Maskless photolithography

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **Maskless photolithography**, submitted by **Nipun Sai M**, to the Indian Institute of Technology, Madras, for the award of the degree of **Bachelor of Technology**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Optical maskless photolithography ; Maskless projection lithography ; Digital mask ; Low cost lithographic system.

Filters for the Terahertz frequencies (0.1 - 10 THz) require Cartesian structures such as Split Ring Resonators or Fishnet structures, currently being developed in our laboratory. The critical sizes of these structures ranges from $10\mu m$ to $100\mu m$ and these are typically fabricated using a proximity/soft-contact photolithography system using a specially designed mask for each structure. Lithography masks are expensive for technology developed in research labs for THz applications, especially, when the complete knowhow of the devices are still exploratory and several different design modifications need to be made to obtain a single functional device.

In this thesis, a simple low cost Maskless Photolithography setup was constructed using a Digital Light Processor (DLP) based projector, focusing optics and holders. Patterns were designed on a computer and projected on a Photoresist coated wafer to expose desired regions. Pattern sizes, exposure color, exposure timing, Photoresist development parameters were systematically changed to obtain desired patterns etched on the Photoresist. Using this simple setup, tens of microns sized patterns were obtained repeatably with the minimum feature size obtained being $18\mu m$, on glass and Silicon substrates.

The thesis also aimed at making an extremely low cost (< INR 50,000 $\approx$ \$850) photolithographic system for academic institutions and Laboratory classes for graduate students at IIT Madras to enable students to perform photolithography in a laboratory session.

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ABBREVIATIONS

E-beam	Electron beam
RGB	Red Green Blue
UV	Ultra Violet
PPR	Positive Photo Resist
NPR	Negative Photo Resist
TCE	Trichloroethylene
IPA	Isopropyl alcohol

CHAPTER 1

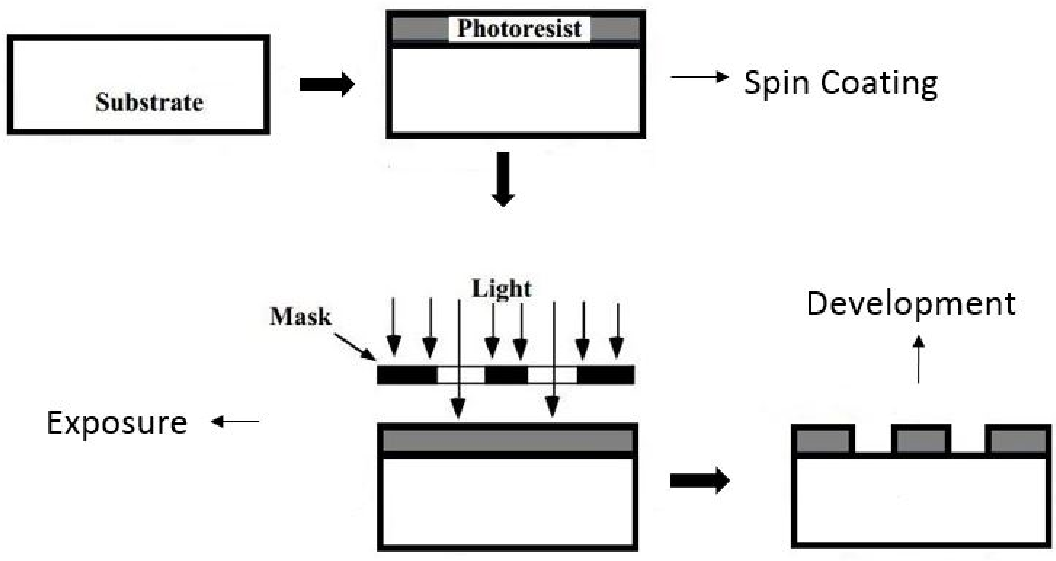
INTRODUCTION

1.1 A primer to Photolithography

Photolithography refers to the process that makes use of light to define patterns on a light sensitive high molecular weight material called Photoresist. In planar material processing technologies such as semiconductor devices, a semiconductor wafer is coated with a photoresist using spin coaters (or spray systems - less common, but getting popular). There are two common types of photoresists, positive and negative. Positive photoresists undergo a molecular scission upon exposure to light, while the negative photoresists undergo a polymerization upon exposure. The wafer coated with photoresist is exposed to light of specific energy (or wavelength) at desired locations. The result of the scission/ polymerization is a different solubility than the unexposed areas in a certain chemical known as developer. The wafers are developed by immersing them in these developers for precise amounts of time and desired patterns are obtained on the photoresist due to the differences in solubility between exposed and unexposed regions. Following the photolighography process, the patterns present on the photoresist layer are transferred to the layers of the wafer below by a variety of processes such as Wet/Dry Etching, Metallization and Lift-off etc.

In order to define the precise regions on the wafer that need to be exposed, a glass mask is usually used. The glass mask consists of transparent regions and opaque regions whereever desired. The light of specific wavelength is shone from one side of the mask and on the other side, the wafer coated with photoresist is placed. The wafer is exposed in regions where light falls through the transparent regions of the mask and regions on the mask that are opaque do not alter the molecular properties of the photoresist in those regions. The equipment used to define such patterns are known as Photolithography Mask Aligners. Typically, a lens system may also be used in the optical path to reduce to size of patterns on the wafers. In the semiconductor industry, tens of lithography steps may be performed on the same region of the wafer to complete the structure of the device. The limit of the size of the patterns that can be made is called the Diffraction Limit ($\approx \frac{\lambda}{2\,NA}$) where NA is the numerical aperture of the lens used to condense the light and λ is the wavelength of the light used. UV (365 nm) and deep UV (193 nm) are commonly used in commercial photolithography mask aligners. Currently, the photolithography mask aligner available in Microelectronics laboratory are capable of defining micron sized patterns. Although diffraction limit is the major barrier in making smaller patterns, vibration control, beam distortion due to lens aberrations, beam cross-section non-uniformity, photoresist thickness non-uniformity, substrate thickness non-uniformity, wafer bowing and several other factors can actually restrict the minimum attainable feature sizes in a photolithography mask aligner. Fig. 1.1 shows a diagramatic illustration of the photolithography process.

