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Dual-beam super-resolution direct laser writing nanofabrication technology

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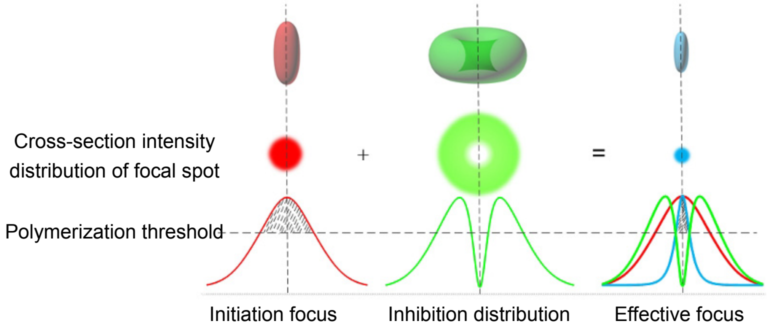

Schematic diagram of dual-beam super-resolution fabrication.

Abstract: With the development of nanotechnology, emerging nanotechniques compel dramatically increasing demands on fabrication technique for realizing nanostructures. As an important approach, direct laser writing has demonstrated extraordinary capabilities in fabricating three-dimensional (3D) micro/nanostructure, which stems from spatially resolved focal spot by tightly focusing laser beams. The unique 3D feature fabrication allows volumetrically integrating multiple electro- or opto-functionalities in micro/nanodevices, and thus, is promising for advancing various modern scientific technological fields such as next generation of micromechanics and opto-nanodevices. However, the feature size of structures as fabricated as well as resolution in fabrication is subject to a fundamental limit set by the diffraction nature of light. In this regard, the minimum feature size of structures as fabricated is commonly constrained from half the wavelength of the light output by the laser source. To improve resolution beyond the optical diffraction limit, in this review, we introduce a dual-beam super-resolution direct laser writing technique. Combined with two-photon polymerization (TPP) method and stimulated emission depletion (STED) principle, the technique has successfully realized resolution much finer than its counterpart being obtained based on Abbe's law, and uphold exceptional 3D nanofabrication scheme. The principle of dual-beam super-resolution laser direct writing and recent progress in improving line width and resolution have been demonstrated in the review. In general, two beams are employed in the fabrication. One beam, so called initiating beam, is used to initiate optical reactions such as photo-polymerization, and the other, namely the inhibiting beam, is used to inhibit the optical reaction. While the initiating beam is modulated to Gaussian shape, the inhibiting beam can be shaped into Laguerre-Gaussian mode with zero light intensity in the center. By overlapping these two beams in the focal region, the inhibiting can inhibit the fabrication in its out ring, leaving the center of the initiating beam in function. As a result, a super-resolved focal spot can be obtained with tuning the intensity ratio of the two beams. To further improve resolution to nanoscale, delicate design to the photoresin material and the focal field is required. For instance, optimizing the inhibition efficiency upon the exposure to the inhibiting beam enables 9 nm free-standing line equivalent to one eighty-ninth of the wavelength of the initiating beam. Moreover, we have also summarized emerging applications of dual-beam super-resolution laser direct writing in relevant fields, such as opto-devices with photonic band gap in visible region and biology. Eventually, challenges in how to fulfill low-cost, high efficiency, large area and multi-functional materials' fabrication and its future development are discussed.

Keywords: direct laser writing; photo polymerization; stimulated emission depletion; optical super-resolution; 3D nanostructures

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