Photolithography module report

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A photolithography process was performed on a Si wafer. A desired resist thickness of 4000 nm was achieved using a spin speed of 4000 rpm for the negative resist Ma-N 440. Three different development times were applied to optimize the process, but an undercut was not achieved due to old chemicals. Resist thickness was measured using reflectometer and profilometer, and the resist cross section was imaged using scanning electron microscopy.

Introduction

Group B1 was assigned the task to conduct photolithography and to perform an optimization process. A parameter is optimized by investigating how the undercut is affected by the parameter space. Sample set of of 4 wafers were chosen. And the parameter that was optimized was the development time. Instruments used were a mask aligner (MJB3) in the student laboratory, table-top SEM, sputter coater, reflectometer and profilometer.

The outline of the text is: a theoretical background of the processes and the tools used. Followed by methods and finally results from the methods used.

1 Theory

1.1 Photolithography

Photolithography is a 10 step process done in semiconductor-related industries in order to transfer a pre-determined pattern onto a wafer. The mask is made of quartz. Pattern transfer occurs because of a combination of illumination through a mask together with a light sensitive material, called a photoresist, placed on top of the wafer.

The 10 steps are:

1) Sample cleaning
2) Dehydration
3) Wafer Priming
4) Spin Coat
5) Soft Bake
6) Alignment and Exposure
7) Post-Exposure Bake
8) Develop
9) Hard Bake
10) Develop Inspect

A closer presentation of the steps in the photolithographic process can be found in the Methods section.

In photolithography two types of resist can be used: positive and negative resists. The differ-

ence between them is that when a positive resist is exposed the exposed area becomes soluble and can be removed by a developer. For the negative resist the exposed area becomes unsoluble and area around the exposed area is removable by a developer.

1.2 Scanning Electron Microscope (SEM)

The scanning electron microscope (SEM) is the most widely used type of electron microscope. It examines microscopic structures by scanning the surface of materials, with very high resolution and great depth of field.[1] The electrons emitted from an electron gun have a certain value and they interact with the atoms in the sample that further leads to images of the sample's surface topography and composition.

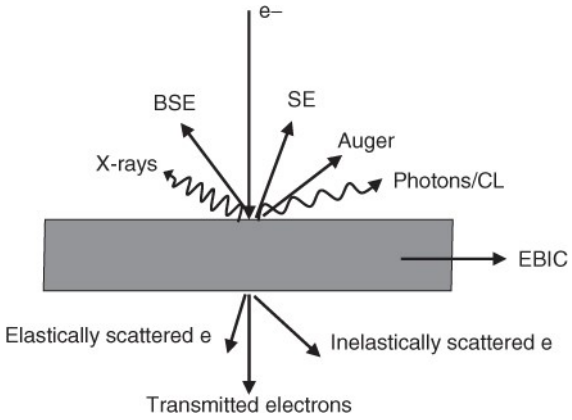

Figure 1: Schematics that shows how the electrons are incident on a sample and how they get emitted.

Accelerated electrons in a SEM carry significant amounts of kinetic energy, and this energy is dissipated as a variety of signals produced by electron-sample interactions when the incident electrons are decelerated in the solid sample. These signals (look at figure above) include electrons (that produce SEM images), backscattered electrons (BSE) and diffracted backscattered

electrons (EBSD).

On figure 1 this phenomena can be clearly seen. When high-energy electrons strike a specimen, they produce either elastic scattering (gives backscattered electrons) or inelastic scattering that gives secondary electrons which are electrons that are ejected from atoms in the specimen after it experiences primary radiation. BSE has little loss in energy, while SE has a lot of loss in energy. The different form of electrons escape from different places in the specimen, where they are collected by a detector.

1.3 Sputter coating

Sputter coating is a PVD (Physical Vapor Deposition) method to deposit metals and other materials on a sample. In sputter coating, high energy particles hit a solid of high purity target material and physically eject atoms.[2] These atoms migrate through a vacuum and deposit on a wafer.

The advantages with sputtering is: better step coverage than the comparable method evaporation, less radiative damage than e-beam evaporation and easier to deposit alloys.
Disadvantages with sputtering is: some plasma damage including implanted argon.

