Fabrication and Optimization of Lenses using Two-photon Polymerization Technology

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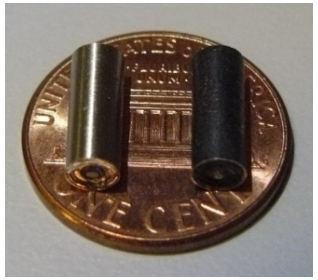
Overview

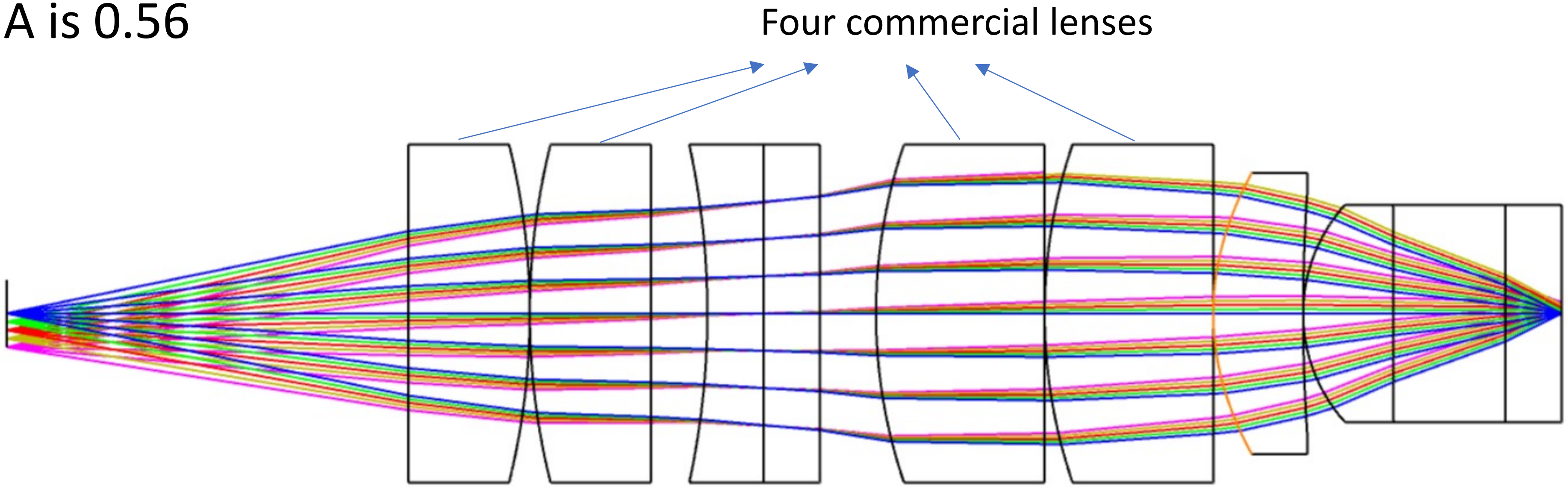
Miniature objective lens

- Ideal for weight and size-sensitive applications, such as endoscopic microscopy

Research objective: An optical system for two-photon fluorescence imaging

- Four commercial lenses + three 3D printed lenses
- Input numerical aperture (NA) is 0.2
- Output NA is 0.56





