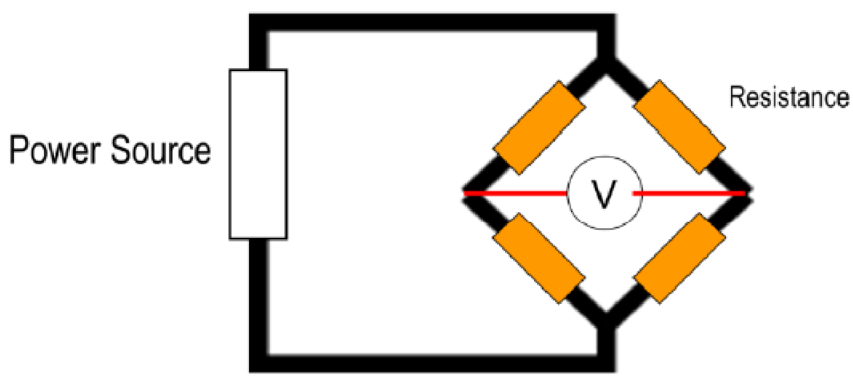
Keio University

Miki Norihisa & Takahashi Hidetoshi's course - 2020

MEMS: design and fabrication
Report 6: Etching techniques



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Academic year 2019-2020
Tsuda Hiroyuki's Laboratory

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Contents

1 Introduction

The microfabrication of MEMS is divided into many different processes. At first, there is a Silicon wafer, on this one a thin film is deposited. Then, the next step is to put, on top of the thin film, a photoresist coating which will react with UV light and create a particular pattern after the development process. Finally, an etching process is performed, using the photoresist layer as a mold, and then the photoresist layer is removed. Therefore, on the top of the Si wafer, we have a thin film with the same pattern as the one from the mold.

Various etching techniques exist. The choice of a particular technique in a particular process depends on factors such as: the resolution, the profile (i.e. how the cross section will look like), the etching rate (influencing the overall process time and therefore cost), the etching depth (how deep it can be etched), the selectivity of the etching (if it target properly the good material), the process conditions(T, vacuum, ...), the uniformity, the total cost or even the environmental impact.

Through this report, etching techniques are used under three different approaches for building a Wheatstone bridge. For each approaches, the proper masks must be chosen. Those approaches are the following:

1. A copper substrate (Insulator + Copper + positive photoresist)
2. Electroplating of copper on glass substrate with positive photoresist
3. Lift-off of gold on glass substrate with negative photoresist

2 A copper substrate (Insulator + Copper + positive photoresist)

In this case, the initial material used to work with is already containing 3 different layers. The first one being the basic insulator layer, for preventing short-circuiting of copper lines. The second layer, the copper one, which as the be etched and from which, finally, the Wheatstone wires are made of. And, on top of everything, the photoresist (positive) coating exposed to light and undergoing development process.

2.1 Mask

Here, because this approach involves using a material already including the copper layer on insulator, it means that all the copper present on the insulator has to be removed besides the one forming the wires of the Wheatstone bridge.
Therefore, because a positive photoresist is already present, the previous statement implies that the mask will let light passing everywhere besides above the copper wires to build, to protect those during the etching process.

Figure 1 present the possible masks to use and how these are flipped to obtain the final pattern described on the right side of figure 1, that will enter into contact with the photoresist. The red arrows represent the direction through which the rotation is carried.

