Brief Review on Thermal Properties of Graphene-Aluminium Metal Matrix Composites

K. Vamsi Krishna Reddy, Ch. Abhinav

Abstract: ***In this paper we report an obvious review of the thermal properties of graphene and aluminium sheet reinforced with graphene layer. Graphene is one of very few materials with exceptionally high thermal conductivity due to the scattering of phonons. The experimental results revealed that the thermal conductivity of graphene is very high when compared to carbon nanotubes (CNTs). To increase the thermal properties of aluminium, graphene can be used as reinforcement in producing metal matrix composites. The reported results revealed that the fabricated composites showed enhanced thermal conductivity as compared with the various metal matrix composites like aluminium, copper, beryllium, silver and their alloys. The thermal conductivity of graphene reinforced aluminium increased from 324 W/mK to 783W/mK and has the potential to provide the sufficient thermal conductivity for food drying process and can be used in heat exchangers.***

Keywords: Graphene; Al MMC; Thermal properties.

I. INTRODUCTION

Now-a-days, extensive research works have been carried out for developing a strong, light weight material with high thermal conductivity. Aluminium alloys have high thermal conductivity in contrast to other composite materials. But, these alloys were not used in heat exchangers due to their inefficient thermal conductivity [1]. Concurrently, carbon allotropes possess large thermal conductivity at room temperature. It ranges from 0.01W/mK (amorphous carbon) to 2,000 W/mK (diamond). In type 2 diamond the thermal conductivity reaches to 10,000Wm/k at 77K [1-3]. Nevertheless, carbon allotropes have high thermal conductivity, they cannot be used in heat exchangers as they are expensive and amorphous in nature. This necessity for a material with high thermal conductivity is fulfilled after the advancement of nanotechnology. Graphene a carbon allotrope is one such material formed by the sp^2 bonds between adjacent carbon atoms which are arranged hexagonally in a single two-dimensional (2-D) plane. These sp^2 bonds are much strong in nature when compared to sp^3 bonds between carbon atoms in diamond [3]. Some unique properties like high young's modulus (~1TPa), high fracture strength (125 Gpa), thermal conductivity (~5300 W/mK), charge-carrier mobility (200,000 $cm^2 V^{-1}s^{-1}$), surface area ~ (2600 $m^2 g^{-1}$) makes graphene a strongest and high thermal conductive material [1,4,5]. Strong bonding and low mass of carbon atoms are the reasons for high thermal conduction of graphene [3].

Revised Version Manuscript Received on November 21, 2016.

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The thermal conductivity of graphene changes with the number of layers which ranges from $(4.84 \pm 0.44) \times 10^3$ to $(5.30 \pm 0.48) \times 10^3$ W/mk in suspended single-layered graphene at room temperature [6] and which is very high when compared to the thermal conductivity of carbon nanotubes 3000 W/mK to 3500 W/mK [2,5]. Further, the thermal conductivity decreases from ~2800 to ~1300 W/mK with increase in the number of atomic planes from 2 to 4 [6-10]. Although the thermal conductivity is less in multilayer graphene, it exhibits good elastic properties [11]. The main reason behind the high thermal conductivity and thermal transport in graphene is phonons [5, 12-13] which are to be examined to completely understand the thermal properties of graphene [3, 12 and 14]. Micro-Raman spectroscopy [12, 14-15], micro resistance thermometry techniques [12, 14-15] are used to find the thermal conductivity (k) of graphene. Moreover, the thermal conductivity is also affected by the defects which can be either point or vacancy defects. With the increase in defects the thermal conductivity will also be reduced [14-17].

As the graphene, cannot be used directly it is used as reinforcement on aluminium alloys by fabricating metal matrix composites (MMC). Graphene acts as good corroboration to improve the thermal conductivity of aluminium alloys [1]. Due to its high strength, lighter weight than standard metals, alloys make these metal matrix composites (MMC) a vital material in automobile, electronic and aerospace industries [4, 7, 18]. There are numerous manufacturing methods to produce MMC like powder metallurgy, processes based on casting and some other physical methods like mechanical peeling, chemical vapour deposition can be used but they can lead to high probability of vacancies and dislocations [16]. In the views of above consequences friction stir process (FSP) is developed. FSP includes a rotating tool that generates heat due to friction between the tool and the surface of the material. some constraints like the uniform dispersion of nanoparticles on a surface and cost makes these processes of no use. The surface of the material is softened due to the generated heat resulting in the production of fine grains resulting in the modification of the microstructure of material [1].