Current method and challenges

Diamond turning technique

- Uses a diamond tool to cut the required surface geometry of the lens

Drawbacks

1. Time-consuming
2. Expensive
3. Difficult to fabricate free-form lenses
4. Manual alignment and assembly are required

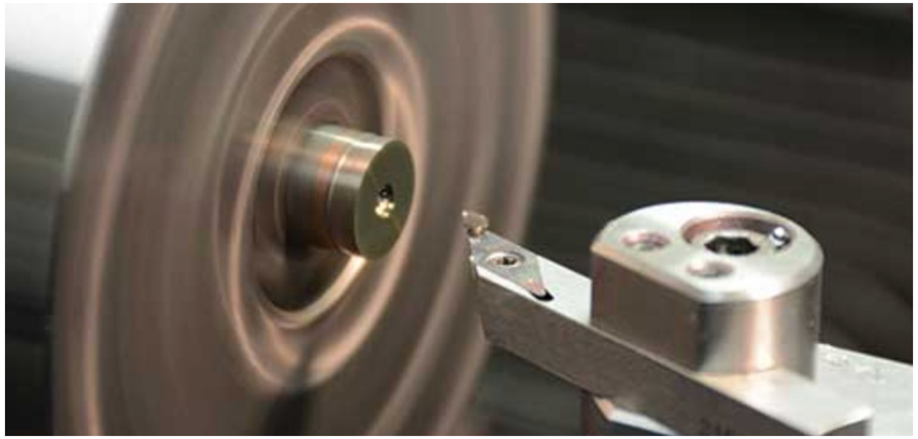


Fig 1: Diamond turning (Photonics Media, 2018)

Fabrication technique

Two-photon polymerization technology

- Uses a femtosecond pulse laser in the near-infrared region
- Sequentially illuminate the photosensitive resin

→Laser beam focused by a objective lens triggers the polymerization process

➔150 nm feature sizes and 10-15 nm surface roughness

Advantages

1. Fast
2. Cheap
3. Fabricates lenses with automatic alignment features

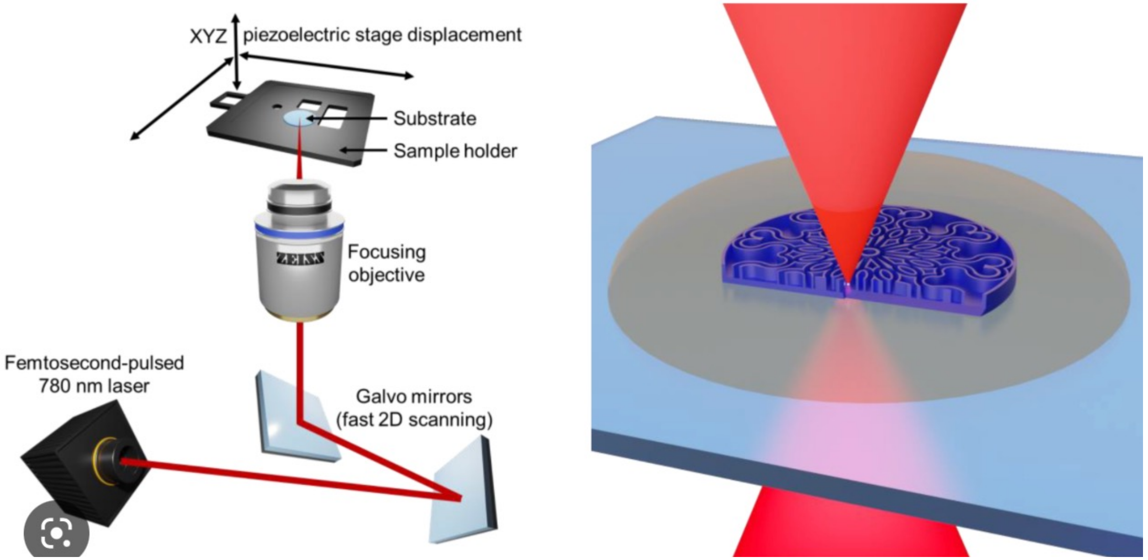


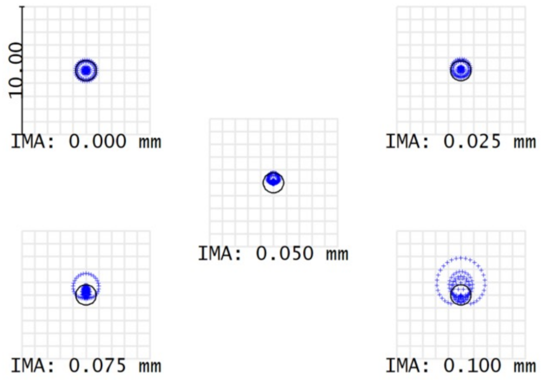
Fig 2: Two photon polymerization (Bunea et al., 2021)