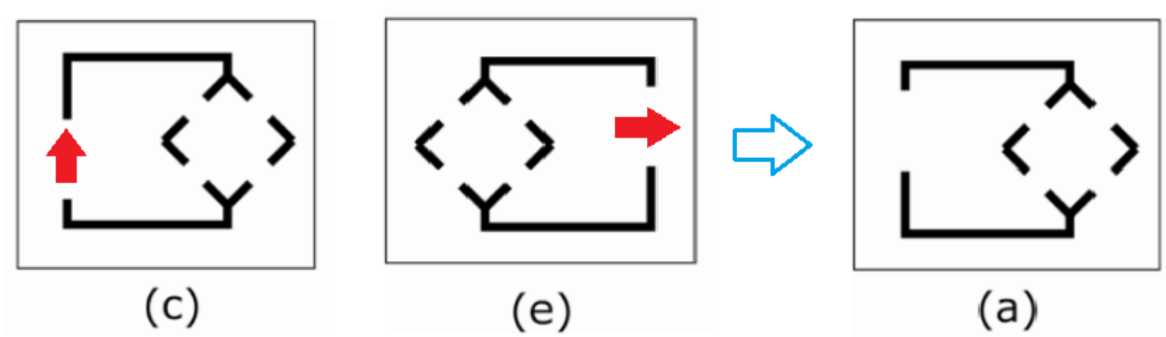

Figure 1: On the left, the masks that can be used, the red arrows representing the direction of rotation to obtain the final mask seen on the right, after the blue arrow. This last mask is put into contact with the photoresist material [2]

2.2 Process

The mask is positioned above the photoresist material, after this the UV light is illuminated on the mask and as a result illuminates the photoresistive coating. After this, the coating is developed such that there is no more coating besides above the wires to be build.

Then the etching process can be either realized using dry etching. In the case of copper etching, this is performed using the substances circled in red on figure 2.

Poly-Si	Cl_2, Cl_2/HBr, Cl_2/O_2, CF_4/O_2, SF_6 etc.
Si	SF_6, CF_4/O_2, Cl_2 etc.
Si_3N_4	CF_4, CF_4/O_2, CF_4/H_2, CHF_3/O_2 etc.
SiO_2	CF_4, $C_4F_8/O_2/Ar$, $C_5F_8/O_2/Ar$ etc.
Al	BCl_3/Cl_2, $BCl_3/CHF_3/Cl_2$, $BCl_3/CH_2/Cl_2$ etc.
Cu	Cl_2, $SiCl_4/Cl_2/N_2/NH_3$, $SiCl_4/Ar/N_2$ etc.

Figure 2: Substances used for performing dry etching [3]

2.2.1 Dry etching

The process of dry etching is such that an electric field is applied and guide the species to the targeted surface to etch. There is both an action of chemical reaction between the species contained in the gas/plasma and the copper surface and a mechanical abrasive effect (from the charged particles and the kinetic energy).

Although this technique is good, it can be improved. If the goal is to etch deeper (10 or more micrometers), by using the Deep Reactive Ion Etching using ICP plasma and the Bosh process (iteration of etching and passive deposition), this technique prevent the accumulation of the byproducts at the bottom of the etching zone, which could prevent the etching substance from accessing the surface. Those dry etching processes are anisotropic. This process is highlighted, in figure 3.

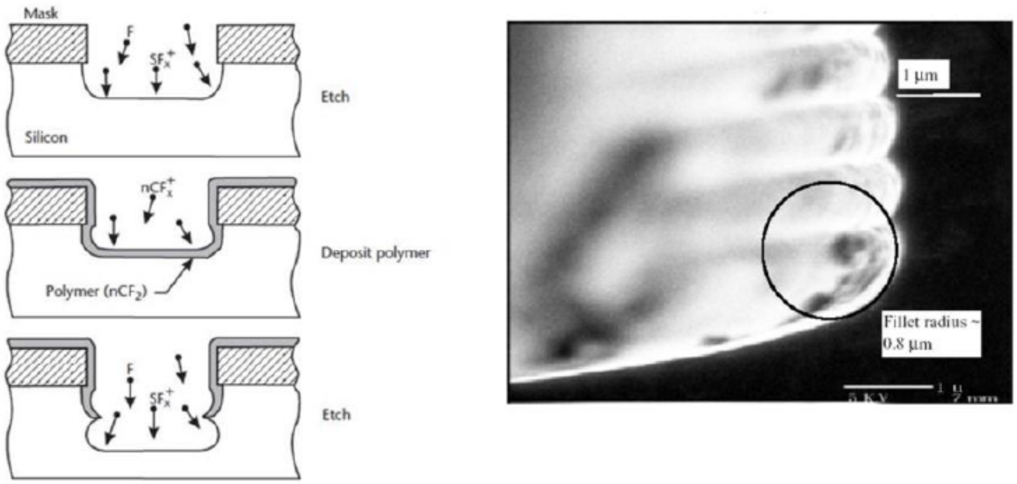

Figure 3: Bosch Process [4]

2.2.2 Wet etching

Besides dry etching, wet etching could be used, using an appropriate solution. It could, in some way, be profitable in this case because the surface to be etched is quite large therefore a higher etching rate is better, also the cost would be reduced. An example of the wet etching can bee seen on figure 4.

