

From Laser–Matter Interaction to Functional Materials: Small Particles, Big Impact

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Laser-based surface engineering is commonly associated with structuring, machining, and surface modification. Yet, beyond geometry, laser irradiation can fundamentally alter how surfaces, interfaces, and materials form, transform, and evolve. Under highly localized nonequilibrium conditions, laser–matter interactions create materials with unique structural, chemical, and functional characteristics that often persist far beyond the initial interaction event. This concept is particularly evident in laser synthesis and processing of colloids, where extreme heating and cooling rates, transient pressure fields, and confined reaction environments provide access to material states far from equilibrium and often inaccessible by conventional synthesis routes. Recent advances in understanding laser-induced heating, stress generation, fragmentation, and phase transformations increasingly enable these processes to be engineered rather than merely observed.

Microparticle laser fragmentation in liquids (MP-LFL) serves as an illustrative example. Here, micrometer-sized feedstocks are transformed into surfactant-free nanoparticles through photothermal and photomechanical processes [1,2]. Remarkably, near-quantitative microparticle-to-nanoparticle conversion can be achieved under suitable processing conditions (Fig. 1a), highlighting MP-LFL as a scalable route for the efficient production of functional nanomaterials [2]. Importantly, these nanoparticles are not merely products of laser processing, but carriers of a distinct processing history reflected in their microstructure, defect chemistry, interfaces, and surface state [3].

Rather than being viewed as an end product, such particles can serve as functional building blocks for subsequent material transformations. Their laser-defined history provides new opportunities to tailor microstructure evolution, surface functionality, and material performance in downstream manufacturing processes. In this perspective, the future of laser-based surface engineering may lie not

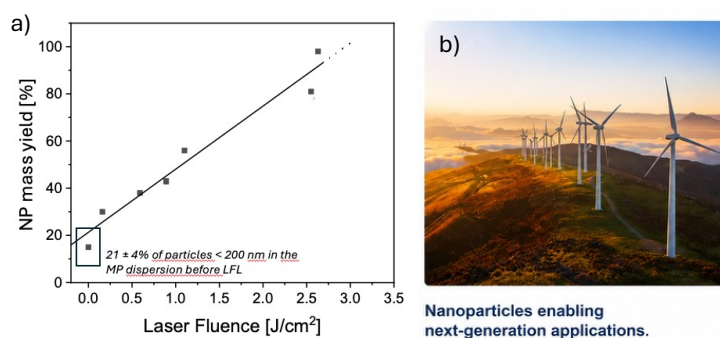


Figure 1: (a) Laser fluence dependence of nanoparticle yield during nanosecond MP-LFL [2]. (b) Application perspective: feedstock engineering with laser-generated nanoparticles for additive manufacturing, from polymer prototyping to permanent magnets

only in structuring surfaces, but in programming material functionality through controlled nonequilibrium transformations across interfaces and length scales. The integration of laser-generated nanoparticles into advanced manufacturing routes offers a pathway from fundamental laser–matter interactions to technological implementation (Fig. 1b), ranging from feedstock engineering in additive manufacturing [4] to functional materials for sustainable energy technologies [5].

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