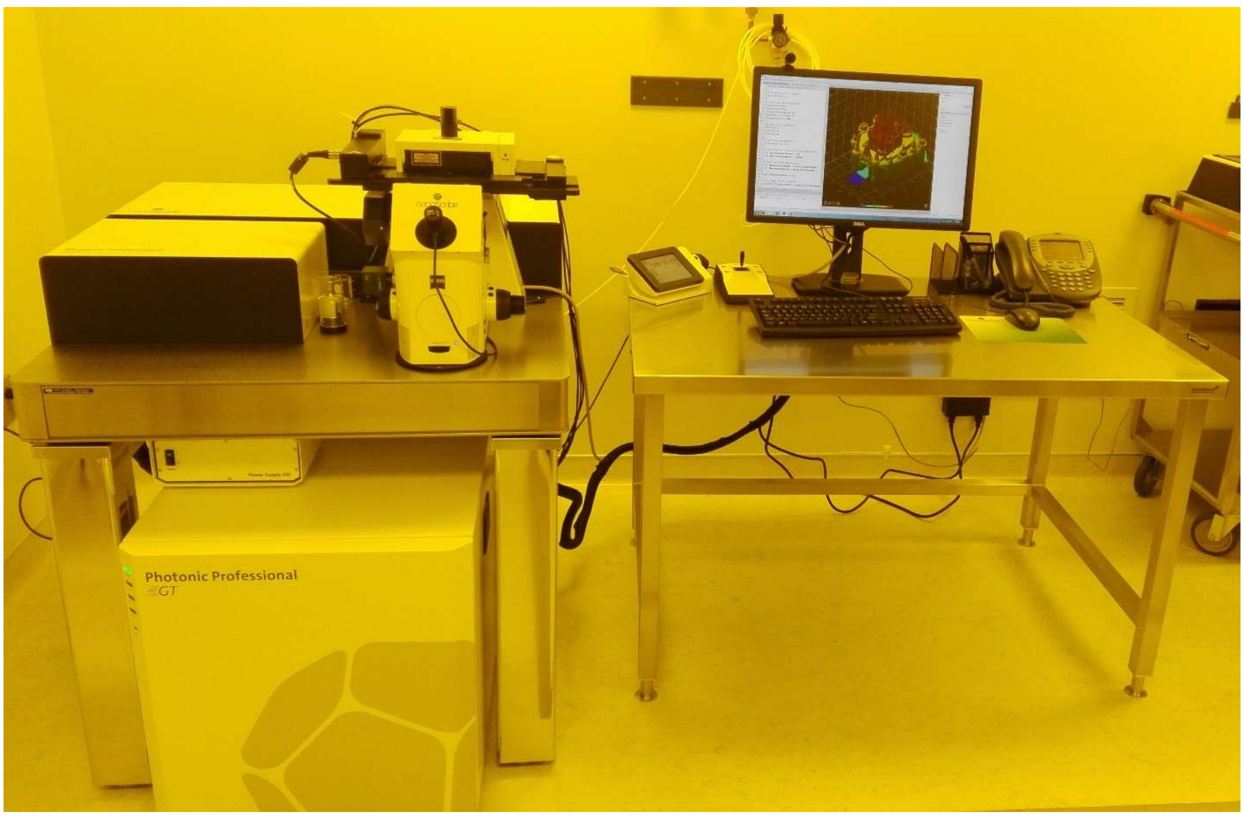
University of Pittsburgh NFCF Nanoscale Fabrication & Characterization Facility nanoscribe

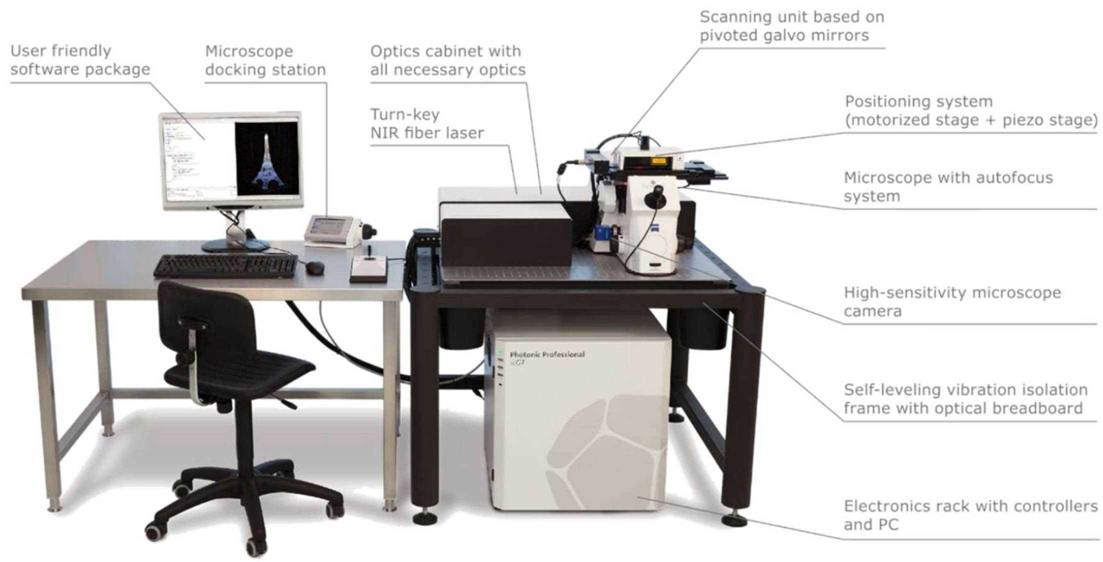
Nanoscribe Photonic Professional (GT)

--- Nano 3d Printer



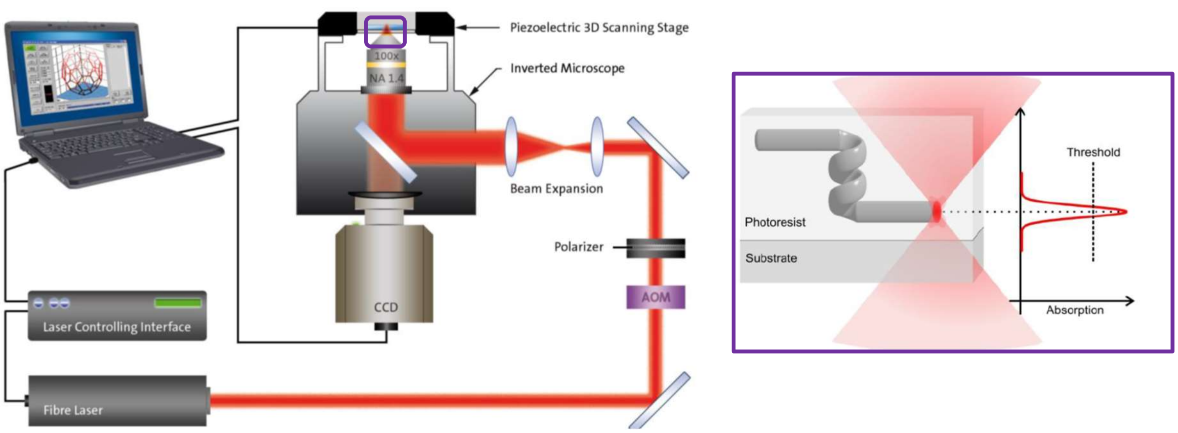
The Photonic Professional (GT) is intended to be used as a lithography system to manufacture 2D, 2.5D and 3D polymer structures with feature sizes from sub-micron to the millimeter scale. This system can be configured as Dip-in Liquid Lithography mode (DiLL), or conventional Direct Laser Write mode (DLW, or Oil mode). Currently there are three objectives available: **63×** for high-resolution printing (down to 200 nm), **25×** for large-scale printing (up to cm), and **20×** for air mode.

System setup



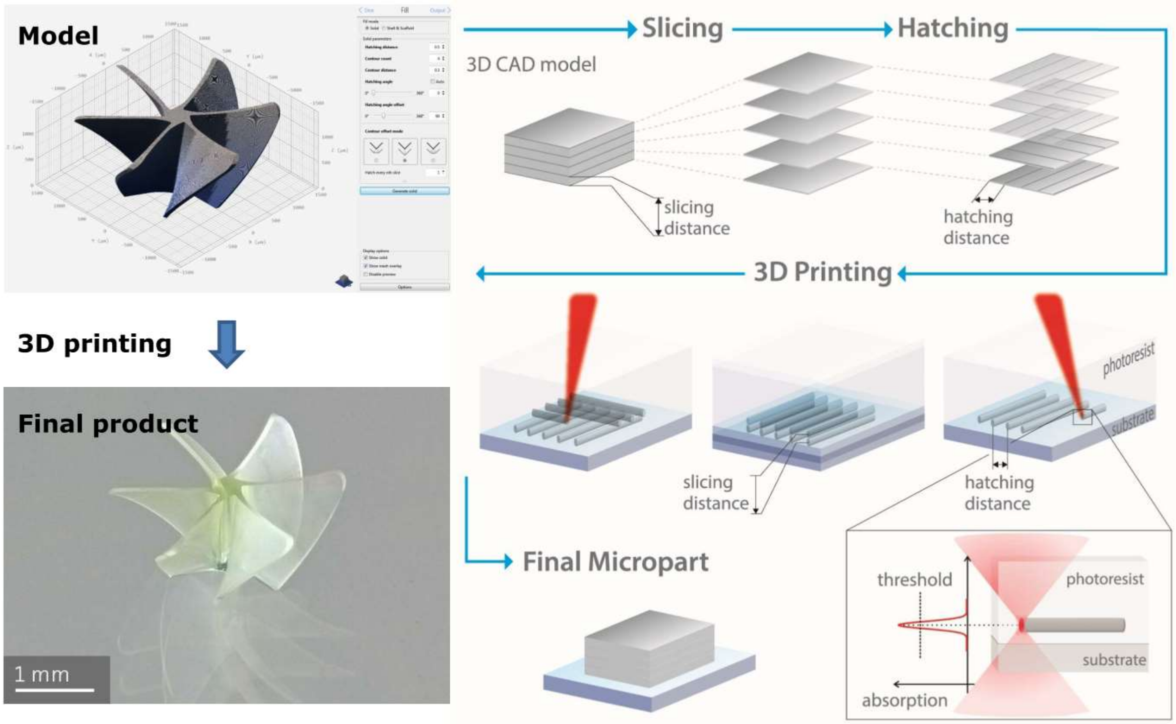
The system contains optical cabinet (laser), microscope and autofocus system, piezo and motorized stage, Galvo laser scanning system, electronic rack and control software 'Nanowrite'.

