Supplementary Information

Experimental investigation of thermal transport properties of carbon nanohybrid dispersed nanofluid

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1. Analysis of Raman data

Raman spectra undergo changes that are similar to those observed in the graphite to amorphous carbon transition after functionalization. When carbon based materials are functionalized, the G band broadens significantly and displays a shift to higher frequencies (blue-shift) and the D band grows in intensity. Curve fitting has been done using Lorentzian function. Figure 1, 2 & 3 corresponding to curve fitting corresponding to f-MWNT, f-HEG and f-MWNT+f-HEG. The fitting parameters are given in table 1. f-MWNT is more graphitic in nature compared to f-HEG. The G-band peak position of f-MWNT+f-HEG and f-HEG has been blue shifted compared to that of f-MWNT. There are several possible explanations for this blue shift. First, in f-MWNT with a sufficient concentration of defects, there is another band, D□-band, located at 1607 cm^{-1}, which can partially merge with the G band. The explanation given for the appearance of this band is that in graphite, there is a non-zero phonon density of states above the G band; such phonons, which are usually Raman-inactive, become active due to phonon confinement caused by the defects [1]. Second, when going from a graphite crystal to a single graphene sheet, the G band shifts; this shift could also be partially responsible for the higher G band frequencies [2]. Finally, isolated double bonds resonate at higher frequencies than the G band of graphite, [3] although the specific patterns of the double bonds causing such an up shift. Compared to the G band of graphite, the blue-shifted peaks due to the first two causes are usually relatively weak.

The G-band in f-HEG is broadened compared to that in f-MWNT. The G-band is normally due to the one to one vibration of carbon atoms. So the broadening in f-HEG can be due to the 2 dimentional structure of graphene which gives more carbon-carbon vibrational sites. In addition to G-band, there is a small D□-band in f-MWNT. In the case of f-MWNT+f-HEG, the G-band is more broadened. This may be because of the merging of G-band in f-HEG and D□-band in f-MWNT.

Lorentz function used for fitting

$$y = y_0 + \frac{2A}{\pi}\frac{W}{4(X - Xc)^2 + W^2}$$

The fitting parameters

Parameters	f-MWNT	f-HEG	f-MWNT+f-HEG
y_0	1009	1052	1017
Xc1	1339 cm^{-1}	1366 cm^{-1}	1357 cm^{-1}
W1	57 cm^{-1}	162 cm^{-1}	100 cm^{-1}
A1	5085	20029	4759
Xc2	1568 cm^{-1}	1599 cm^{-1}	1589 cm^{-1}
W2	42 cm^{-1}	65 cm^{-1}	66 cm^{-1}
A2	4291	6792	3440
Xc3	1607 cm^{-1}		
W3	22 cm^{-1}		
A3	336		

y_0 = Y- intercept, Xc1= D-band position, W1= width of D-band, A1= area under D-band, Xc2= G-band position, W2= width of G-band, A2= area under G-band, Xc3= D□-band position, W3= width of D□-band, A3= area under D□-band.

