IMPS LAB ENGINEERING LAB--Photolithography

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In this lab we will transfer patterns onto the device you are engineering. We will make use of some of the techniques which are also used to make microelectronics such as computer chips. Life may be like a box of chocolates, but microelectronics is like a layer cake with decorations on each layer. It all starts with a substrate; for your device this will be a piece of glass, but for microelectronics it is usually a thin wafer sliced from a single crystal cylinder of silicon. One or more layers of some useful material are deposited or grown on the substrate, then patterned (the cake decorations)--more on that in a moment. For example, if we deposit a metal layer, we could pattern it by cutting away all except for a few narrow strips which would then serve as wires. Then we could deposit an insulator on top of the metal, and pattern it to cut some holes in it down to touch our wires. In depositing a second metal layer on top of that, a connection would be made through these holes to the first metal wire. Then we could pattern the second metal layer into another set of wires. Chip designers also make patterns of impurities in the silicon; these dopants form transistors. These patterns can be so small that millions of them can fit in a square centimeter!

So, microelectronics is enabled partially by our ability to make patterns on a microscopic size scale. How is this done? In this lab the patterns were designed on a Macintosh computer, using a graphics program similar to MacDraw[1], but more sophisticated in the way it handles small size features and multiple layers. They are then printed on an ultra high resolution laserwriter. The resolution of this printer is 4000 dpi (dots per inch), which corresponds to 6 microns (micro meters) per dot. This is an order of magnitude better than that of most laserwriters on campus. You could put about a dozen such dots across the diameter of a human hair. This may be small, but state of the art microelectronic designs are much smaller yet--they incorporate features which are more than an order of magnitude smaller. That is too small to make or see with visible light, even under a microscope; instead they use ultraviolet light or electron beams[2]. To make life easier, our features will be much larger than this, with sizes of about 25 microns and up (several times smaller than an ordinary human hair diameter). The printer puts the pattern onto plastic film rather than paper because film is more dimensionally stable (it stretches and shrinks less) and because it is easier to then transfer the pattern onto our sample. We call this film a mask, for reasons that will become apparent. In the example below, we will show just two features:

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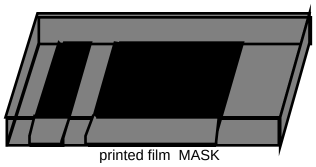
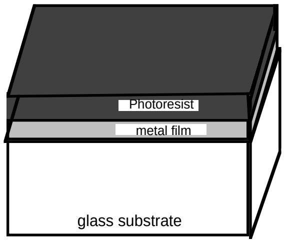
[1] We use L-Edit, which is available at Dartmouth on the Public Fileserver in the unsupported keyserved folder. Feel free to try it out if you are interested; you can open examples from the micromachining folder.

[2] See question 4 below.

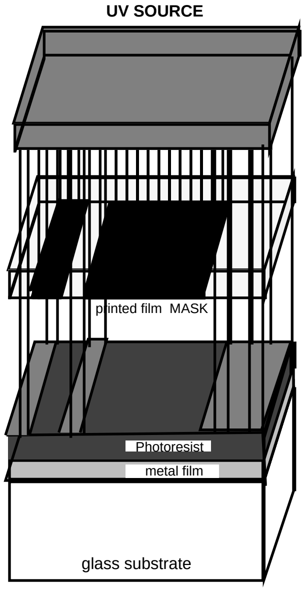
a short rectangular wire and a square pad. Here's what the mask for this example would look like. The dark area represents laserwriter toner on the bottom of the mask. In the end, we want wires in our metal film to follow this same pattern. The next step is to transfer this pattern onto our sample. This is done by a technique called photolithography. In our lab this is similar to "contact printing" in photography. First we need to make our sample sensitive to light. The sample is cleaned and covered with a puddle of photosensitive liquid called photoresist.



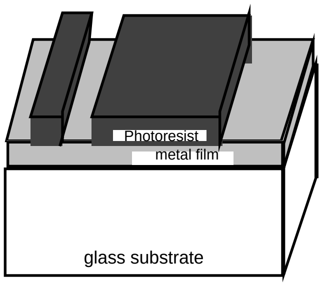


The sample is then spun at high speeds. Excess photoresist is thrown off the edge of the sample by centrifugal force. The thickness of the remaining layer is determined by the photoresist viscosity, the surface tension, and the spin speed. For the photoresist we use, spinning at 4000 RPM results in a uniform film 1.3 microns thick, with thickness variations of only about 1 percent (130 angstroms!) in the center region. The photoresist is then baked to drive off excess solvents.

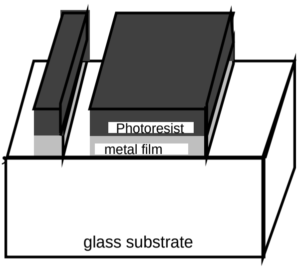
Now we are ready to transfer the pattern to the photoresist. The mask is pressed tightly against the photoresist on the sample, and the sandwich is exposed to ultraviolet light. In this figure we show the mask displaced from the photoresist for clarity. Where there are dark features on the mask, the UV light is blocked (masked) and the photoresist is unexposed. Where the mask is clear, the UV hits the photoresist underneath and causes chemical changes. In some photoresists these changes are as simple as breaking long polymer chains into shorter ones (called chain sission). The shorter chains are then easily washed away in a developer solution.



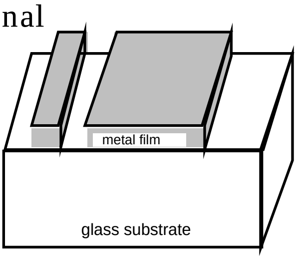
The changes in our photoresist involve a more complex photochemical reaction--a degradation by UV light of a dissolution inhibitor, but the net effect is the same: where UV light has hit, the photoresist dissolves away when we pour a puddle of developer (a basic solution) on it.



