Fiber Bragg Gratings

URA Summer 2019 | Haley So | Professor Bajcsy

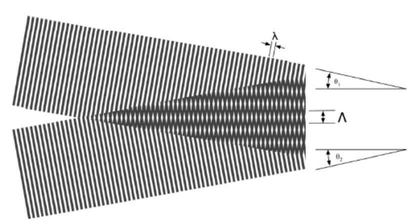
This summer, I worked to implement Bragg gratings within hollowcore fibers, a project based on *Implementing Bragg mirrors in a hollow-core photonic-crystal fiber* by Jeremy Flannery et. al. I started with UV interference lithography, working towards the goal of creating a grating within hollowcore fibers.

Overview

To increase light-matter interaction, one technique is to confine an atom within a tight space for which a specific wavelength of light can be used to interact with the atom. In this project, we're essentially finding new ways to do cavity QED. The goal is to load the fiber with the atom inside a cavity resonant on the wavelength of the bandgap or transition frequency from the atom's ground state to a specific excited state. The reflective surfaces can be made through Bragg gratings. Since we want to leave the opening of the fiber unobstructed however, we will try to selectively fill auxiliary holes with a fluid, expose the fluid to a interference pattern to create the alternating indices of refraction to make the Bragg gratings. Because we are using Cesium atoms, we'll be specifically looking at 852 nm and 895 nm wavelengths.

Laser Interference lithography:

Interference lithography is a process for which we split and recombine a beam of light to produce a interference pattern. In our experiment, we will be using a glue with n = 1.46 uncured and assume the index of refraction increases to 1.48 when exposed, following the paper assumptions. The periodicity of the alternating cured and uncured should be refined for the wavelength of light we hope the stack will reflect.



$p = \frac{\lambda}{2sin\theta_i}$ where p is the periodicity, λ is the wavelength of the laser, and θ_i is the angle from the normal to the surface of exposure. Below is a diagram of the setup for better understanding.