Zemax design

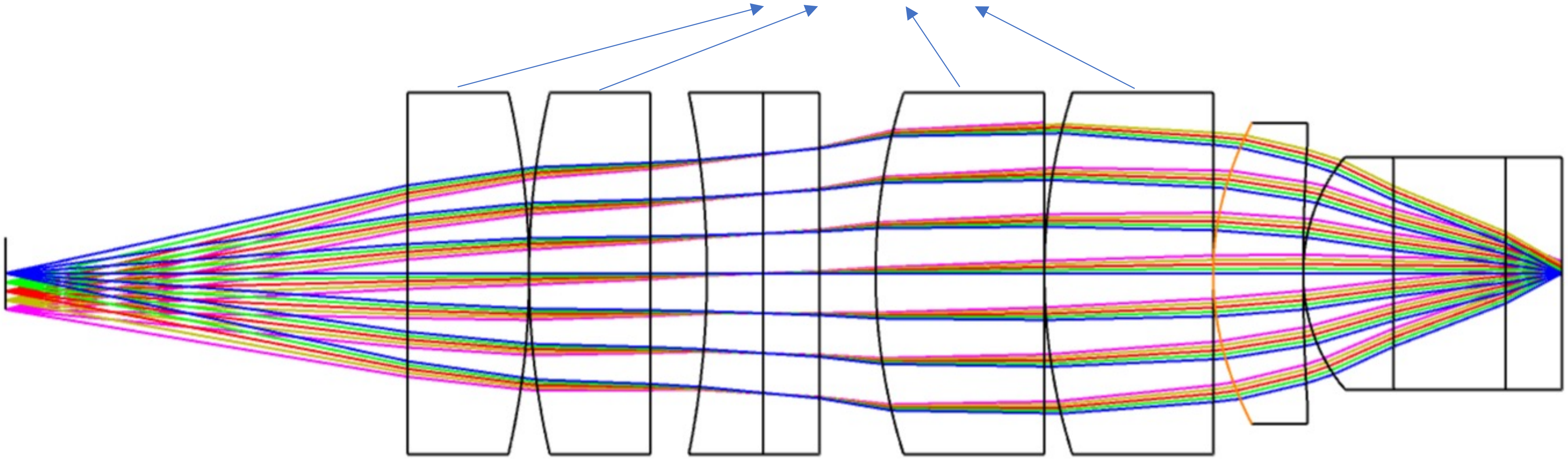
Right Half for testing

- The right half can be tested in air since it still has diffraction-limited performance

➔ Enables finalization of all printing parameters with either 25X or 10X objectives