Figure 1.1: Figure showing photolithography process steps



On casual look, the concept of photolithography may wierdly resemble that of a chicken and egg, in the sense that to make a mask one would need photolithography and to perform photolithography, one needs a mask. But, a clear distinction needs to be made to understand the difference between making a mask and using the mask for photolithography. Masks are usually made only when same patterns need to be transferred to several thousand wafers repeatedly, for example, to define a square contact on all devices of a specific manufacturer, a single mask may be used. But, masks themselves are usually made custom to order typically using a Maskless lithography system (Typically an electron beam lithography system - discussion of which is out of scope of this thesis). The cost of making a Mask is several times more expensive than a wafer made using this mask, since each mask is made custom to order. Many manufacturers may also decline making a mask for a customer since they cannot maintain a sustained profitable business with their clients for longer periods of time, if the customer can make all their devices using their masks.

In this thesis, a maskless lithography system was constructed for 3 purposes

- To create tens of microns sized patterns on substrates for making Cartesian structures for THz filter applications.
- To create masks on glass substrate using a simple projection setup
- To develop an extremely low-cost, simple, low maintenance system for academic labs to experiment with several designs in a research problem to arrive at a final design.

The following are the considerations that have been taken into account in this work

- No component shall be costly or expensively custom made. All the components shall be commonly available
- The total cost of the system shall not exceed INR 50,000.
- Minimum feature sizes that can be made should be tens of microns. Such sizes may not need a Class 1000 cleanroom.
- The photoresist material used shall be the most common material that is used in academic research (i.e. Shipley S1813 positive photoresist).
- Developer shall be alkali based and not commercial.
- The mask design and projection should be simple and possible using easily available softwares such as Octave and Powerpoint (or a PDF viewer).
- The total time needed for the entire process be less than 2 hours.
- This work should enable students and academicians from IIT-M and other institutes to perform hands-on experimental work with structures needing photolithography.

CHAPTER 2

The projection lithography setup

2.1 Setup

The schematic diagram of the projection lithography setup is shown in Figure 2. The consumer projector used was manufactured by EIKI LC-XBL20. An image containing pattern is projected through the projector from a computer. The highest resolution which can be projected with the help of this projector is 1920 x 1200 pixels. The projected beam is then focused with the help of collection of common hand lenses. The parameters of the hand lens are not specific and not mentioned. The magnification of the lens vary from +5 to +10. We the help of 3 such lens the beam was focused onto an area of 3.45cm x 2.16cm. By relating the resolution of the image and the area on which it is focused, we arrive at a relation *1 pixel* = *18μm*. It is the minimum feature size possible with this setup.