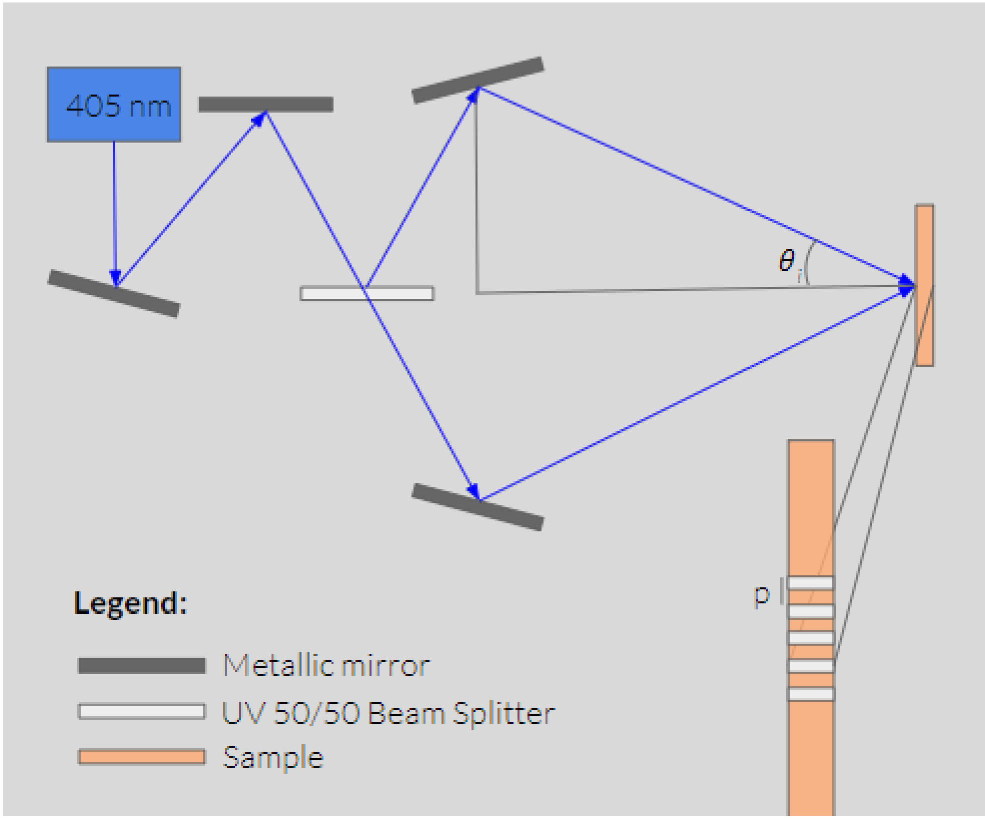
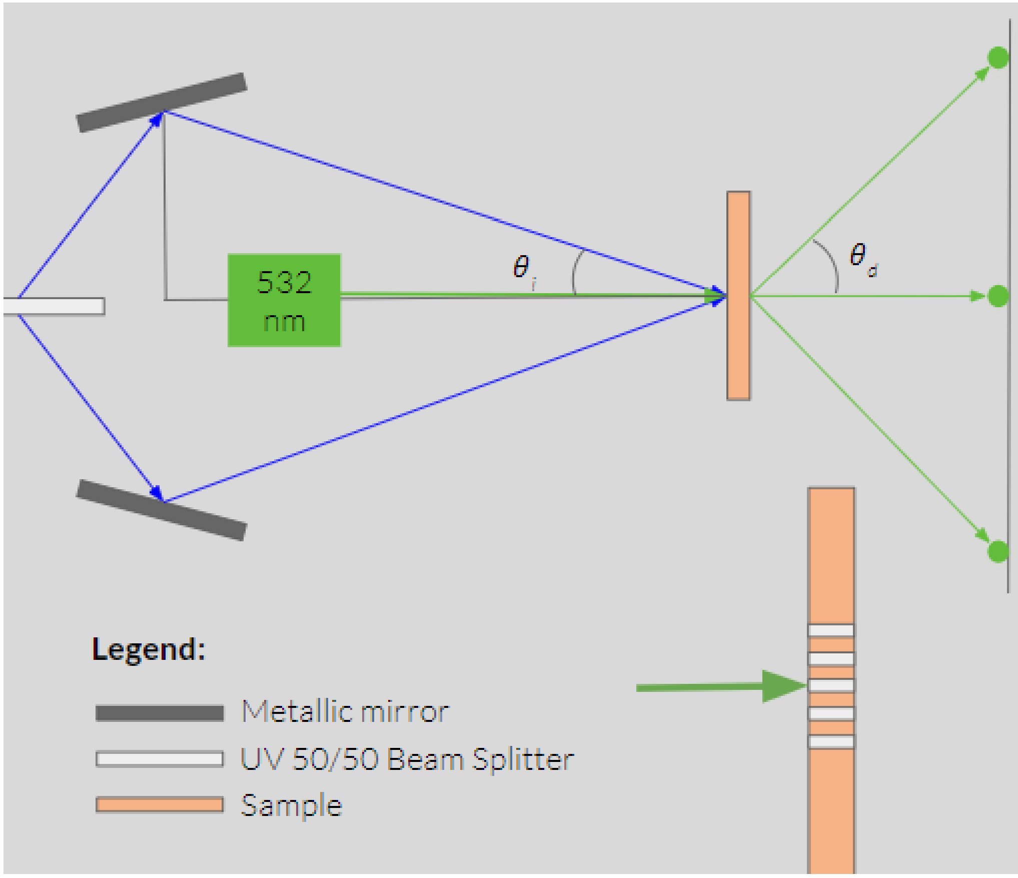


Diagram of my setup

Observing the diffraction

In order to observe the grating, we want to be able to see the first order diffracted spot when shining a laser normal to the grating. Evidently, we cannot just use any laser since it may not be able to resolve it, but with a simple calculation, we can find exactly where a spot should show up for a given grating a wavelength.

$sin\theta_d = \frac{m\lambda}{p}$ where θ_d is the angle for which the mth diffracted spot will appear for a given periodicity p. We can make a simple modification to the setup to see if we succeeded in creating a diffraction grating. We add in a 532 nm laser and shine it on the sample.



