

Photothermal properties of nanofluid containing graphene oxide- copper nanoparticle hybrid materials prepared by using *Paramignya trimera* extract

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2.1. Preparation of *Paramignya trimera* extract

The extraction workflow and images of the obtained extract are shown in Fig. S1. *Paramignya trimera* plants were collected in Phu Quoc Island (Vietnam), washed several times with tap water and distilled water, then dried at 60 °C for 12 h. The dried samples were cut into small pieces (1 – 3 mm), ground, and dried again at 60 °C for 6 h. Next, 10 g of *P. trimera* powder was boiled with 150 mL of distilled water at 90 °C for 120 min under magnetic stirring at 800 rpm. The resulting solution was cooled and filtered twice to remove the residue, collecting the pure *P. trimera* extract. This extract was stored at 4 °C for later use in the synthesis of copper nanoparticles (CuNPs).



Fig. S1. Schematic diagram of the process for preparing *P. trimera* extract

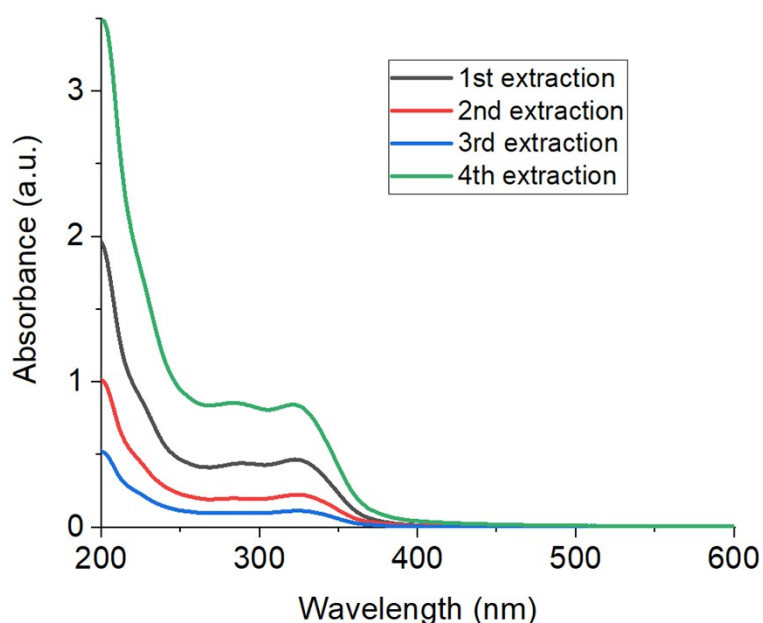


Fig S2. UV-Vis absorption spectra of *P. Trimera* at different extraction times

Figure S2 presents the UV–Vis absorption spectra of the extract obtained from four consecutive extraction batches. All spectra show a strong absorption band in the 220–300 nm region, which is characteristic of phenolic and flavonoid compounds. These biomolecules act as natural reducing and stabilizing agents in the green synthesis of Cu nanoparticles. The decreasing absorbance from the 1st to the 4th extraction reflects the expected reduction in phytochemical concentration with repeated extraction.