Figure 2.1: Drawing of the setup

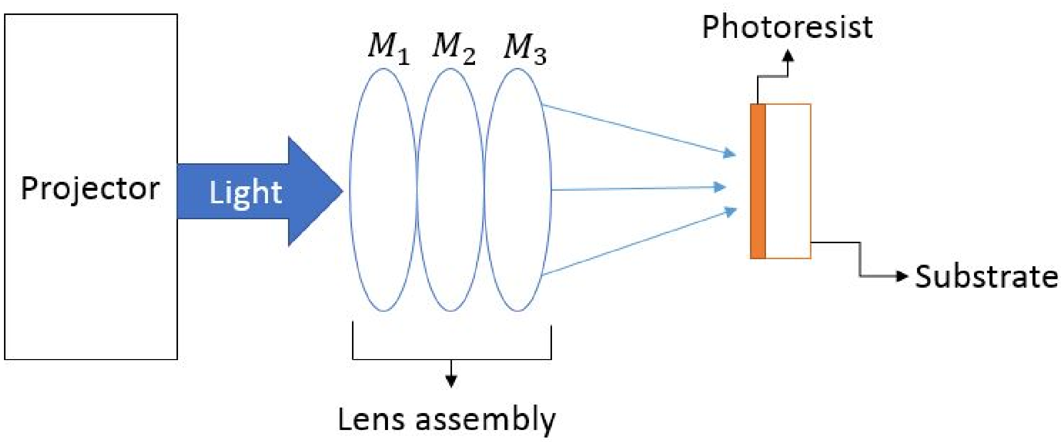


Figure 2.2: The setup with top and side views

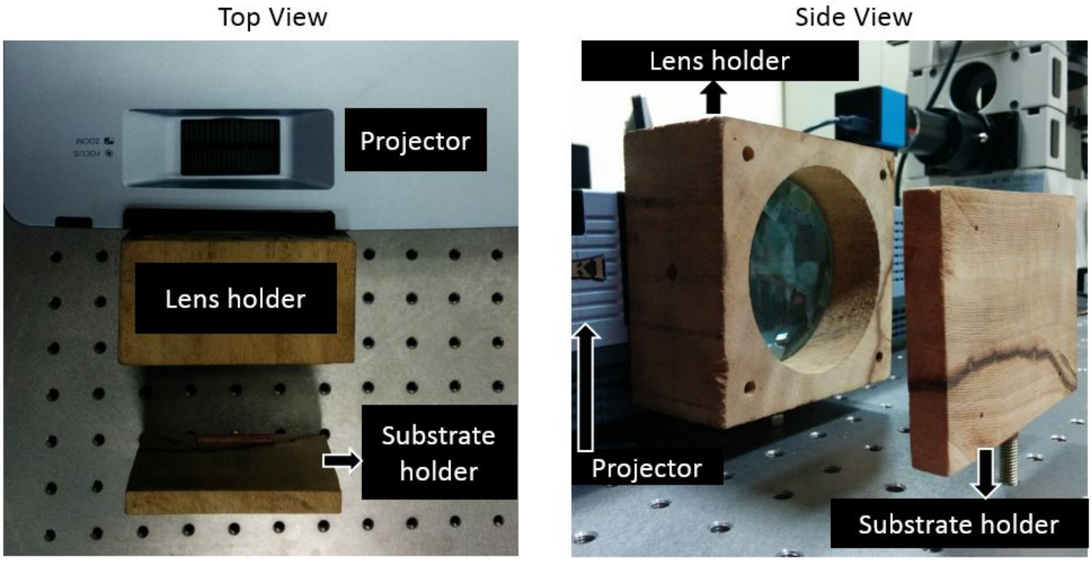
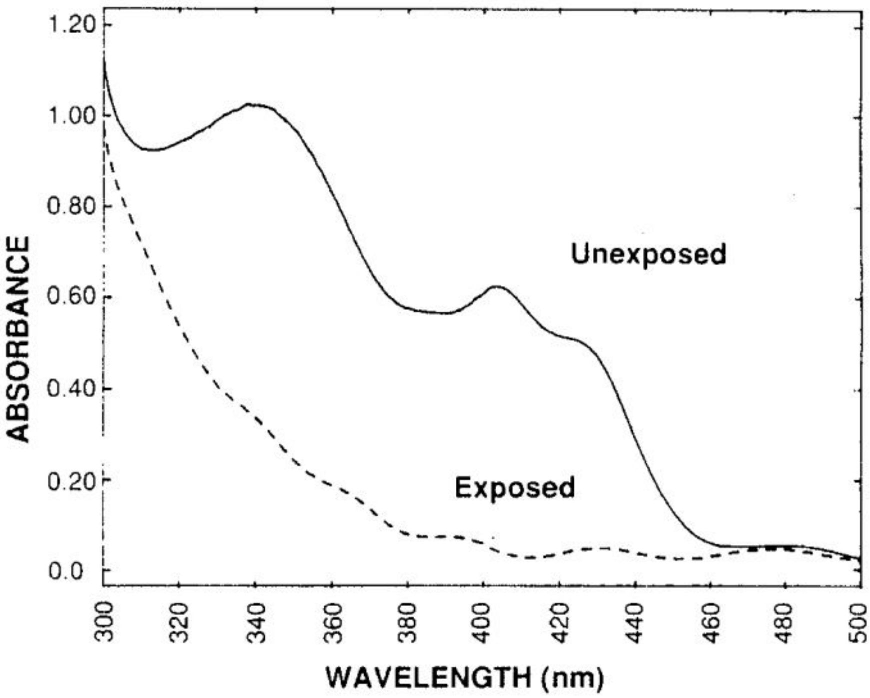


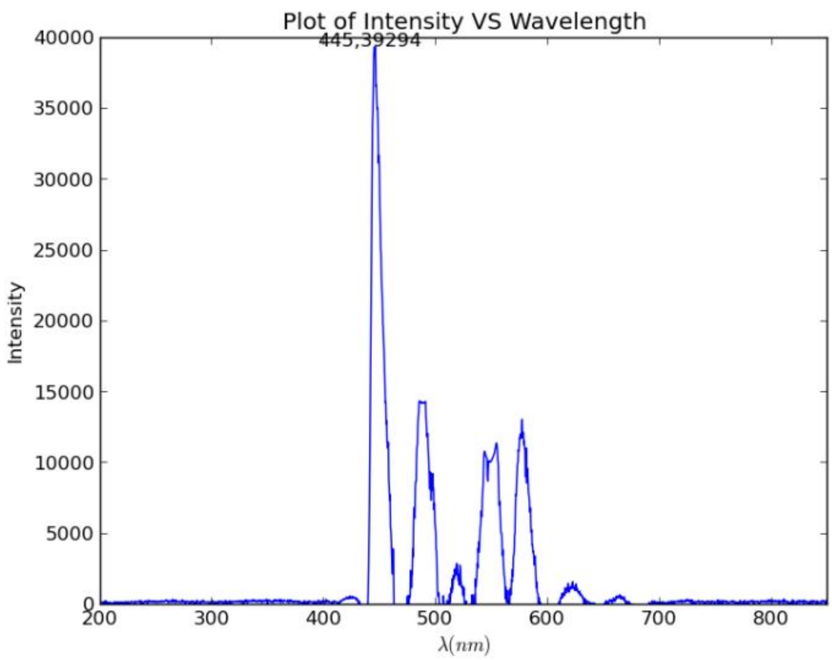
Figure 2.3: The absorption spectrum of the PPR