There are 6 basic step in sputtering:
1. Positive argon ions are generated in a plasma in high vacuum chamber and accelerated towards a target material with a negative potential.
2. During the acceleration the ions receive momentum and hits the target
3. Ions physically eject the atoms from the target. The target has the desired material composi-

tion

4. The ejected atoms migrate to a wafer surface

5. The sputtered atoms condensate and create a thin film on the wafer surface with basically the same composition as the target

6. Excess material is removed from the chamber by a vacuum pump.

A threshold energy for release of an atom from the target exists. Below this energy, atoms will not be ejected.

2 Experimental methods

2.1 Photolithography

The process was initiated by scribing four separate wafers.

Sample cleaning: The wafers were cleaned by the use of acetone and isopropanol, before being blow dried by pressurized nitrogen

Dehydration bake: The sample was baked on a hot plate for 5 minutes at 125 degrees.

Spin coating: A three step method was followed: 4 seconds acceleration , 30 seconds at 4000 RPM and 4 seconds deceleration. The resist, MaN-440, was applied by the use of a 3 ml pipette.

Soft bake: Soft bake was conducted for 5 minutes at 95 degrees.

Alignment and Exposure: The negative resist was exposed with UV-light with a Karl Suss MJB-3 HP mask aligner. Ma-N 440 needs an exposure dose of $(1300 \pm 40)\,\mathrm{mJ(cm)^{-2}}$. The mea-

sured intensity of the mask aligner was $12.6\,\mathrm{mJs}^{-1}$, giving an exposure time of 103 seconds. The mask with the second largest lines was used, in the positive version due to the inverting of the pattern via development and lift-off steps.

Development: 3 beakers were used. One with developer Ma-D 332-8 and the two others with water. The sample was held at the developer for a chosen time, before being transferred to the first water beaker for 1 minute and then finally the second water beaker for 2 minutes. The wafers were placed in the developer for 3 different time periods.

2.2 Profilometer

In the steps between soft bake and alignment and exposure, the reflectometer and profilometer were used to measure the thickness of the resist. The measured profile acquired from a profilometer is the profile resulting from scanning the surface of a material with a probe called the stylus. The method was based on precision in moving the stylus. Finding the thickness of a resist is done by subtracting the valley (lowest point of the surface) from the peak (the highest point of the surface).

2.3 SEM

The wafer was scribed into smaller pieces to obtain a cross section sample. A cross section holder in the SEM holds the sample for the characterization.

3 Results and discussion

3.1 Thickness of resist

The spin speed for the resist was chosen based on the spin curve provided by the supplier, see figure 2. The spin curve indicates an optimal spin speed of 4000 rpm for a film thickness around

3800 nm.

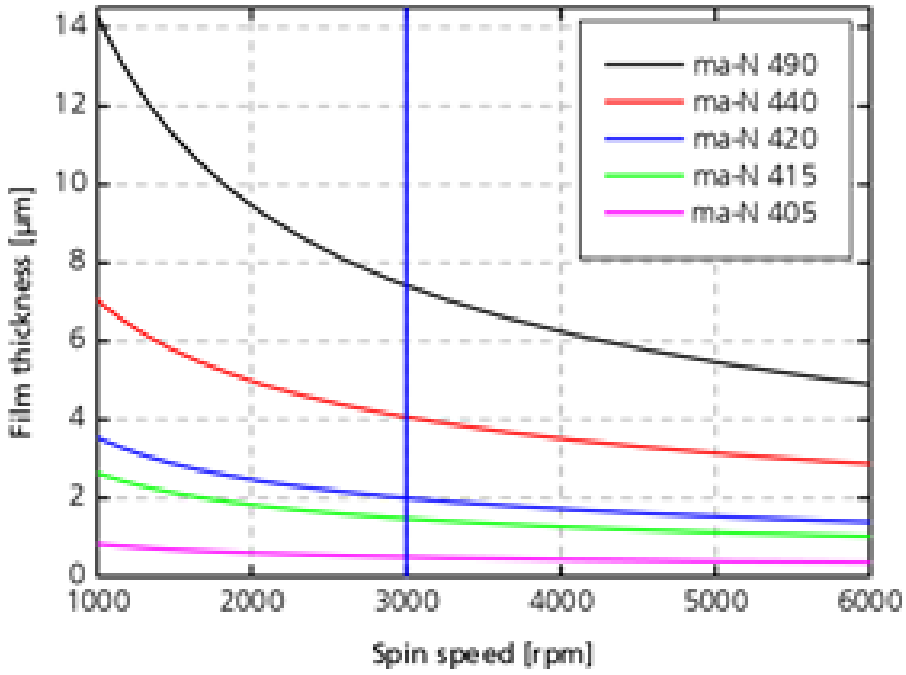

Figure 2: Spin curve showing the photo resist film thickness at various spin speed

