論文の内容の要旨

# Thermal conductivity enhancement of liquid and solid with single-walled carbon nanotubes

（単層CNTを用いた液体／固体の熱伝導率増大効果）

シブシャンカラン　ハリーシュ

Fluids with higher thermal conductivities are necessary for cooling applications especially in micro-electronic devices. The low thermal conductivity of conventional heat transfer fluids remains a limitation in improving the performance of micro-electronic cooling systems. Metallic and metal oxide particles possess significantly higher thermal conductivity than those of the conventional heat transfer fluids. Hence it is speculated that the addition of such highly conductive particles may enhance the thermal conductivity of heat transfer fluids. Advancement in the development of Nano science and Nanotechnology in the last decade have attracted the heat transfer engineers to utilize nano sized particles for this purpose because of their stability against sedimentation and, as a result, reduction in potential for clogging a flow circulating system. Recent experimental reports of anomalous enhancements in thermal conductivity above the predictions of classical Maxwell theory with low volume fraction of metallic and metallic oxide nano-particles have drawn much focus among the heat transfer researchers. This has led to numerous experimental and numerical investigations on the thermal conductivity of nanofluids suspensions.

Despite numerous efforts, it still remains unclear whether the thermal conductivity enhancement in nanofluids is anomalous or within the predictions of classical theories. Non reproducibility and lack of agreement among the nanofluids community is due to the lack of proper materials synthesis and characterization techniques and inability to form suspensions with long term stability.

To understand the real potential of nanofluids, systematic investigation of the thermal conductivity enhancement is carried out with spherical, one-dimensional and two dimensional carbon allotropes is carried out in this present research. Single-walled carbon nanohorns, single-walled carbon nanotubes and exfoliated graphite nanoplatelets were used as the nano inclusions. Stable nanofluids suspensions were created using sodium deoxycholate as the surfactant in water and ethylene glycol. The nanofluid suspensions were thoroughly characterized using transmission electron microscopy, optical absorbance spectroscopy, dynamic light scattering, photoluminescence spectroscopy and atomic force microscopy.

Thermal conductivity measurements were carried out using a custom built transient hot-wire technique for different temperature and loadings of nano inclusions. Thermal conductivity enhancement results were analyzed based on effective medium theory considering the nano-scale effect of interfacial thermal resistance. The experimental results reveal that the aspect ratio of the nano inclusion plays a significant role in the thermal conductivity improvement owing to its high specific surface area and ability to form high heat transport pathways.

Experimental results show that two-dimensional inclusions lead to higher thermal conductivity improvement followed by one-dimensional and spherical inclusions. It was also found that the thermal conductivity enhancement in ethylene glycol is higher than the case of water irrespective of the nature of nano inclusion. Dynamic light scattering studies, optical absorbance and atomic force microscopy clearly reveals the nature of agglomeration is different in the case of ethylene glycol compared to the case of water. This leads to the conclusion that the particle agglomeration has a profound effect in the thermal conductivity enhancement on nanofluid suspensions. The experimental results are in reasonable agreement with the predictions of effective medium approach which leads to the conclusion that the thermal conductivity enhancement in nanofluids is ‘not anomalous’ and the classical heat conduction approach holds for nano suspensions for well characterized and stable suspensions.

In the last part of this work, fine tuning the thermal conductivity enhancement via temperature regulation is demonstrated for a phase change alkane by successively melting and freezing the alkane with different nano inclusions. Solidification of n-Octadecane resulted in higher thermal conductivity enhancement in the solid state compared to the liquid state irrespective of the dimensionality of the nano inclusion. In the solidified state carbon nanotubes outperformed graphite nanoplatelets and carbon nanohorns due to their ability to form percolating networks at low loading. It is hypothesized that this phase-dependent enhancement is due to the formation of a quasi-two-dimensional percolating structure, which is formed by the nanotubes during the phase transition. The present experimental results will stimulate further theoretical research on developing models to explain such behaviour, and will contribute to the development of high conductivity thermal energy storage materials for buildings and in solar power plants.

REFERENCES

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