Four commercial lenses



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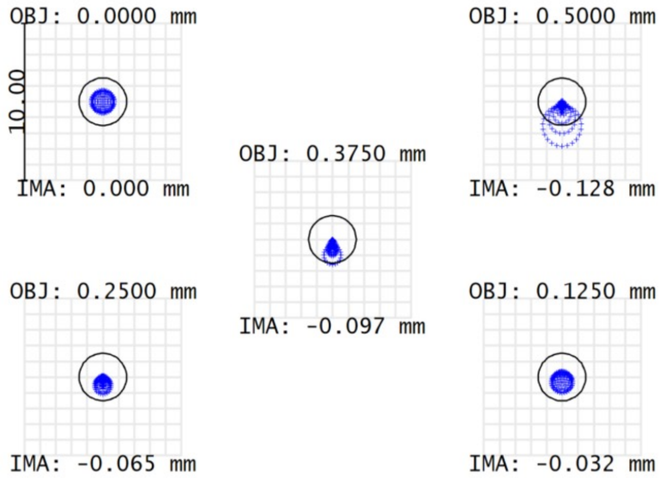
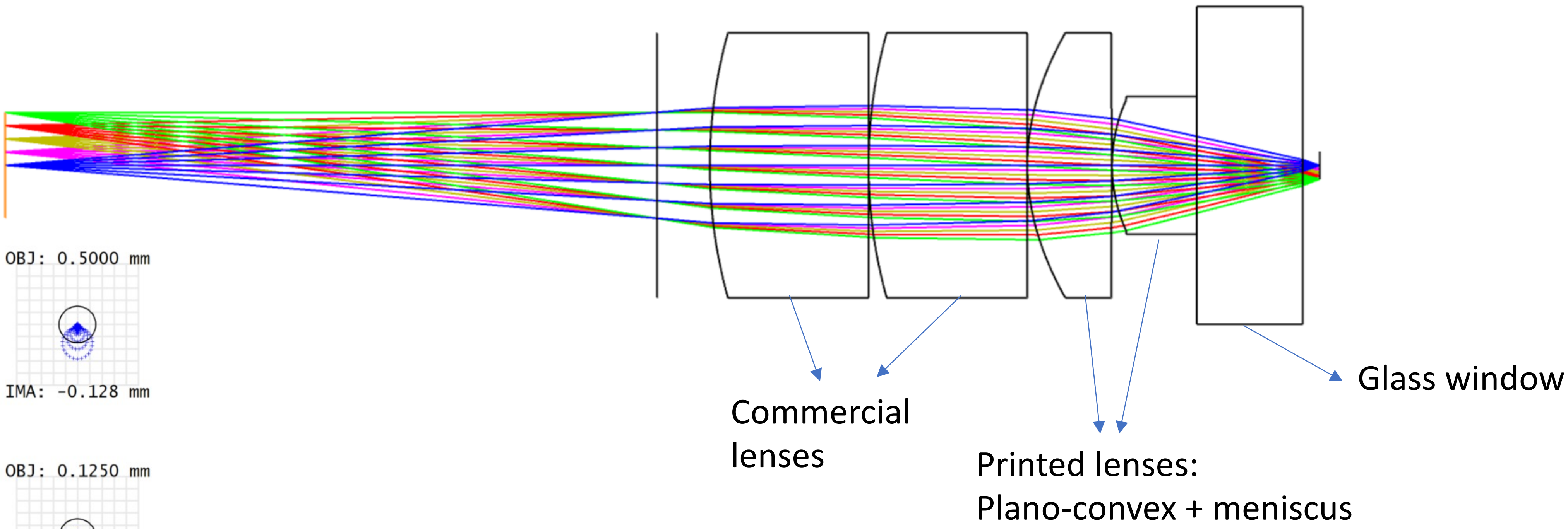
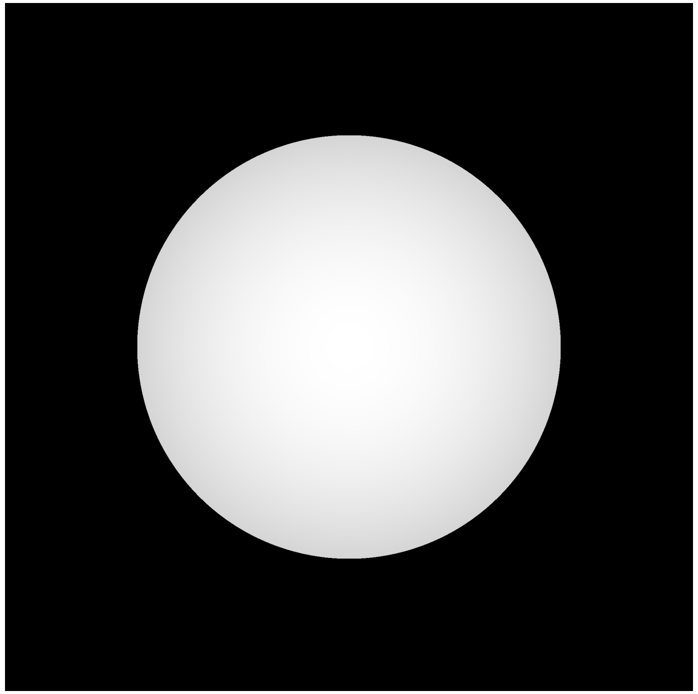




Generating 3D printing files

- The general MATLAB code for generating grayscale images

```
% iniate some parameters
step_size = 1; % unit is micron

x = -1000:1:1000;

[X,Y] = meshgrid(x,x);

% lens parameters
R = 1496;
r = 616;
sag_n = sqrt(R^2-r^2);
ET = 667;

% sphere
Z = sqrt(R^2 - (X.^2 + Y.^2));
Z(Z<sag_n) = sag_n;
Z(Z>sag_n) = Z(Z>sag_n) + ET;
Z = Z - sag_n;

% convert to 16 bit
scale = 65535/(max(Z(:))-min(Z(:)));
Z_new = (Z-min(Z(:)))*scale;

%save images
imwrite(uint16(Z_new), 'FirstLens.png');
```