This resulted in a measured thickness of 3739 nm using a reflectometer, and 4146 nm using a profilometer, giving an average value of 3943 nm. Spin curve indicated a value at around 3800 nm. Based on that, the value obtained by the reflectometer is closer than the one obtained by the profilometer. The reason for the difference in values is most likely due to human error during the process of obtaining the value with a profilometer.

By testing different spin speeds, a custom spin curve for the specific batch of chemical can be made. This can be helpful in accurately achieving a desired resist thickness. In this case, the value provided by the manufacturer proved to be sufficiently accurate.

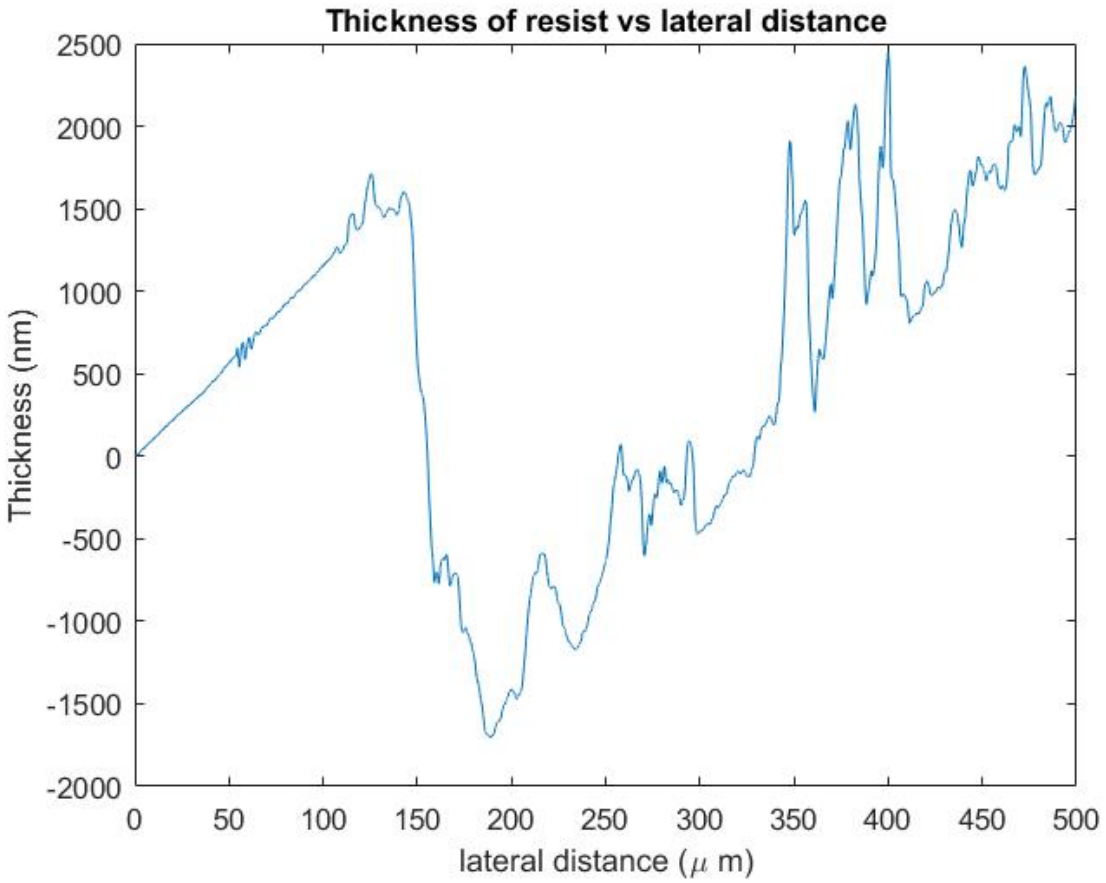

Figure 3: Profilometer measurements of the thickness

3.2 SEM characterization

The sample that was developed for 5 minutes was imaged using SEM, see figure 4. The lack of undercut is clearly visible, indicating that the sample was not sufficiently developed. Based on this, one can assume that the other two samples also lack an undercut.

