Electronic Supplementary Information

Encapsulating carbon nanotubes with SiO_2: a strategy of applying them in polymer nanocomposites with high mechanical strength and electrical insulation.

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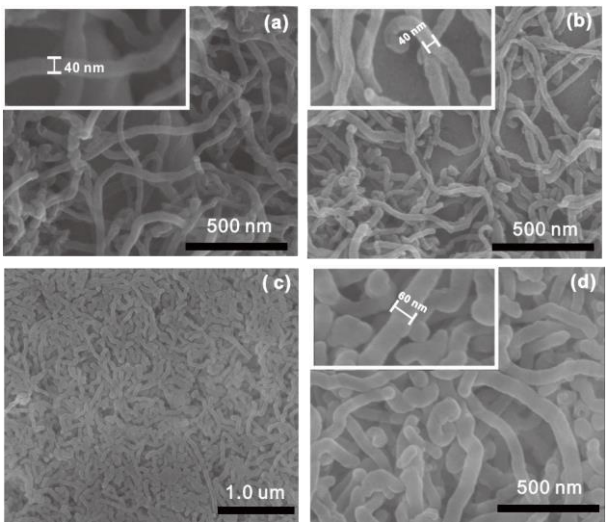

Figure S1. SEM images of pristine MWCNTs (a), MWCNTs-COOH (b), and MWCNT@SiO_2(c, d).

As shown in Figure S1(a) and (b), the length and diameter of MWCNTs are not changed by the oxidation process with HNO_3. For the MWCNT@SiO_2 particles, free SiO_2 particles are not detected, as shown in Figure S1(c). The diameter of MWCNT increases from 30-40 nm for pristine MWCNTs (Figure S1(a)) to approximately 60 nm for the MWCNT@SiO_2 (Figure S1(d)), indicating uniform formation of SiO_2 layer with a thickness of 10 nm on the sidewall of MWCNTs, which is consistent with the TEM results.

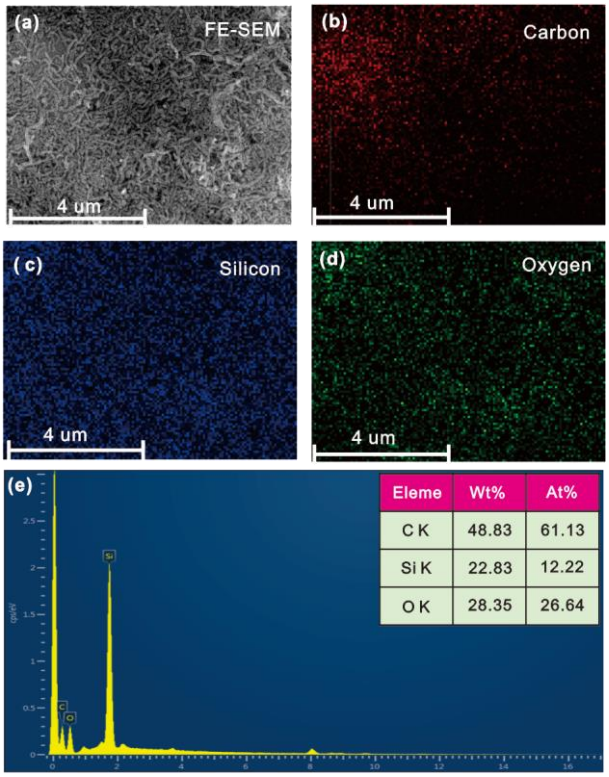

Figure S2 (a) SEM image of MWCNT@SiO_2. Elemental mapping of the MWCNT@SiO_2: (b) carbon, (c) silicon, (d) oxygen, and (e) EDX spectra of MWCNT@SiO_2.

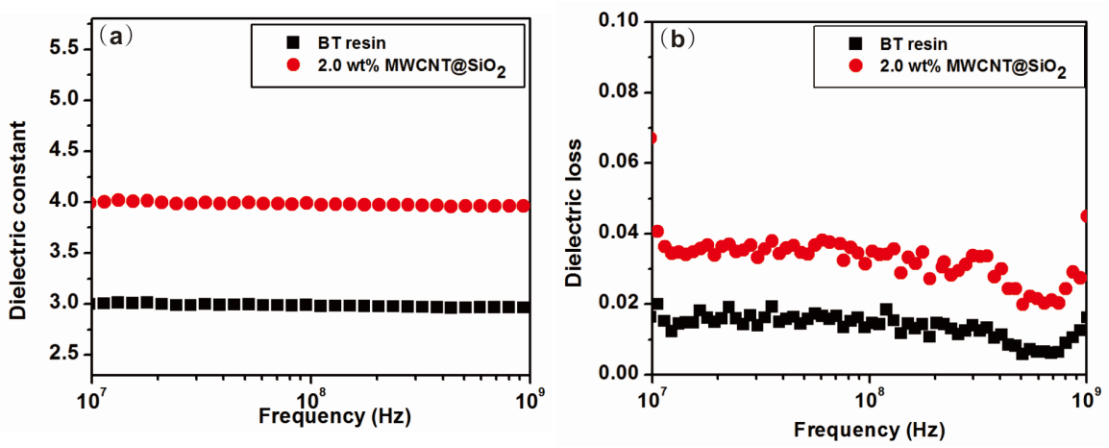

Figure S3. Dielectric constant (a) and loss (b) of BT resin/MWCNT@SiO_2 with 2.0 wt% loading.