The output grayscale image

Printing parameters

- **Slicing**: separates the object into many layers
- **Hatching**: differentiates the materials and areas with parallel lines

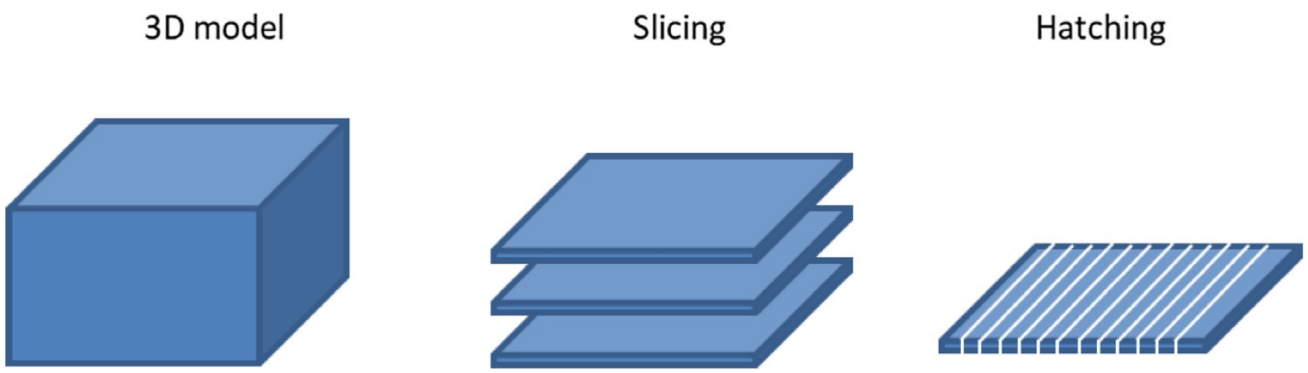


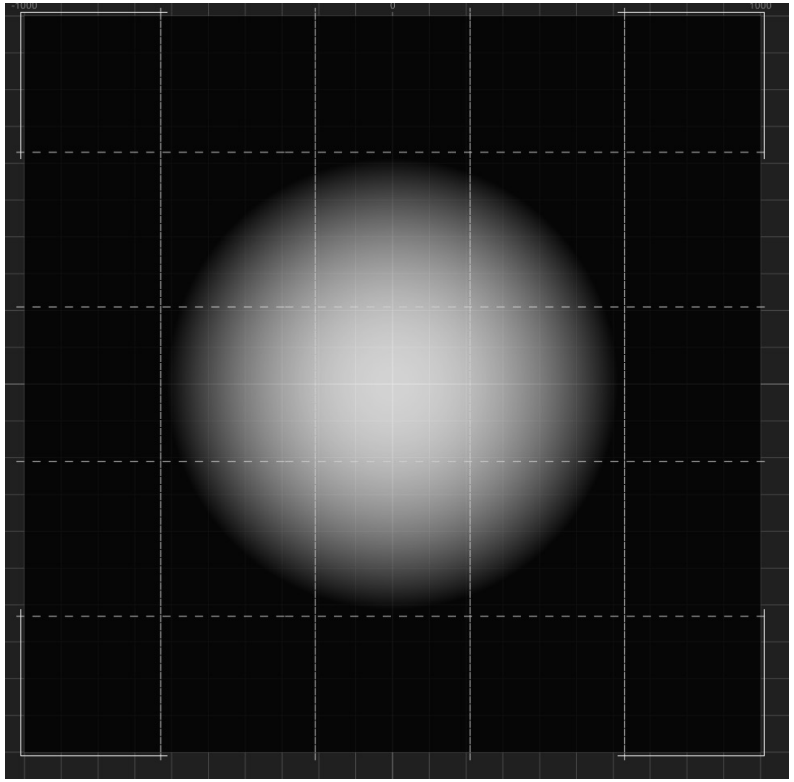
Fig 4. Slicing and hatching (Saraswat et al., 2020)