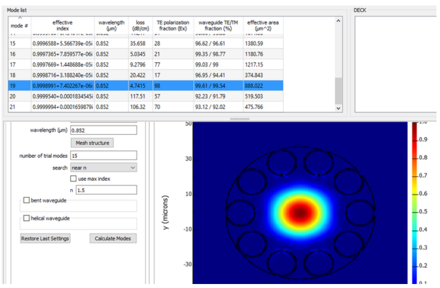
In the experiments, our sample of glue sits on a glass slide or inside a glass capillary. We must then add in a correction to take into account the layers of glass. For a glass slide, only the diffraction angle will change, but when trying to expose glue within a capillary, we need to modify the interference angle so when it hits the glue, it will create the correct periodicity.
To take into account this correction, we can use Snell's Law:
$n_1 sin\theta_1 = n_2 sin\theta_2$

Bragg Condition:
To find the periodicity needed to reflect $\lambda = 852$ nm with an effective index of n = 1.46, we do the following calculation:
$\frac{2\pi}{p} = \frac{2(2\pi)(n_eff)}{\lambda}$ where p is the periodicity. Therefore $p = \frac{\lambda}{2n_eff}$
For our experiment, we conclude the needed periodicity is 291.78 nm. The angle needed is then:
$\theta = sin^{-1}(\frac{405nm}{(2)(291)}) = 44.1^{\circ}$

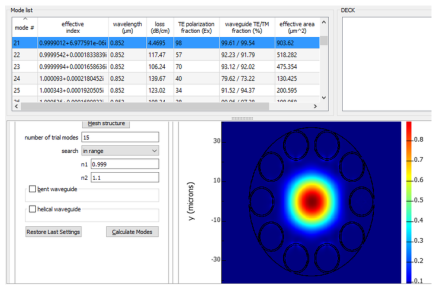
Lumerical

I initially started with simulations for wavelengths 852, but as I continued trying to make gratings inside the capillary, I realized the 405nm light won't make it into the glue since it would all get reflected by the glass. But, I included the simulations regardless:

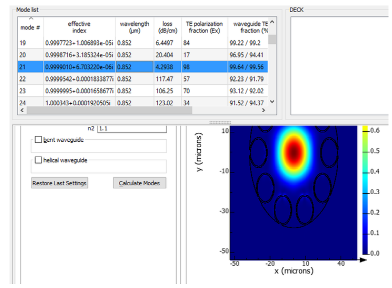
852 nm



852 nm no fill. The loss of the fundamental mode: 4.74 dB/cm



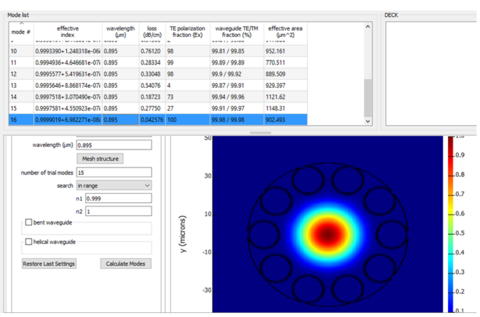
1 aux capillary filled with n = 1.46. The loss of the fundamental mode: 4.46 dB/cm



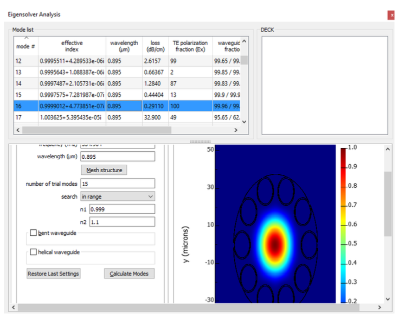
1 aux capillary filled with n= 1.48. The loss is 4.29 dB/cm

From the simulations, we can see this fiber has heavy loss at 852 nm too.

