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Dependence of thermal diffusivity on particle size in Au nano-fluid

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In this paper we report the measurement of thermal diffusivity of gold nanofluid prepared by γ-radiation with various particle sizes ranging from 7.0 nm to 18.7 nm. The thermal lens technique is used to measure thermal diffusivity of gold nano-fluid. In this technique a diode laser (wavelength 514 nm, power 80 mW) and He-Ne laser were used as the excitation source and probe beam respectively. Experimental results showed that thermal diffusivity values of nanofluid increase when the particle size increase

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1. Introduction

Metal nanoparticles with 1–100 nm in diameter possess many interesting unique electronic and optical properties. The applications of nanofluid such as heat transfer fluids in automotive, electronic cooling, as optical switching and electronic devices, Medical therapies and drug delivery and so many other applications have been recently studied [1-7].

Thermal diffusivity of nanoparticle becomes the important parameter determining the performance of many engineering systems. The application of nanoparticles for increasing the efficiency of thermoelectric energy conversion enhanced heat conduction in heat transfer fluids. All of these applications depend on the thermal transport between the nanoparticles and the base fluid [8].

Among the photothermal techniques, thermal lens technique (TL) is most sensitive and reliable technique for measuring thermal diffusivity of fluid. This technique relies on temperature gradient attribute by absorption of optical radiation and nonradiative relaxation of the excited molecules. In TL experiment the excitation laser beam must have a Gaussian profile, which can produces the temperature distribution with radially dependence. Furthermore this temperature gradient produces a refractive index gradient which behaves like a converging or diverging lens depending on whether, dn/dT is positive or negative and the laser beam can be diverge or focus by this lens, any change in intensity of laser will be detected by detector and related to the thermo optical parameter of sample [9-10]. In this article we present study on thermal diffusivity of nanofluid with different particle sizes to investigate the effect of size on thermal diffusivity.

2. Experiment

We prepared Au nanoparticle in polyvinyl alcohol (PVA) by using of hydrogen tetrachloroaurate (III) hydrate, premion (metals basis), ($HAuCl_4.3H_2O$ with 99.999% purity), 2.5 g PVA and 1 ml isopropanol. The PVA and isopropanol were used as a colloidal stabilizer and radical scavenger of hydroxyl radical, respectively. The PVA solutions were prepared at room temperature by dissolving PVA powder in 50 ml deionized water, magnetically stirred for 20 minutes and bubbled with nitrogen gas used to remove oxygen. The concentration of Au nano-particle in PVA was calculated to be 1.4715×10^{-4} M.

The sample solution was then irradiated with γ-radiation at different doses, i.e 10, 30, 50 and 70 kGy to produce samples with different particle sizes ranging from 7.0 nm to 18.7 nm. The samples were quoted as S1, S3, S3 and S4, accordingly. In this process, γ-irradiation produces hydrated electrons that reduce the gold ions to gold atoms, which then aggregated to a certain particle size and distributed homogenously in the solution. The average diameters of Au nanoparticles was measured using nanophox machine (Sympatec GmbH, D-38678) and Optical absorption spectra were obtained using a UV visible spectrophotometer (Shimadzu-UV 1650PC). Transmission electron microscopy (TEM) observation was performed using a Hitachi (H-7100) electron microscope at accelerating voltage of 120 kV. The particle shapes and the polydispersity of samples were notified

The thermal lens (TL) experimental setup is shown in Fig. 1. Measurements were carried out using a diode laser (532 nm and 80 mW) as an excitation light and a He-Ne laser (632.8 nm and 0.5 mW) as a probe beam. The excitation beam was focused by a lens with 21 cm focal length and the sample was positioned at its focal plane. A

chopper with variable frequency controls the exposure of the sample to the excitation beam. The probe beam was focused by a lens with 5 cm focal length and aligned at an angle smaller than 1.5° with respect to the excitation beam. The focused probe beam waist is positioned around $\sqrt{3}\,z_c$ to the cuvette. A bandpass filter was placed over the pinhole to prevent stray light entering the photodiode (PD). The output of the PD was sent to the storage oscilloscope for further analysis. The LabVIEW software was used to capture the time history data from oscilloscope and to normalized it with respect to signal at time $t = 0$.

