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Influence of Concentration of Graphene Oxide to Thermal Diffusivity in Nano-liquid Form Using Thermal Lens Method

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Abstract
This study examines the effect of graphene oxide (GO) concentration on thermal diffusivity in nano-liquid formulations using the thermal lens method. Nano-liquid samples with varied GO concentrations were prepared and analyzed. Results indicate an increase in thermal diffusivity with rising GO concentration up to a threshold, beyond which further increments yield diminishing returns. This behavior is attributed to the unique thermal transport mechanisms enabled by GO nanosheets. These findings offer insights for optimizing GO-based nano-liquids for thermal management applications. Moreover, the study underscores the efficacy of the thermal lens method for probing thermal properties in nanofluid systems.

Keywords: *thermal diffusivity, graphene oxide, concentration*

INTRODUCTION

Thermal lens spectrometry (TLS) is first explained by Gordon et al. (1965). According to Zamiri et.al (2011), thermal lens spectrometry (TLS) is one of the precise photothermal methods, which is based on the temperature slope due to retention of optical radiation and non-radiative relaxation of the excited atoms. It is proven in the paper published by Shahriari et.al (2016) that the mode-mismatched thermal lens method provides larger signal-to-noise output. Thermal lens (TL) method is one of the effects of photothermal. Thermal lens method is a method that is using a laser with a Gaussian intensity profile as an excitation laser beam that induces the beam temperature in a laser [1]. According to Shahriari et. al (2016), the heat produced is the strongest at the center as the concentration of the beam is the highest at the center. This temperature gradient by the heat produces a refractive index gradient which behaves like a converging or diverging lens depending on the change rate of refractive index with respect to temperature, $\mathrm{d}n = \mathrm{d}T$, is positive or negative [2]. The thermal lens method is very sensitive which makes it suitable for measuring thermal diffusivity of nanofluid [3]. The thermal lens method can be used to measure low optical absorption coefficients of transparent samples either in gasses or fluids [4].

British Chemist, B. C. Brodie (1859) discovered a highly oxidized form of natural graphite, named "graphon" which is currently known as "graphite oxide" or "graphene oxide". However, it has been re-emerged as a material of interest after the groundbreaking discovery of graphene and its diverse methods of synthesis [5]. Graphite oxide can be considered as a highly oxidized form of graphite with a higher inter-layer spacing due to the presence of a large number of oxygen functionalities [6]. The GO is a non-stoichiometric macro-molecule having controlled physical and chemical properties depending on the synthetic variables such as graphite precursor, type of the oxidant and the dose, stirring or sonication strength, oxidation temperature and duration. The most acceptable structural model proposed for GO is Lerf-Klinowski model in which, basal planes of GO are decorated by hydroxyl and epoxide groups, whereas the edges are mainly occupied by carboxyl and carbonyl groups in a random manner resulting in mixed sp2-sp3 carbon

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containing sheets.

The oxidized form of graphene named "Graphene oxide" (GO) is produced by the oxidation of bulk graphite powders via chemical oxidation processes. Graphene oxide have has a mixed structure bearing a variety of oxygen-containing various functional groups like epoxy (> O), hydroxyl (eOH), carbonyl (C=O) and carboxylic (eCOOH) groups [7].

In this study, powdered Graphene Oxide is diluted with distilled water to different concentrations of the nano-liquid with a ratio of 1g to 100ml of distilled water. In this study, the nano-liquids used were 0.5g/ml, 1.0g/ml, 1.5g/ml, 2.0g/ml and 2.5g/ml [8].

EXPERIMENTAL METHOD

The GO nano-liquids prepared by measuring the ratio of GO powder to distilled water in fixed ratio of 1g to 100ml. The solutions prepared are in varied concentrations 0.5g/ml, 1.0g/ml, 1.5g/ml, 2.0g/ml and 2.5g/ml. The prepared solutions are then stirred using magnetic stirrer for 60 minutes, and the solution is maintained at 25°C before placing the solution for thermal diffusivity testing by using dual-beam mode-mismatched thermal lens method [8].

Dual-beam mode-mismatched thermal lens method is due to its sensitivity which makes it suitable to measure thermal diffusivity of nanofluid [3]. Prior to the study, the beam profiling of thermal lens was performed to optimize the laser source for probe beam and excitation beam as well as to achieve the maximum outpower from the thermal lens system.

In this study, the higher power laser of the blue laser (λ=473nm) was used as excitation laser whereas the slightly lower power laser of the green laser (λ=543nm) was as the probe beam laser. The output signal of the system was detected by photodiode sensor. The output signal detected will then transferred to the lock-in amplifier to be lock-in before analysis is done. The default settings of the lock-in amplifier were set as 100ms sensitivity, and 300ms time constant. The reason to set the setting of lock-in amplifier to 100ms sensitivity is because there is no any pre-amplifier connected to the setup. So, in order to obtain maximum output signal, the sensitivity has to be set at lower sensitivity values although the graphs will be more fluctuated. The optical arrangement of the thermal lens setup is as was shown in the Figure 1.

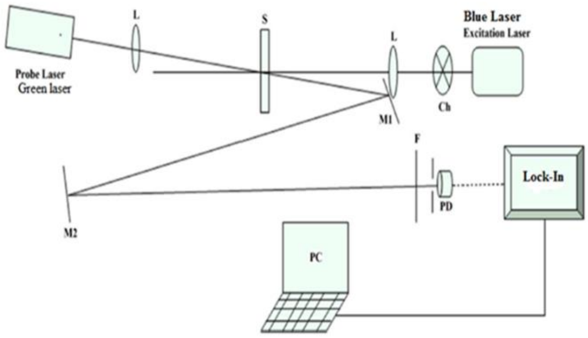

Figure 1. Schematic diagram of the dual-beam mode-mismatched lens method setup.

