Supporting Information: B914887F

Well-Aligned Multi-Walled Carbon Nanotubes Emitting Natural White-Light under Microwave Irradiation

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Experimental

Dispersion. The preparation of multi-walled carbon nanotubes (CNTs) has been achieved through a mixture of C_2H_4, CH_4 by using chemical vapor deposition. Firstly, the CNTs used in this work purified by 6 M HNO_3 reflux (48 hr) follow by cross-flow filtration. CNT material was then purified according to the following procedure. 500 mg of CNTs was heated in air at 400 ^oC for the removal of amorphous carbons and then was stirred in 500 mL HCl (6M) for 3 h. The purified CNTs were recovered by ultracentrifugation with deionized water. By repeating this process three times, TGA data show that only one weigh loss of 99 % CNTs was observed at 600 ^oC. We mixed 100 mg/L CNTs with SDS (25 mg) surfactant concentrations and then sonicated the suspension using a high power tip sonicator (SONICS® VCX750, 20 kHz) for a very short time (5 mins). The resulting suspensions remained homogeneous dispersion at

least 4 months; neither sedmentation nor aggregation of nanotubes bundles was observed by using this sonication procedure. Based on this fast dispersive technology, well-dispersed individual CNT in a water-soluble PVA polymer were accomplished. Firstly, PVA (12.5 g) (M_w = 18 000 – 20 000 g/mol, Sigma-Aldrich) was suspended in hot distill water (100 mL, 90 ^oC), stirred until complete dissolution, and then cooled down to room temperature. After that time, the obtained PVA solution was added into the CNT dispersion and agitated in the ultrasonic oscillator for 3 mins, and finally a uniform PVA/CNT composite solution with a weight ratio of PVA:CNT = 40:1 was obtained.

Physical Measurements. Morphology of the PVA/CNT composites was observed by field-emission scanning electron microscopic (FESEM) using Zeiss URTRA 55 field-emission scanning electron microscope. DSC measurements of 2.8 – 3.5 mg PVA/CNT composites using Al pans were carried out in air atmosphere using a DSC7 (Perkin-Elmer). A heating scan from 30 to 250 ^oC was carried at 10 ^oC/min and T_g was determined as the temperature corresponding to half the complete change in heat capacity. The measurements of sheet electrical resistances of the as-coating films are carried out on a two-pillar Cu holder and recorded by a Keithley 4200 system.

CNT-forest lighting. The CNT electrodeless lamp was made according to the following procedure. The CNT-forest were simply fabricated onto a glass slide (1.3 ×

1.3 cm) and then it was put into a low-vacuum flask. Initially the flask was filled with argon, abbreviated as argon-CNT-lamp. To generate CNT lighting, the CNT flask-bulb is spun at 6 rpm and is simultaneously bombarded with microwave using homemade microwave oven. The emission spectra measurements were performed on CNT electrodeless lamps using USB2000-UV-Vis emission spectroscopy. Accordingly, the luminous flux was measured by using the equation, $\Phi_{lum} = 683$ lm/W $\int_\lambda V(\lambda)P(\lambda)d\lambda$; where $P(\lambda)$ is the spectral density, $V(\lambda)$ is eye sensitivity function, and 683 lm/W is a normalization factor for optical power. The optical power emitted by a light source is then given by $P = \int_\lambda P(\lambda)d\lambda$. Thus the luminous efficacy is defined as Φ_{lum} / P. The CIE 1931 coordinates for CNT lighting and Nichia LED white-light were given by color matching functions.