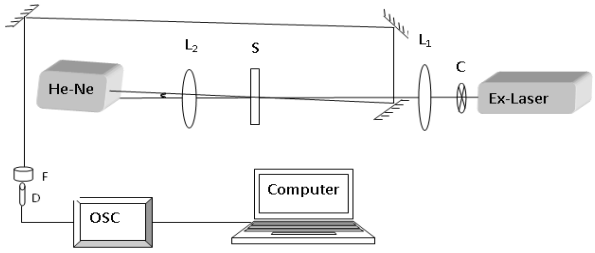

Fig. 1. Schematic diagram of experimental apparatus.

3. Results and discussion

The probe beam intensity at the detector plane can be written as an analytical expression for the absolute determination of the thermo-optical properties of the sample, as [10]:

$$I(t) = I(0)\left[1 - \frac{\theta}{2}\tan^{-1}\left(\frac{2mV}{\left[(1+2m)^2+V^2\right]\frac{t_c}{2t}+1+2m+V^2}\right)\right]^2 \quad (1)$$

where

$$V = \frac{z_1}{z_c};\ \theta = -\frac{p_e A_e L}{\kappa\lambda}\left(\frac{dn}{dt}\right);\ m = \left(\frac{w_p}{w_e}\right)^2;\ D = \frac{w_e^2}{4t_c}, \quad (2)$$

Here, $I(0)$ is the initial intensity when t is zero, p_e is the excitation beam power (80 mW), A_e is the absorption coefficient (cm^{-1}), L is the sample thickness, λ is the laser wavelength (632.8 nm). The dn/dT is the change refractive index of the sample, $z_c = w_0^2/\lambda$ is the confocal distance (cm),

Z_1 is the distance of the probe laser beam waist to sample, D is the thermal diffusivity of the sample (cm^2/s), t_c is the characteristic thermal time constant. The parameter, θ and t_c can be determined by fitting the experimental data to Eq. (1). Thus thermal diffusivity was calculated using Eq. (2).

UV-Vis absorption spectra for Au nanofluid are shown in Fig. 2. The absorption peak at 528 nm is due to the surface plasmon absorption (SPR) of free electron at surface of Au nanoparticle.

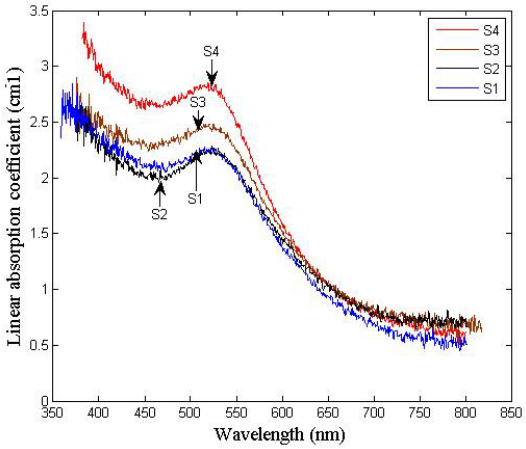

Fig. 2. Optical absorption spectra of fluids containing Au nanoparticles.

SPR can be imaged classically by this way that, the electric field of an incoming wave induces a polarization of the electrons with respect to much heavier ionic core of silver nanoparticles. Consequently a net charge difference occurs which in turn acts as a restoring force. This creates a dipolar oscillation of all the electrons with the same phase. Also from the graph it is clear with the increasing particle size the optical absorption peak shift to higher wavelengths.

Fig. 3 shows a typical TEM image for the prepared Au nanoparticles particle with size of 18.7 nm. The image shows that the produced nanoparticles are spherical and homogenously distributed in the solution. To confirm accuracy of our set up we measure thermal diffusivity of toluene as standard sample. Fig. 4 shows the normalized TL time evolution signal, for toluene where the solid lines corresponding to their best fitting to Eq. (1). From this fitting the adjustable parameter values θ = (5.798 ± 0.028) and t_c = (0.166 ± 0.002) s were obtained and the calculated value of thermal diffusivity D was (1.088 ± 0.12) $\times 10^{-3}$ cm^2/s. The thermal diffusivity of toluene reported in the literature is 1.090×10^{-3} cm^2/s [11].

