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Engineering Next-Generation Materials: From Multifunctional Nanocomposites to Reconfigurable Nanoarchitectures

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ABSTRACT

This work explores three interconnected research directions that address critical challenges in developing advanced and adaptive materials. The first focus is on **multifunctional nanocomposites**, where polymer matrices are reinforced with carbon nanotubes, graphene, or MXenes. Novel processing techniques—such as supercritical foaming and microcellular structuring—are employed to optimize filler orientation and connectivity, leading to enhanced thermal management, high electrical conductivity, and effective electromagnetic interference (EMI) shielding in lightweight architectures.

Building on these advances, the second research thrust examines the **nanomechanics of nanoscale constituents**, such as 2D materials and polymer thin films. Using friction force and nanoindentation analyses with advanced atomic force microscopy, this work reveals how nanoscale phenomena—including chain folding in polymers and surface termination effects in 2D materials—govern mechanical properties such as elasticity, wear resistance, and interfacial stability. These insights provide critical guidelines for optimizing thin-film systems in flexible electronics and tribological applications.

Lastly, these materials and techniques are integrated into **nanoarchitected systems** with hierarchical, 3D frameworks. Electrochemical microactuators built on these 3D architectures are combined with microfabrication-compatible, stimulus-responsive materials, enabling ultra-low-power operation in compact designs. This approach paves the way for reconfigurable micromachines, sensing platforms, and microscale energy devices, with applications spanning biomedical instrumentation and portable electronics.

Together, these three research directions establish a cohesive framework for designing next-generation materials and devices, demonstrating how nanoscale breakthroughs can drive transformative technologies in energy storage, sensing, and micromechanical systems.