2.2 S1813 absorption and minimum wavelength specifications of the projected light

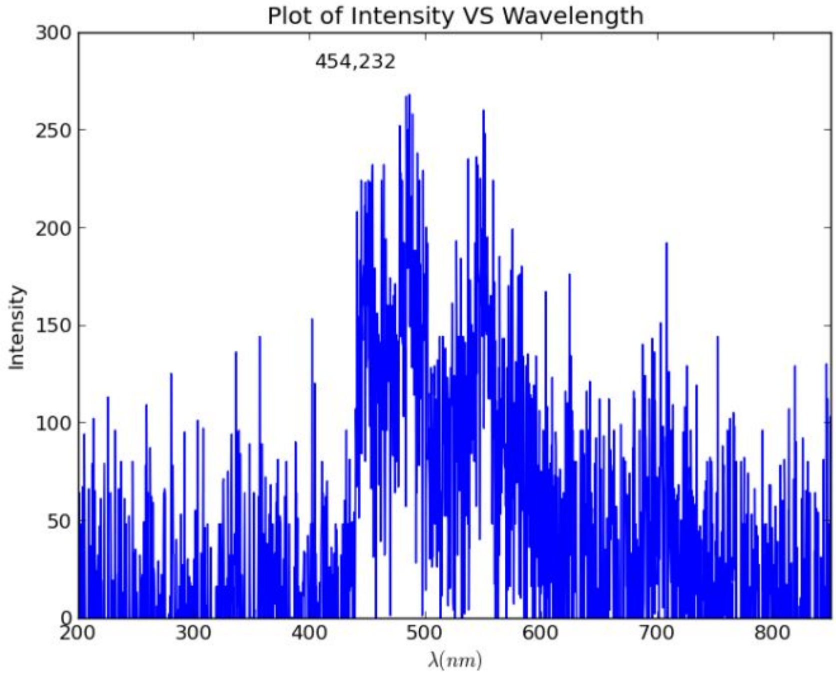
Figure 2.3 shows the manufacturer quoted absorption spectrum for S1813. The absorption can be noted to be almost complete at 300 nm to 370 nm wavelength and is almost none from 450 nm. According to the manufacturer specifications, the energy density needed for exposure for a thickness of 1200 nm is $110 mJ/cm^2$, wherein the absorbance of the photoresist is almost 0.9. The intensity of the beam from the projector on the sample surface was measured by using scanning power meter for different color patterns projected on the sample surface. The spectrum for the White and Black colors projected by the projector is shown in Fig. 2.4 and Fig. 2.5.

Figure 2.4: The output spectrum of White (255,255,255)



The filters in projector were adjusted such that the red and green colors are suppressed more than the blue color. The measured spectrum indicated that the minimum wavelength that could be projected by the projector with high intensity is about 445 nm. The ratio of intensity of 445 nm light of white color to black color was measured to be 177 times. Hence, it was clear that there would be a clear contrast between exposed and unexposed regions in the sample if the projector were to be used. The next step was to determine the color of the pattern that needed to be projected so that the mask could be

Figure 2.5: The output spectrum of Black (0,0,0)



a double color mask consisting of Blue regions for exposing certain regions and Black color for not exposing other regions. The spectra of shades of blue while keeping green and red components of the projected pixels to '0' are taken. The color the pixels were varied from (0,0,0) to (0,0,255) in steps of 25 and the spectrum for each of the shades of blue were obtained. It was seen that (0,0,255) had the highest intensity at 445 nm (confirming the intuition). The second peak that occured in these spectra at 486 nm, was out of absorption region of S1813 and posed no effect on the exposure of the resist. To reduce the clumsiness, we are plotting blue, partial blue and black in Fig. 2.6

Table 2.1 shows the measured intensity of different shades from black to white. From these measurements, the RGB values (0,0,255) having a wavelength of 445 nm had an intensity of 0.401 mW/cm^2. The exposure time from these measurements were calculated using the formula
The energy requirement is $110mJ/cm^2$. For that given our intensity of $0.4mW/cm^2$ and absorbance of 0.2.

It was calculated to be 22 minutes. It should be noted that in the photolithography mask aligner system available in the microelectronics laboratory, the typical exposure time is only 7-8 seconds. This meant that the setup needed to be stable and on a vibration isolation table.

Figure 2.6: The output spectrum of Black (0,0,0)

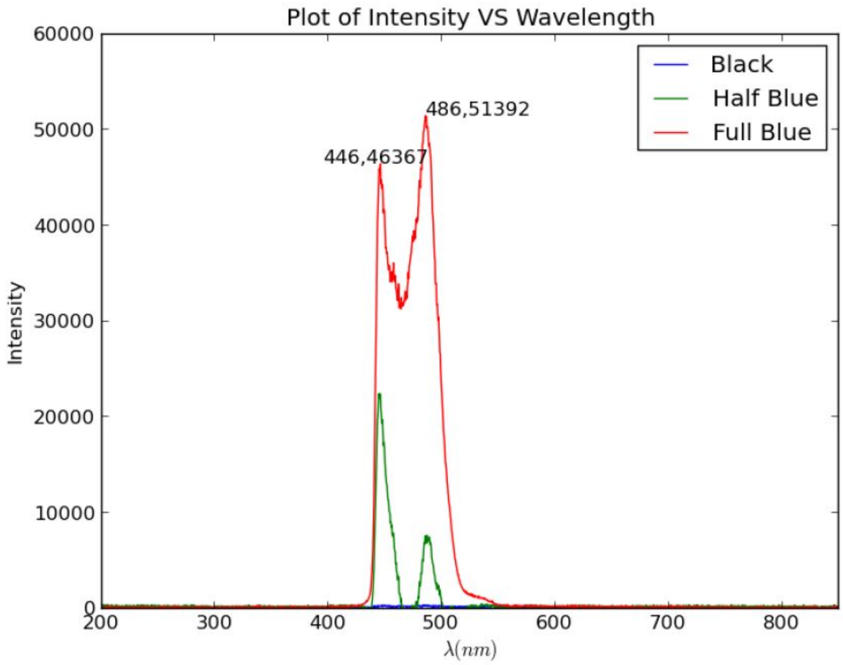


Table 2.1: Intensities of different colours

Red	**Green**	**Blue**	**Power(mW)**	**Intensity (mW/cm^2)**
0	0	0	0.33	0.005
127	127	127	26.3	0.413
255	255	255	68.3	1.074
0	0	255	25.5	0.401
0	255	0	37.2	0.585
255	0	0	14	0.22
0	0	127	15	0.236
0	127	0	6.1	0.096
127	0	0	2.7	0.042
127	127	0	9.6	0.151
0	127	127	22.2	0.349
127	0	127	17.7	0.278
255	255	0	53.2	0.836
127	255	0	41.6	0.654
0	127	255	33	0.519

CHAPTER 3

Photolithography process steps and Results

The photolithographic procedure combines several steps in sequence. There are some advanced treatment steps in the procedure. But, we focus on the steps involved in our maskless photolithography process. The recipe was arrived at after several trials.