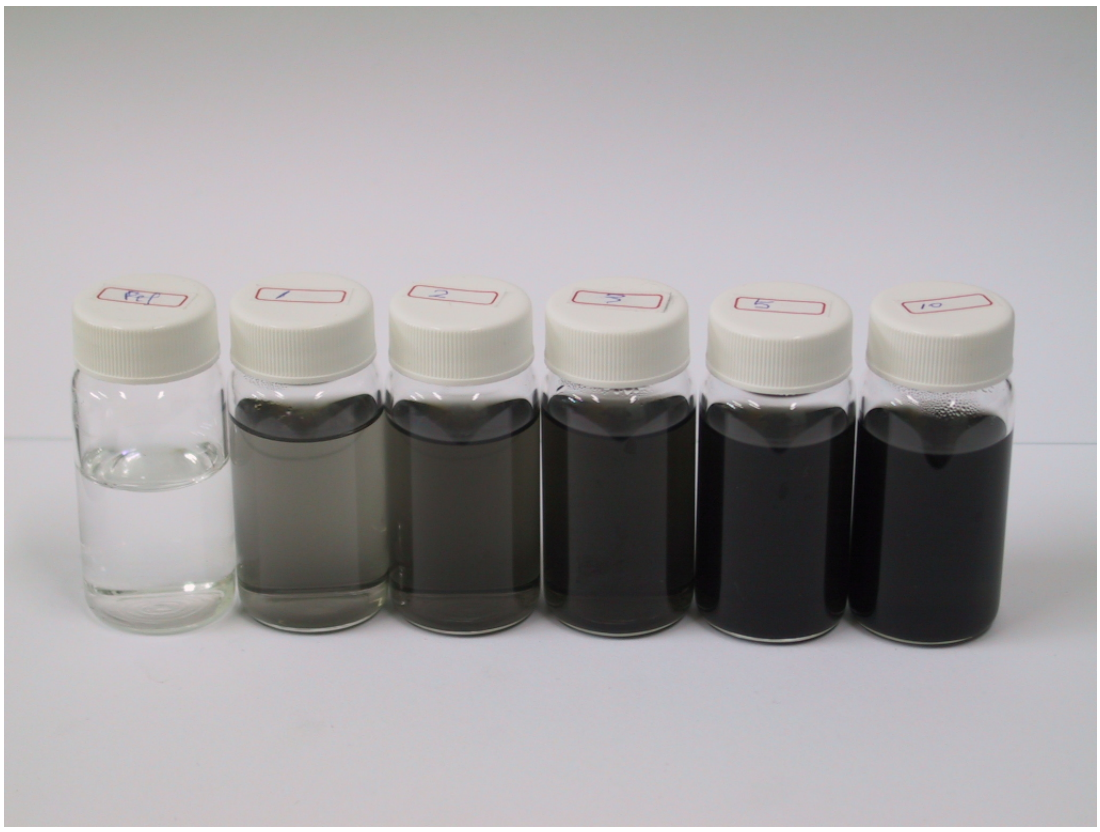

Figure S1. Optical micrograph of PVA/CNT composite water solution, showing that CNTs dispersion in vials appears free-homogenous even after 6 months of sitting at room temperature. These results show that exfoliation of individual native CNT in the polymer matrix was achieved during the processing composites.