3D laser writing is implemented by 3D scanning of stage and focused Gaussian beam composited of high-density 780 nm photons, illustrated as follow:



From digital model to final product

3d design stl file is loaded into Describe, where you can set the conditions for slicing/hatching/splitting and save as gwl file, later loaded into Nanowrite for printing, shown as below:



Attention Before Use!!!

1. **By default, you can only use the standard setting: DiLL high resolution. If you would like to use other settings, you should let NFCF staff (primarily Jun Chen) know at least one day before! We will change the settings for you.**

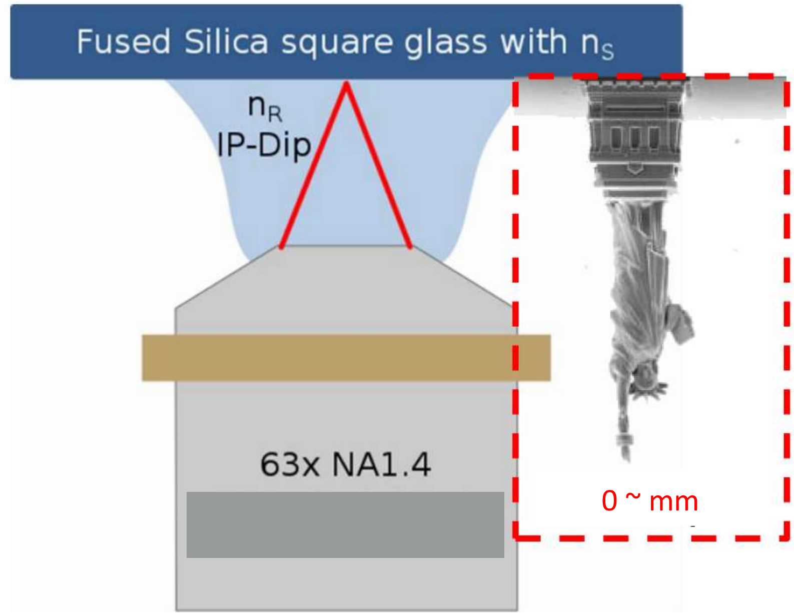
System configurations						
Config. Type	**Objective**	**Resist**	**Oil**	**Subs. type**	**Subs. size**	**Z-height**
DiLL high Res.	63×	IP-Dip	Not apply	fused silica	Square:30×30 ×0.7 mm^3	up to a few mm
Standard setting: DiLL large scale	**25×**	**IP-S**	**Not apply**	**ITO coated glass**	**Square:30×30 ×0.7 mm^3**	
Air mode	**20×**	Solid resist	Not apply	any	Square or circle	Depends on resist thickness
DWL (oil)	**63×**	IP-L 780	Apply	borosilicate coverslip	Circle: Φ30mm ×170 um	within 150 um

For any non-standard resin or substrate, please consult NFCF staff for permission!

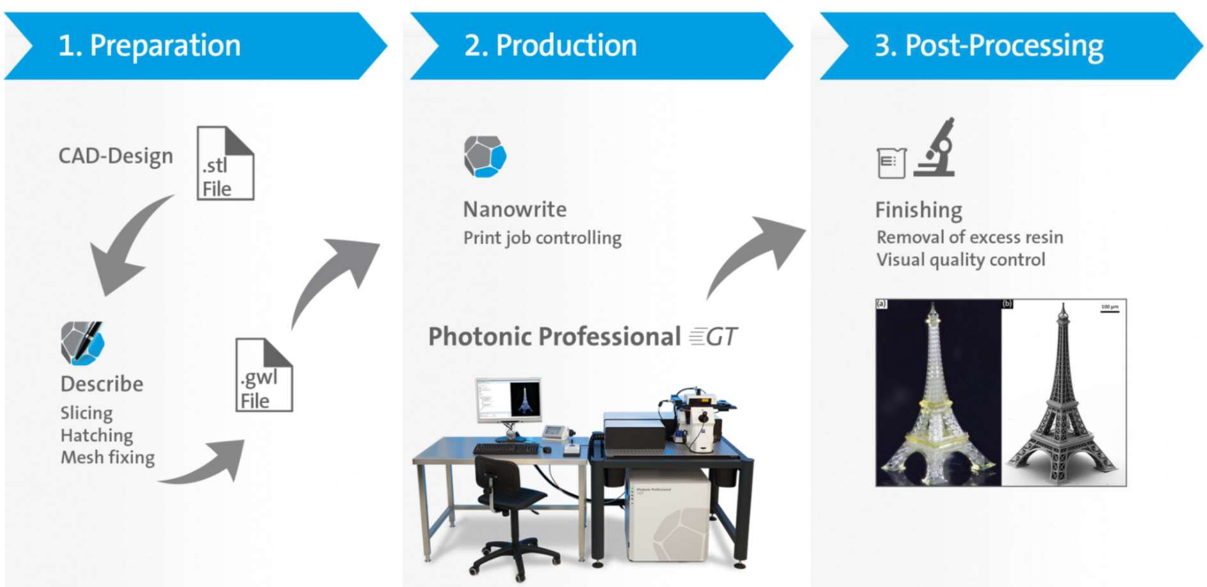
2. **To use other settings, objective needs to be cleaned and changed, which ONLY can be done by NFCF staff for now. Please do not attempt to do this by yourself.**
3. **After every use, please make sure it's in 'exchange holder' status then SHUT DOWN Nanowrite software only.**

4. **Please ALWAYS use online shared drive to transfer data, personal flash drive is not allowed!**