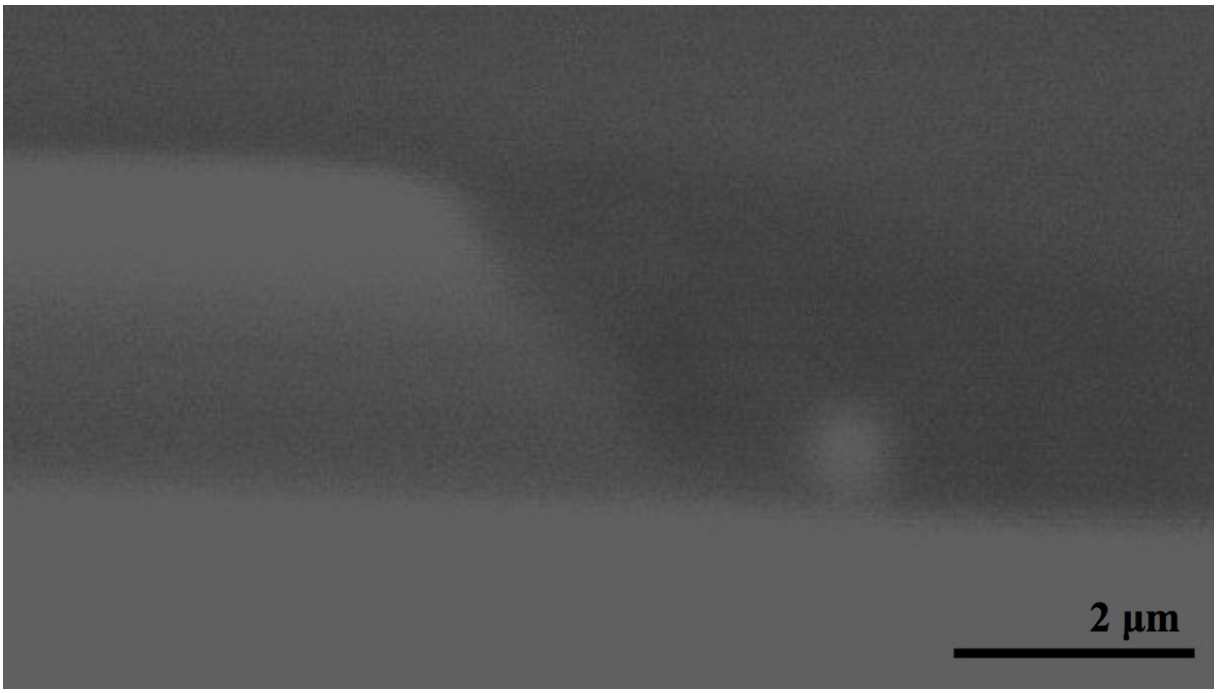

Figure 4: SEM micrograph taken perpendicularly to the resist pattern, showing a clear overcut of the resist.

The evident lack of undercut was unexpected, taking into consideration the long development time compared to standard values from the manufacturer. The batch of Ma-D 332/S used was expired in

?? , ie xx months before the use.

Expired developers significantly reduces the development rate, and it seems reasonable to assume that this caused the long development time.[3] Therefore, to successfully achieve an undercut using this batch of the chemical, a development time in the range 7 - 10 minutes is suggested. The ideal solution would be to use chemicals that have not expired, using the manufacturers suggested development times.

4 Conclusion and future work

A resist pattern was successfully created on Si wafers, but SEM images showed no undercut. An undercut is necessary for successful metallization and lift-off, and can be accomplished by longer development times or a newer chemical.

A spin speed of 4000 rpm was used for the resist, resulting in a thickness of 3943 nm as measured by reflectometer and profilometer. After an undercut is achieved, a metal line pattern can be completed by sputter coating the wafer with Ti and Cu before performing lift-off.

References and Notes

1. Y. Leng, *Materials Characterization: Introduction to Microscopic and Spectroscopic Methods* (Wiley-VCH Verlag , 2013).
2. M. Quirck and J. Serda, *Semiconductor Manufacturing Technology,* (Pearson College Division, 2000).
3. Microchemicals, *Lithography Trouble Shooter*, (2017).
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