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Scalable 3D Nanofabrication via Upconversion

Stanford researchers have created a system that enables efficient fabrication of complex three-dimensional (3D) nanostructures via triplet-triplet-annihilation upconversion (TTA-UC).

There is a growing interest in fabricating complex micro and nanoscale 3D structures for various clinical and research applications. One of the most well-established techniques for nanoscale 3D fabrication is two-photon polymerization (2PP). However, 2PP is slow and expensive, because it uses high-powered lasers that allow for only monovoxel printing per light source.

Researchers at Stanford have proposed TTA-UC, which uses lower power sources, as an alternative to 2PP. Materials involved in this process contain a sensitizer-annihilator pair, a photoinitiator, and monomers. The sensitizer absorbs lower energy photons to make the annihilator emits higher-energy photons. The photoinitiator then triggers the assembly of the monomers, or polymerization by absorbing the upconverted photons. The researchers have identified a resin with an ideal ratio of appropriate components for TTA-UC. They then demonstrated that TTA-UC can be parallelized by incorporating a digital micromirror device to project millions of voxels simultaneously. Additionally, they developed algorithm that makes grayscale and sparser versions of the intended design to prevent unintended polymerization in neighboring pixels, allowing them to print more complex 3D structures.

Stage of Development
Functional prototype

Applications

- Fabrication of nanotools in the fields of

    - Plasmonics
    - Nanophotonics
    - Microoptics
    - Nanooptics
    - Robotics
    - Biomedicine
    - Extended reality

Advantages

- Improved speed and resolution
- Industry scale production possible
- Can be adapted to other materials such as glass and ceramics
- Can be adjusted to incorporate biocompatibility

Publications

- Schloemer, T., Narayanan, P., et al. (2023). Nanoengineering Triplet-Triplet Annihilation Upconversion: From Materials to Real-World Applications. *ACS nano, 17*(4), 3259–3288.
- Schloemer, T. H., Sanders, S. N., et al. (2023). Controlling the durability and optical properties of triplet-triplet annihilation upconversion nanocapsules. *Nanoscale, 15*(15), 6880–6889.
- Sanders, S. N., Schloemer, T. H., et al. (2022). Triplet fusion upconversion nanocapsules for volumetric 3D printing. *Nature, 604*(7906), 474–478.
- Schloemer, T. H., Sanders, S. N., et al. (2022). Triplet Fusion Upconversion Nanocapsule Synthesis. *Journal of visualized experiments : JoVE,* (187), 10.3791/64374.

Patents

- Published Application: WO2025101801

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