Standard setting: DiLL high



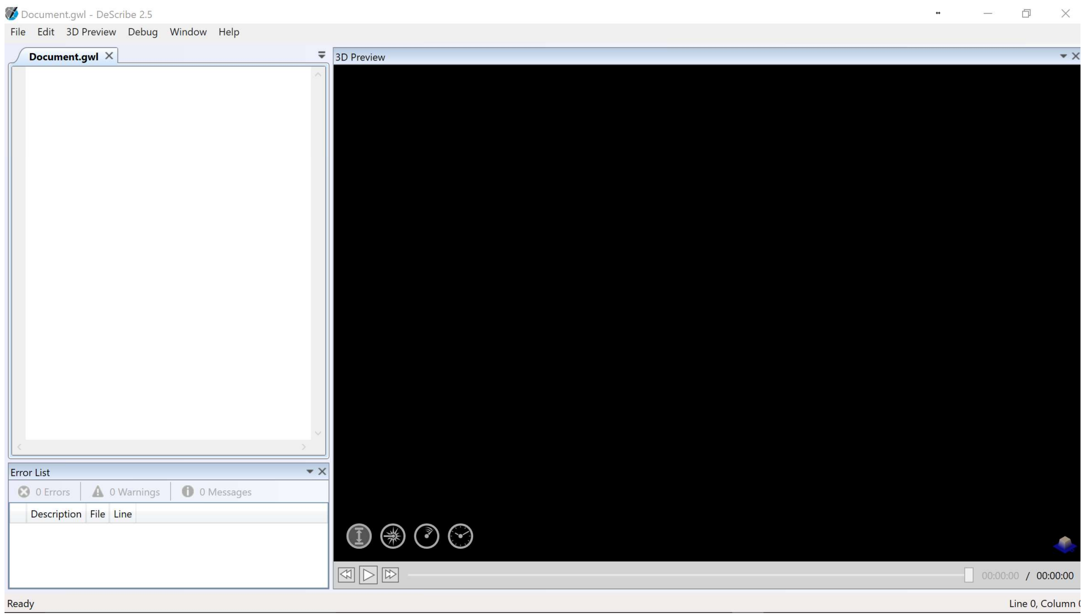
Workflow



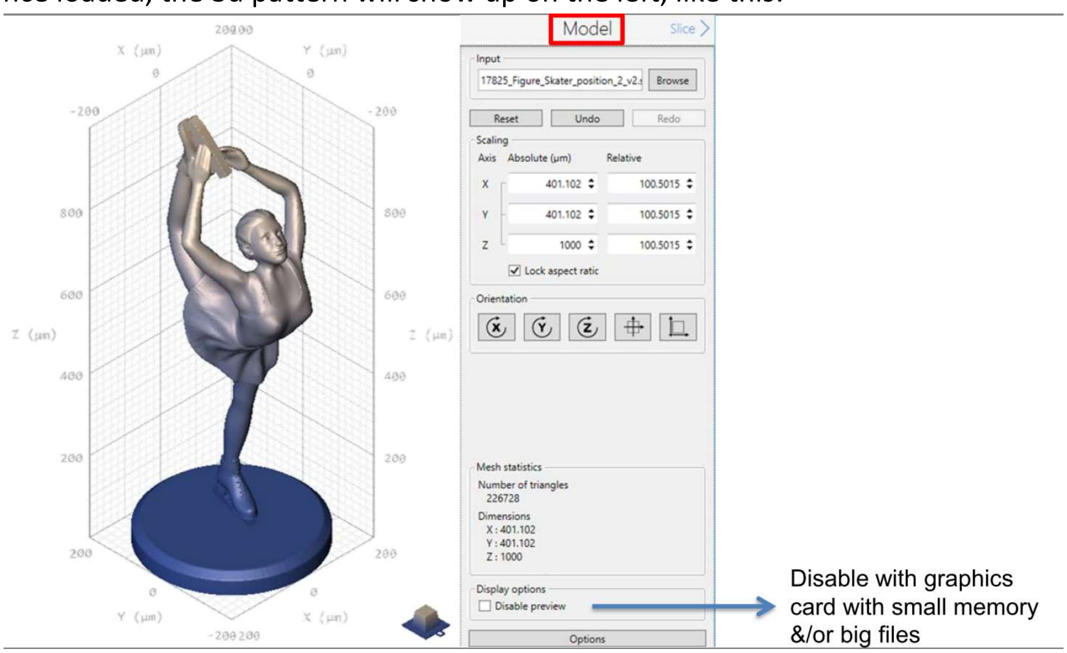
1. 3D design from Autodesk Fusion/ Inventor or Solidworks, saved in .stl file.
2. Convert stl file to gwl file through Describe software. You can convert the file from your own computer or Nanoscribe PC. Another option is to convert your file from the PC characterization room, which has high configuration.

   Convert stl file to gwl file:

   1) Open DeScribe and the software interface will pop up:

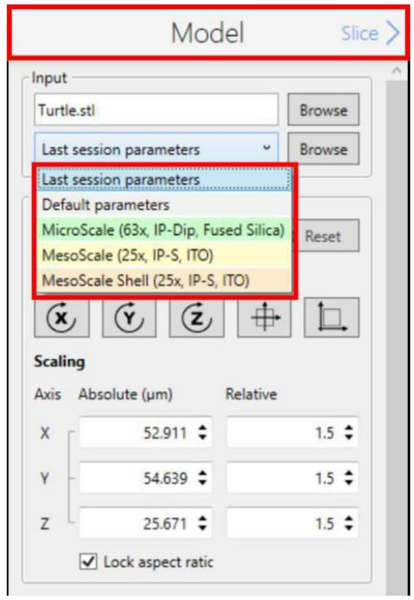


2) Click File/open, open your stl file under user folder
3) Once loaded, the 3d pattern will show up on the left, like this:



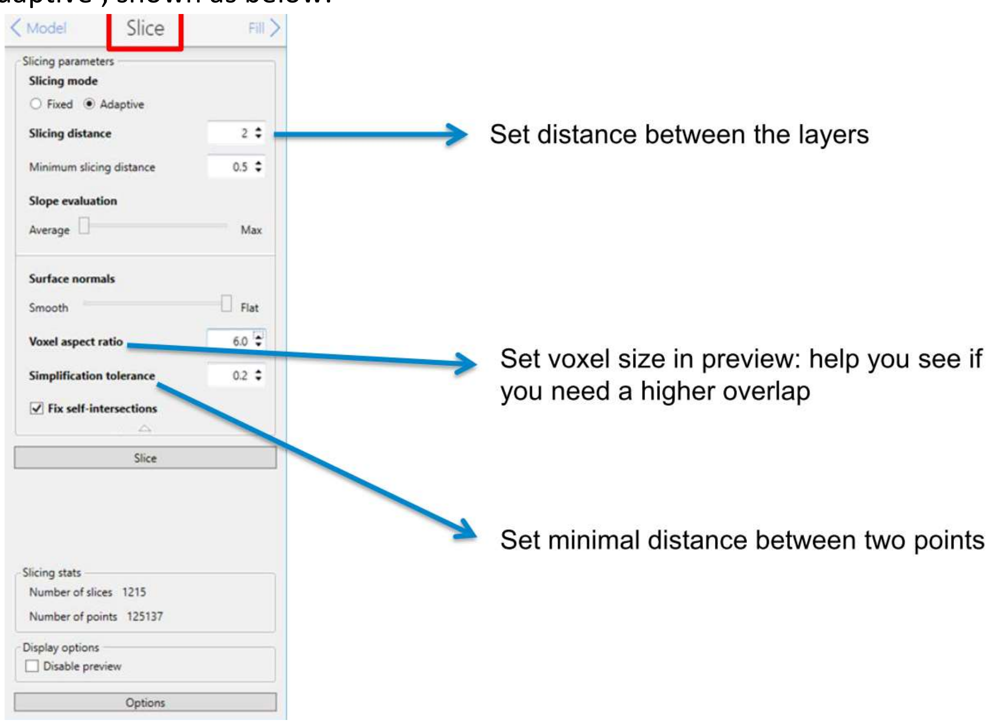
If the pattern is very big, it may take a long time for preview. You can check 'Disable preview' to proceed without preview.

4) Select the predefined parameters:



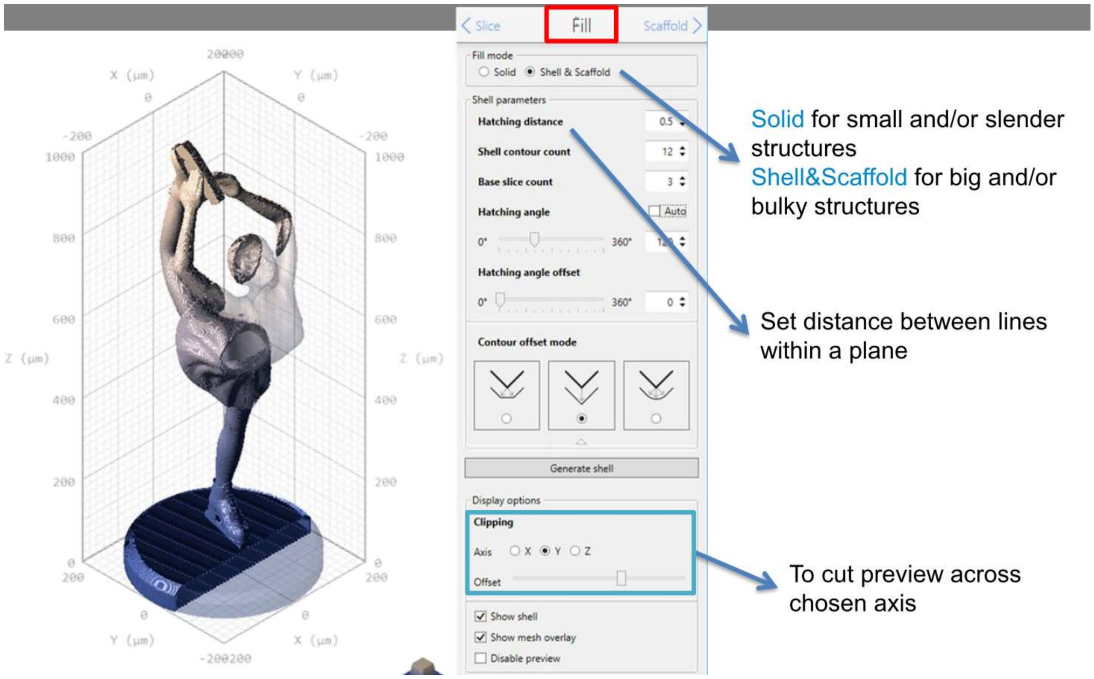
By default, use ‘MicroScale (63×, IP-Dip, Fused Silica)’. You can change the scaling of the pattern here, either in absolute value (µm), or in relative value. To keep the aspect ratio, check the ‘lock’ button. You can also change the orientation of the pattern by rotating along X, Y or Z direction. It is advisable to click ‘center at the origin’ to put the bottom center of the pattern at origin point.

5) Click ‘Slice’ to set parameters for slicing, you can select mode as ‘Fixed’ or ‘Adaptive’, shown as below:



For high resolution, select ‘Adaptive’, set ‘Slicing distance = 0.2~2 (μm)’. Then click ‘Slice’ button to see the preview. If necessary, you can always change the parameters and check the preview if satisfied.