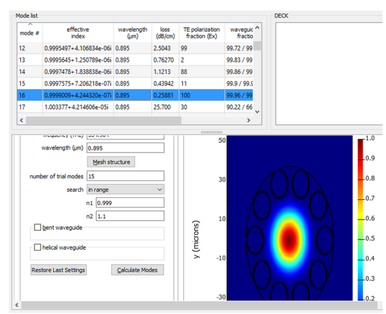
895 nm



No fill 895nm. Loss is .0426 dB/cm



1 fill 1.46 index of refraction, unexposed glue. .291 dB/cm



1 fill 1.48 index of refraction to emulate exposed glue .259 dB/cm

We can calculate the reflectivity of the stack with $R = e^{-2(\alpha_1 z_1 + \alpha_2 z_2)}$ where α_1, α_2 are the attenuation coefficients, z_1, z_2 are the total distance travelled in each layer. Also, a_1, a_2 are the bragg length/condition. For wavelength 895nm, we see the stack would be ~ 99.998% reflective.

$R \approx e^{-2(\alpha_1 z_1 + \alpha_2 z_2)}$

α_1, α_2 attenuation coef

z_1, z_2 total dist. travelled in each layer

a_1, a_2 bragg length / condition

Bragg condition $a = \frac{\lambda}{4n}$

$z_1 = \frac{895}{4(1.46)} = 153.25$ $\quad z_2 = \frac{895}{4(1.48)} = 151.18$

The penetration depth $z_p = \frac{a}{\pi} \frac{W_0}{\Delta W/2}$

a = length of ind. bragg period

$\alpha_1 = .291$ dB/cm $= 29.1$ dB/m $\quad \alpha_2 = .259$ dB/cm $= 25.9$ dB/m

$$R \approx e^{-2(29.1 \times (153.25 \times 10^{-9}) + 25.9(151.18 \times 10^{-9}))}$$

$$R \approx .99998326$$

$= 99.998\%$ reflectivity

Experimental Progress:

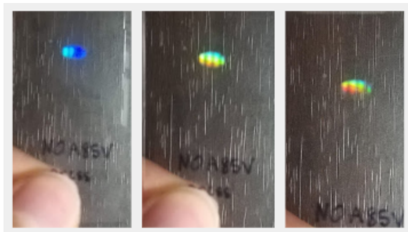
UV lithography setup & process:

Using the setup illustrated in the diagram, I broke up the experiments into a few subgoals:

a. create clean gratings on a sample of glue sitting on a glass slide
b. create gratings within a capillary
c. create gratings within the hollowcore fiber

a. ***Procedure for gratings on glass slides:***

1. Using NOA85V, put a droplet of glue on a slide. Either spin coat or press between two slides.
2. Expose the glue to the 405 nm.
3. Monitor efficiency to determine optimal amount of time of exposure for the given thickness*
4. Repeatedly wash with isopropanol and dry with air gun until only the grating remains