The steps in our maskless photolithographic process are

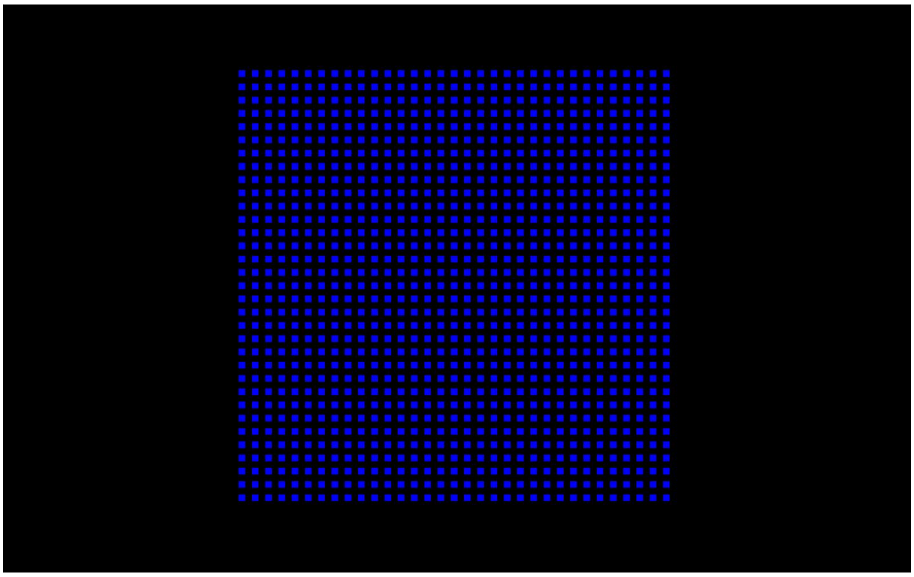
- Clean - Trichloroethylene 5 mins followed by Acetone 5 mins followed by IPA 3 mins, DI water rinse, Nitrogen Blow Dry
- Dehydration bake - $80°$ C for 10 mins in a convection oven
- Photoresist application (Spin coating) - Speed of 4000 rpm, Acceleration of 400 rpm/sec and Time of 40 sec
- Pre bake - $80°$ C for 20 mins in a convection oven. This is to remove the solvent in the photoresist
- Exposure - Using Projector lithography systen
- Develop - 5 pellets of NaOH in 250 ml of DI water. Development time was found to be pattern dependent.
- Hard bake (Post bake) - $80°$ C for 10 mins in a convection oven
- Characterization - Confocal Microscope

3.1 Mask Design Process

From the previous measurement of the entire field size (3.5 cm X 2.16 cm), corresponding to 1920 X 1200 pixels, the size corresponding to one pixel (assuming the pixel to be square) was found to be $18\mu m$ on the sample plane. Using this as an input, masks consisting of periodic patterns were designed on a resolution of 1000 X 1000 pixels using Octave, which come out to be 1.8cm x 1.8cm on the sample plane. A sample mask consisting of 256 μm side blue squares separated by black region corresponding to a period of 512 μm is shown in Fig. 3.1.

For the programming of mask, a sample code for 18μm squares can be found in the APPENDIX A

Figure 3.1: 256μm squares mask



3.2 Results

Since the minimum feature size possible with this setup is 18μm. We started from 1000μm and went till 18μm.

3.2.1 1000μm Squares

The parameters are

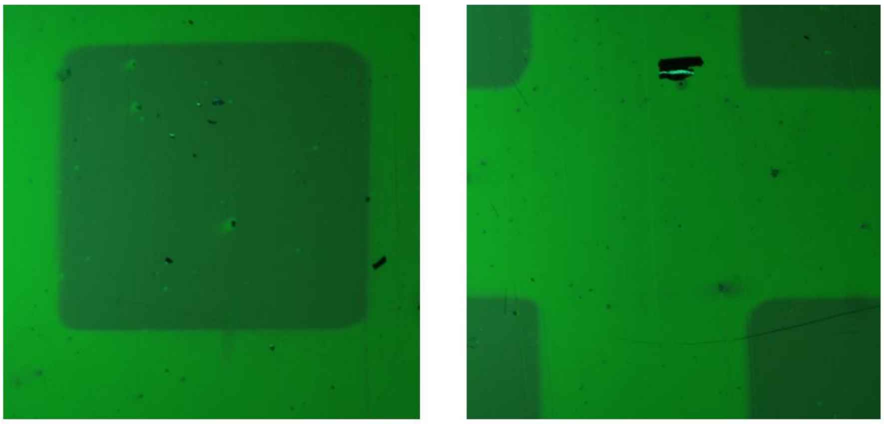
- Substrate : Silicon.
- Exposing time : 60 minutes.
- Developing time : 30 seconds.
- Developer solution : 3 pellets of NaOH in 250ml of DI water.

