Design–Synthesis–Performance Framework for Advanced Nanomaterials using Continuous Flow

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The rapid, sustainable synthesis of advanced nanomaterials is essential for meeting global energy, environmental, and catalytic challenges. Our work employs continuous flow, a unique supercritical fluid-based process utilized in less than 1% of reported hydrothermal methods, offering clean solvent alternatives, rapid kinetics, and molecular-level control. This approach enables scalable, cost-effective, and durable nanomaterials production across diverse applications. Our materials portfolio spans carbon nanostructures, from graphene derivatives to carbon quantum dots (CQDs) [1-5]. Nitrogen-doped CQDs demonstrate enhanced photoluminescence properties (QY up to 40%, lifetimes of 13 ns), excitation-independent emission, and exceptional sensing performance for heavy metals such as chromium (VI). Life-cycle assessment confirms continuous flow as a greener alternative to batch synthesis. Beyond carbon systems, we engineer functionalized 2D nanostructures with controlled crystallinity, homogeneous composition, and high conductivity, achieving flexible films with conductivities up to 4×10^4 S cm^{-1}. Furthermore, strain-engineered nanocomposites reveal tunable band structures and work functions, enabling dual catalysis under visible light and mechanical activation. Coupled with density functional theory (DFT) modelling, our research advances a structure–property–performance framework, accelerating rational materials design. These findings establish continuous flow as a transformative technology, closing the loop between design, synthesis, and application, and supporting the vision of "making materials that matter."

References

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