6) Click ‘Fill’ to set the filling parameters as below:

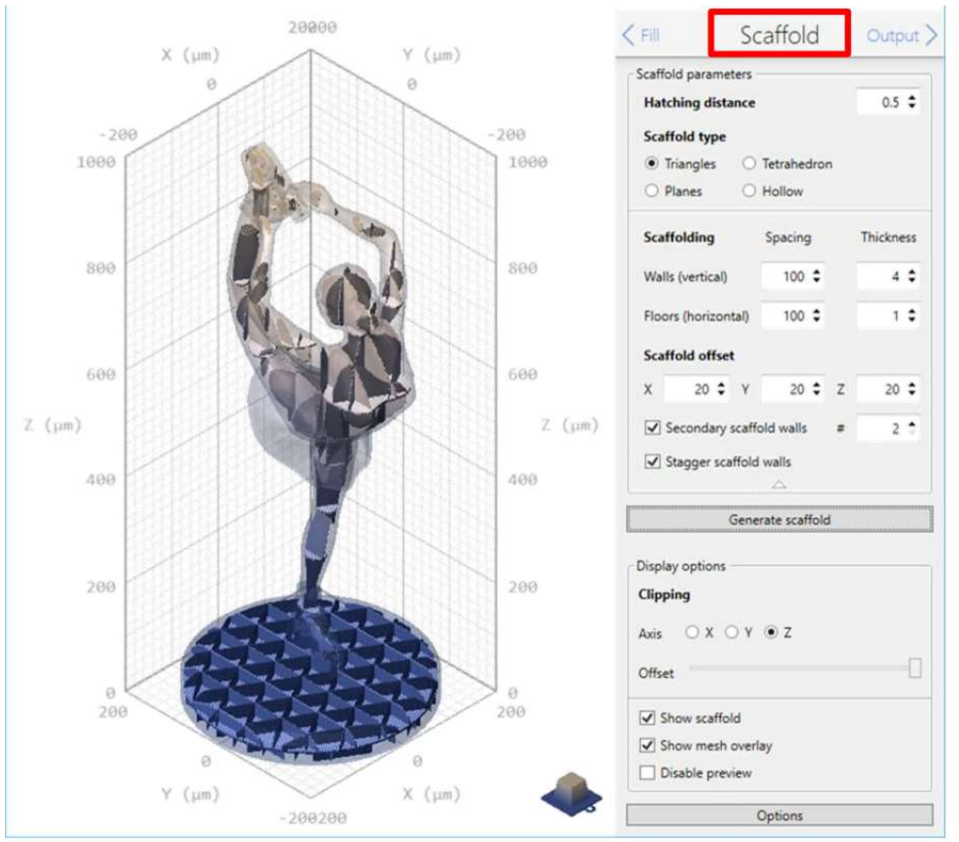


There are two fill mode: Solid or Shell & Scaffold. Solid mode will print every voxel. In comparison, Shell&Scaffold mode will print the shell in high resolution, but print the inner body in Scaffold pattern, which can dramatically save the printing time!

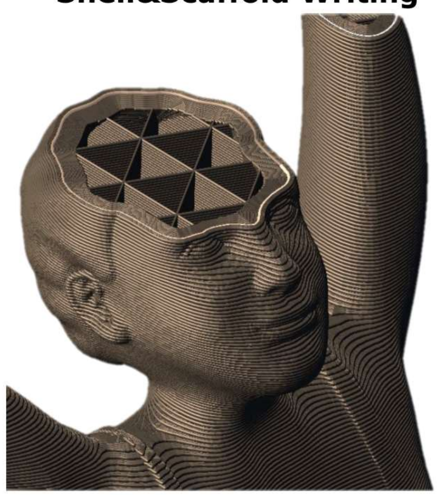
In ‘solid’ mode, you can set the hatching distance, 0.2 for high resolution; Base slice count(by default 6) will allow you to write a few slice below the interface to avoid any unwritten segment between the pattern and the substrate interface.

In Shell & Scaffold mode, Shell contour count will set the shell size (12 by default). The inner body part can be fully exposed by a UV flood (1.2 W/cm^2 for 5~20 mins) after the printing. After done, click ‘Generate shell’.

7) Proceed with ‘Scaffold’. The default setting for Scaffold is ‘Triangles’ which is the strongest shape. Set Scaffold walls and Floor spacing and thickness. Click ‘Generate scafflod’ to accept this setting.



Shell&Scaffold Writing



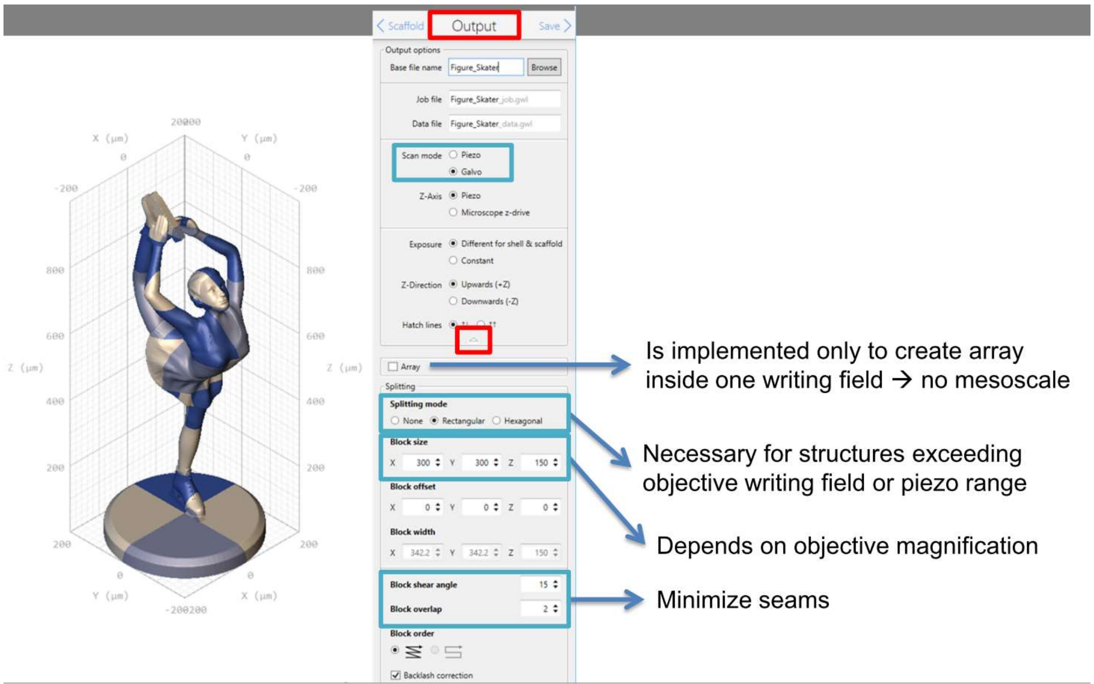
To speed-up

Splitting

To go beyond piezo and objective writing field

8) Proceed with 'Output'.
   Scan mode: Galvo mode is suggested, which is 100 times faster than Piezo mode. But Piezo mode has higher resolution(no abbreation).
   Z-Axis: Piezo has higher resolution and is suggested
   Exposure: Different for shell & Scaffold

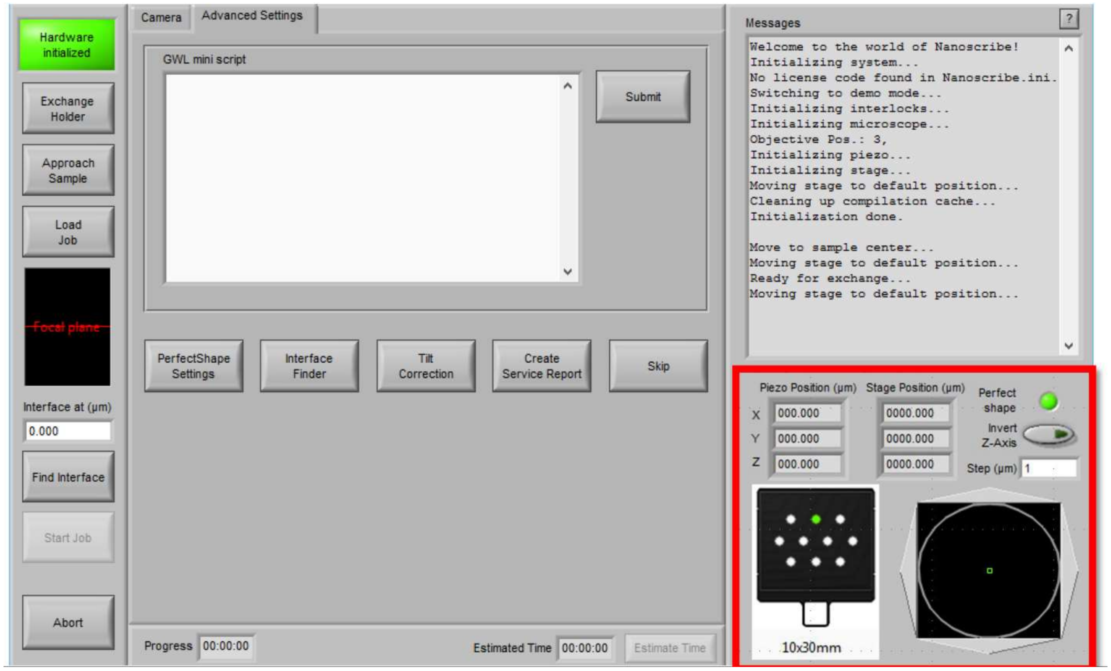
Z-Direction: by default ‘upwards’, which will print from bottom to top (Z direction). Otherwise from top to bottom.
Hatch lines: ↑↓ by default
Splitting: this setting is related to stitching on Z direction. You can adjust Block size/ Block width to move the splitting boundary to less important area.
Also, set Block shear angle = 15 (degree), which can minimize the stitching gap.



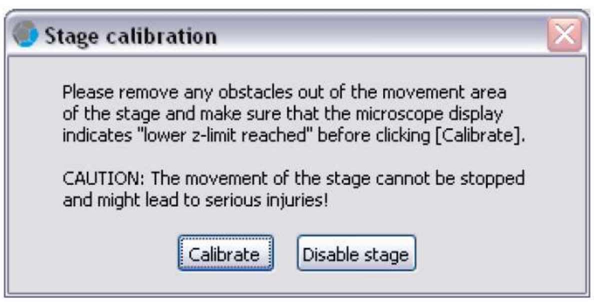
9) Finally, click ‘save’ to save to file. A gwl file will show up in Describe. Press F5 to create all the necessary files and show the pattern. You can now display the pattern in color by height, laser power, or print time. If you make any changes in the gwl file(coding), you need to press F5 to save the change. It will also show the estimated printing time.
10) Copy **both the gwl file and job folder** to the Nanoscribe PC for printing.

