Graphene Thermal Properties and Applications for Heat Removal in the Phase Change Materials

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Lithium-ion (Li-ion) batteries are attractive alternatives to other types of batteries owing to their high-energy storage density and competitive cost. However, their applications are limited because of strong self-heating effects coupled with the adverse effect of temperature on the battery life-time. The battery packs utilize multiple Li-ion cells, which are stored close together to provide high electric power. This arrangement leads to increased temperatures that degrade the battery life. Traditional cooling systems, which use air-cooling with an electric fan, are not attractive solutions due to their bulkiness and additional power requirements. Prior work on thermal issues in Li-ion battery packs has demonstrated that a passive thermal management system, which uses phase-change materials (PCM), is a promising approach. The PCM thermal management uses the latent heat stored in the material as its phase changes over a small temperature range. However, PCMs typically have low thermal conductivity. They store heat from the batteries rather than transfer it outside. For this reason, the usefulness of PCM passive thermal management for the high-power Li-ion batteries is limited. In this talk we describe a possibility of using graphene and few-layer graphene (FLG) as fillers for PCM for increasing PCM's thermal conductivity while preserving its ability for the latent heat storage.

Graphene's superior intrinsic thermal conductivity, flat geometry and demonstrated capability for integration with other materials make graphene very promising for thermal management applications [1-7]. Our measurements revealed that the large-area (~ 10 – 20μm long) single-layer graphene flakes have an extremely high room-temperature thermal conductivity exceeding that of diamond (~2000 W/mK) [1-4]. For comparison, the thermal conductivity of silicon is 145 W/mK at room temperature. The thermal conductivity of graphene sheets depend on their width [4] and the number of atomic planes as one goes from graphene to graphite. The thermal conductivity of graphene flakes incorporated within different materials can degrade due to strong coupling to the adjacent layers and phonon scattering on defects and edges. At the same time, the thermal conductivity of graphene and FLG in different composite materials can remain relatively high compared to conventional materials.

We investigated a possibility of using graphene as a filler material in thermal interface materials (TIMs) and PCMs [6-7]. It has been found the room-temperature thermal conductivity of the epoxy can be increased by an addition of the chemically derived graphene by ~500% at a very small loading fraction of ~5 vol % [7]. Graphene fillers cam be used in combination with other fillers such as metal particles. It was also found that the thermal conductivity of paraffin-based PCM can be increased by 50 times at 1-wt% of graphene and FLG fillers [8]. The increase in the thermal conductivity is much stronger than that with the conventional filler materials. The obtained results are important for the proposed applications of graphene and FLG in thermal management.
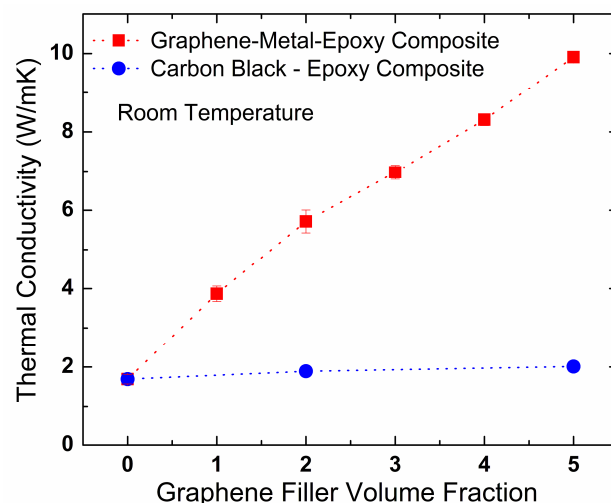
Figure 1: Thermal conductivity of the hybrid graphene-FLG-silver-epoxy composite as a function of temperature for 1%, 3% and 5% of the volume fraction of graphene-FLG filler loading. Note that the thermal conductivity almost does not change in the examined range, which is important for TIM applications. The data is after V. Goyal and A.A. Balandin, Applied Physics Letters, 100, 073113 (2012).

REFERENCES
[1] A.A. Balandin, et al., "Superior thermal conductivity of single-layer graphene," Nano Letters, 8: 902 (2008)
[2] D.L. Nika, E.P. Pokatilov, A.S. Askerov and A.A. Balandin, "Phonon thermal conduction in graphene: Role of Umklapp and edge roughness scattering," Physical Review B 79, 155413 (2009)
[3] S. Ghosh, W. Bao, D.L. Nika, S. Subrina, E.P. Pokatilov, C.N. Lau and A.A. Balandin, "Dimensional crossover of thermal transport in few-layer graphene," Nature Materials, 9 555 (2010).
[4] A.A. Balandin, "Thermal properties of graphene and nanostructured carbon materials," Nature Materials, 10, 569 - 581 (2011).
[5] Z. Yan, G. Liu, J.M. Khan and A.A. Balandin "Graphene quilts for thermal management of high-power GaN transistors," Nature Communications 3, 827 (2012).
[6] K.M.F. Shahil and A.A. Balandin, "Graphene - multilayer graphene nanocomposites as highly efficient thermal interface materials," Nano Letters, 12, 861 (2012).
[7] V. Goyal and A.A. Balandin, "Thermal properties of the hybrid graphene-metal nano-micro-composites: Applications in thermal interface materials," Applied Physics Letters, 100, 073113 (2012).
[8] For details, see at http://ndl.ee.ucr.edu