomly dispersed in resulted composite materials [4]. This leads to much reduced electrical conductivities of composites, e.g. ~10^{-6} S/cm for CNT/poly(methyl methacrylate) composites at room temperature. A possible solution is to directly use CNT arrays in which CNTs are highly aligned. Here we synthesize highly aligned CNT/polymer composites with much improved conductivities by synthesizing high-quality CNT arrays.

Experimental

Commercial polystyrene (Mw = 2.3×10^5 g/mol) and poly(methyl methacrylate) (Mw = 1.5×10^4 g/mol and 1.2×10^5 g/mol, respectively) from Aldrich were used in this work. Polystyrene and poly(methyl methacrylate) were dissolved in tetrahydrofuran with a concentration of 133 mg/mL. CNT/polymer composites were then produced by dropcasting polymer solutions onto CNT arrays, followed by evaporation of solvents.

Results and discussion

The key point for this approach is to grow dense and robust CNT arrays. Most arrays will not maintain the initial alignment on the substrate when coated with solutions [5]. We have grown required CNT arrays by a chemical vapor deposition process. Fig. 1a shows the top view of the array. The top surface is flat, clean and no obvious dirty or undesirable particles are observed. Fig. 1b provides the side view of the array. The CNTs are highly aligned and vertical to the substrate. The density of CNTs in the array is 10^9 cm^{-2}.

Fig. 1c and 1d shows SEM images of aligned CNT/ poly(methyl methacrylate) composites. The top view in Fig. 1c indicates that the surfaces of CNT/polymer composites remain even and flat. This is important for their applications as electrodes which require even surfaces at contacting faces to show good electrical contacts. The side view of the above composites in Fig. 1d further confirms that the arrays maintain the original morphologies with highly aligned CNTs.

One main advantage of this synthesis over other approaches is the highly aligned CNTs, which enable the composite materials with much improved electrical conductivities. We measure the conductivities of these composites by a two-probe method, and the experimental setup is schematically shown in Fig. 2a. Two ends of a composite were first coated with thin layers of Ag, followed by the connections to copper wires. The small contact resistances between the composite and copper wires were neglected during the calculation of conductivities. The conductivities of CNT/poly(methyl methacrylate) composites with

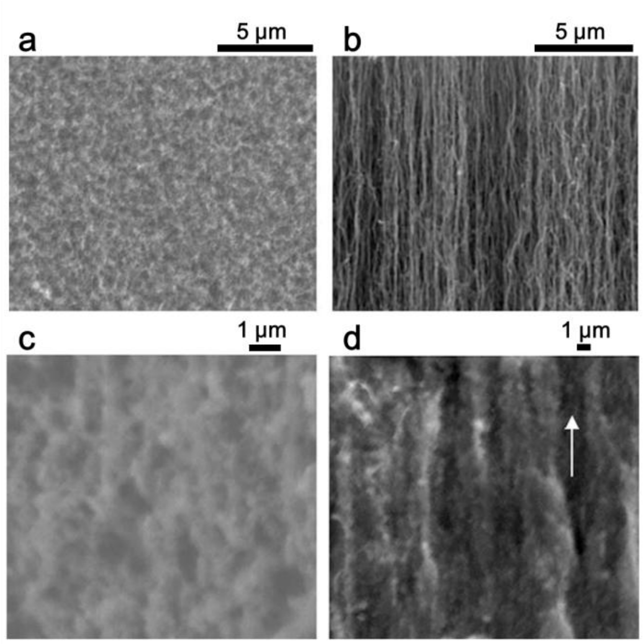

Fig.1 Scanning electron microscopy (SEM) images of CNT arrays, (a) top view and (b) side view, and CNT/poly(methyl methacrylate) composites, (c) top view and (d) side view.

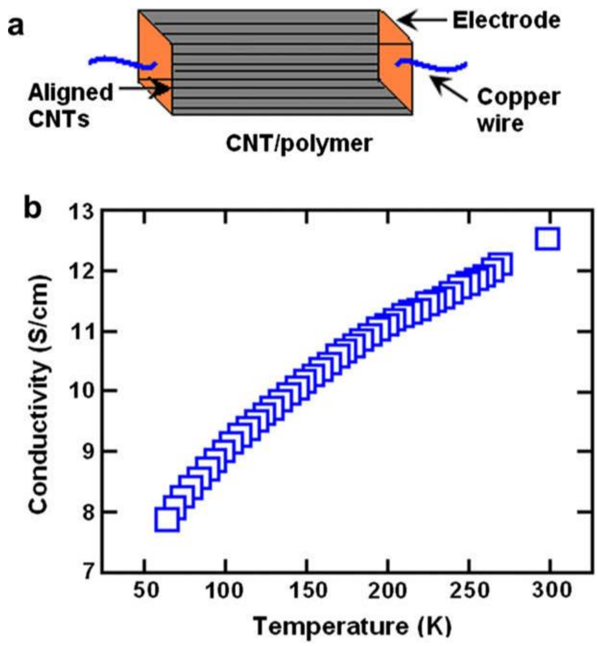

Fig.2 Electrical properties of CNT/poly(methyl methacrylate) (Mw = 1.5×10^{4}g/mol) composites. (a) Schematic illustration of the measurement of the conductivity by a two-probe method. (b) The temperature dependence of the conductivity

weight-average molecular weights of 1.5×10^{4} g/mol and 1.2×10^{5} g/mol were measured as 12.5 S/cm and 10.0 S/cm at room temperature, respectively. The CNT/polystyrene composite shows a conductivity of 13.3 S/cm at room temperature. For the above plastic polymers with close molecular weights, the resulting composites do not show an obvious difference of conductivities. Nevertheless, the conductivities of these composites can be improved by using semiconducting polymers. Fig. 2b further shows the temperature dependence of the conductivity for the CNT/poly(methyl methacrylate) (Mw = 1.5×10^{4}g/mol) composites. The conductivities increase with temperature, suggesting a semiconducting behavior for the above composite materials.

Conclusion

In summary, this work reports the synthesis of highly aligned CNT/polymer composites by directly casting polymer solutions onto dense and robust CNT arrays, followed by evaporation of solvents. Compared with other CNT/polymer composites, these composite materials exhibit much improved electrical conductivities and show potential applications as electrodes or in optoelectronic devices.

References

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