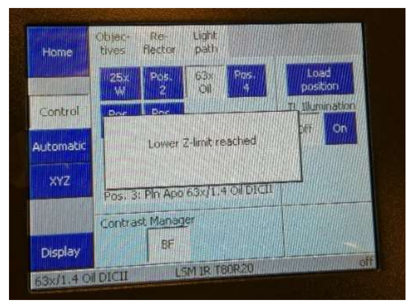
3. Printing with Nanowrite

1) Log in to CR- Nanoscribe.
2) Open Nanowrite software. Wait for initialization. Shown as below:



Follow this warning, make sure no obstacles on the stage, and on the microscope





control panel it shows Lower Z-limit reached. If this does not show up, turn the knob (down direction) to show it up. Then click ‘calibrate’.

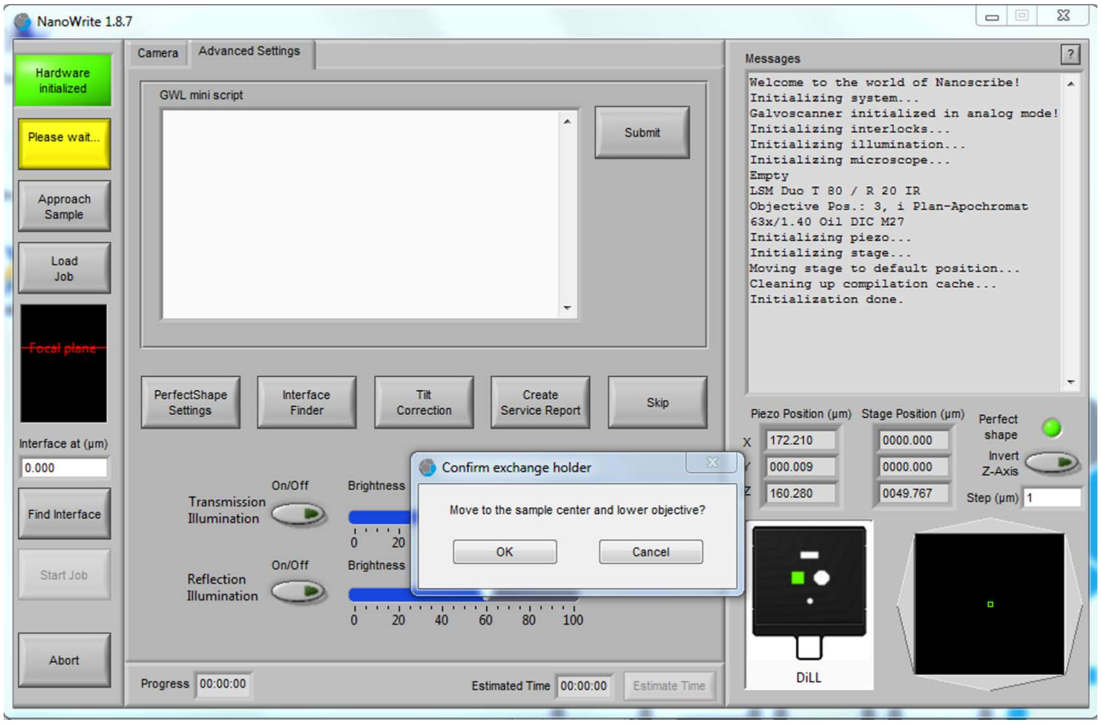
3) Prepare substrate.
First, select the substrate holder. We have 3 holder: Universal holder, multi-DiLL holder and 5’’ mask holder. The standard holder is **Universal holder**. Sample preparation area is show as follow:

DiLL config.: Put the holder bottom up, mount the substrate onto the predefined position with the tape. Then dip a droplet of resist to the center of the substrate.
Oil config.: Put the holder bottom up, mount the substrate onto the predefined position with the tape. Then dip a droplet of oil to the center of the substrate. Flip the holder and dip a droplet of resist to the backside center of the substrate.

Standard setting: DiLL config. , resist IP-dip, 63× objective

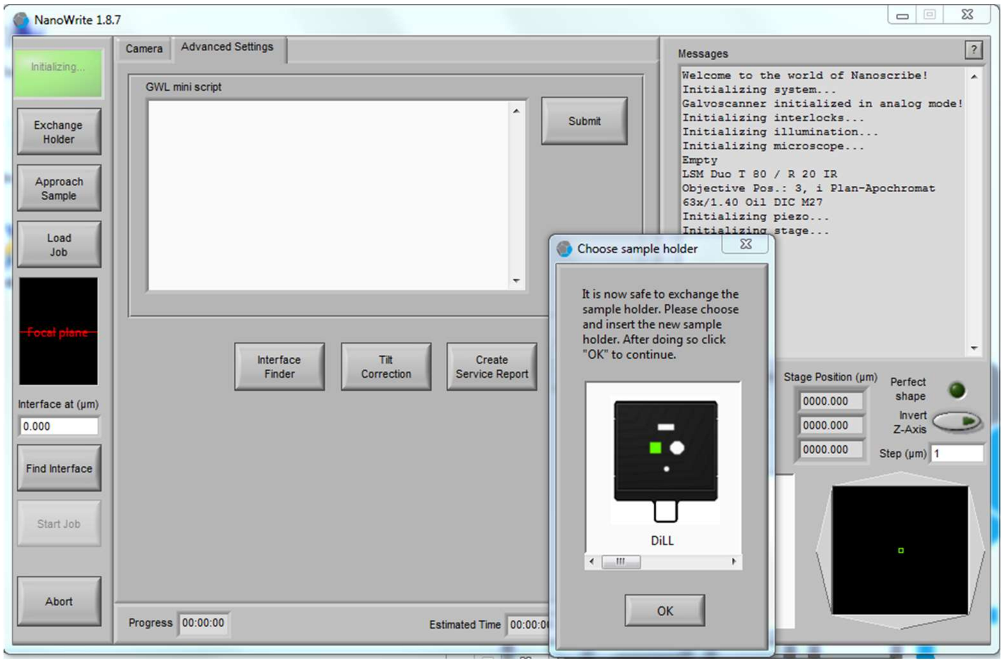
4) Back to the PC, click 'Exchange Holder' on the Nanowrite 

Confirm exchange holder, sample holder map will show up.

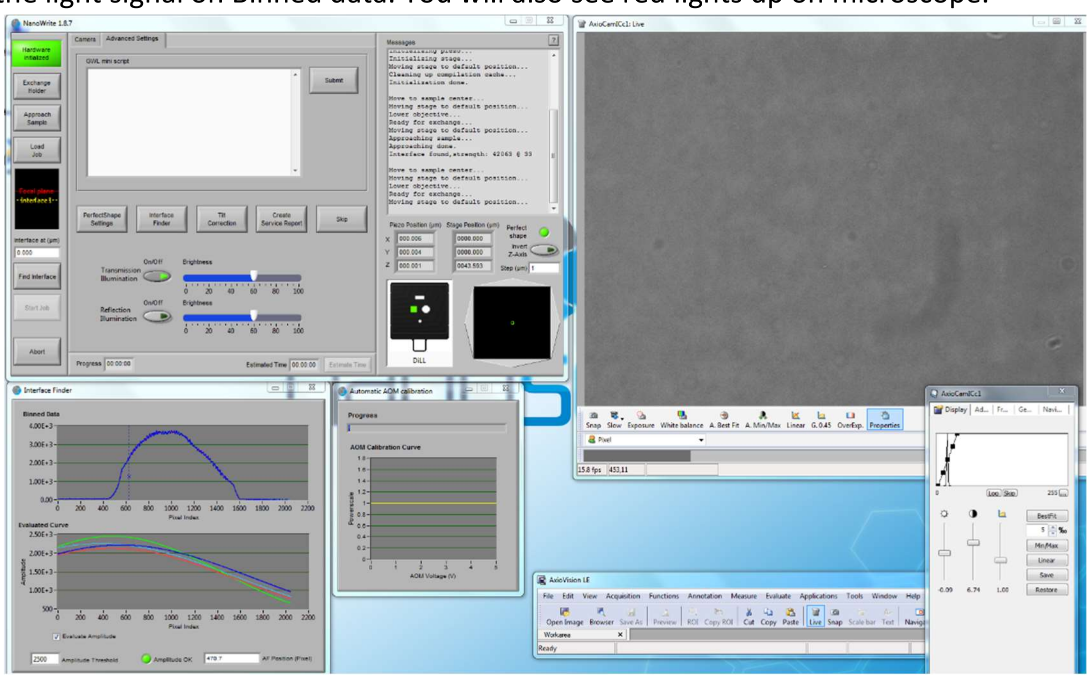


5) Take out the sample holder and flip it to make the top up. Then carefully insert the sample holder into the stage until aligned as below:

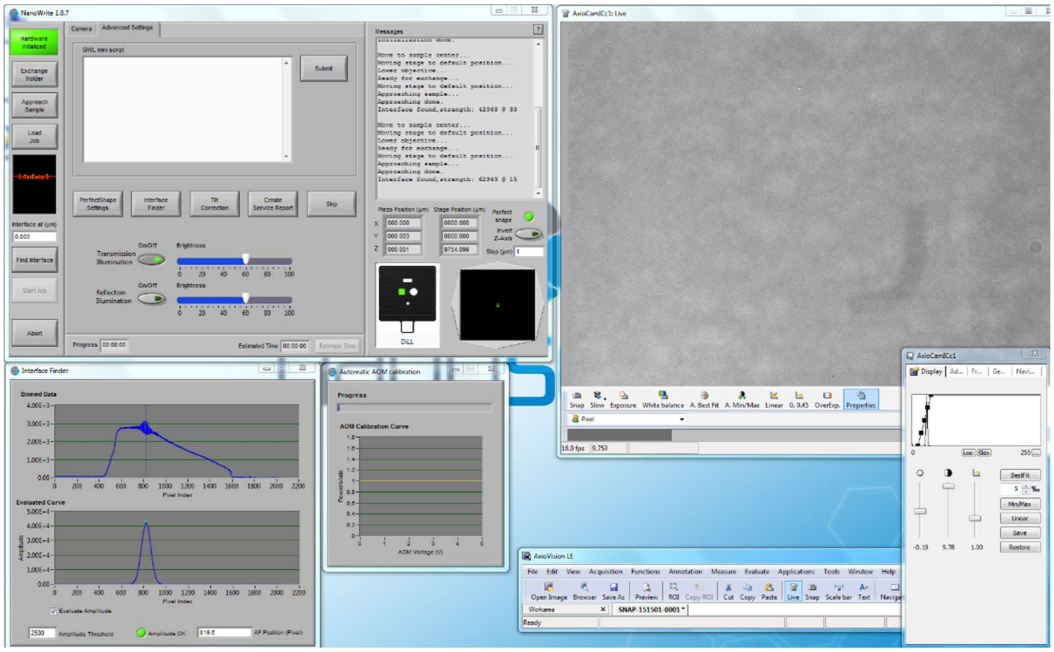
Select the right sample holder on Nanowrite and click on the right position. After done, click ‘OK’ to proceed.



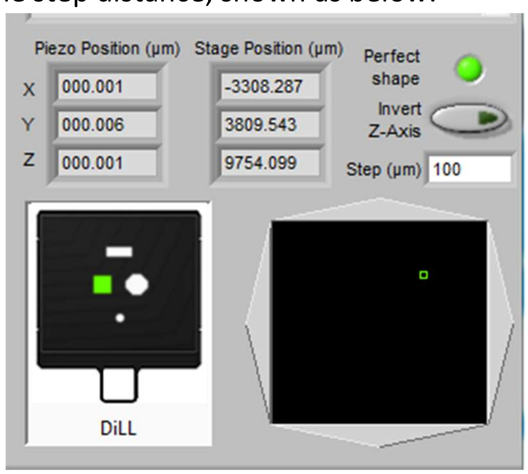
6) Now you will see the following interface, turn on 'Transmission Illumination', notice the light signal on Binned data. You will also see red lights up on microscope.



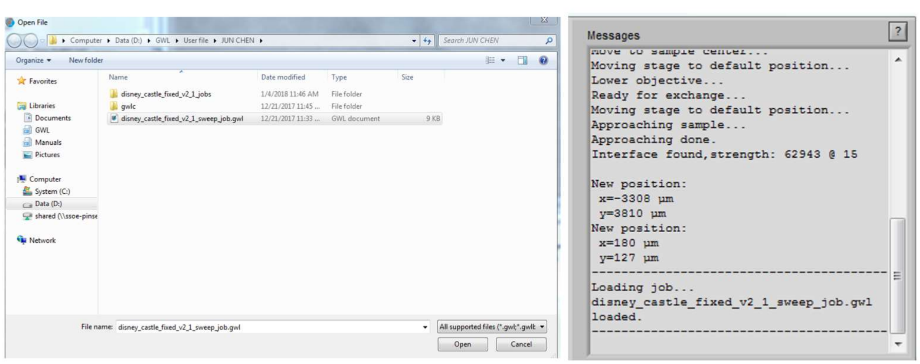
7) Click 'Approach Sample', you will see the resist from the camera panel as well as interference pattern on the pinned data, which means the interface of the resist and substrate is found. Now you can adjust the Axio camera software to get the best image.



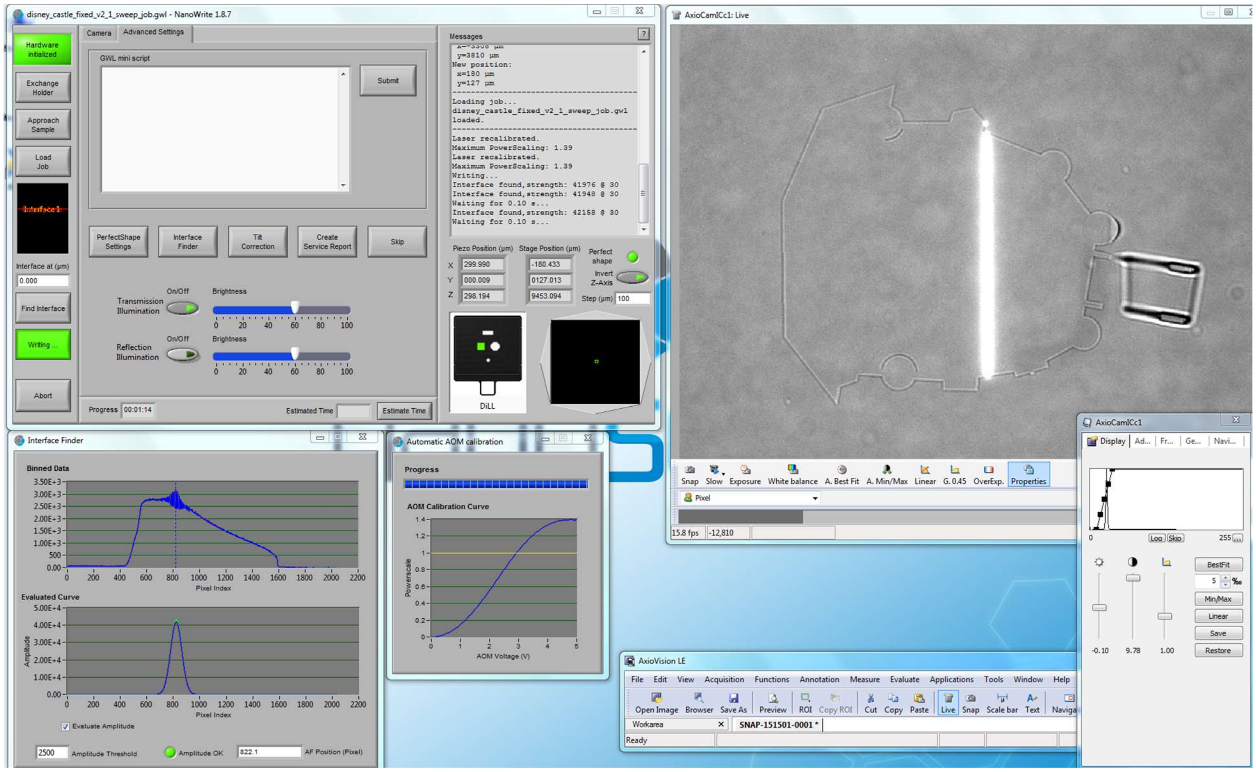
8) Now move the stage to the designated area by dragging the little green square. By default, it is located at the center. You can also move it by clicking the up/down or left/right knob, with the step distance, shown as below:



9) Load the job by click 'load job', then select the gwl file, and make sure you have the job folder also included under the same folder. Once loaded, on the message panel it will show 'loaded'.



10) Finally, you can start the printing by click 'writing'. You can see the writing on the camera panel on live.



11) After printing done. Simply click 'Exchange holder' and the objective will be retracted. Then pull out the substrate and put on the work station.
12) Carefully remove the tape and take out the sample for developing.
13) Developing: put sample in SU8 developer for 20 mins, then IPA for 1 min, take out and leave at RT for drying (DO NOT BLOW DRY!!!), it typically take 10 ~ 30 mins.
14) Check the printing under SEM if necessary.

For SEM check, first sputter coat 10~15 nm Pd/Au for discharging layer.

You can request trainings on 'Sputter coater, Denton' and 'SEM, Joel', please indicate your available time and mention that these trainings are for Nanoscribe printing.