The pictures of the substrate after exposing is in the Fig. 3.2. From the figure the squares are visible perfectly. In the figure left part shows the complete square and the right part shows the square edges.

3.2.2 512μm Squares

The parameters are

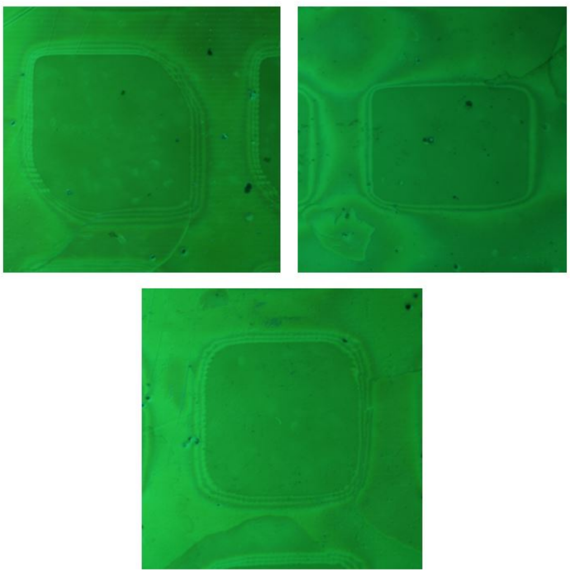
Figure 3.2: Substrate after exposing with 1mm squares



- Substrate : Glass.
- Exposing time : 45 minutes.
- Developing time : 20 seconds.
- Developer solution : 5 pellets of NaOH in 250ml of DI water.

The pictures of the substrate after exposing is in the Fig. 3.3. The images of the substrate were taken in 3 regions. In the top left image, the square is distorted due to the inclination of the substrate diagonally during the exposure. similarly in the top right image, the square is distorted horizontally by making it a rectangle. The bottom one is a square.

Figure 3.3: Substrate after exposing with 512μm squares



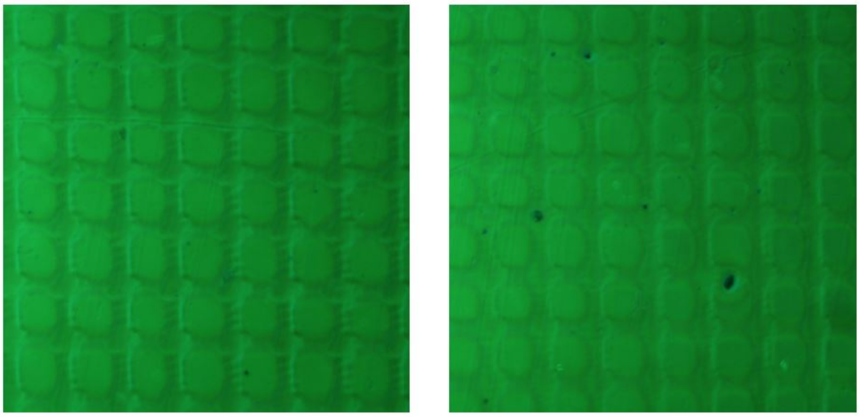
3.2.3 108μm Squares

The parameters are

- Substrate : Silicon.
- Exposing time : 30 minutes.
- Developing time : 5 seconds.
- Developer solution : 5 pellets of NaOH in 250ml of DI water.

The pictures of the substrate after exposing is in the Fig. 3.4.

Figure 3.4: Substrate after exposing with 108μm squares



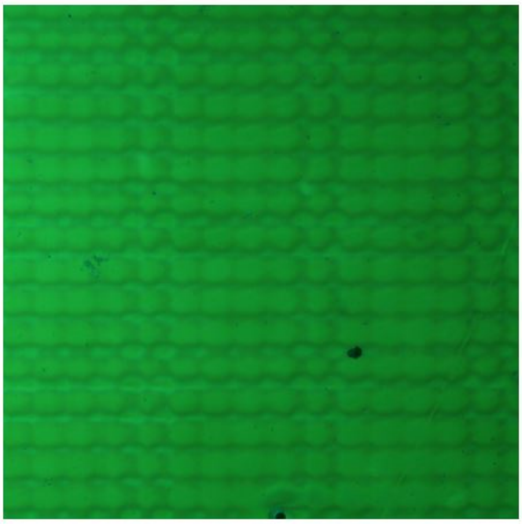
3.2.4 54μm Squares

The parameters are

- Substrate : Silicon.
- Exposing time : 10 minutes.
- Developing time : 5 seconds.
- Developer solution : 5 pellets of NaOH in 250ml of DI water.

The picture of the substrate after exposing is in the Fig. 3.5. The squares are almost visible at 50μm patterns.

Figure 3.5: Substrate after exposing with 54μm squares



3.2.5 18μm Squares

The parameters are

- Substrate : Silicon.
- Exposing time : 5 minutes.
- Developing time : 4 seconds.
- Developer solution : 5 pellets of NaOH in 250ml of DI water.

The picture of the substrate after exposing is in the Fig. 3.6. From the figure we can see that interference has occurred. As the size reduced, inference has come into picture. Though we can still see each pixel converting into a square on the sample.

3.2.6 Names mask

A new mask was used to expose apart from the 2D array of squares. The mask can be seen in the Fig. 3.7. The thickness of the letters in the name is 36μm. And the substrate after developing can be seen in the Fig. 3.8.