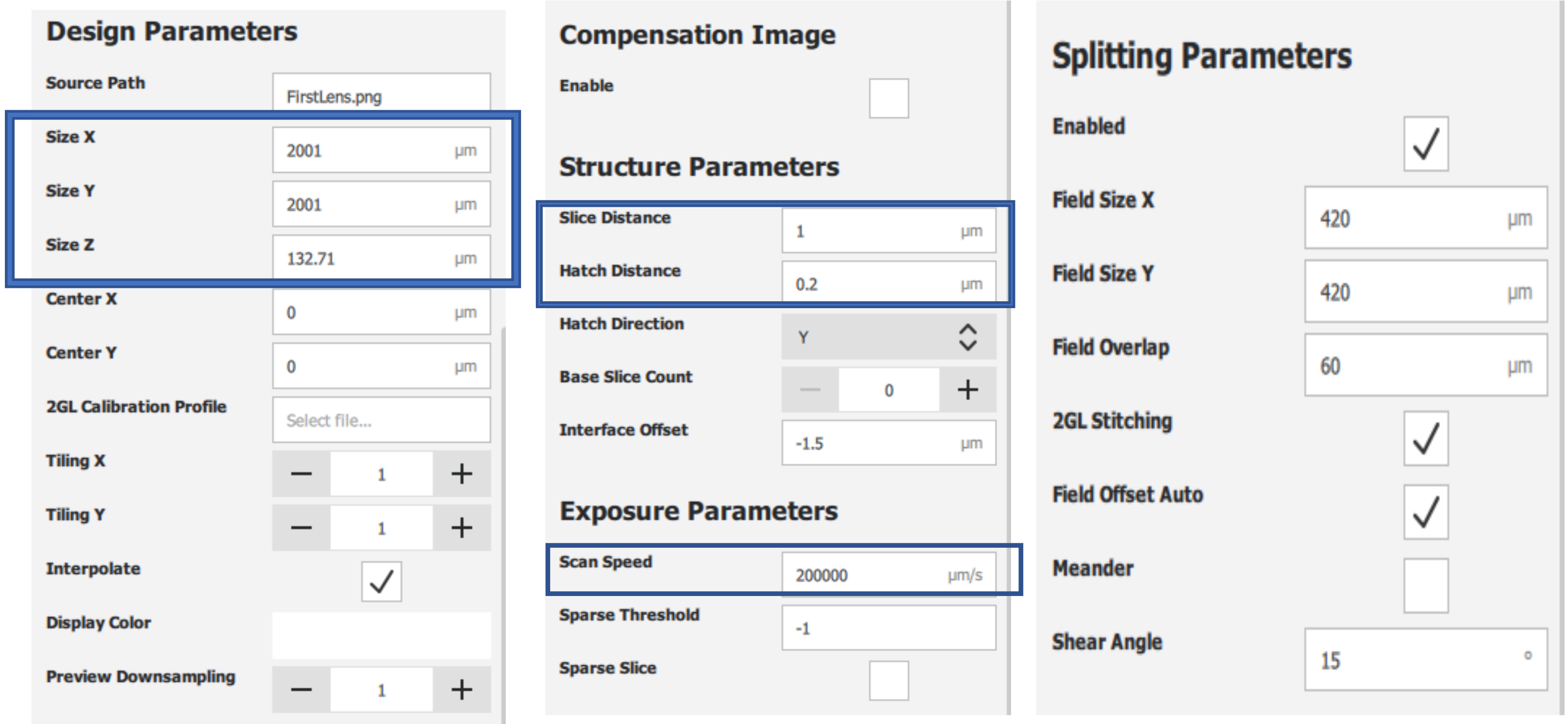
The first several trials gave us some estimation of the printing time:

1. 25X objective, 1-micron slicing, 0.2-micron hatching: **16-17 hours**
2. 10X objective, 1.6-micron slicing, 0.2-micron hatching: **12-13 hours**
3. 10X objective, 1.6-micron slicing, 0.6-micron hatching: **3-4 hours**