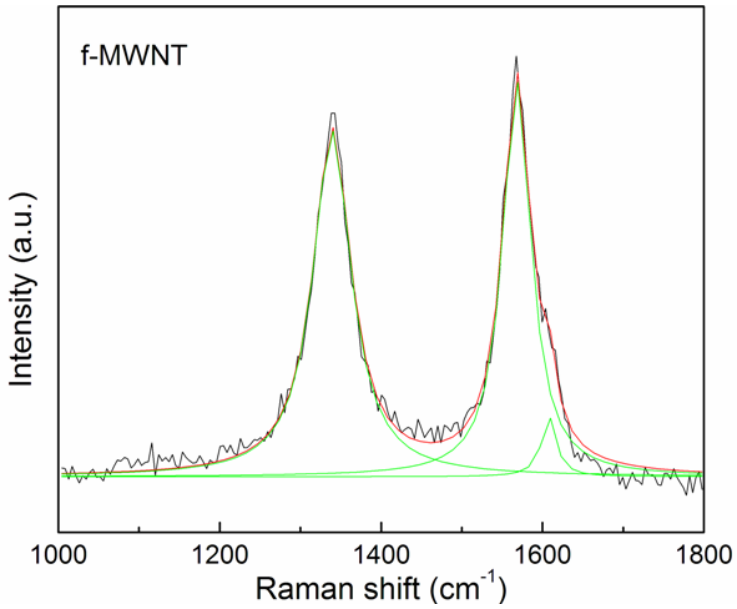

Figure 1. Curve fitting for f-MWNT

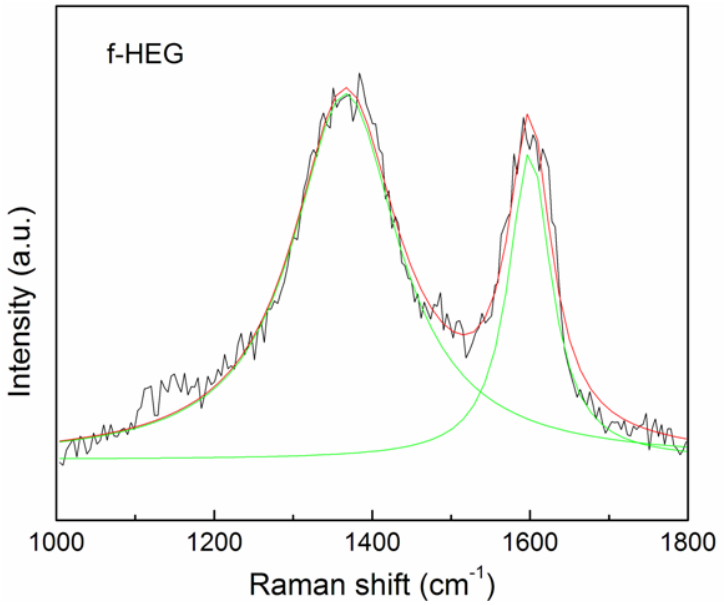

Figure 2. Curve fitting for f-HEG

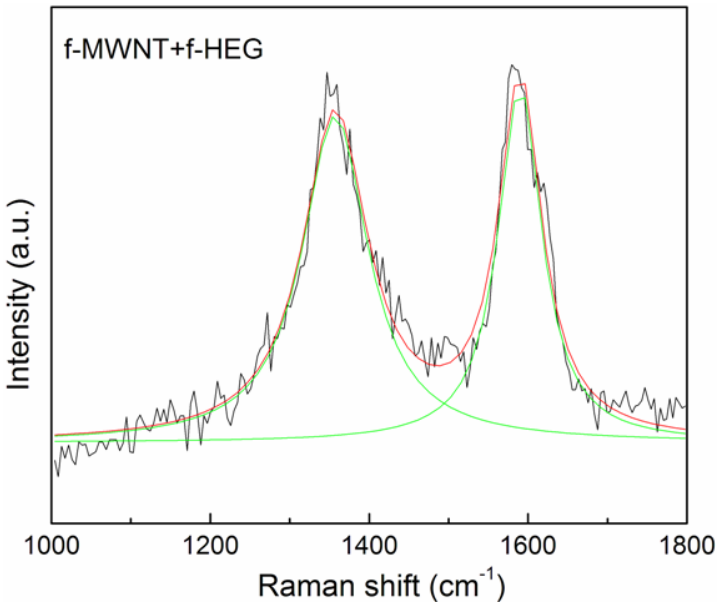

Figure 3. Curve fitting for f-MWNT+f-HEG

2. Mechanism

The figure 4 explains the possible role of f-MWNT in f-MWNT+f-HEG in powder form. f-MWNT acts as spacer between the few layer graphene sheets as shown in figure. This avoids the restacking of graphene sheets.

Figure 4. Role of f-MWNT in powder f-MWNT+f-HEG

When f-MWNT+f-HEG is dispersed in base fluid, the sheets will separate further. f-MWNT acts like a network which connect the f-HEG layers (see figure 5). If the percolation is more then, the conductivity also will be more. When the volume fraction increases also the particle – particle contact increases.

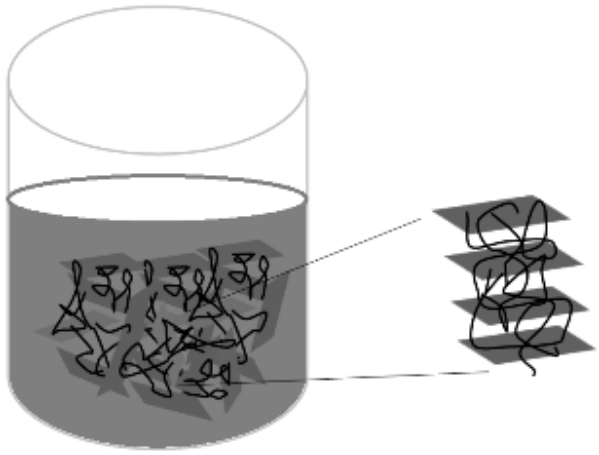

Figure 5. Role of f-MWNT in nanofluid contains f-MWNT+f-HEG

References

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[2] Graf, D.; Molitor, F.; Ensslin, K.; Stampfer, C.; Jungen, A.; Hierold, C.; Wirtz, L. *Nano Lett.* **2007**, *7*, 238.

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