Figure 3.6: Substrate after exposing with 18μm squares

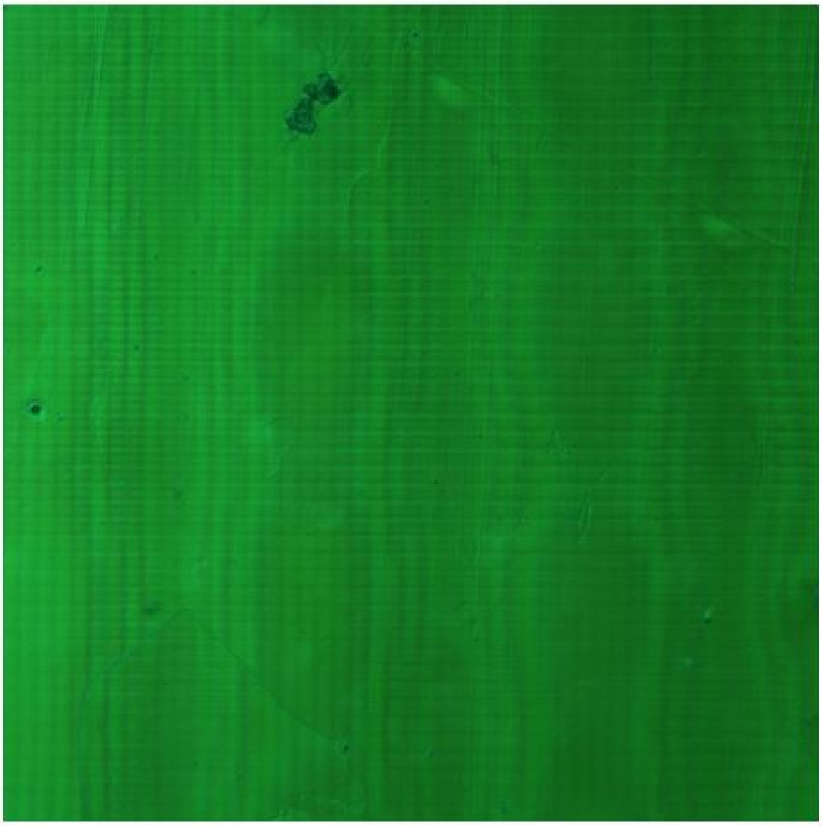


Figure 3.7: The mask containing names

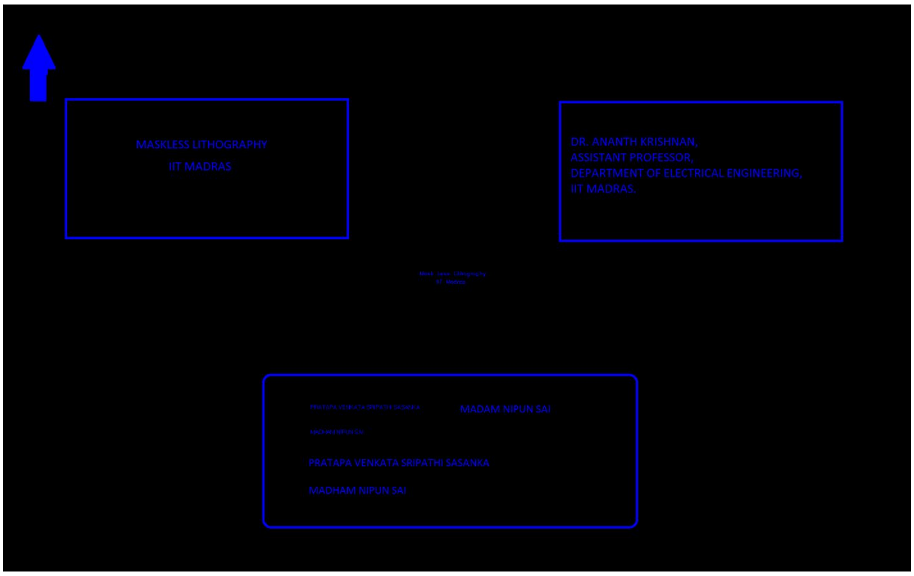
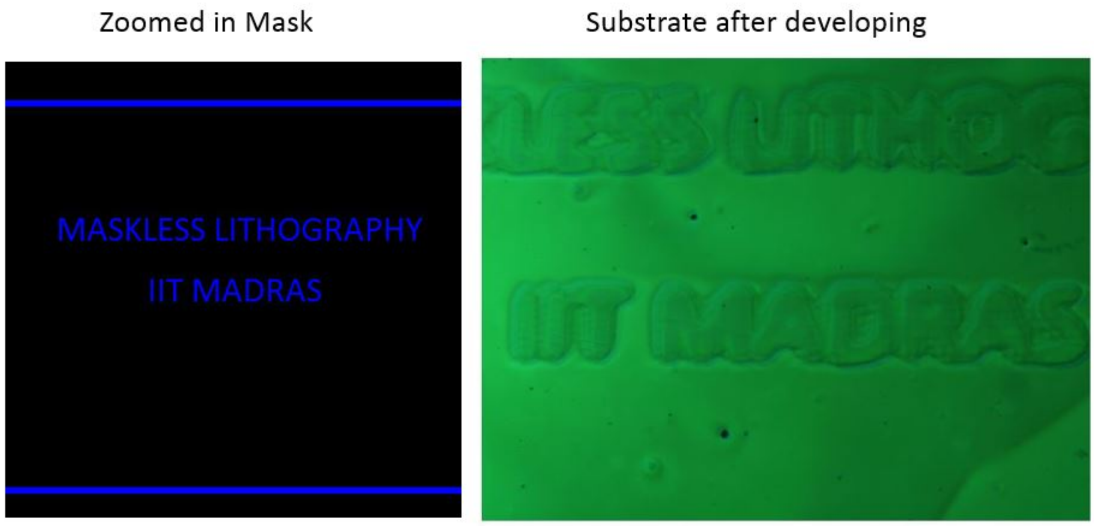


Figure 3.8: Substrate after exposing with 36μm thick name



CHAPTER 4

Conclusion

4.1 Conclusions

As mentioned in the introduction, in this thesis, a maskless lithography system was constructed for 3 purposes

- To create tens of microns sized patterns on substrates for making Cartesian structures for THz filter applications.
- To create masks on glass substrate using a simple projection setup
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- The total time needed for the entire process be less than 2 hours.
- This work should enable students and academicians from IIT-M and other institutes to perform hands-on experimental work with structures needing photolithography.