II. EXPERIMENTAL INVESTIGATION OF HEAT CONDUCTION IN GRAPHENE

Even though there are numerous methods to measure the thermal conductivity of nanomaterials but these methods are not efficient to determine thermal conductivity of graphene. A new non-contact optical technique (Raman spectroscopy) is developed to determine the thermal conductivity of graphene. Graphene exhibits unique trends in Raman spectra with a G peak and 2D bands. This can be considered as a clear sign of strong thermal dependence. The G peak and 2D bands are also used to illustrate the number of layers. The

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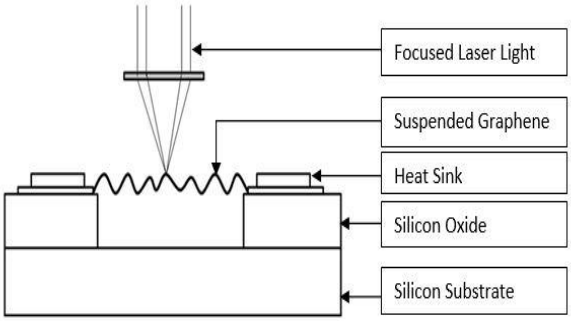
thermal conductivity of graphene depends on the amount of the heat dissipated. As graphene is a high thermal conductive material, even a little amount of the heat can lead to a huge swing in the G peak position. [8, 19-20]

As the chief agenda is to govern the thermal properties of graphene, laser excitation method or Raman spectrum method is used. The temperature coefficients are then correlated with the bulk graphite. The change in peak position is determined using micro-Raman spectrometer which functions as a thermometer. Raman spectroscopy is a non-destructive technique to investigate the physical and electronic properties of the carbon-based materials like diamond, carbon nanotubes (CNTs) and graphite. It is mainly used to understand the fine atomic structure and thermal properties of a material like thermal expansion, thermal conductivity and specific heat [8, 20]. Raman spectroscopy has three primary components Excitation source, Sampling apparatus and Detector. But over years this has been modified and developed around using a Laser as an excitation source, a spectrometer as a detector and a fibre optic probe as sampling apparatus.

Micro-Raman Spectrometer



The spectral bands vary depending on the wavelength of the laser, it is a fact that the shorter the wavelength the stronger the Raman signal. The experimental Raman spectroscopy setup for the graphene consists of a Si substrate as the base and the graphene layer is suspended on the silicon oxide wafer which acts as a supporting platform on either side leaving a trench below, heat sinks are also kept on either sides of the graphene layer. A Laser light is focused on the graphene layer and the calibration are noted using the detector and a sampling apparatus [8, 19, and 20]. The intensity of the Raman scattering is determined to find out the thermal properties of the graphene layer. The thermal properties of graphene and graphene nanoribbons are determined in the following table.

Table 1. Thermal conductivity of graphene and graphene nanoribbons [21]

Sample	Method	*K* (W/m K)	Description
		Experimental data	
SLG	Raman optothermal	~3000-5000	Suspended; exfoliated
	Raman optothermal	2500	Suspended; chemical vapour deposition (CVD) grown
	Raman optothermal	1500-5000	Suspended; CVD grown
	Raman optothermal	600	Suspended; exfoliated; T~660 K
	Electrical	600	Suspended; exfoliated
	Electrical Self-heating	310-530	Exfoliated; chemical vapour deposition grown;
FLG	Raman optothermal	1300-2800	Suspended; exfoliated; n= 2-4
	Heat- spreader method	50-970	FLG, encased within SiO_2; n=2….,21
	Electrical Self-heating	150-1200	Suspended and supported FLG; plyometric residues on the surfaces

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	Modified T-bridge	302-596	Suspended; n=2-8
Bilayer Graphene	Electrical Self heating	560-620	Suspended; plyometric residues on the surface
FLG	Electrical Self heating	1100	Supported; exfoliated; n<5
Nanoribbons	Electrical Self heating	80-150	Supported
	Theoretical Data		
SLG	BTE, $\gamma_{LA,}\gamma_{TA}$	1000-8000	Strong size dependence
	BTE, $\gamma_s(q)$	2000-8000	Strong edge, width and grunaisen parameter dependence
	BTE, 3_{rd} order interatomic force constants (IFCs)	~2430	*K* (graphene)≥ *K (*carbon nanotube)
	BTE	100-8000	Strong length, size, shape and edge dependence
	Continuum approach +BTE	2000-4000	Strong isotope, point defects and strain influence
	Ballistic	4000	Strong with dependence
	MD simulation	2900	Strong dependence on the vacancy concentration
	VFF + MD simulation	20000	Ballistic regime, flake length ~15µm; strong size dependence