Printing parameters

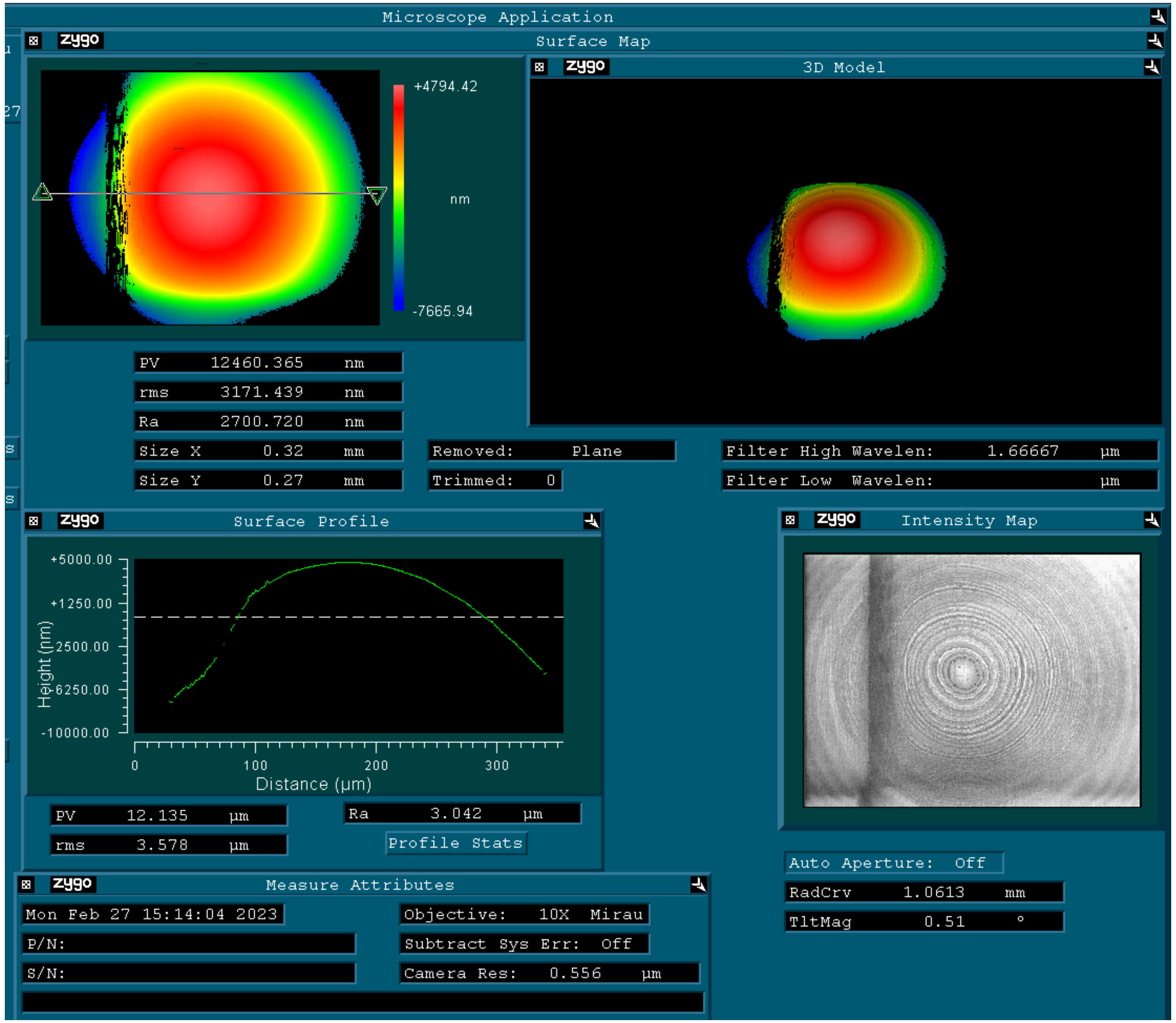
- Printing setup for 25X objectives





Characterization of the lens

Zygo white light interferometer – 10X



Problems encountered

1. Curvature deviation
2. Stitching defects

Proposed solutions

1. $R_{new} = \frac{R_{measure} - R_{design}}{2} + R_{design}$
2. Optimize laser power