After that, the experiment to determine the thermal diffusivity of the nano-liquids is repeated 3 times and an average value of the thermal diffusivity is obtained. The experimentally obtained data is then compared to theoretical thermal diffusivity values.

RESULTS AND DISCUSSION

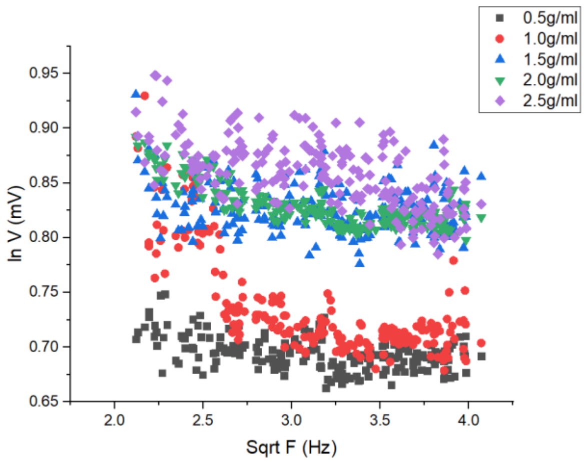

Figure 2. Dependence of amplitude signal as function of Sqrt Frequency, F of GO with at different concentration.

From Figure 2, it shows that when the concentration ratio g/ml increases, the amplitude signal of voltage higher, resulting in an increment of the slope of graph (ln V/sqrt F) as summarized shown in Table 1 and Figure 2.

Table 1. Thermal diffusivity of GO with different concentrations.

Concentration (g/ml)	**Experimental Thermal Diffusivity** ($\times 10^{-7} m^2 s^{-1}$)
0.5	0.14±0.013
1.0	0.15±0.013
1.5	0.18±0.012
2.0	0.21±0.016
2.5	0.24±0.015

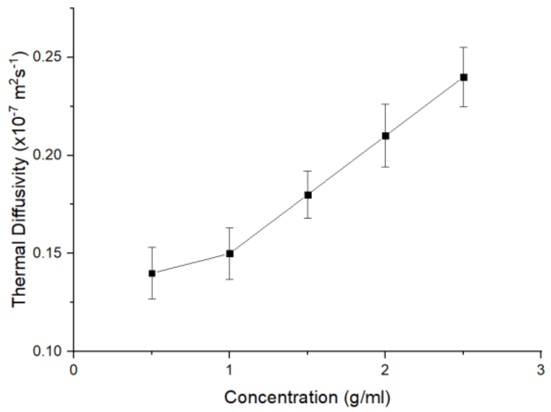

Figure 3. Graph of different concentrations against thermal diffusivity.

From Table 1, it is clearly noticed that when the particle concentration of the GO solutions increases, thermal diffusivity also increases [9] [10]. As predicted by the thermal equilibrium model, the nanofluid's decreased specific heat capacity explains the increase in thermal diffusivity [11]. As the concentration of nanoparticles increases, so does the specific heat capacity. The observed enhancement of the thermal diffusivity is a result of both a drop in specific heat capacity and an increase in thermal conductivity [12]. Additionally, when the concentration of nanoparticles increases, optical absorption rises as well, improving thermal diffusivity [13] [14].

Increasing the concentration of graphene oxide can have a significant impact on the thermal diffusivity of materials. Several studies provide insights into how changes in graphene oxide concentration influence thermal properties. For instance, research on graphene-based lubricants indicates that the thermal conductivity and viscosity of graphene lubricants increase with higher graphene concentrations [15]. Similarly, in composite materials, the thermal conductivity can increase with the rising content of reduced graphene oxide [16].

Moreover, the addition of functionalized graphene oxide to materials like polyetherimide has been shown to enhance thermal conductivity [17]. However, it is essential to note that the relationship between graphene oxide concentration and thermal diffusivity may not always follow a linear trend. Studies on dispersions of silicon oxide nanoparticles suggest that the thermal diffusivity can pass through a minimum threshold with increasing concentrations [18].

Furthermore, the thermal diffusivity of graphene composites can be influenced by the quantity of introduced graphene, with differences in thermal diffusivity observed between different directions as the graphene content increases [19]. Additionally, the thermal conductivity of nanofluids containing graphene oxide nanosheets can be significantly enhanced with higher loading levels [20].

The decrease in specific heat capacity with increasing graphene nanoparticle concentration, as observed in studies, can explain the increase in thermal diffusivity. When graphene nanoparticles are suspended in a fluid, the specific heat capacity of the suspension decreases as the nanoparticle concentration rises. This reduction in specific heat capacity is attributed to the lower heat storage capacity of the graphene nanoparticle suspension compared to the base fluid. Consequently, the decrease in specific heat capacity contributes to the increase in thermal diffusivity of the material, as noted in the research on graphene nanofluids [21]. The enhanced thermal properties of graphene dispersions, as highlighted in the study by [22], further support the notion that changes in specific heat capacity due to graphene concentration variations can influence thermal diffusivity.

CONCLUSION

This study successfully showed the thermal diffusivity measurement by using dual-beam mode-mismatched thermal lens setup. When the particle concentration increases, thermal diffusivity increases.

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