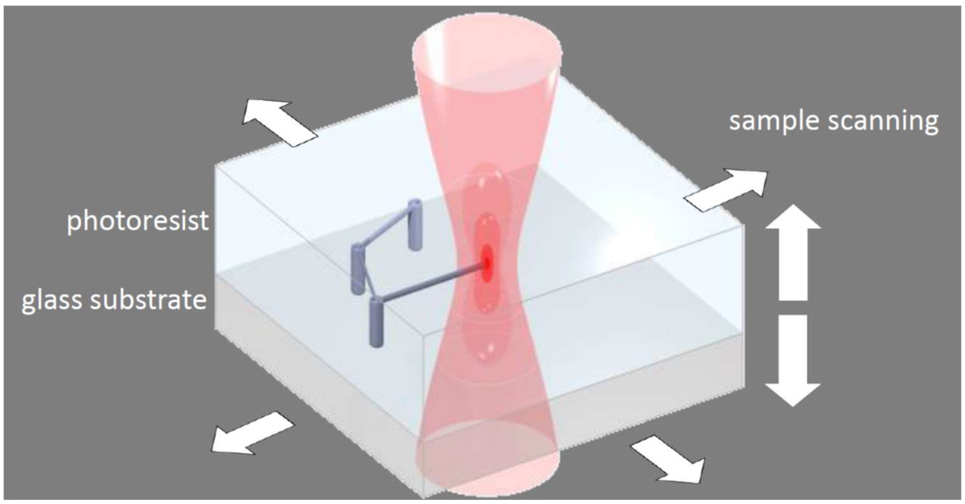
Appendix

3D Scanning system

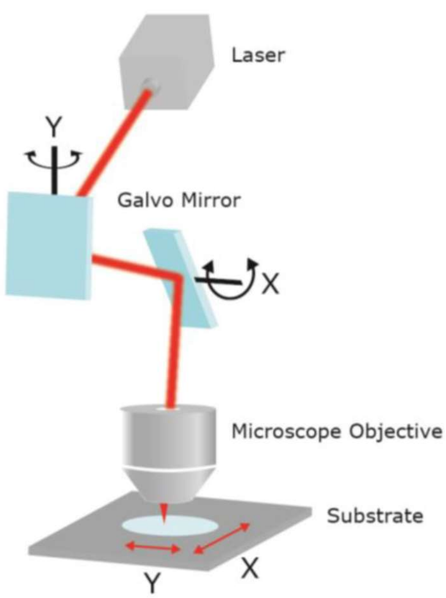
Piezo 3d scanning (XYZ): 300×300×300 μm^3 →highest resolution

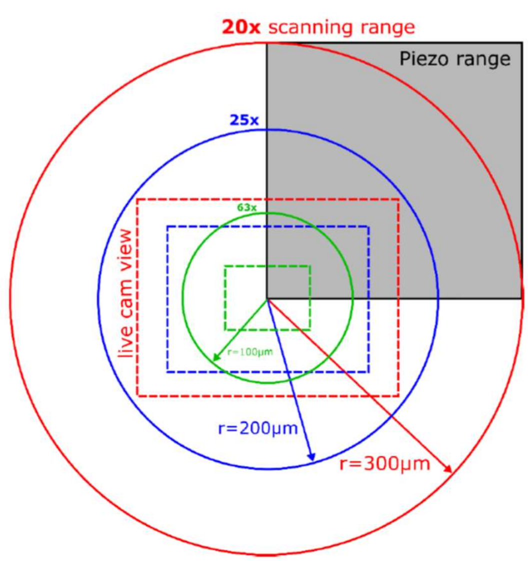
Stage movement (XY): up to 5 inch

Objective movement (Z): depends on sample thickness (within 2 mm)



Galvo scanning (XY): →high speed (100 times faster than Piezo mode)





Galvo scanning range:

For 63 × objective: 100×100 μm^2

For 25 × objective: 200×200 μm^2

Scanning modes

ScanMode	Coordinates	Range	Regime	Max. Speed	Optimal Repeatability
PiezoScanMode	Origin: current stage position	300x300x300μm^3	Vectorial	300µm/s	5nm
GalvoScanMode	Origin: current stage and piezo position	**63x obj.:** r = ±**100µm** **25x obj.:** r = ± **200µm**	layer-by-layer	obj. dependent >50mm/s	63x obj.: 14nm
StageScanMode	Origin: FIXED at the sample center	XY = full area	vectorial	500µm/s	1.5µm

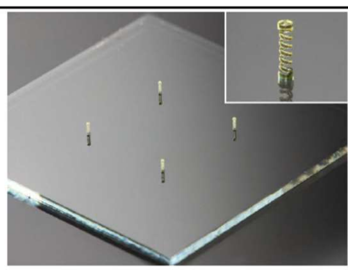
+ typical noise of 10-20nm

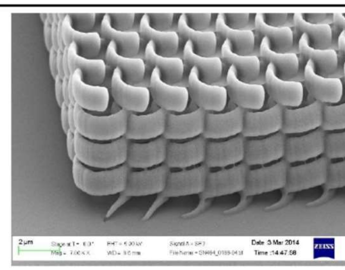
Objectives

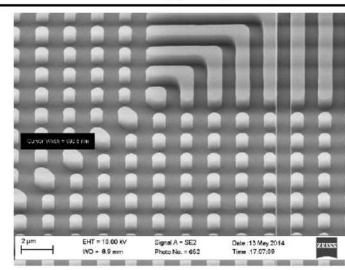
25x NA0.8 for mesoscale structures

63x NA1.4 for high-resolution structures

20x NA0.5 for 2D maskless lithography







Objective	25x NA 0.8	63x NA 1.4
Immersion	Resist	Resist / oil
Working Distance (WD)	170* + 210 µm	170* + 190 µm
Type	Low-resolution for meso-scale 3D printing	High-resolution for 3D micro-structuring
Writing Field Galvo Ø	400 µm	200 µm
Standard Resist	IP-S	IP-Dip
Typ. Slicing Distance	1000 nm	300 nm
Typ. Hatching Distance	500 nm	200 nm
Δn Required @830nm	*>0.1*	*>0.05*

**When working in Oil configuration, 170 µm are occupied by the glass thickness. Hence, the remaining accessible range is = WD – 170 µm*

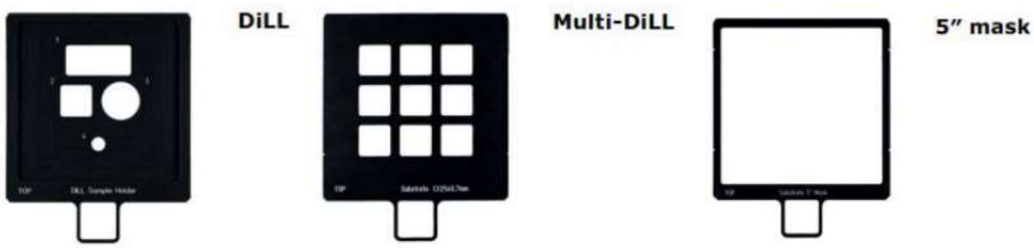
Photoresist and substrate

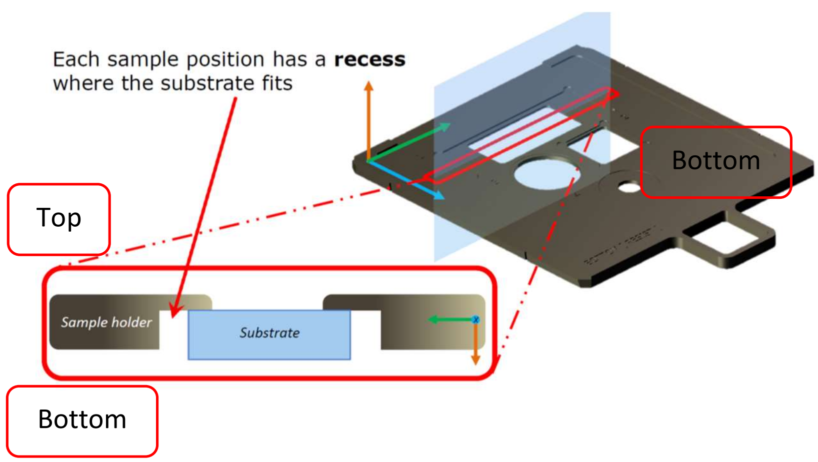
Name	Type
IP-L 780	liquid high resolution resist with low shrinkage
IP-Dip	liquid high resolution resist for DiLL with high NA-objectives
IP-S	liquid resist for mesoscale structures with high proximity effect and low shrinkage

Glass cover slips	borosilica	conventional / air
DiLL glass substrates for mesoscale applications	ITO coated glass *	DiLL
DiLL glass substrates for high resolution applications	fused silica	DiLL

Material	n @ 780 nm
IP-Dip	**1.52**
IP-S	**1.48**
IP-L780	**1.48**
Borosilicate coverslip	**1.52**
Fused silica	**1.45**
ITO coated glass	**1.7**
Oil	**1.52**
Silicon	3.71
SU-8	1.58

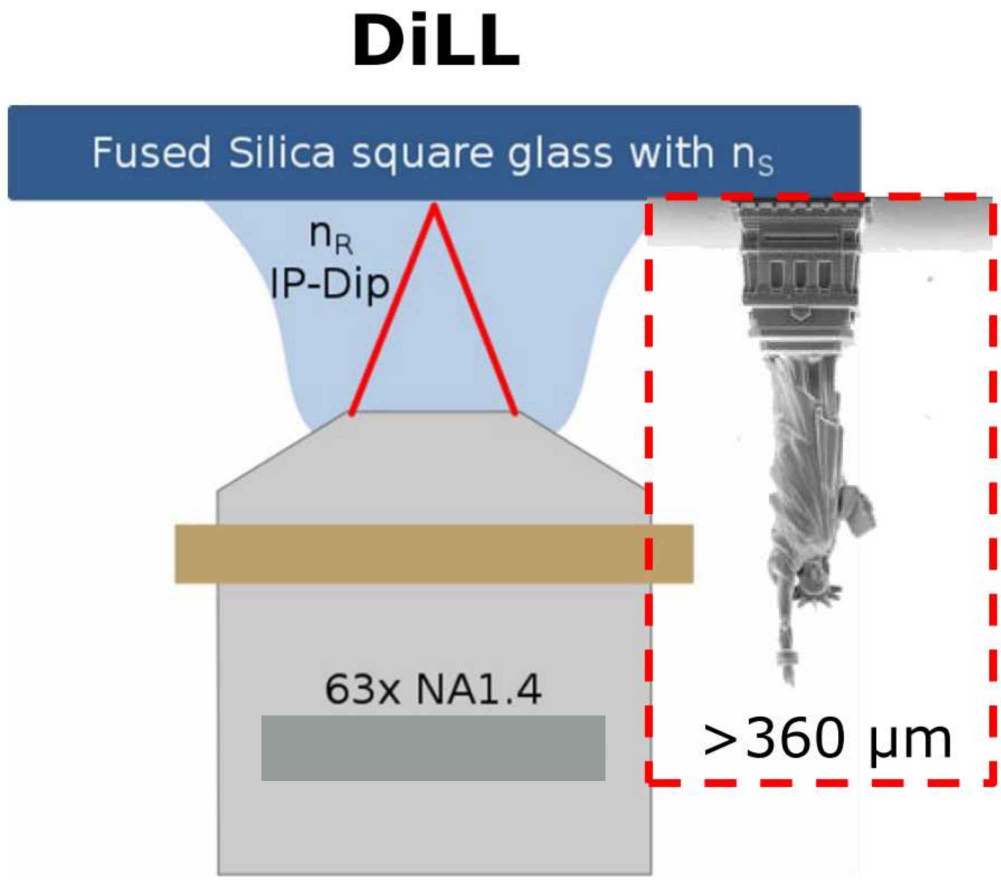
Sample holder





Sample Configurations

1. **Standard configuration(DiLL mode, high resolution):**



- Aberration constant → high resolution, down to 200 nm
- Height > WD possible, height can be up to a few mm
- Opaque substrates possible, by default Fused Silica glass