The pattern is now reproduced in the photoresist, but we still need to transfer it to our metal film. We do this by etching. The entire sample is placed in an acid bath. Where the photoresist is missing, the exposed metal is etched away, but where photoresist remains it protects the metal and "resists" etching by the acid (hence the name photo-resist).



With the pattern now reproduced in our metal film, we can use an organic solvent (acetone) to dissolve away the remaining photoresist. The final result as shown here is just the wire and pad we wanted.



THE CLEANROOM[3]

Some of the wires you will be making are several times narrower than a human hair (and a thousand times thinner). If a hair or dust particle falls on your sample over the photoresist, then it could block the UV light where you wanted it to go and make an unwanted wire (perhaps "shorting out" your device). For this reason we need to control the amount of dust (and hair) in the room in which we do this processing. Learning to make very clean rooms has been critical to the microelectronics industry (and to a lesser degree, medical research). The Dartmouth Engineering School Microengineering Laboratory is a class 100 microelectronics grade cleanroom. This means that in each cubic foot of air there are less than 100 particles of 1/2 micron size. That's pretty clean when you consider that just walking around you shed several MILLION particles a minute.

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[3] If you like, you can take a virtual tour of the cleanroom lab you will be using. The URL is:
http://engineering.dartmouth.edu/microengineering
You can click on various pieces of equipment on the floorplan displayed.
Specific equipment we'll be using includes:
Photoresist Spinner: http://engineering.dartmouth.edu/~microeng/equipment/spinner/spinner.html
Bake Ovens: http://engineering.dartmouth.edu/~microeng/map/oven.html
Acid Hood: http://engineering.dartmouth.edu/~microeng/map/acidhood.html
Mask Aligner: http://engineering.dartmouth.edu/~microeng/map/mask.aligner.html

To protect the cleanroom from you and your particles, and to protect you from its chemicals, you will need to put on special garments over your street clothes. In addition, there are special high efficiency filters in the ceiling always bringing in clean air to sweep away any particles you generate.

PRELAB ASSIGNMENT:

1. Read this entire handout.
2. Consider which of the available patterns you would like to use for your device. What sort of pattern is best if you want to measure a very small leakage current from one wire to another across the glass (due to, say, moisture)? You will have an opportunity to make some adjustment in the resistance of your wires (by making them thinner); what sort of resistance would you like for your device--high or low? Are there patterns that might be useful for optics, such as patterns with many closely spaced parallel lines that could make up a diffraction grating? You will have the opportunity to make both optical and electrical devices by etching metal lines on the glass, or to make only optical devices by removing all metal and just etching the patterns directly into the glass. While you can't make all the engineering decisions for a device in just two lab periods, you will have the opportunity to make some of these decisions; we'll talk about this further in lab.
3. If you like, you can take a virtual tour of the lab you will be using. The URL is: http://engineering.dartmouth.edu/microengineering
4. Turn in your answers to the following pre-lab questions:

DUE AT THE BEGINNING OF THE LAB PERIOD:

Q1: If we want to make a thicker photoresist layer, how and why should we change (increase or decrease): (a) the spin speed (b) the photoresist viscosity

Q2: Suppose we wanted to make a two dimensional square array of black dots using the ultra high resolution laserwriter discussed in this handout, with white dots between them (to the right, left, up and down). How many black dots could we fit on our two inch square sample?

Q3: Suppose you want to detect "leakage current" between two unconnected wires with your device. For example, this leakage might be caused by putting a water film between them. What kind of design would maximize such leakage? Should the wires be close to each other or far away? Should they be long or short? Choose one or more of the four patterns attached for your device and explain why you might use it for a leakage current device. The black lines are wires, the big squares are "contact pads" where you can connect a battery or meter.

Q4: (a) Why can one make smaller features using ultraviolet light than using visible light? How about electrons? Quantum mechanics tells us that particles such as electrons are also act like waves with a wavelength (deBroglie) that depends on their momentum: $\lambda = \frac{h}{p} = \frac{6.62 \times 10^{-34} \text{J s}}{mv}$. (b) What momentum must an electron have in order that its wavelength be one tenth angstrom? (c) What kinetic energy does this correspond to (the electron mass is 9.1×10^{-31} kg)? If we accelerate an electron by passing it in a vacuum between plates connected to a battery of 1000 volts, it will have a kinetic energy of 1000 "electron volts" = $1000 \times 1.6 \times 10^{-19}$

Joules; the energy is proportional to the voltage. (d) What potential difference (in volts) is required to obtain an electron with this wavelength (0.1 Å)? Such electrons can be used to write or examine features which are easily sub-micron (i.e. less than a micro meter), but not as small as 0.1 Å for other physical reasons.

LAB PROCEDURE:

You will be shown how to complete the following in the cleanroom:

1. Clean your sample (substrate).
2. If desired, etch the metal for a controlled time to thin it and increase the resistance. Alternatively, you may completely etch off the metal for enhanced optical devices.
3. Spin on photoresist.
4. Bake the photoresist.
5. Align your sample with the pattern on a film (some choice here).
6. Expose your sample to UV through the film.
7. Develop the photoresist.
8. Rinse the sample and bake it dry.
9. Etch the sample.
10. Strip off the photoresist.
11. Inspect your device under a microscope (time permitting).

LAYOUTS: See IMPS01layout.pdf. You will need to zoom in with the magnify tool to see what is going on. Details of Device A and Device E are shown below.