Thermal study of porous and compact SiO_2 nanoparticle nanoliquids by TWRC technique

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Background – Photothermal studies were carried out to evaluate the thermal characteristics of silicon nanoparticles (NPs). Compact and mesoporous silicon NPs were synthesized using the modified Stöber method. Thermal wave resonance cavity (TWRC) technique was used to determine the thermal diffusivity and effusivity of compact and porous SiO_2 water based-nanoliquids by scanning the cavity length by moving a cylindrical probe relative to a photopyroelectric (PPE) detector in a liquid medium in a thermally thick region. This technique has potential in the measurements of the thermal diffusivity and effusivity of small volumes of nanoliquids and thick non-transparent samples. The complementary technique dynamic light scattering (DLS) was used to determine the particle size.

Methods – For the synthesis of compact SiO_2 NPs, 60 mL of ethanol containing 25 mL of distilled water, 1 mL of TEOS and 4.2 mL of ammonia hydroxide were employed. The reaction solution was stirred (300 rpm) for 3.5 h at room temperature to carry out the TEOS hydrolysis and condensation process. The resulting colloidal suspension was centrifuged (4000 rpm, for 15 min). The particles were recovered in a methanol/water wash in a 1:1 volume ratio, repeating the process at least 5 times. Finally, they were left to dry in a muffle at 70ºC [1].

On the other hand, for the synthesis of porous SiO_2 NPs, 0.2 g of CTAB surfactant were added to 100 mL of distilled water with 1 mL of NaOH at 2 Molar at a temperature of 80º C. At this point, 1 mL of TEOS was injected and maintained at 500 rpm. Synthesis was left for 2 h. The solution was separated by centrifugation at 4000 rpm for 10 min and the white precipitate was placed in a flask and stirred at 200 rpm for 10 min with distilled water. This procedure was followed at least 3 times to wash the NPs. When the particles were washed, to remove the surfactant, they were subjected to a thermal treatment in a muffle. The white precipitate was placed in a high temperature crucible and ramp heating at 10ºC/min was used until it reached 550ºC, at which point it was left for 4 h at this temperature and allowed to cool to room temperature. A white powder was obtained for the mesoporous NPs. It was pulverized in a mortar for further use [2].

Results – For the diffusivity analysis, the theoretical model of the TWRC was used, for thermally thick samples, where qLs>>1, so the sensor output voltage of the magnitude of the complex expression, Eqn. 1 can be deduced as:

$$V(Ls) = V_0 e^{-qLs} \qquad \text{Eqn. 1}$$

For the analysis of the effusivity, the theoretical model was used:

$$\theta(\omega) = \frac{[(1-e^{\sigma_p l_p})(1+b)+(e^{-\sigma_p l_p}-1)(1-b)]}{[(g-1)(1-b)e^{-\sigma_p l_p}+(1+g)(1+b)e^{\sigma_p l_p}]} \qquad \text{Eqn. 2}$$

where $\theta(\omega)$ is the output signal of the pyroelectric detector, $\omega = 2\pi f$, $\sigma_p = \frac{1+i}{\mu_p}$, $\mu_p = \sqrt{\frac{\alpha_p}{\pi f}}$, α_p, l_p are the pyroelectric thermal diffusivity and its thickness respectively, $b = \frac{e_s}{e_p}$ y $g = \frac{e_g}{e_p}$, con e_s, e_g, y e_p the thermal effusivities of sample, gas (air), and pyroelectric, respectively. Taking the PPE signal as a function of the frequency sweep, it is possible to obtain the thermal effusivity of the sample from the best fit of Eqn. 2 to the experimental data, taking b as the adjustment parameter [3,4].

Table 1. Thermal properties values for the graphene NPs /resin

Type	Diameter	$\alpha_{Amplitude}$ $\times10^{-7}$(cm^2/s)	Effusivity ($Ws^{1/2}$/mk)	Thermal conductivity (W/mK)	Enhancement %	Literature value
Distilled water	--	1.4	1580	0.5606	-	
Compact SiO_2	211 ± 12nm	1.49 ± 0.02	1672 ± 36	0.6914	15.1%	0.95×10^{-7} [2]

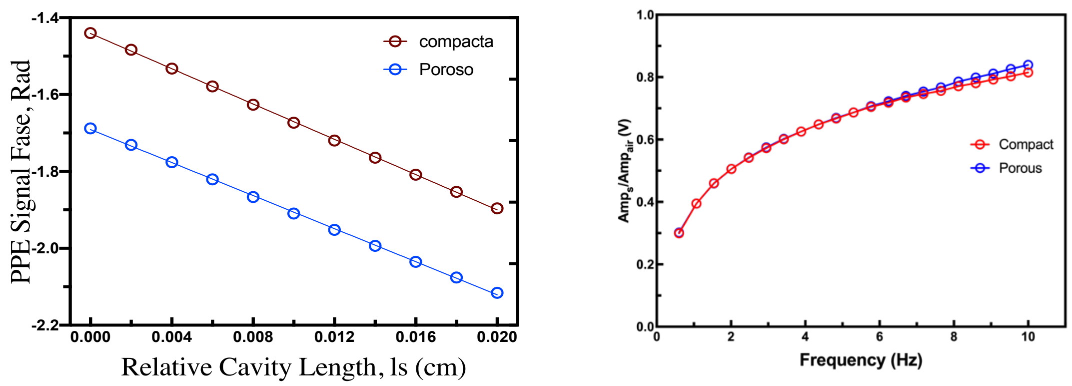

Fig. 1. (a) Thermal diffusivity of SiO_2 nanoparticles porous and compact. (b) Thermal effusivity of SiO2 nanoparticles porous and compact

The compact and porous silica NPs were analyzed using the TWRC technique to determine the diffusivity, effusivity and thermal conductivity, where an increase in the thermal diffusivity of the porous SiO_2 NPs of 23.33% was obtained compared with the diffusivity of water and a 15.1% enrichment of compact SiO_2 compared to the diffusivity of water.

Conclusions – Compact and porous SiO_2 NPs were synthesized with monodisperse Stöber and modified Stöber method. The analyzes showed that having a larger surface area in the porous SiO_2 nanoparticles increases the thermal diffusivity compared to the diffusivity of the compact SiO_2. The TWRC technique is a promising technique for analyzing transparent, opaque, and thermally thick nanofluids.

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