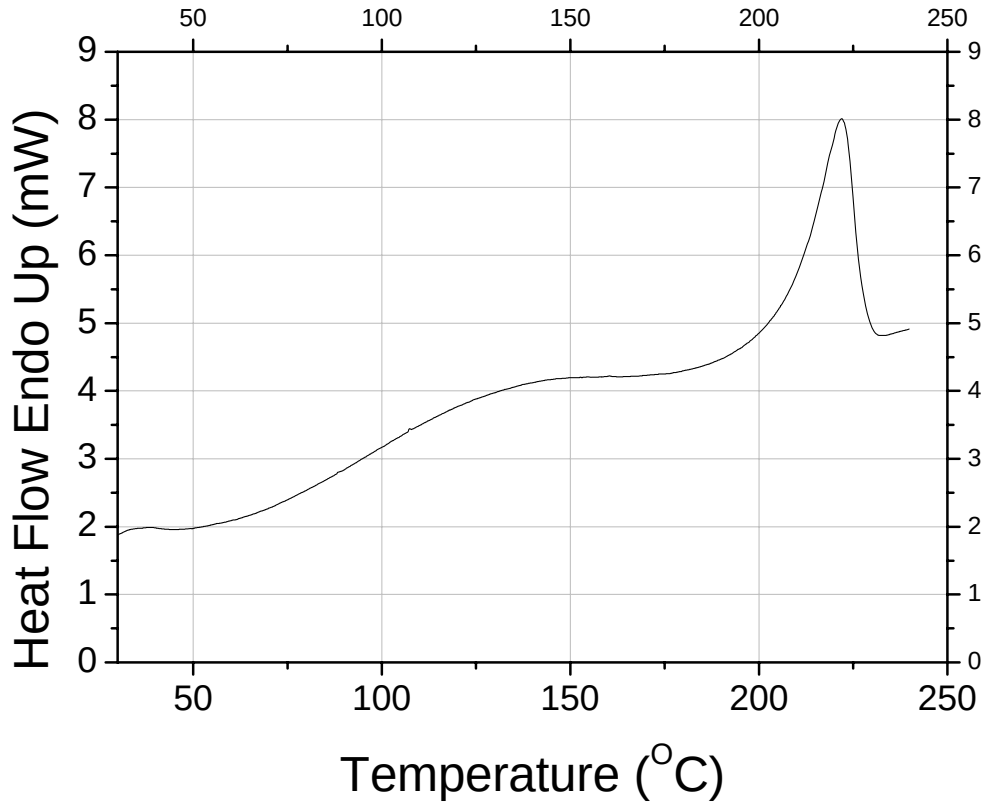

Figure S2. DSC heating curves for PVA/CNT composite at a scan rate of 10 ^{o}C/min.

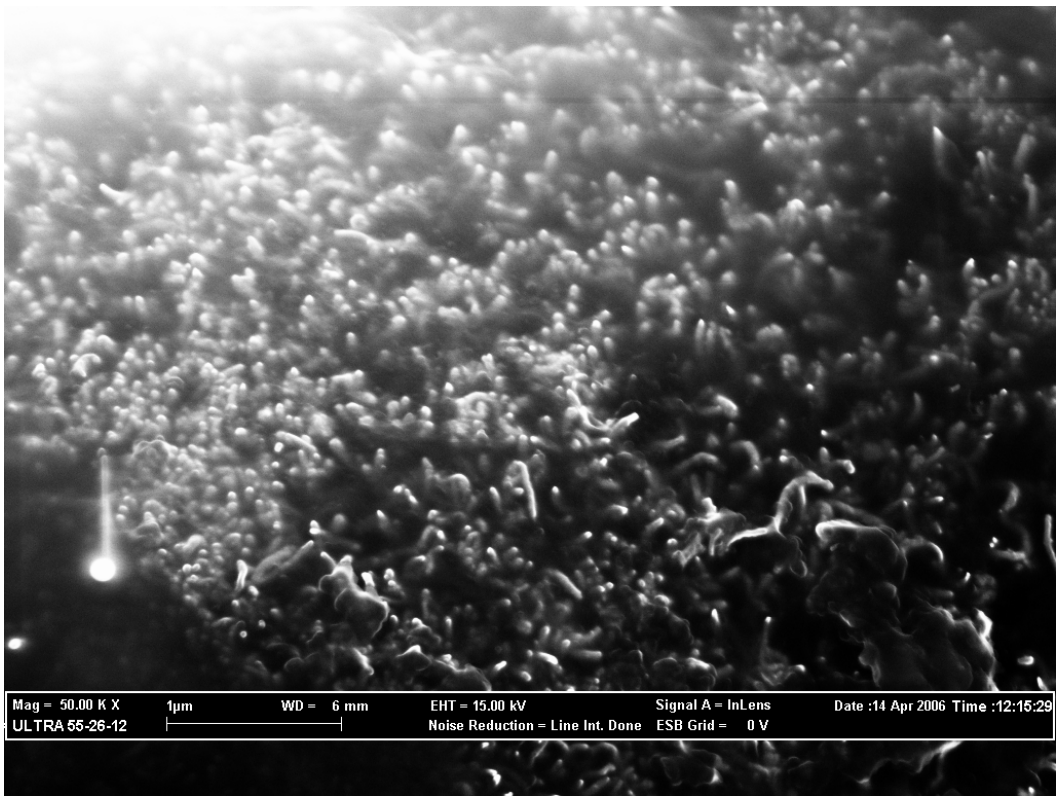

Figure S3. FESEM image of CNT-forest. Tip structure of Free-standing CNT was observed via the gasification combustion of the PVA/CNT composites, heating at 450^{o}C in nitrogen for 1 hr.

