Graphene nanoplatelets for thermally conductive polymer nanocomposites

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Abstract

Thermally conductive polymer composites offer new possibilities for replacing metal parts in low temperature heat exchangers, thanks to the polymer advantages such as light weight, corrosion resistance and ease of processing. The search for polymer based materials that conduct heat well has become essential for several applications, thanks to the following benefits:

- Superior <u>corrosion resistance</u>, which is an intrinsic property of the polymer matrix, allowing to attain durable components with no maintenance required
- <u>Large design flexibility</u> for an intensive exploitation of the available volume beyond the limitations of state-of-art heat exchangers; new heat-conductive polymers will enable new heat exchanger designs and manufacturing routes thereby potentially opening new application opportunities.
- <u>Significant cost reduction</u> of the innovative materials compared to metal materials used in highly corrosive contexts which will turn into a cost reduction for the complete appliances
- <u>Weight reduction</u>

Current interest to improve the thermal conductivity of polymers is focused on the selective addition of nanofillers with high thermal conductivity. Unusually high thermal conductivity makes carbon nanotubes (CNTs) and graphene nanoplatelets (GNP) the best promising candidate particles for thermally conductive composites [1-4]. However, to exploit the potential of such nanoparticles, both the dispersion of nanoparticles and the properties of thermal interfaces between nanoparticles has to be carefully designed and controlled [1]

Thermal transport in CNTs and graphene can be dominated by the intrinsic properties of the strong sp2 carbon lattice, rather than by phonon scattering on boundaries or by disorder, giving rise to extremely high K values. Indeed, for graphene, the phonon mean-free path was estimated to be ~775 nm near room temperature, which evidences for very weak phonon scattering on the single particle. However, the intrinsic K strictly depends on the boundaries for the particles, especially in terms of support or inclusion into a matrix of a different material. Furthermore, the conductivity of graphene materials strictly depends on the number of layers and defectivity (partial oxidation, incomplete graphitization etc.)
When graphene is embedded in polymer nanocomposites, the large surface area of the nanoparticles, maximizes the extent of polymer/particle interfacial area. Furthermore, in the case of percolating network, the number of contact points between particles increases with decreasing particle size. It is therefore reasonable to expect a significant role of the interfaces in thermal conductivity of nanocomposites.
From a theoretical point of view, the scattering of phonons in composite materials is mainly due to the existence of an interfacial thermal barrier from acoustic mismatch. In a simplified model, the transmission of a phonon between two phases depends on the existence of common vibration frequencies for the two phases. Thus, it was supposed that only low frequency phonon modes of graphene are effective when GNP interact with a matrix only via weak dispersion forces
Another source of interfacial resistance is the imperfect physical contact between GNP and matrix, which primarily depends on surface wettability

Due to the very low mean free path for phonons in the polymer (a few angstroms) compared to the mean free path on GNP (hundreds of nanometers), the theoretical scenario of perfectly dispersed GNP having no contact with each other and exchanging heat with the surrounding matrix does not appear to be convenient when aiming at efficient heat conduction. Indeed, preferential conduction of thermal energy along particles forming a percolating network is the basic idea behind the use of highly conductive and high aspect ratio nanoparticles such as GNP

However, contact area between adjacent CNTs is relatively small and a significant temperature drop can be assumed for each contact point, which has previously been taken into account by considering GNP as a nano-plate coated with a very thin interfacial thermal barrier layer.[5]

To overcome current limitations in thermal conductivity of graphene-based nanocomposites, different routes are being pursued in this PhD thesis, including:
- Combination with cofillers (graphite, alumina, boron nitride)
- non-covalent functionalization to promote dispersion during melt compounding and thermal contact between particles
- Predispersion of GNP in liquid moieties (e.g. plasticizer) before melt compounding

Recent achievements will be described in this paper.

References

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