Tunable Laser Nanostructuring for van der Waals Materials

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Two-dimensional (2D) layered transition metal dichalcogenides (TMDCs) have attracted tremendous research interests due to their unique properties for developing new-generation electronic and optoelectronic devices [1]. Nanostructures made from transition metal dichalcogenides represent unique platform for nanophotonics due to its high dielectric constants and nontrivial excitonic physics. The important feature of TMDCs nanoparticles (NPs) that distinguishes them from pure all-dielectric silicon NPs is the possibility of realization of Mie-exciton coupling regime that boosts light-matter interaction at the nanoscale manifesting itself in resonant enhancement of second harmonics generation [2], light scattering [3] and photothermal response [4]. However, it is worth noting that despite the recent significant progress in the field of dichalcogenide nanophotonics, the problem of nanostructuring of TMDCs remains open. On the one hand, it can be solved using standard technological approaches (such as lithography, ion beam etching). However, these methods have several limitations. For instance, they do not facilitate the production of spherical TMDCs nanoparticles. Meanwhile, various theranostic approaches rely on resonant spherical nanoparticles (NPs). These NPs enable both the visualization of nanoparticles within biological tissues and the treatment of malignancies through nanoparticle-enhanced phototherapy.

This study addresses the challenge of nanostructuring vdW materials by showcasing, for the first time, the remarkable versatility of the femtosecond laser synthesis method for producing colloidal nanoparticles (NPs) from vdW materials and perovskites. Our approach enables precise control over the morphology, size, composition, and optical properties of NPs, achieving high colloidal stability and maintaining the original crystalline structure of over 50 vdW materials. We have demonstrated that laser synthesis can produce a diverse array of nanostructures, including fullerene-like, polygonal, and pyramidal shapes from transition metal dichalcogenides (TMDCs), single-crystalline NPs from M(A)Xenes, and crystalline nanocubes from perovskites. Additionally, it was shown that the size of colloidal vdW nanoparticles can be varied from 10 to 150 nm. Molecular dynamics simulations further elucidate the crystallization processes involved, revealing that both heterogeneous and homogeneous nucleation mechanisms contribute to the formation of these nanostructures, with the size and core-shell ratio being dependent on the cooling rate.

The successful demonstration of this method not only provides a new tool for fabricating vdW-based NPs but also opens vast potential for further innovations in scientific research and technological applications. The ability to create such diverse and well-defined nanostructures paves the way for advancements in numerous fields and offers exciting prospects for future exploration beyond the current applications of layered materials.

References

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