Laser-Assisted Functionalization of Graphene with High-Entropy Alloy Nanoparticles for Improved Dispersion in Epoxy Systems

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Abstract
Achieving uniform and stable dispersion of graphene in epoxy matrices remains a persistent challenge due to strong π–π interactions and the resulting tendency for restacking and agglomeration. In this study, a laser-assisted approach is employed to functionalize graphene with high-entropy alloy (HEA) nanoparticles, enabling the formation of hybrid nanostructures with modified surface characteristics. Laser-assisted defect engineering enables site-specific anchoring of HEA nanoparticles on graphene, transforming it into a hybrid nanostructure with enhanced dispersion stability and interfacial activity in epoxy systems. Controlled laser irradiation introduces localized defect sites on graphene surfaces, which act as nucleation centers for HEA nanoparticles and promote strong attachment, reducing graphene restacking and agglomeration. The dispersion stability was quantitatively evaluated using multiple light scattering (backscattering, BS) analysis over the sample height (~0–42 mm) and time. The BS profiles exhibit minimal spatial variation, with fluctuations confined within ~±0.2–0.3%, and no significant temporal drift or phase separation, indicating excellent colloidal stability without sedimentation. Notably, the absence of pronounced BS gradients across the full height confirms homogeneous particle distribution and suppressed migration during measurement. In addition, spatial mapping reveals a largely uniform intensity distribution across the sample, with only minor local fluctuations, supporting the presence of a homogeneous dispersion state.

References

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[2] Wang, L., Yin, K., Xiao, J. *et al.* *Nat Commun* **17**(2026), 2121

Figures

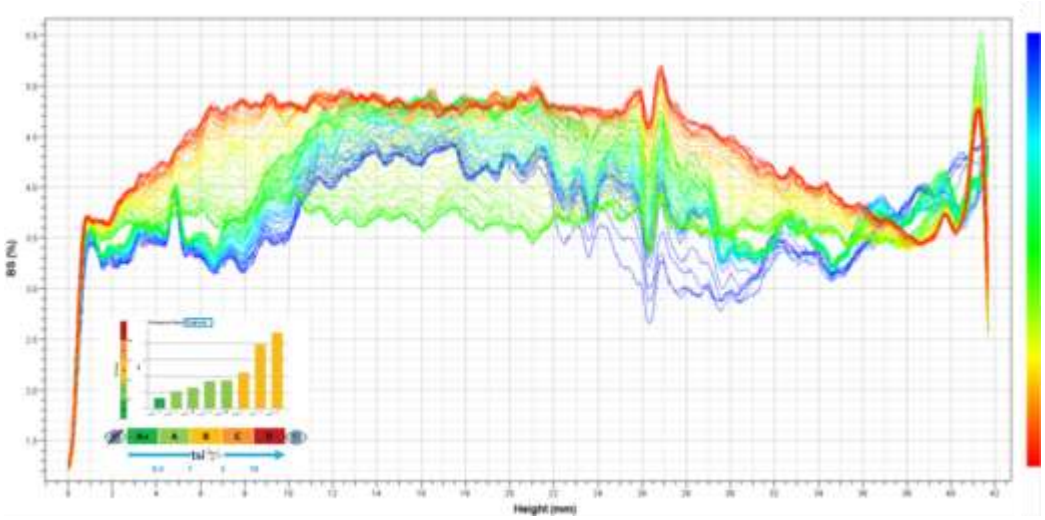

Figure 1: Backscattering (BS) profiles as a function of sample height (0–42 mm) over time, obtained from multiple light scattering analysis of HEA–graphene dispersed in epoxy.