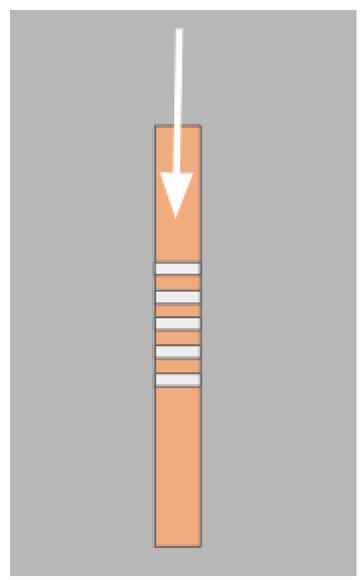


Above: press technique, exposed for 11.52 s for a grating p = ~950 nm

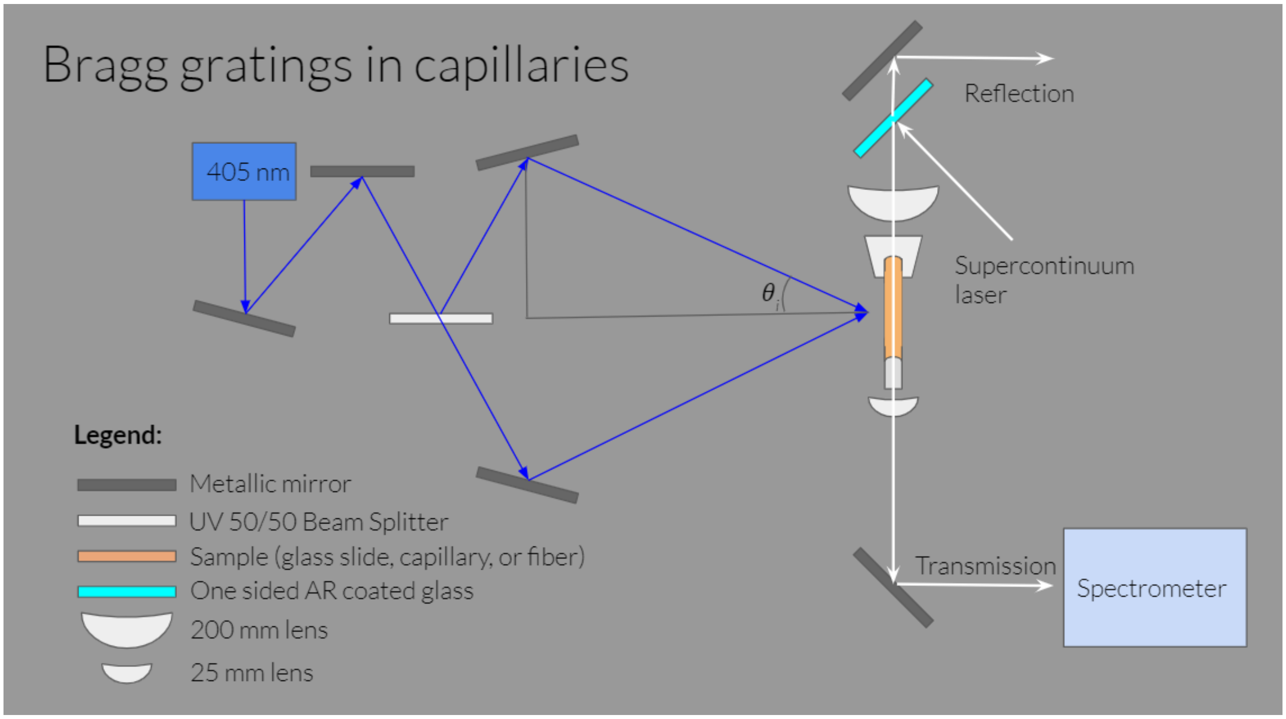
In the samples shown, we can clearly see we successfully made a diffraction grating. I also used the green laser to verify the periodicity.
I also looked into the different techniques of making a thin layer of glue to see which yielded a better grating.

Slide	exposure time	input power	power of 1st diffracted spot (1 spot)	power of 0th spot	not diffracted %	1st spots %
Pressed	11.52 s	1.81 mW	7.1 uW	1.56 mW	86.19%	0.78%
30s 1500 rpm	11.52 s	1.81 mW	7.1 uW	1.61mW	88.95%	0.78%
45s 1500 rpm	11.52 s	1.81 mW	7.1 uW	1.56 mW	86.19%	0.78%

It would also be beneficial to find the best exposure time, so in the future, I would go back and do so.