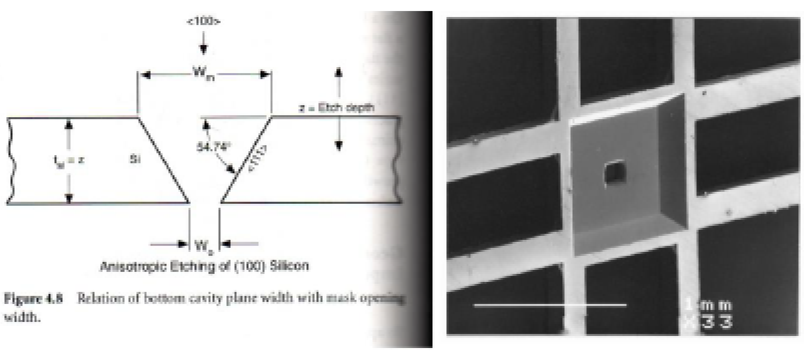

Figure 4: Example of wet etching of Si using a base (KOH, TMAH) [5]

3 Electroplating of copper on glass substrate with positive photoresist

3.1 Mask

In this case, the copper wires will be built by the electroplating process. Since positive photoresist is used, it is necessary to have a mask which lets pass the light rays just on the zone where the wires will be electroplated. As a result, the coating will be used as a mold where the copper is aimed to be inserted.

For the previous reasons, the following figure 5 presents the possible masks to use and how these are flipped to obtain the final pattern described on the right side of figure 5, that will enter into contact with the photoresist. The red arrows represent the direction through which the rotation is carried.

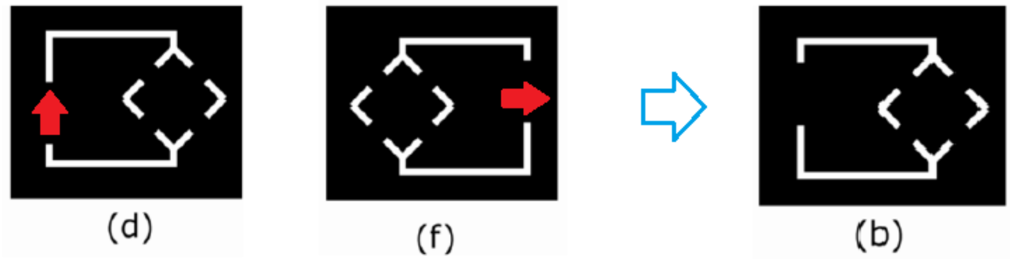

Figure 5: On the left, the masks that can be used, the red arrows representing the direction of rotation to obtain the final mask seen on the right, after the blue arrow. This last mask is put into contact with the photoresist material [2]

3.2 Process

As the basic layer is just a glass, prior to execute the electroplating process, adhesive and seed layer must be built on it. The first thing to be executed is to put a chromium layer for improving adhesion with the glass, then a seed layer of copper on which the electroplating will be grown. Those layers are grown using sputtering or vapor deposition.

After this preparation step, photoresist is patterned to form the mold for electroplating. Then, electroplating is conducted and photoresist is removed. Finally, the seed layer is patterned by immersing the substrate into etching solution. This process was given as an example in the course, the various steps behind it are displayed on figure 6.