Preparation of GO

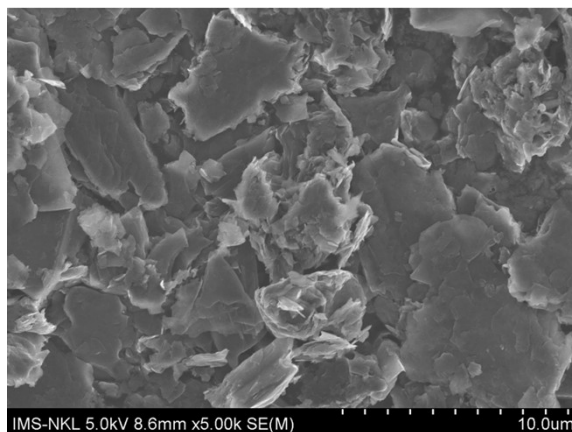


Fig. S3. Graphite powder

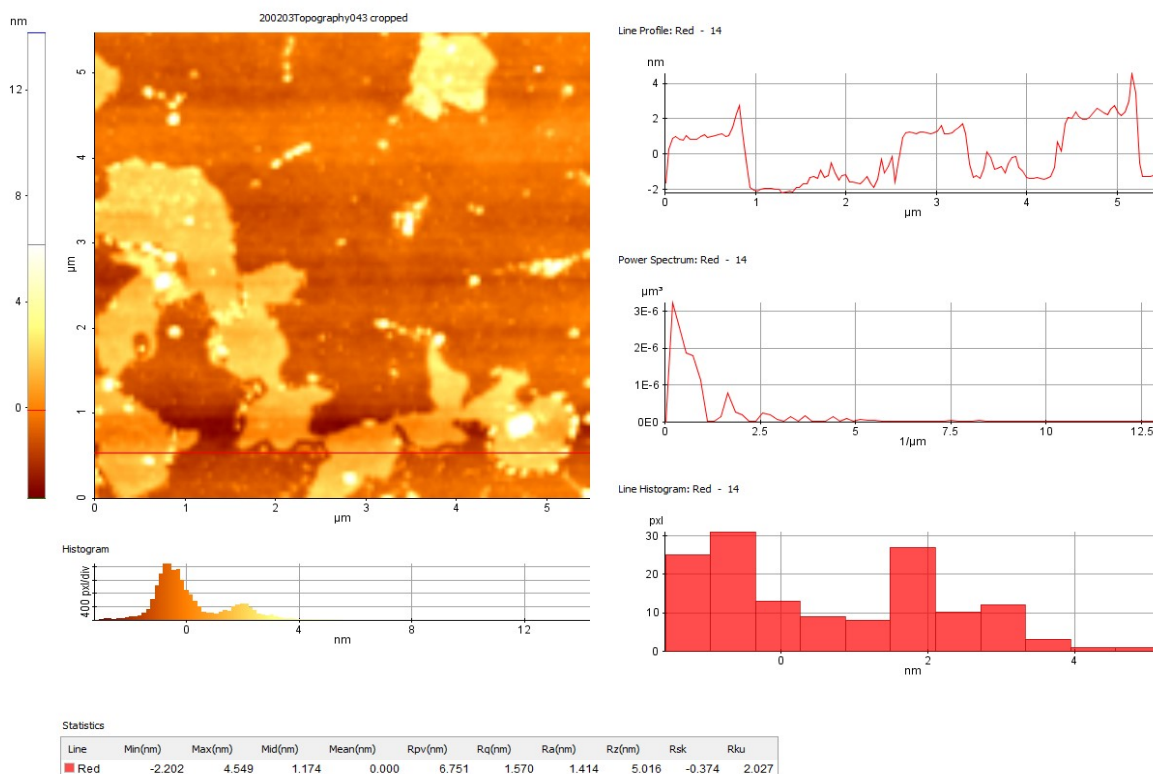


Fig. S4. AFM image of the prepared graphene oxide

Graphene oxides were prepared by using the Hummers method. Firstly, 1 g of graphite (Sigma-Aldrich) was put and stirred in 50 mL of H_2SO_4 , then an amount of 3.5 g of $KMnO_4$ was slowly added to the solution. The temperature was raised to $35^\circ C$ under continuously stirring for 2 h. After that, 10 ml of H_2O_2 was added dropwise into the solution until the bubbling was completed. Finally, the obtained sample was filtered and cleaned with a 10% HCl aqueous solution and distilled water to obtain GO. The obtained GO was then dispersed in distilled water using bath ultrasonication for 45 min (40 kHz, 150 W, Elmasonic S 30 H) to create the nanofluid with concentrations of 0.01 vol.% GO.

2.2. Preparation of CuNPs

10 mL of the *P. trimera* extract obtained from *P. trimera* roots was slowly added to 20 ml $CuSO_4$ (0.1M) solution under continuous stirring. The mixture under constantly stirring for 12 hours at room temperature. After that, the obtained solution was centrifuged at 10 000 rpm to separate the CuNPs (Fig. S5). The obtained CuNPs were then dispersed in distilled water for 45 minutes using bath ultrasonication for 45 min (40 kHz, 150 W, Elmasonic S 30 H) to create the nanofluid with concentrations of 0.01 vol.% CuNPs.

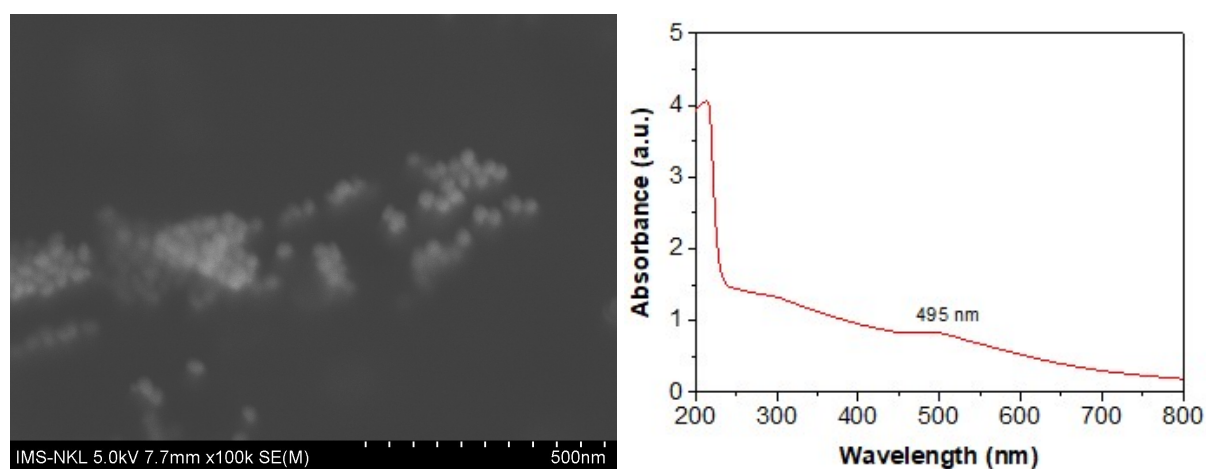


Fig. S5. SEM and UV-VIS of CuNPs prepared by using *P. trimera* extract as reducing agent

2.3. Thermal conductivity measurement

To validate the measurement technique, the thermal conductivity of DI water was measured at temperature of $30^\circ C$ using an HTL-04 having a maximum uncertainty of $\pm 2.0\%$ supplied by Eternal Engineering Equipment Ltd., India. HTL-04 is designed according to the principal of guarded hot plate method and compared with the reference value of $0.614 W \cdot m^{-1} \cdot K^{-1}$. The measured thermal conductivity of $0.607 W \cdot m^{-1} \cdot K^{-1} \pm 0.004$ for DI water is slightly lower than the reference value about 0.12 %. The experimental result is an average of 5

measurements for each nanofluid. The pressure, humidity and environment temperature were kept constant during the experiment.