Two-Photon Polymerization (2PP) Lab Work Description

International College on Modern Applications of Optics and Photonics (MAOP)

Duration: 90 minutes | Level: Master's students
Conference Website: https://photonicsai.com/home_maop2026/

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1. Introduction and Learning Objectives

1.1 Course Overview

This laboratory work introduces students to the fundamental principles and practical application of Two-Photon Polymerization (2PP), a state-of-the-art additive manufacturing technique used to fabricate complex 3D micro- and nanostructures. Utilizing a tightly focused femtosecond laser, this direct laser writing method initiates localized polymerization within a photosensitive resin, enabling the creation of intricate geometries with sub-diffraction-limit precision.

During the 90-minute session, students will gain hands-on experience with the entire experimental workflow. This includes setup alignment, focus calibration, determination of polymerization thresholds, microstructure fabrication, post-processing, and subsequent dimensional characterization. A primary focus of the lab is to analyze how laser exposure parameters influence the final physical dimensions of the fabricated features.

1.2 Learning Objectives

Upon successful completion of this lab, students will be able to:

1. Understand the physical principles of non-linear two-photon absorption and its application in high-resolution 3D printing.

2. Perform alignment and calibration checks on a standard 2PP experimental setup.
3. Locate the focal plane precisely at the substrate interface and within the volume of a photoresist.
4. Determine the polymerization threshold of a specific hybrid photoresin (SZ2080).
5. Fabricate microstructures (test lines) by systematically varying laser power parameters.
6. Perform post-processing development steps to reveal the fabricated structures.
7. Characterize the height and width of the fabricated microstructures using optical microscopy.

2. Scientific Background

2.1 Principles of Two-Photon Polymerization

Two-Photon Polymerization (2PP) is a direct laser writing technique that leverages the non-linear optical phenomenon of two-photon absorption (TPA). Unlike conventional single-photon polymerization which typically utilizes ultraviolet (UV) light to initiate polymerization throughout the entire beam path 2PP employs visible/near-infrared (NIR) femtosecond laser pulses.

Because the probability of simultaneously absorbing two photons is proportional to the square of the light intensity, the absorption process is strictly confined to the focal volume (voxel) of a highly focused objective lens where photon density is highest. This extreme spatial confinement allows for true 3D fabrication capabilities and enables the creation of features with resolutions below the diffraction limit of the light used. This technique is widely utilized in fields such as micro-optics, metamaterials, and biomedical engineering.

2.2 Materials for 2PP

Photosensitive resins (photoresists) used in 2PP typically consist of monomer/oligomer matrices mixed with specialized photoinitiators. When the photoinitiator molecules simultaneously absorb two photons, they transition to an excited state and generate reactive species (such as free radicals) that trigger the local cross-linking of the surrounding monomers.

In this lab, we will use SZ2080, a widely recognized hybrid organic-inorganic photoresist. SZ2080 is highly valued in microfabrication due to its negligible shrinkage during development, high mechanical stability, and excellent optical transparency, making it ideal for producing robust, high-fidelity microstructures.

3. Lab Procedure

3.1 Experimental Setup and Alignment

1. **Initial Setup Check:** Verify the general alignment of the 2PP system. Ensure the laser beam path is correctly aligned through the beam conditioning optics, beam expander, scanning mirrors, and into the microscope objective.
2. **Substrate Focus Finding:** Place a clean microscope slide on the 3D translation stage. Using the system's imaging software and manual controls, locate the precise focal plane of the objective lens on the top surface of the glass slide.
3. **Photoresist Loading:** Carefully dispense a droplet of SZ2080 photoresist onto the microscope slide.
4. **Focusing in Photoresist:** Adjust the Z-position of the stage to move the laser focus into the bulk of the loaded SZ2080 photoresist. Refer to Figure 1 in the Appendix for a schematic of the experimental setup.

3.2 Process Parameter and Threshold Determination

1. **Polymerization Threshold Identification:** With the focus positioned inside the photoresist, gradually increase the laser power (using either the software control interface or a manual attenuator) until the onset of polymerization is visually observed. Conversely, you can decrease the power until polymerization just ceases.
2. **Threshold Recording:** Record this minimum power value from the software interface. This represents your polymerization threshold.
3. **Real Power Measurement:** To ensure accurate data collection, measure the actual laser power corresponding to this threshold using a calibrated powermeter.

3.3 Fabrication of Microstructures (Line Printing)

1. **Pattern Design:** Prepare a design consisting of a series of parallel, straight lines, each with a length of 0.5 mm.
2. **Parameter Variation:** Set the initial laser power to a value slightly above the determined polymerization threshold.
3. **Line Fabrication:** Print the series of lines. For each subsequent line, increase the laser power by a step of 2 W (as indicated by the control software). Keep the scanning speed and all other parameters constant.
4. **Power Calibration:** For each printed line, measure and record the actual laser power (in mW) using the powermeter to map the software values to physical power levels.

3.4 Post-Processing (Washing and Drying)

1. **Development (Washing):** After the printing process is complete, carefully remove the sample and immerse it in a washing solution of MBIK-isopropanol. Gently agitate the solution to dissolve and remove all unpolymerized photoresist, leaving only the cross-linked, fabricated lines on the substrate.
2. **Drying:** Gently dry the developed sample allow it to air dry in a dust-free environment.

3.5 Microscopic Characterization

1. **Microscope Setup:** Place the dry sample under an optical microscope.
2. **Dimensional Measurement:** For each fabricated line, measure and record its width and height.
3. **Imaging:** Capture representative microscope images of each line to document the structural quality and any potential defects (e.g., over-exposure or structural collapse).

4. Data Analysis and Reporting

Line #	Laser Power (Software, W)	Laser Power (Measured, mW)	Line Width (µm)	Line Height (µm)	Microscope Image
1					
2					
3					
4					
5					
...					

Record all experimental and characterized data in the structured table below.

Discussion Guidelines:

- Plot the measured line width and height as a function of the measured laser power (mW).
- Analyze the relationship between laser power and the resulting voxel/line dimensions. Discuss how variations in laser power affect the polymerization volume.
- Explain the physical significance of the polymerization threshold and discuss potential sources of experimental error (e.g., focus drift, power fluctuations, development issues).
- Propose methods for optimizing the process parameters to achieve the highest spatial resolution.

5. References

[1] Pertoldi, L., Zega, V., Comi, C., & Osellame, R. (2020). Dynamic mechanical characterization of two-photon-polymerized SZ2080 photoresist. Journal of Applied Physics, 128(17).

Appendix

Figure 1. Experimental setup of 2PP (Illustrative)