Near-perfect absorber consisted of a vertical array of single-wall carbon nanotubes and engineered multi-wall carbon nanotubes: supplement

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Near-Perfect Absorber Consisted of Vertical Array of Single-Wall Carbon Nanotubes and Engineered Multi-Wall Carbon Nanotubes

1. MODELLING OF ENGINEERED MWCNT

Reflection of light from the air-CNT array interface depends on the top surface area. As depicted with ‘blue arrows’ in Figure S1, larger top surface area has greater possibility of reflecting any incident light. The same light ray can be bypassed to penetrate into the array if the top surface of the tube is minimized, which is evident from the ‘blue arrows’ of Figures S2 and S3, respectively for MWCNT dual diameter and cone-shape-top MWCNT array.

To explain this phenomena, we resort to the theoretical modeling based on effective medium approximation [1]. According to this model, nanotube array can be approximated as a uniform medium, where effective refractive index of the array depends on the volume fraction of CNT. In dual-diameter and cone-shaped-top MWCNT arrays, volume fraction of the top surface is less than that of MWCNT array. As a result, effective refractive index of the top surface is reduced in the former two structures, which in turn results in a lower value of reflectance from the air-CNT interface in dual-diameter and cone-shaped-top MWCNT arrays.

Fig. S1. Modelling of MWCNT array with effective medium approximation.

2. VARIATION OF OPTICAL CHARACTERISTICS WITH STRUCTURE PARAMETERS

A. Effect of Diameter

Reflectance and transmittance for SWCNT with diameters ranging from 1.5 – 3.5 nm, having an occupation area of 20 % and tube height of 5000 nm, are illustrated in Figures S4(a) and S4(b), respectively. It is evident from the figures that reflectance and transmittance both decreases along with increase in diameter. Thus, absorbance is maximum for 3.5 nm diameter, which indicates better performance of SWCNT in terms of absorbing light with higher diameter.

Again, Figures S5(a), S5(b), and S6 respectively represent the Reflectance, Transmittance, and Absorbance spectra of MWCNT array with different diameters having identical occupation area of 50 % and tube height of 5000 nm. As evident from the figure here, 20.5 nm diameter provides
Fig. S2. Modelling of MWCNT dual diameter array with effective medium approximation.

Fig. S3. Modelling of MWCNT cone-shaped-top array with effective medium approximation.

Fig. S4. (a) Reflectance and (b) Transmittance spectra for SWCNT with different diameters having 20% occupation area and 5000 nm tube height. Insets of each graph represent enlarged view of the corresponding spectra.
slightly higher reflectance while the transmittance is same for all. As a result, Absorbance is minimum for 20.5 nm diameter and almost same for the other two diameters. Thus, MWCNT array shows no significant differences in its optical characteristics with variation in diameters.

![Fig. S5.](image)

Fig. S5. (a) Reflectance and (b) Transmittance spectra for MWCNT with different diameters having 50 % occupation area and 5000 nm tube height. Insets of (a) shows enlarged view of the spectra.

![Fig. S6.](image)

Fig. S6. Absorbance spectra for MWCNT with different diameters having 50 % occupation area and 5000 nm tube height. Inset represents enlarged view of the corresponding spectra.

### B. Effect of Cone Height in Cone-shaped-top MWCNT

Introducing the concept of cone-shaped-top in MWCNT, cone height is varied to observe its effect on the optical characteristics. Figures S7(a) and S7(b), respectively depict the Reflectance and transmittance spectra for different cone height with the overall diameter and occupation area being constant at 20.5 nm and 50 % respectively. As can be seen from the figures here, with the increase of cone height reflectance is significantly reduced, while transmittance increases slightly. Thus, increasing cone height from 25 nm to 570 nm enhances the absorption of light in MWCNT array. However, it is noteworthy to mention that after 570 nm, absorbance becomes almost constant for further increases in cone height.
Fig. S7. (a) Reflectance and (b) Transmittance spectra for MWCNT with variation in height of cone-shapes-top, having 50% occupation area and 5000 nm tube height. Inset of (a) shows a prototype of cone-shape top MWCNT, and inset of represents enlarged view of the corresponding spectra.

Fig. S8. (a) Reflectance and (b) Transmittance spectra for dual diameter MWCNT with variation in height of the inner core top region, having 50% occupation area and 5000 nm overall tube height. Inset of (a) shows a prototype of dual diameter MWCNT, and insets of (a) and (b) represent enlarged view of the corresponding spectra.
C. Effect of Inner Core Height in Dual Diameter MWCNT

Varying the height of inner core top region in MWCNT dual diameter, Reflectance, Transmittance, and Absorbance spectra are observed and depicted in Figures S8(a), S8(b), and S9, respectively. While reflectance slightly decreases for larger height of inner-top region, it is countered by the increase in transmittance. As a result, absorbance remains almost same. The overall height of the CNT being constant at 5000 nm, much higher compared to penetration depth, slight variation in inner core height have negligible significance in terms of enhancing absorbance.

![Absorbance spectra for MWCNT dual diameter with variation in height of inner core top, having 50 % occupation area and 5000 nm overall tube height. Inset shows enlarged view of the corresponding spectra.](image)

D. Flat-edge and Round-edge MWCNT Comparison

Comparison of flat edge and round edge MWCNTs in terms of Reflectance, Transmittance, and absorbance are illustrated graphically in Figures S10(a), S10(b), and S11, respectively. It is evident from the figure that results for both are comparable with round edge CNTs providing better performance in terms of absorbance as it decreases the reflectance slightly.

REFERENCES

1. F. Garcia-Vidal, J. Pitarke, and J. Pendry, “Effective medium theory of the optical properties of aligned carbon nanotubes,” Phys. review letters 78, 4289 (1997).
Fig. S10. (a) Reflectance and (b) Transmittance spectra for MWCNT round edge vs flat edge, having 50 % occupation area and 5000 nm overall tube height.

Fig. S11. Absorbance spectra for MWCNT round edge vs flat edge, having 50 % occupation area and 5000 nm overall tube height. Inset represents enlarged view of the corresponding absorbance spectra.