All the purposes are achieved by taking into account all the considerations.

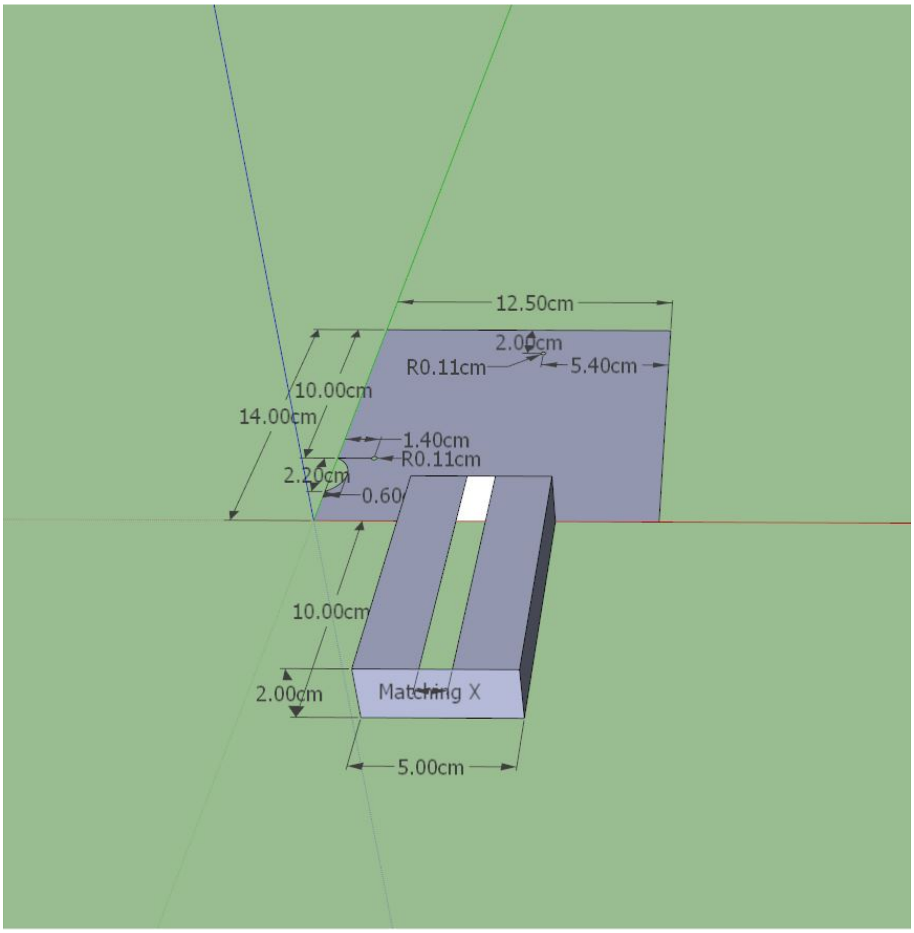
4.2 Difficulties

- The exposure room is not clean. Because of the dust, dark patches appear on the substrate.
- The setup is not completely rigid due to improper bottom stand made in the department workshop. The quality of this piece can be greatly increased if done outside at a machine shop.
- The time lag between spin coating to exposure and exposure to developing should be minimized or avoided for better results.
- The software is not rendering the image as it is.
- Due to a lot of other processes going on in the system, there is a chance of errors popping up and disrupting the whole process. (For example, screensavers, automatic power conserving modes, operating system related message popups etc.)

4.3 Suggestions for overcoming difficulties

- By moving the setup to a clean room, the dark patches on the substrate can be avoided.
- By making more rigid setup, the wafer will stand straight. For making a rigid setup, we can introduce a stand. The CAD diagram for stand can be seen in the Fig. 4.1
- By using different software to project or by changing the graphics card may eliminate the interference.

Figure 4.1: CAD diagram of the stand



APPENDIX A

CODE USED FOR GENERATING MASKS

```
clear all;clc;
total_height=1920; %pixels are rotated by 90 degrees
total_width=1200;
pixel_conversion=18e-6;%1 pixel is this distance

pattern_width=920;%in pixels
pattern_height=920;%in pixels

patternable_width_left=total_width/2-pattern_width/2;
patternable_width_right=total_width/2+pattern_width/2;

patternable_height_top=total_height/2-pattern_height/2;
patternable_height_bottom=total_height/2+pattern_height/2;

mask_red_channel=zeros(total_width,total_height);
mask_green_channel=zeros(total_width,total_height);
mask_blue_channel=zeros(total_width,total_height);
total_mask=uint8(ones(total_width,total_height,3));
for i=patternable_width_left:2:patternable_width_right
    for j=patternable_height_top:2:patternable_height_bottom
        mask_red_channel(i,j)=0;
        mask_green_channel(i,j)=0;
        mask_blue_channel(i,j)=255;
    end
end
total_mask(:,:,1)=uint8(mask_red_channel);
total_mask(:,:,2)=uint8(mask_green_channel);
total_mask(:,:,3)=uint8(mask_blue_channel);
```

```
imwrite(total_mask,'square_area_exposure_region
                                    _squares_18u.bmp','bmp');
```