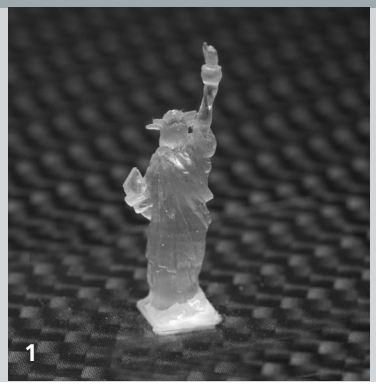
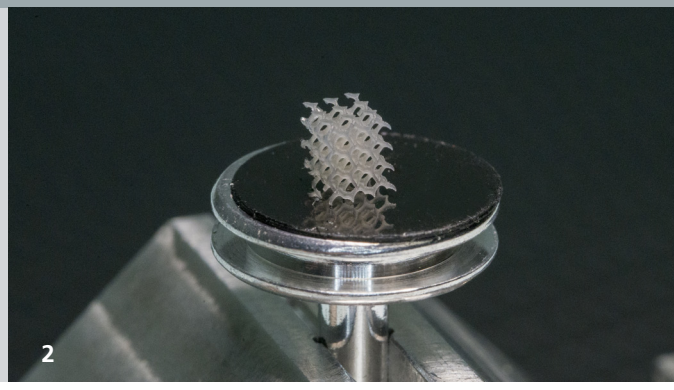
Fraunhofer
ISC

FRAUNHOFER INSTITUTE FOR SILICATE RESEARCH ISC


1


2

TWO-PHOTON POLYMERIZATION

FEMTOSECOND LASER PULSES AS A TOOL FOR TRUE 3D MICROMACHINING

1 *Statue of Liberty fabricated by using two-photon polymerization (2PP) technology*
2 *3D porous scaffold structure for application in tissue engineering*

Fraunhofer Institute for Silicate Research ISC

Neunerplatz 2
97082 Würzburg, Germany

Contact

Marie Richard-Lacroix
Optics and Electronics
Phone +49 931 4100-515
marie.richard-lacroix@isc.fraunhofer.de

www.isc.fraunhofer.de

Two-Photon Polymerization (2PP) is a new technology suited for the fabrication of nearly arbitrary 3D micro- and macro-structures. In contrast to conventional 3D printing, 2PP is not limited to a layer-wise fabrication of the desired structure. In fact, it is an inherently 3D process technology. This is possible by tightly focusing femtosecond laser pulses into a transparent photopolymer. The photon-polymerization triggered by the laser pulses is strongly confined to the focal volume as the underlying process – Two-Photon Absorption (TPA) – can only occur, if the intensity is sufficiently large. As a consequence, the site of the reaction i.e. the solidification of the material is located in the tiny focal volume. For 3D fabrication the focal volume is scanned in 3D space followed by a solvent wash to separate the rest of the liquid photon-polymer from the solidified 3D structure. In addition to being a true 3D process, 2PP is not limited to the optical diffraction limit as the photon-polymerization is a threshold process.

By adjusting the photon dose only slightly beyond the polymerization threshold, feature sizes in the order of 100 nm can be achieved.

Applications

Being inherently capable for 3D fabrication, 2PP offers huge potential in the fabrication of innovative and very sophisticated microstructures.

This includes:

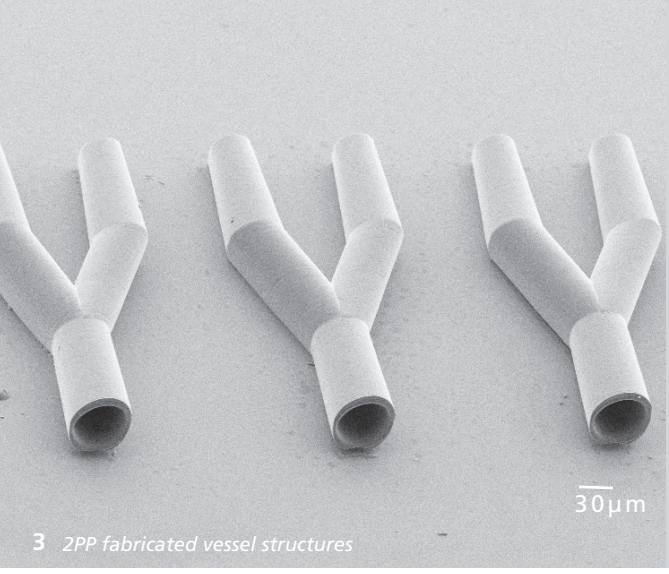
Metamaterials

- Photonic crystals

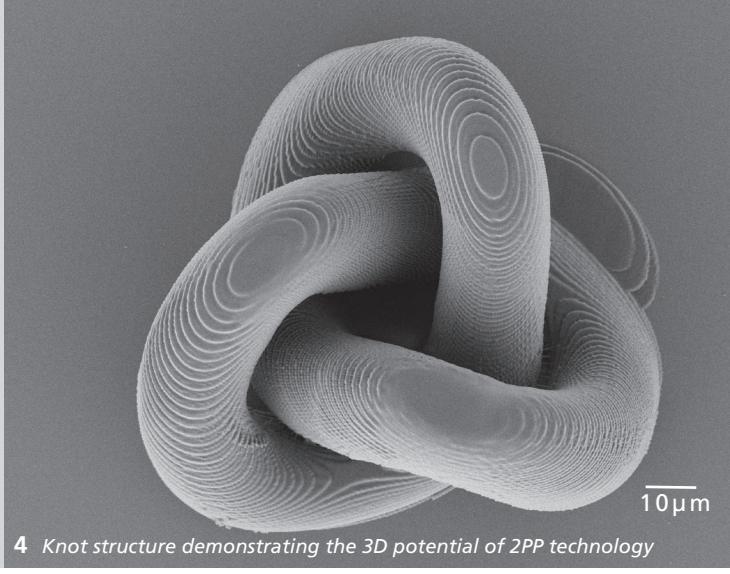
In this field of application the functionality of the structure is not determined by the material(s) but by the architecture. 2PP as an inherent 3D technology can enable new designs for metamaterials and photonic crystals.

- Freeform microlenses/micro optics

2PP allows the fabrication of more complex topographies, particularly non-spherical or free-form designs.



3 *2PP fabricated vessel structures*



4 *Knot structure demonstrating the 3D potential of 2PP technology*

■ Diffractive optical elements
Multi-level and continuous-level DOEs with arbitrary pixel size and pixel count can be fabricated using 2PP technology.

■ Waveguides for optical interconnects
2PP can also be used to modify the refractive index in bulk polymer layers. Consequently index patterning is possible along arbitrary trajectories for establishing an optical waveguide between different opto-electronic components.

By adapting the illumination strategy, which means particularly choosing appropriate focusing conditions, it is also possible to fabricate larger (macro) 3D structures with very high accuracy and resolution.

These structures can be used in:
- Drug delivery devices
- Bio scaffolds for cell cultivation
- Opto- and microfluidics

Specifications

At Fraunhofer ISC two different devices for 2PP are available. Typical specs are:

- High-precision and large travel air bearing systems
  ⇨ Max. substrate size: 4" / 6" wafer
  ⇨ Writing velocity:
    • From 100 µm/s to 30 mm/s using linear stages
    • Up to 100 mm/s for galvoscanner use
  ⇨ Accuracy and repeatability: < 1 µm

Wide range of wavelengths for patterning of non-standard photopolymers
- 515 nm + 1030 nm
- 680 – 1080 nm

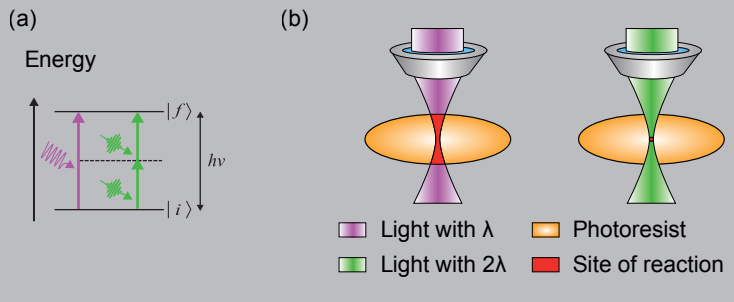
- Substrate type: silicon, borosilicate glass, fused silica, (transparent and opaque possible)
- Automatic substrate detection for precise axial positioning
- Available optics:
  - 1.4 NA (100x) oil-immersion
  - 0.6 NA (40x);
  - 0.45 NA (20x) and more on demand

- Feature size: down to 100 nm
- Maximum structure height (yet): 2 cm*

Please inquire for more details or non-standard specifications.

We offer

- Feasibility studies for the fabrication of customerdesigned micro- and macrostructures
- Optimization of 2PP process for non-standard materials and substrates
- Development of new materials for 2PP processong with tailorable pro perties (e.g. mechanical, optical and chemical properties)
- Optimization of throughput by tailored hatching strategies and new galvo-scanner (approx. 100x faster than stage-based fabrication) and semi-automated fabrication
- Spectral and topological characteri-zation by e.g. Laser Scanning Micro-scopy, Atomic Force Microscopy, Scanning Electron Microscopy, Scan-ning Nearfield Microscopy, Micro Raman Spectroscopy
- Strategies for high-precision in volume fabrication and avoidance of optical aberrations
- Dip-In lithography for fabricating structures independently from the working distance of the focusing optics



(a) Quantummechanical scheme of 1PP (magenta) and 2PP (green) (b) Reaction volumes in 1PP vs. 2PP: Only 2PP enables the confinement of the photoreaction to the tiny focal volume.

**Footnote: Overall structure dimensions and fabrication durations strongly depend on the desired accuracy/feature size.*