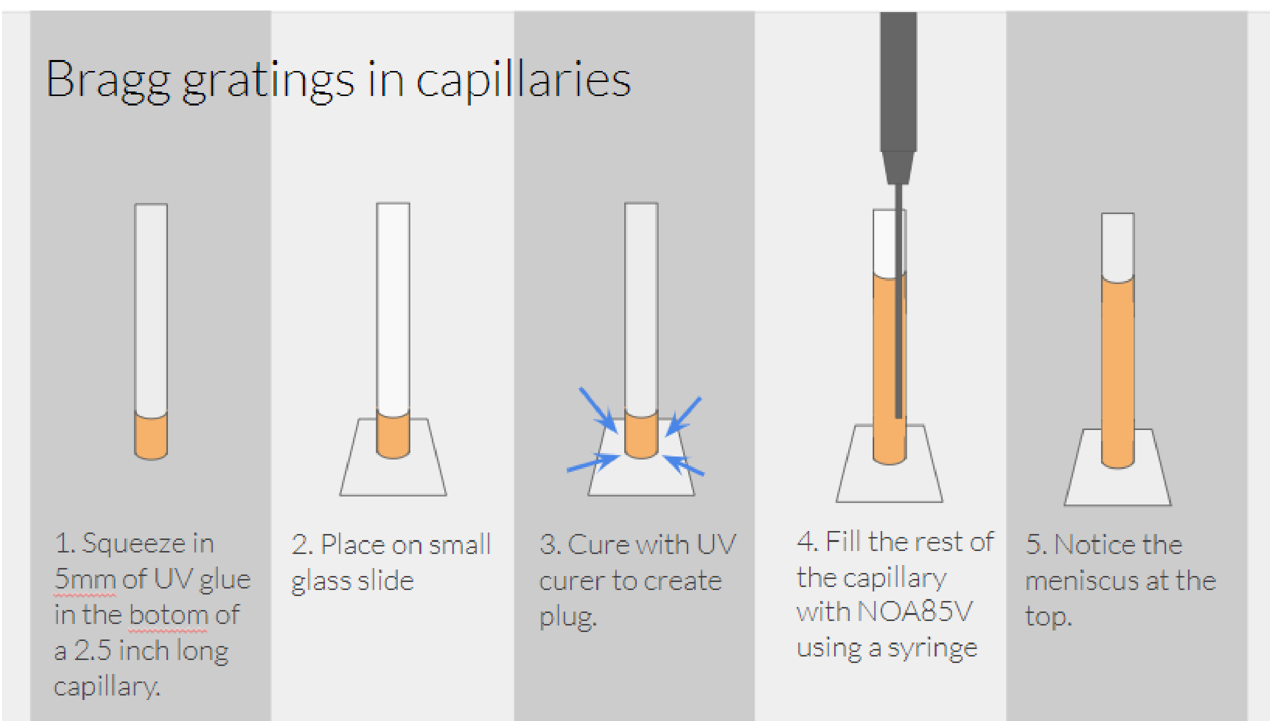
b. ***Procedure and progress for making gratings within capillaries***
The bulk of my summer was spent trying to figure out how to make gratings within capillaries, since they emulate the structure of the hollowcore fibers.
I first modified the setup so we could shine the lasers through alternating layers of index of refraction. In theory, when a supercontinuum laser is shown through the grating, in the output of the spectrometer, we should see a dip in transmission at wavelength 852 nm or whatever wavelength that fits the Bragg condition for that periodicity.



Modified setup to include a supercontinuum laser and spectrometer.

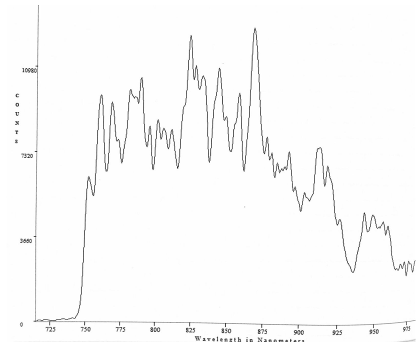
Doing a quick calculation, I found it's not possible to make a grating to reflect 852 nm inside the capillary due to the glass correction. From then on, I worked on making gratings for 895 nm.

The technique that I was developing to create gratings in capillaries goes as so:



Challenges

The difficulties come with observing the grating since a meniscus effectively acts as a lens. While I was able to find a way to rid of one of the lenses, there's still one meniscus, and if the glass slide were not completely flush at 90 degrees, then the light may go in at an angle. Additional difficulties include the moving fluid that would destroy the grating as the grating was being created. Possible solutions included exposing the capillary straight up and down, but the lithography setup would have to be heavily modified, turning the whole setup 90 degrees, taking tons of vertical space.



This is the counts from the spectrometer.

Ideally, if we did create a grating, we would be able to see a dip at 895nm, however we cannot be sure if we made the grating and just cannot observe it due to lensing issues, or if we didn't create the grating at all.

Research into selective filling of hollowcore fibers:

We then started the works of using caps to selectively fill the auxiliary capillaries. To be continued!

Additional things I've learned:

- 3D printing design for the capillary holder
- fiber coupling using the splicer
- fiber coupling using translation stages
- troubleshooting the interference setup