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Microtube fabrication based on femtosecond Bessel beam and its flexible driving with external magnetic field

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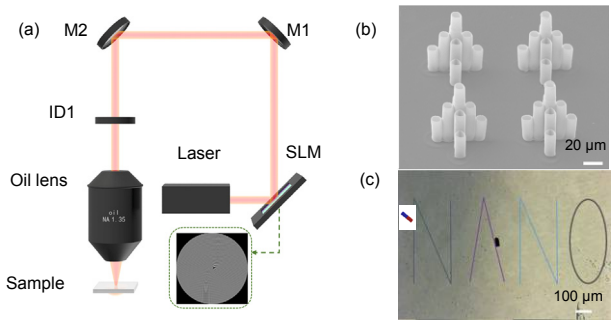

Schematic diagram of femtosecond Bessel beam processing system, SEM image and Magnetic driving of microtubes. (a) Schematic diagram of femtosecond Bessel beam fabrication system. (b) SEM image of 9 tubes microrocket. (c) Microtubes complete "NANO" type trajectory.

Abstract: Microtube, with simple and uniform geometry, is one of the basic structures in micro/nano field. Mircotube is widely used in the fields of microoptics, biomedical devices, microfluidics, micropumps, microsensors and micromotors, especially magnetically driven motors are envisioned to be involved in various tasks such as directed drug delivery, isolation of biological targets, microsurgery, bioassay, bioimaging, environmental monitoring, remediation processes, and so on. But current fabrication methods such as self-rolling of organic or inorganic films, accumulation of nanoparticles, mask-based diffraction lithography and holographic lithography are only suitable for the preparation of microtubes with certain periodic or specific profiles due to the limitation of inherent fabrication principles, and thus suffered from low flexibility and weak designability. We present a method for the fabrication of magnetic drivable microtubes, by direct femtosecond laser writing combined with magnetron sputtering with metal layer. Femtosecond laser beam is modulated into Bessel beam with spatial light modulator (SLM), and then Bessel beam is focused with a high numerical aperture objective. Microtubes are fabricated by scanning focused femtosecond Bessel beam, a circular beam pattern, in a sample anchored on a three dimension stage. This technology keeps the high resolution of two-photon polymerization and greatly reduces the consumed time by two magnitudes. Followed by magnetron sputtering a nickel layer, the microtubes exhibit paramagnetic property and can be flexibly driven by external magnetic field. The propagation and high numerical aperture focusing properties of femtosecond Bessel beams are investigated, which constructs a solid base for the fabrication parameters optimization. By modulating the phase hologram loaded to the SLM, the intensity distribution of femtosecond laser beam is controlled. Microtubes, with well controlled diameter, length and distribution are efficiently fabricated. Complicated microtube arrays, including 2×1, 2×2 arrays, 5 tubes microrocket and 9 tubes microrocket are fabricated rapidly within several seconds. Individual microtube in these arrays keeps its original shape without any deformation and interaction with each other. A sputtered 80 nm Ni layer imposes the microtubes with paramagnetic property. Rapid steering of the nickel coated microtubes along specific route in fluid environment with external magnetic field produced by columnar magnet has been realized. Controlled driving of microtubes along a "NANO" type trajectory has been achieved. The magnetic driving of microtubes will not be affected by environmental variation, electric signal, temperature signal and optical signal. This method is flexible, controllable as well as efficient, and the fabricated drivable microtubes have promising applications in noninvasive surgery, targeted drug delivery, bioimaging or biosensing and microenvironment cleaning.

Keywords: microtube; spatial light modulation; Bessel beam; magnetic driving

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