Preparation of copper clad laminate containing MWCNT@SiO_2

Materials

Copper (Cu) foils were purchased from Chang Chun Plastics Co., LTD. Sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH), ammonium persulfate ($(NH_4)_2S_2O_8$) were acquired from Sinopharm Chemical Reagent Co., Ltd. Resistor and capacitor were purchased from Yageo Corporation, China. The 555 timer integrated circuit was purchased from Shenzhen Chengyu Micro-electronics Co., Ltd, China. LEDs were purchased from Shenzhen Getian Opto-electronics Co., Ltd, China.

Experimental

The Cu clad laminate containing MWCNT@SiO_2 was prepared, so that we can use copper wire as electrical circuit. The BT resin and 0.8 wt% MWCNTs@SiO_2 particles were dispersed in methyl ethyl ketone and ultrasonicated to form a stable colloid. Then a little hardener (2-ethyl-4-methylimidazole) was added and the mixture was stirred for 2 hours. The obtained solution mixture was deposited on 20×20 cm Cu foil (35 μm) by coating method (RK, K202 Control Coater). After baking and solvent evaporation at 100 °C for 2 hours, two pieces of the composite coated Cu foil were laminated together at an optimized temperature (130 °C) and pressure (10 MPa) for 150 minutes. In order to remove the entrapped air, the vacuum was applied. The thickness of composite film was mainly determined by the viscosity of the composite solution, size of coating bar, and the pressure of lamination. Typically, the laminated composite thickness is about 70 μm. Figure S3 shows the schematic illustration of the fabrication process used for the creation of the copper clad laminate.

Figure S4. Schematic illustration of the fabrication process used for the creation of the copper clad laminate.

Fabrication of electrical circuit by subtractive process

We used subtractive process which is the most popular method for PCB manufacture, to prepare electrical circuit. In subtractive process, the unwanted copper was removed to leave only the desired copper pattern. The photoengraving method was chosen to form the desired copper pattern. Photoengraving used a photomask and developer, can selectively remove a photoresist coating. The remaining photoresist protects the copper foil, so that subsequent etching removes the unwanted copper. Figure S4 presents schematic process flow for fabricating electrical circuit by UV photoengraving method. The dry resist films (20 μm) were attached on both sides of the copper clad laminate by the roll to roll lamination at the temperature of 50 °C and pressure of 0.5 Mpa. One side of the sample was exposed to 365 nm UV light through a quartz mask for 3 minutes, and then developed in 5 wt% Na_2CO_3 aqueous solution. The uncured dry resist film was removed. The exposed Cu was removed by $(NH_4)_2S_2O_8$ etching solution. The residue photoresist was stripped with 5 wt% NaOH aqueous solution. The sample was rinsed with deionized water and dried under vacuum at 60 °C for 12 h. After the printed circuit board (PCB) was fabricated, electronic components were attached to form a frequency “flasher” circuit.

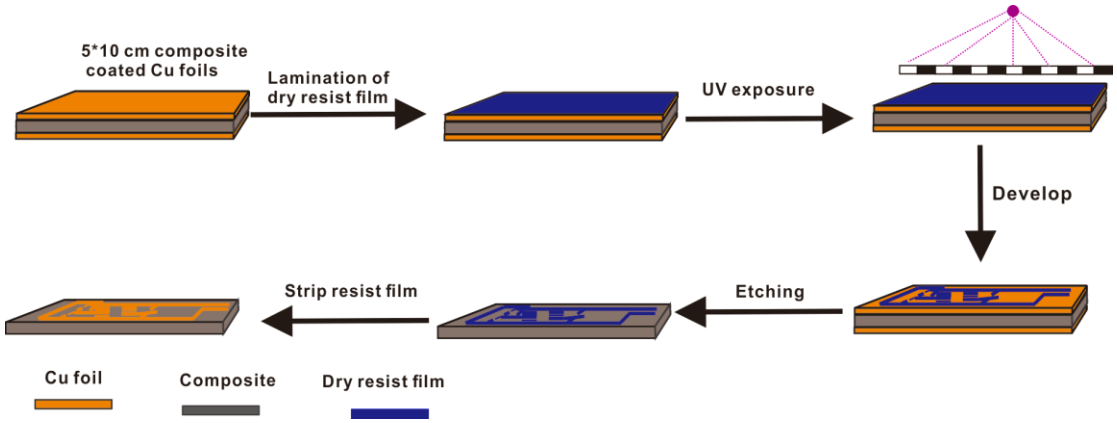

Figure S5. Schematic showing the process flow for fabricating electrical circuit by UV photoengraving method.