Objective: 63 × NA1.4

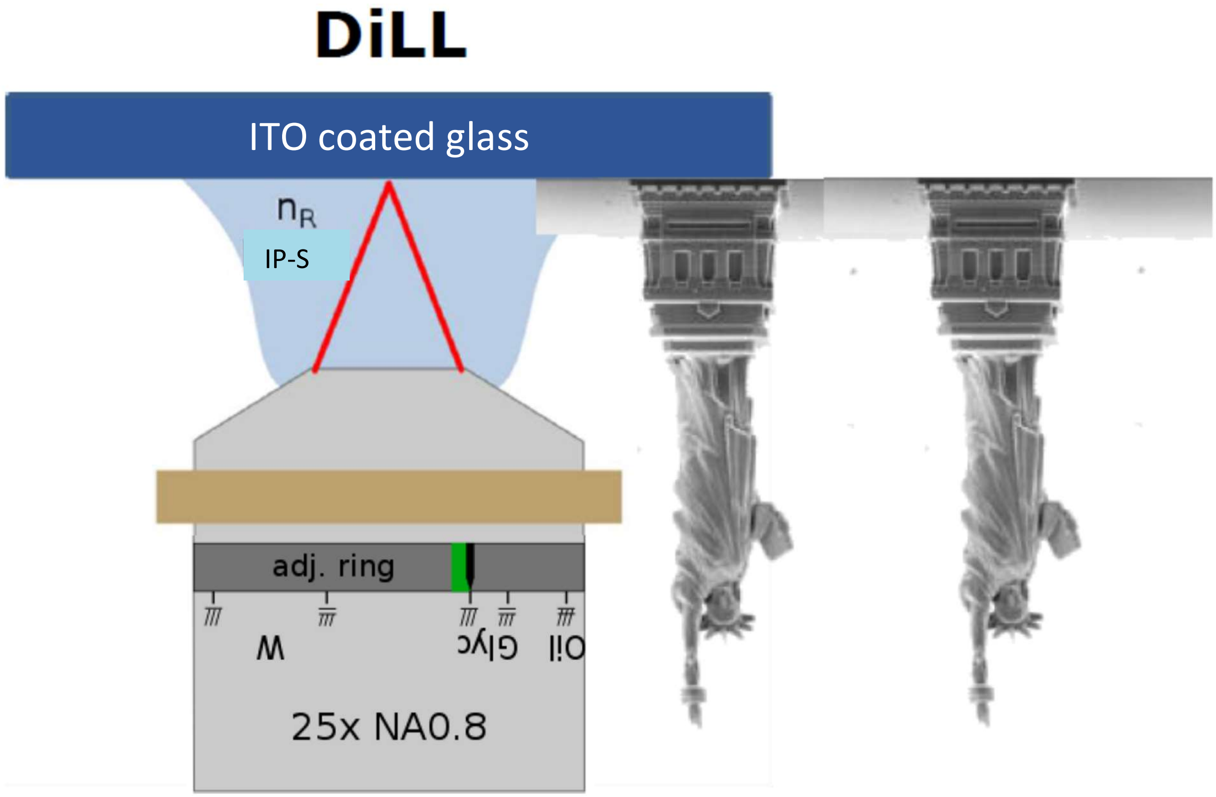
Resist: IP-Dip (n=1.52)

Substrate: Fused silica square glass or opaque substrate, must fit the substrate holder

Typical XY plane range: within 200 um

Printing direction: top down (from resist/substrate interface)

2. **Mesoscale configuration (DiLL mode, mesoscale)**



- Aberration constant
- Larger scanning range → mesoscale structures
- Opaque substrates possible, by default Fused Silica glass

Objective: 25 × NA0.8

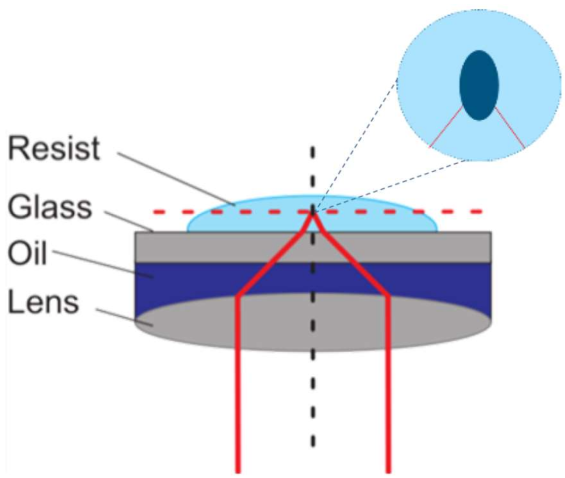
Resist: IP-S (n=1.48)

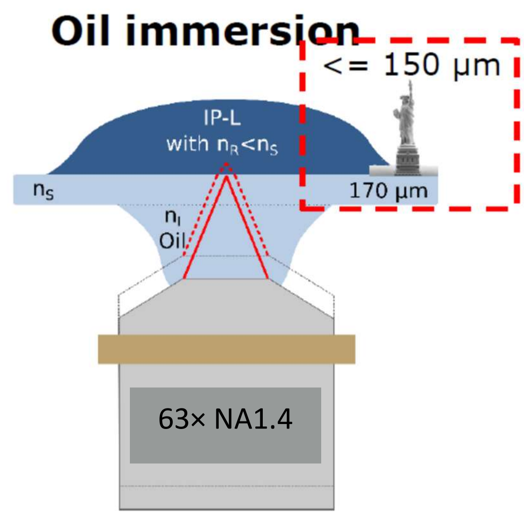
Substrate: ITO coated glass (700 um thick, n= 1.7) or Si (n=3.71), must fit the substrate holder

Typical XY plane range: up to a few mm

Printing direction: top down (from resist/substrate interface)

3. Conventional mode (DWL mode)





- Cover slip between resist and lens
- Aberrations increase with depth
- Height < WD-Cover slip (<=150 um for lens 63×)
- Have to use compatible oil (n=1.48)

Objective: 63 × NA1.4 (25× is not applicable)

Resist: IP-L 780 (n=1.52); may also work for some solid resist, like SU8, AZ resist (not applicable for now)

Substrate: borosilicate coverslip (n= 1.52)

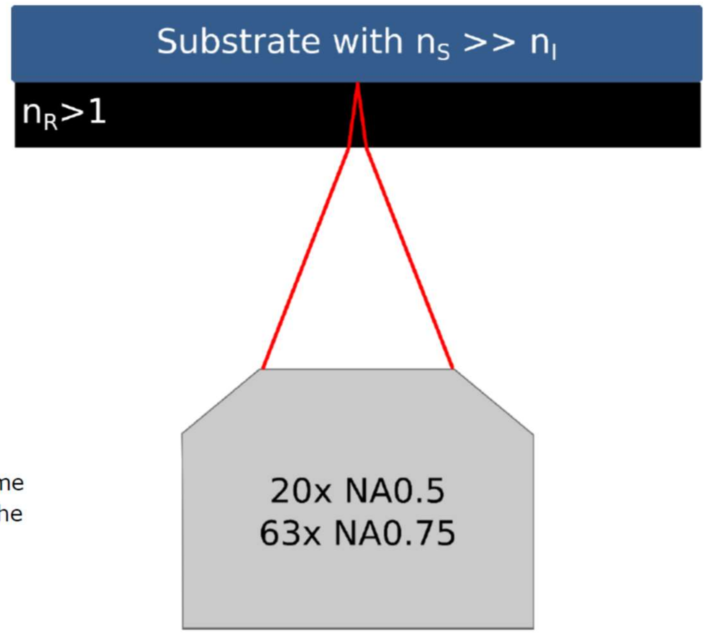
Typical XY plane range: depends on objective

Printing direction: bottom up (from resist/substrate interface)

4. Air mode

2D structures standard for solid resists

- 20x NA0.5 for Galvo & Piezo
- 63x NA0.75 for Piezo
- AZ resists
- Relation of n_R to n_S is not crucial
- No felt ring needed



Working distances
20xNA0.5 = 2.1mm / 63xNA0.75 = 2.3mm

General recommendations

- 01 Rectangles.gwl for dose test
- 02 Voxel_CrossSection for height check

Interface between air to resist and resist to substrate are usually indistinguishable.

Exact position mostly irrelevant due to extreme Voxel height and necessity to write through the entire resist thickness (positive tone resists).