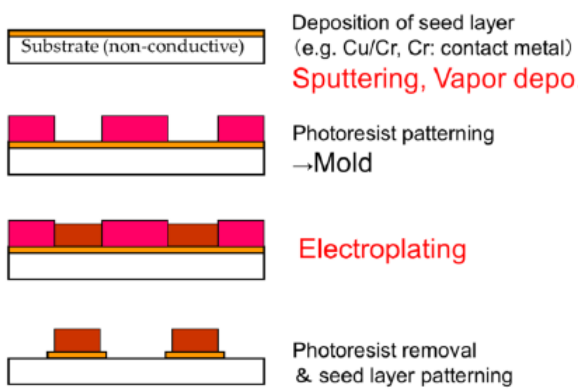

Figure 6: The successive steps for building copper wires using electroplating and positive photoresist [6]

4 Lift-off of gold on glass substrate with negative photoresist

During this step we end up using a negative photoresist. Negative photoresist becomes polymers when exposed to light. This means that it is the part that will be exposed to UV light that will be less soluble, compared to the unexposed part. The goal is therefore to expose the entire mask besides the places where the wires must be built. In such a way, the entire mask becomes polymers (less soluble) but not the coating above the intended place of the circuit lines, thus becoming more soluble and removed during the development.

Also this technique is a bit particular because the process is made oppositely to the conventional technique. It means that the photoresist coating is first deposited and processed before the film deposition process.

4.1 Mask

As the goal is to expose the entire mask besides the circuit lines, the mask used are the same as in the first case. Those masks are diplayed below on figure 7. Again, the red arrow on the left pictures represent the direction of rotation of the mask. Finally, the mask on the right is obtained and put into contact with the photoresist.

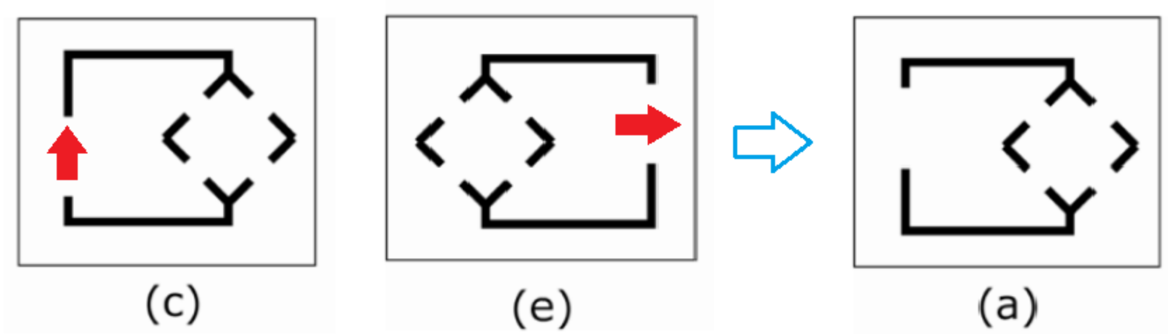

Figure 7: On the left, the masks that can be used, the red arrows representing the direction of rotation to obtain the final mask seen on the right, after the blue arrow. This last mask is put into contact with the photoresist material [2]

4.2 Process

The lift-off process can be observed, step by step on figure 8. It as to be noted that the photoresist needs to be negatively tapered so that the gold layer doesn't form a single continuous cover.

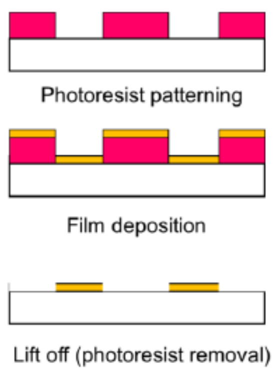

Figure 8: Lift-off process [7]

The steps are :

1. The gold is deposited and forms a cover (wire) on the glass
2. The structure is exposed to an organic solvent and the photoresist is removed
3. At the same time the coating is dissolved, it lifts-off the gold film on it

5 Conclusion

Through this report, the techniques used for depositing and/or etching metals on substrates were investigated through 3 different approaches. Each this a mask was chosen according to the type of photoresist : positive or negative and the kind of process. Step by step, the proper fabrication techniques described to obtain the final pattern of the Wheatstone bridge.

References

[1] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #29.

[2] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #30.

[3] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #13.

[4] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #15.

[5] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #19.

[6] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #5.

[7] Miki Norihisa & Takahashi Hidetoshi's slides of "MEMS: design and fabrication" course. Course #6, slide #3.