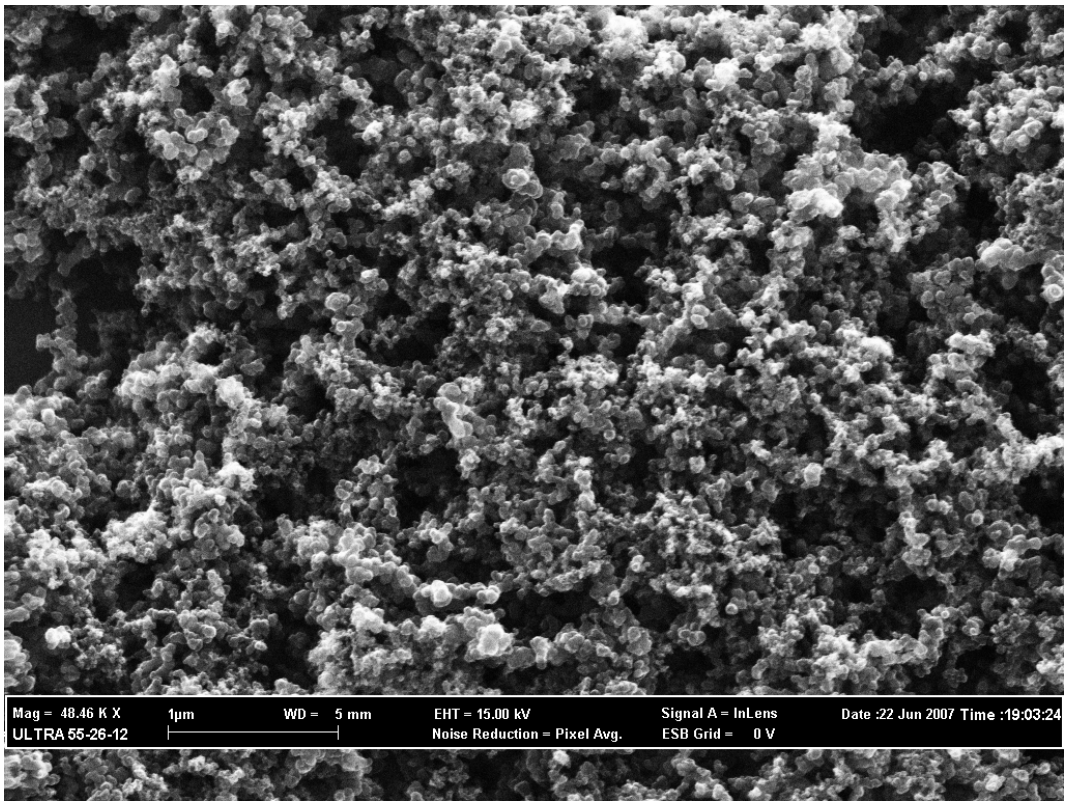

Figure S4. FESEM image showing the formation of carbon-ropes on the tips after microwave irradiation.