Conclusions

What I learned over the past four weeks

- Observed how to design a lens in Zemax
- Participated in the fabrication process (grayscale image generation + 3D printing)
- Fundamental knowledge of optical components, such as lenses and fibers

Future work

- Solve previously encountered problems
- Finish the design and fabrication of the second lens
- Assemble the first and the second lenses

Acknowledgement:

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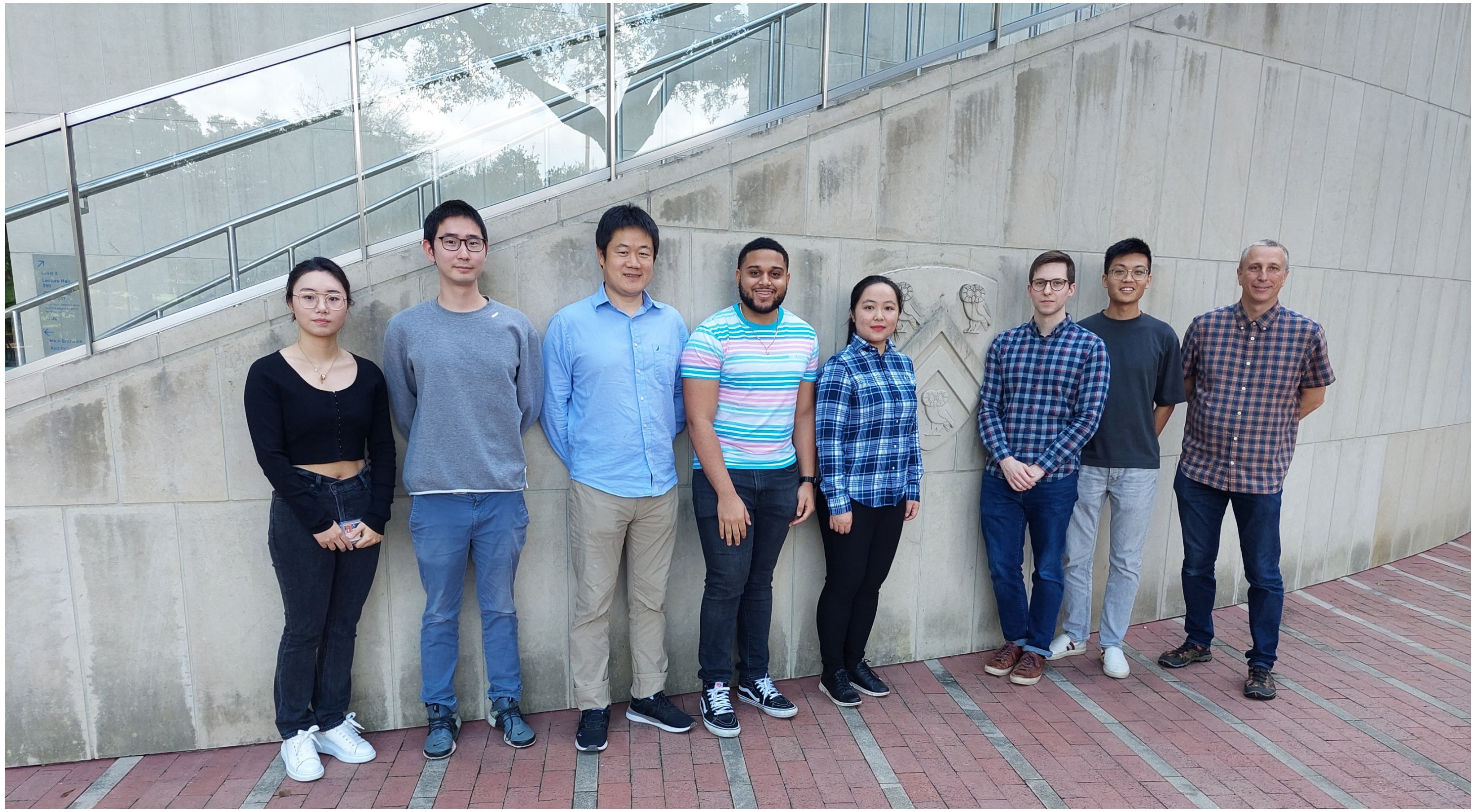

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