Sample	**Method**	***K* (W/m K)**	**Description**
	MD simulation	100-550	Flake length L> 200nm; strong length and defect dependence
	MD simulation	3000	Sheet length ~ 15µm; strong size dependence
	MD simulation	2360	L~ 5µm; strong length dependence
	MD simulation	4000-6000	Strong strain dependence
	MD simulation	1800	6nm x 6nm sheet; isolated
	MD simulation	1000-1300	6nm x 6nm sheet; Cu – supported;

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SLG			strong dependence on the interaction strength between graphene and substrate
FLG	BTE, 3rd order IFCs	1000-3500	n = 5 - 1, strong size dependence
	BTE, $\gamma_s(q)$	1000-4000	n = 8 – 1, strong size dependence
	BTE, 3rd order IFCs	2000-3300	n = 4-1
	MD simulation	580-880	n = 5- 1, strong dependence on the Van-der Vaals bond strength
GNRs	Theory: molecular dynamics, Tersoff	1000-4000	n = 5- 1, strong size dependence
	BTE	5500	GNR with width of 5μm; strong dependence on edge roughness
	MD simulation	2000	T = 400K; 1.5nm x 5.7nm zigzag GNR; strong edge chirality influence
	AIREBO potential + MD simulation	30-80	10 – zigzag and 19 – arm-chair nanoribbons; strong defect dependence
	MD simulation	3200-5200	Strong GNRs width (*W*) and length dependence; 9 nm ≤ L ≤ 27 nm and 4 nm ≤ W ≤ 18 nm
	MD simulation	400-600	$K \sim L^{0.24}$; 100 nm ≤ L ≤ 650 nm
GNRs supported on SiO_2	BTE	100-1000	Strong edge and width dependence
Few-layer GNRs	MD simulation	500-300	10- ZGNR, n = 1….,5

As discussed graphene has high thermal conductivity, when it is coated to aluminium sheet, the thermal properties of the Al sheet are enhanced. The aluminium graphene metal matrix composite is tested out using the same Raman spectra method and the results have huge deflections when related to ordinary aluminium thermal properties.

Table 2.

	Thermal conductivity (W/mK)	Tensile strength (MPa)	Elongation failure (%)
Aluminium	147.644 (0.66)	218.16 (2.64)	18.6 (2.86)
Aluminium FSP alone	150.020 (0.74)	206.21 (3.05)	26.5 (2.98)
Graphene/Al MMC	171.698 (0.87)	191.99 (0.46)	28.0 (0.85)

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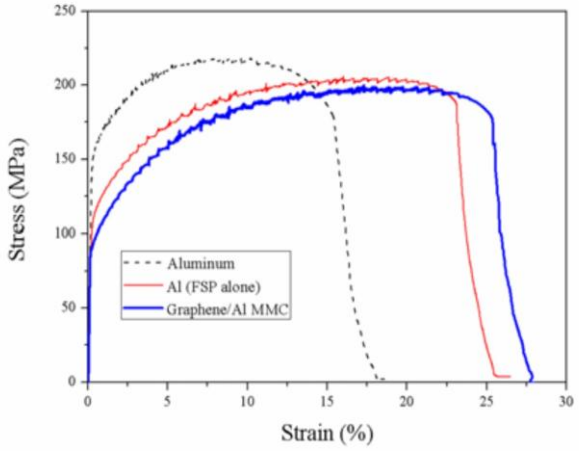
Table ref [1] The measurements are repeated numerous times to prove the reproducibility [8,20].



Graph ref [1]

If interested in graphene based composite materials, thermal management applications, experiments and simulations on thermal transport in graphene nanostructures, thermal conductivity of graphene based MMC's can refer to [22-29].

III. CONCLUSION

The development in the technology led to many researches in material science based on nanotechnology. Materials with structure at nanoscale often exhibit unique electrical, thermal, mechanical properties and graphene is not an exception. As ages passed many researches and experiments were conducted and soon they confirmed that graphene exhibits high thermal properties than aluminum. In closure, we state the review of thermal trends of the graphene, aluminum, graphene-aluminum metal matrix composites. Raman spectroscopy is used to measure the amount of heat dissipation in the graphene and graphene based metal matrix composites. The brief review on these analyses revealed that graphene has high thermal conductivity compared to many other materials and even enhances the thermal and mechanical properties of aluminium.

ACKNOWLEDGEMENT

We thank our Professor Dr. K. Subramanyam, Professor in the Department of Mechanical engineering in RAGHU Educational Institutions, who provided insight and greatly assisted the work. We like to convey our thanks to the teaching staff who have contributed either directly or indirectly for the completion of our paper.

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