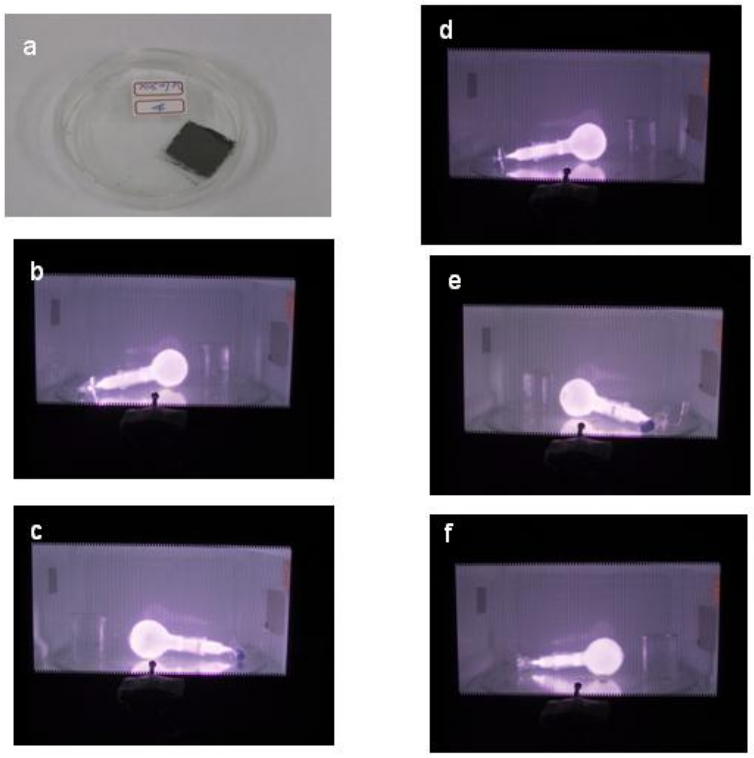

Figure S5. Optical micrograph of the brilliant white-lighting of microwave-assisted CNT excitation. **(A)** CNT-forest(was fabricated onto a glass slide. **(B – E)** Selected optical micrograph for CNT-forest lighting. The flask-bulb is spun at 6 rpm and is simultaneously bombarded with microwave to generate CNT white-light sources.

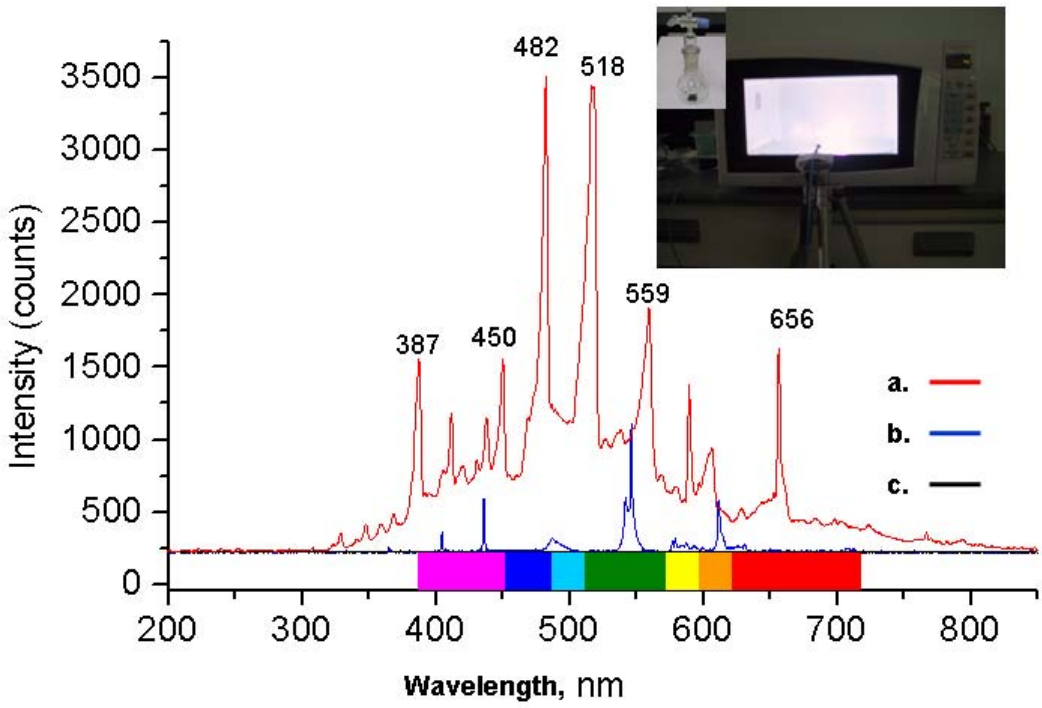

Figure 6. Radiation spectra, **a,** for a CNT-lamp; **b**, for a conventional fluoresce lamp (25000 cd/m^2; 16 watt); **c**. baseline for US2000-UV-Vis instrument. The luminous flux of CNT-forest white-lighting is significantly higher over 14 times that that of the fluorescent bulb (250000 cd/m^2, 16 W) by using the equation 683 lm/W ($\int_\lambda V(\lambda)P(\lambda)d\lambda$) / ($\int_\lambda P(\lambda)d\lambda$; where $P(\lambda)$ is the spectral density, $V(\lambda)$ is eye sensitivity function, and 683 lm/W a normalization factor for optical power.