Fast Multiphoton Microfabrication of Freeform Polymer Microstructures by Spatiotemporal Focusing and Patterned Generation

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Motivation

- Conventional fabrication technique, such as E-beam lithography, nanoimprinting lithography, etc. → Limited to 2D applications

- Two-photon excited (TPE) microfabrication achieves 3D resolution by spatially focusing light to induce nonlinear excitation within focal volume. → Low fabrication speed

**Goal:** To develop a high-speed fabrication technique which can make arbitrary 3D structure. Also, the resolution can achieve sub-micro level.

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Spatial and Temporal Focusing

- **Spatial focusing**
  - The pulse width remains unchanged, and the lateral beam size is focused.

- **Temporal focusing**
  - The pulse width is focused, and the lateral beam size remains unchanged.

Realize Temporal Focusing

Collimated lens

Objective lens

Fourier plane

Temporal focusing plane

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The temporal focusing method is applied to obtain depth-resolved two photon excitation fluorescence (TPEF) images. Furthermore, it can combine a SLM and phase-contrast filter to realize the patterned illumination.
A 3D lithographic microfabrication process has been developed. Due to its high throughput, it offers the possibility for industrial scale manufacturing of 3D microdevices.

Fabrication area is limited by the peak power of a typical Ti:sapphire oscillator.

Sequential insertion of different fixed optical masks at different planes limits the microfabrication throughput.
Patterned Illumination

Monitor #1
Pattern displayed for DMD

Monitor #2
Pattern generated by DMD

User interface

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Optical Setup

- EM CCD camera
- Imaging lens
- Short-pass filter
- Dichroic mirror
- Oil immersion objective lens
- Fabrication chamber
- Triple-axis stage
- Relay lens
- Collimated lens
- Focal plane
- DMD with DLP
- Relay lens
- Blazed grating
- Polarizer lens
- Half-wave plate
- Regenerative amplifier
  Repetition rate: 10 kHz
- DMD: digital micromirror device
- DLP: digital light processor

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System calibrations

Solution:
2mM RB + 75% TMPTA

Objective: 40x oil 1.3

Estimated width: 4.2 μm(a), 2.4 μm(b), and 0.6 μm(c)

Real width: 3.8 μm(a), 1.6 μm(b), and 1μm(c)
Solution: 2mM RB + 75% TMPTA
Objective: 40x oil 1.3
Fabrication power: ~7.5 mW
Scan rate: 1 Hz
Height: 35~40 μm
Fabrication time: 40 s
Scalability

Solution: 2mM RB + 75% TMPTA
Scan rate: 1 Hz
Z step: 1 μm
Power: 8.7 mW(40x); 12.2 mW(20x); 15.7 mW(10x)
Height: ~40 μm
Fabrication time: 40 s
Solution: 2mM RB + 75% TMPTA
Objective: 40x oil 1.3
Height: ~40 μm

Image acquired during fabrication process
Image acquired using point-scanning microscope
Image acquired using wide-field microscope
Conclusions

- A multiphoton (MP) microfabrication system based on spatiotemporal focusing and patterned generation has been developed to enhance fabrication speed by two or three orders and also realize microfabrication of 3D freeform microstructures.

- By simultaneously providing real-time optical sectioning for fabricated microstructures, the MP microfabrication system not only provides the capability of high-throughput microfabrication, but also offers optical sectioning for 3D online inspection.

- Using this system, we can generate arbitrary intensity patterns on any layer in a sample. As a result, it holds potential for other 3D applications, such as 3D microablation, etc.
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