# Graphene Fillers

## Promise Major Improvements to TIM Thermal Conductivity

Thermal interface materials (TIMs) facilitate the transfer of heat from hot chips to heat spreaders. TIMs have soft material components that fill into the air gaps between the package and spreader joining surfaces. One type of TIM is a phase change material that contains a high viscosity fluid, e.g. paraffin, as well as thermally conductive fillers that provide the heat transfer. But, traditional fillers, typically particles of alumina or glass, are inherently limited in their abilities to conduct heat. As a result, thermal transfer into spreaders is limited and chips may not be cooled to the levels they require. With power dissipation rising, there is a need for TIMs with higher levels of thermal conductivity.

The solution may be found at the nanotech level with graphene fillers. Recent studies by Balandin et al [1], along with process improvements, demonstrate that TIMs filled with graphene provide much higher thermal conductivity than conventional TIMs, without a corresponding much higher cost. A graphene flake is shown in Figure 1

Discovered less than a decade ago, graphene is a near two-dimensional sheet of carbon atoms bound together with double electron bonds (called a $sp^2$ bond), in a network of repeating hexagons, within a single plane just one atom thick. Tilak et al. [2] describe graphene as the basic structural element of all other graphitic materials, including graphite, carbon nanotubes and fullerenes. It is the strongest material ever measured and has other remarkable qualities, including high electron mobility, a property that elevates its potential for use in high-speed nano-scale devices of the future.

In 2010, the Nobel Prize in Physics was awarded to Andre Geim and Konstantin Novoselov at the University of Manchester for their innovative experiments regarding two-dimensional graphene.

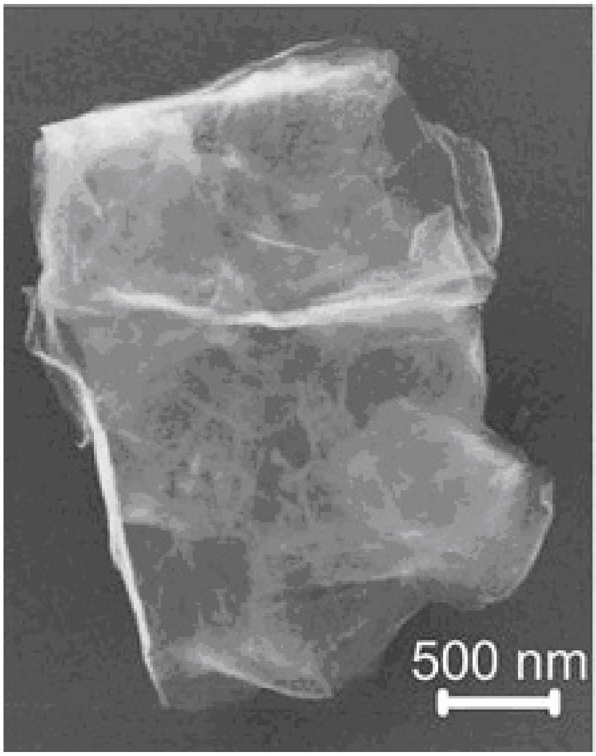


*Figure 1. Scanning Electron Microscopy of a Few-layer Graphene Flake [1]*

## Adapting Graphene for Thermal Interface Materials

With its exciting and unique properties, graphene has been examined and experimented with for its potential as a high performance, thermally conductive filler for TIMs.

In 2008, Balandin et al. reported on their measurements of the thermal conductivity of a suspended single-layer, a-b plane graphene. They found very high conductivity levels ranging from 3000-5000 W/mK and established graphene as an excellent material for thermal management.

Chen et al. [3] describe graphene as a near-two dimensional sheet of carbon atoms bound together with double electron bonds (called an $sp^2$ bond) in a network of repeating hexagons along a plane that is only one atom thick. Figure 2 below illustrates a graphene layer aligned perpendicular to the surface of a heat spreader.

Tilak et al. filed a (US) patent application in 2010 for a thermal management system with a graphene-based thermal interface material. Their thermal management system includes graphene paper disposed between a heat source and a heat sink to transfer heat into the sink. Per the application, the graphene paper is formed by bonding together several layers of graphene. To create the filler material, "the graphene paper is oriented such that the individual layers are substantially perpendicular to the plane of the heat source and the plane of the heat sink to maximize heat transfer." According to the authors, the graphene paper may be formed in several different configurations, such as a spring structure.

In 2011, researchers at the Georgia Institute of Technology reported that a three-dimensional, vertically aligned functionalized multilayer graphene architecture can be an approach for graphene-based thermal interfacial materials (TIMs) with superior equivalent thermal conductivity and ultra-low interfacial thermal resistance between graphene and metal. [4]

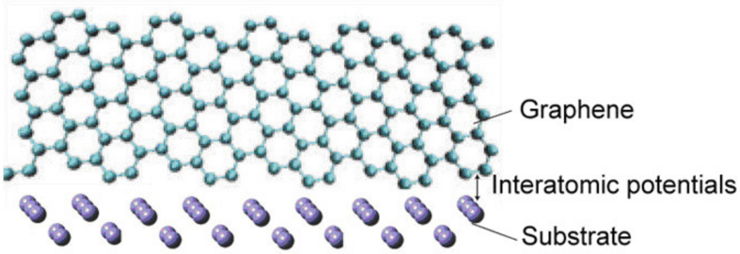


*Figure 2. Chemical Structure of a Two-dimensional Graphene Sheet [3]*

Then, in a 2012 paper, Shahil and Balandin [5] described how an optimized mixture of graphene and multilayer graphene, produced by liquid-phase-exfoliation technique, can lead to a strong enhancement of the cross-plane thermal conductivity, or (K), of the composite. "Laser flash measurements revealed a record-high enhancement of K by 2300% in the graphene-based polymer at the filler loading fraction f = 10 vol %. It was determined that the relatively high concentration of the single-layer and bilayer graphene flakes (10–15%) present simultaneously with the thicker multilayers of large lateral size (1 μm) were essential for the observed unusual K enhancement. The thermal conductivity of the commercial thermal grease was increased from an initial value of 5.8 W/mK to K = 14 W/mK at the small loading f = 2%, which preserved all mechanical properties of the hybrid."

Their modeling results suggest that a graphene–multilayer nanocomposite, used as the thermal interface material, outperforms those with carbon nanotubes or metal nanoparticles, owing to graphene's aspect ratio and lower interfacial thermal resistance at the graphene–matrix interface.

## Lowering the Cost of Graphene

At one time, graphene was referred to as the most expensive material to produce in the world [6]. But many studies have been underway to find low cost ways to mass produce it.

Balandin and Shahil reported "we prepared our own graphene/few-layer-graphene solution using an inexpensive liquid-phase-exfoliation technique. This is a high-yield technique which can be scaled up for industrial production of TIMs. The equipment we used was not very complicated."

In 2011, scientists at Northern Illinois University (NIU) reportedly discovered a simple method for producing high yields of graphene [7]. The NIU researchers reported on a new method that converts carbon dioxide directly into few-layer graphene (less than 10 atoms in thickness) by burning pure magnesium metal in dry ice. "The synthetic process can be used to potentially produce few-layer graphene in large quantities," he said. "Up until now, graphene has been synthesized by various methods utilizing hazardous chemicals and tedious techniques. This new method is simple, green and cost-effective."

With graphene's very high thermal conductivity, along with the prospects of mass production at affordable costs, graphene-filled TIMs may be the first major breakthrough to the continuing need for higher performing interface materials.

**References:**


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