Enhancing the productivity in pulsed laser synthesis of nanomaterials and its applications

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Abstract. Pulsed laser synthesis (PLS) of nanomaterials in liquids is a promising technique for synthesizing high-purity nanoparticles. However, its industrial scalability is limited by low production rates. This contribution discusses strategies to enhance nanoparticle yield as accurate control of the temporal dispersion and spatial beam shaping. Additionally, we explore applications of PLS-derived nanoparticles.

1 Introduction

Nanotechnology is rapidly transforming numerous scientific and industrial fields, driving the demand for advanced materials with enhanced properties. As a result, the development of innovative nanoparticle synthesis techniques has gained significant attention. Traditional high-yield methods, such as wet chemical synthesis or mechanical milling, often suffer from contamination issues, leading to particle aggregation, background noise in analytical applications, toxicity, and catalyst deactivation. In contrast, PLS has emerged as a powerful alternative due to its ability to produce high-purity nanoparticles without chemical precursors or byproducts. This technique encompasses two main approaches: laser ablation and laser fragmentation. In laser ablation, a pulsed laser is focused on a solid target submerged in a liquid—typically water or an organic solvent—inside a cuvette. The intense laser energy causes plasma formation, target ablation, and subsequent nanoparticle generation, which are stabilized electrostatically in the liquid medium. Meanwhile, laser fragmentation involves irradiating a pre-existing colloidal suspension of larger particles, where the laser pulses induce their breakdown into smaller nanoparticles, allowing precise size control and the production of ultra-small nanomaterials. The key advantages of PLS include its simplicity, versatility across a wide range of materials, in-situ functionalization capabilities, and the absence of unwanted contaminants, making it a highly attractive method for the scalable and reproducible synthesis of nanoparticles with tailored properties.

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2 Spatial beam shaping strategies

Pulse duration is a key parameter in PLS since it directly influences the process dynamics and interactions with the surrounding liquid media. Even though the PLS productivity record has been achieved with a picosecond pulsed laser, in this contribution, we will highlight the relevance of improving productivity for other pulse duration ranges. In this direction, various spatial beam shaping strategies have been explored to enhance productivity and improve control over nanoparticle properties [1]. Among the most advanced techniques for femtosecond pulses is the simultaneous spatial and temporal focusing, which optimizes energy delivery by confining the highest intensity to the focal volume while increasing pulse duration outside this region. This approach minimizes nonlinear effects such as filamentation and optical breakdown, leading to improved ablation efficiency and enhanced nanoparticle production. Another effective method is multi-beam laser ablation, which utilizes diffractive or refractive optical elements to split the laser beam into multiple sub-beams, reducing energy losses and increasing processing speed. Additionally, cylindrical lenses have been shown to reduce ablation time and, at high energies, promote the formation of anisotropic nanostructures, such as nanowires.

We will explore various applications of PLS-synthesized nanoparticles developed in our laboratory. These include the synthesis of carbon quantum dots for bioimaging, fluorescence-based glucose sensing [2], and drug delivery; the functionalization of polymers with nanomaterials to enhance mechanical strength, color-changing properties, and other functional characteristics; and the development of biocidal nanomaterials based on silver nanoparticles to combat viruses, bacteria, and fungi. Figure 1 presents some representative examples of these applications.

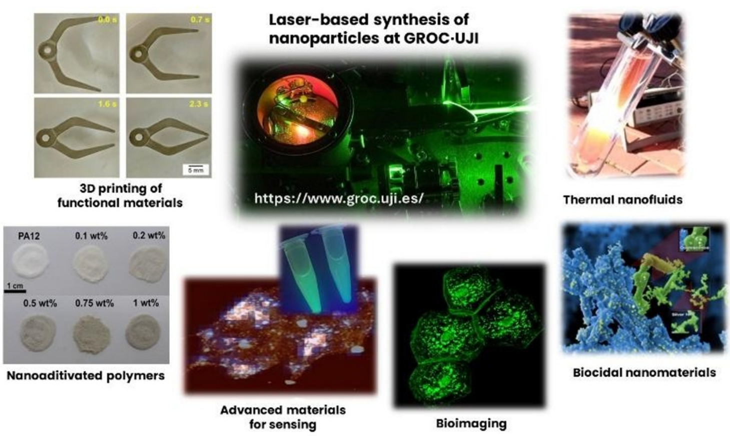

Fig. 1. Different applications of nanoparticles synthesized with PLS at GROC·UJI labs.

References

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