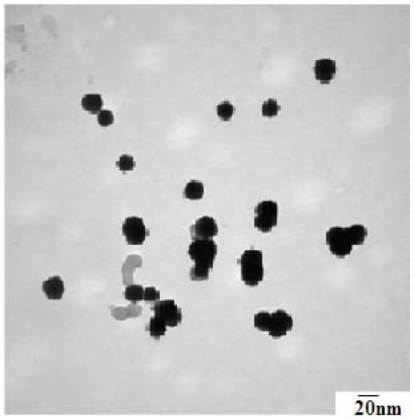

Fig. 3. Transmission electron micrographs of AU nanoparticles prepared by γ-radiation method.

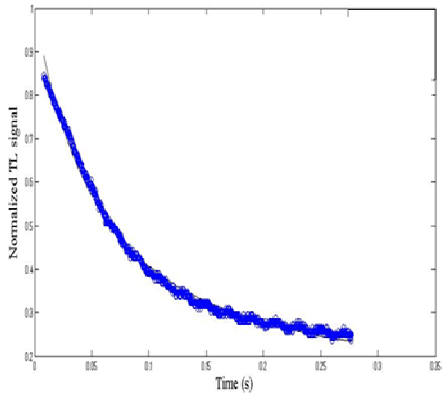

Fig. 4. The normalized TL time evolution signal for toluene. Solid line corresponds to the best fit of Eq. (1) to the TL experimental data.

Fig. 5 shows a typical normalized time evolution of thermal-lens signal for sample S4. After finding θ and t_c thermal diffusivity was calculated using Eq. 2. For example from this fit the values of $\theta = (1.356 \pm 0.015)$ and $t_c = (0.0047 \pm 0.0001)$ s which gives the thermal diffusivity $D = (24.49 \pm 0.53) \times 10^{-3}$ cm^2/s. Similar TL signals were analyzed for the rest of our samples and the value of thermal diffusivities are listed in Table 1.

Table 1. The effect of particle size nano-fluid Au at 1.4715×10^{-4} M concentration on thermal diffusivity.

Nano-Fluid samples	Average particle size (nm)	$t_c\times10^{-3}$ (s)	θ	$D\times10^{-3}$ (cm^2/s)
S1	7.0	8.3 ± 0.2	1.041 ± 0.020	1.405 ± 0.044
S2	10.0	7.8 ± 0.3	1.493 ± 0.032	1.504 ± 0.058
S3	13.0	5.2 ± 0.1	1.124 ± 0.012	2.232 ± 0.004
S4	18.7	4.7 ± 0.1	1.314 ± 0.0165	2.449 ± 0.053

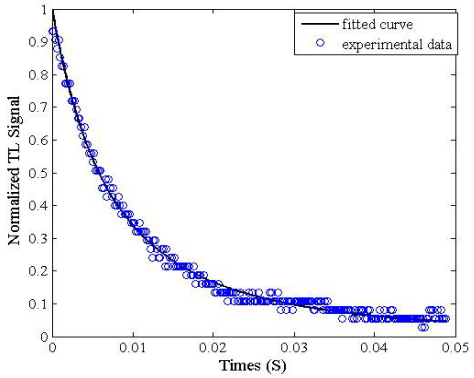

Fig. 5. Time evolution of the thermal lens (TL) signal. Solid line corresponds to the best fit of Eq. (1) to the TL experimental data.

Fig. 6 shows the thermal diffusivity as a function of particles size where thermal diffusivity increases with the increasing in particle size. The solid line indicates the best fitting of experimental data.

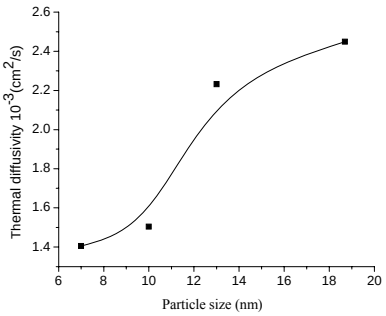

Fig. 6. Thermal diffusivity as a function of particles size.

This increase of thermal diffusivity with increasing particle size is due to increase of volume fraction of nanoparticles [12] dispersed in solution. The phonon scattering at interface of particle and liquid can also have effect on thermal diffusivity.

4. Conclusions

We systematically studied the effect of size on thermal diffusivity of Ag nanofluid prepared by γ-radiation at different doses but with the same concentrations (1.4715×10^{-4} M). The obtained results show that thermal diffusivity of nanofluid increases when the size of particle increases. The increase in thermal diffusivity was attributed to the increasing particle size and phonon scattering at solid liquid interface.

Acknowledgements

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