Exercise 3: Laser writer + contact patterning

Location: CMI

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1. Summary

In this exercise you will perform the last set of device fabrication steps resulting in MoS_2 devices with electrical contacts. Just like in exercise 2, you will make use of photolithography, employing a laser writer to write a pattern in a photoresist layer. This time, you will use a positive tone resist. This will be followed by metal evaporation for contacts and lift-off, the step in which the resist film is dissolved, leaving behind the electrical contacts on the patterned MoS_2 in predetermined locations. The contact deposition is carried out using a metal evaporator. Since this step requires several hours (this is how long it takes to achieve a vacuum level in the evaporator suitable for contact deposition), this step will be carried out by the assistant after the end of the exercise. Similarly, liftoff is usually carried out by soaking the wafer in a solvent during several hours, so this step will also be done outside of the scheduled course hours.

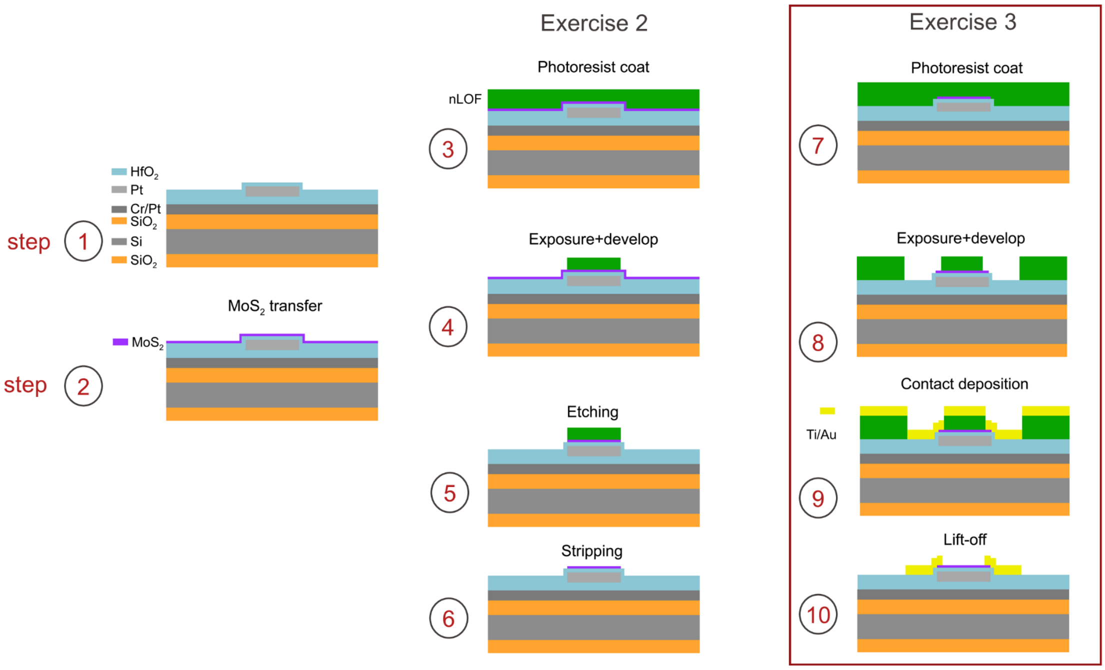


Figure 1. Overview of the complete process flow for the device fabrication in this course. The current exercise is outlined with the red rectangle.

This exercise is conceptually very similar to Exercise 2, both use the same types of equipment for resist coating and exposure. The difference is that here, you use the exposed pattern as a mask for metal deposition and that you will use a positive photoresist.

2. Background

A big portion of micro/nanofabrication procedures could be bluntly categorized into procedures for either removing (subtractive techniques) or adding materials (additive techniques). If you are removing materials, this is referred to as etching, if you are adding materials, this is called deposition.

Since we would like to deposit metals for electrical contacts only in predetermined locations, we will use a mask in the form of a patterned resist. In order to pattern the resist, one can use either light (laser, UV lamp) during photolithography or electrons for e-beam lithography. The interaction with light or the e-beam provokes a chemical change in the resist. Depending on the resist, one could either be breaking chains in a polymer or crosslinking the chains. After the exposure, we perform development to remove either the exposed or the unexposed regions of the resist. We distinguish two basic types of resists, depending on how they react to the beam and development. In exercise 2 you use a negative tone resist, meaning that the portions of the resist that are exposed to the laser are the ones that remain after the development step. In exercise 3, you use a positive tone resist. In the case of positive tone resists, the exposed areas are removed during development and the unexposed areas remain.

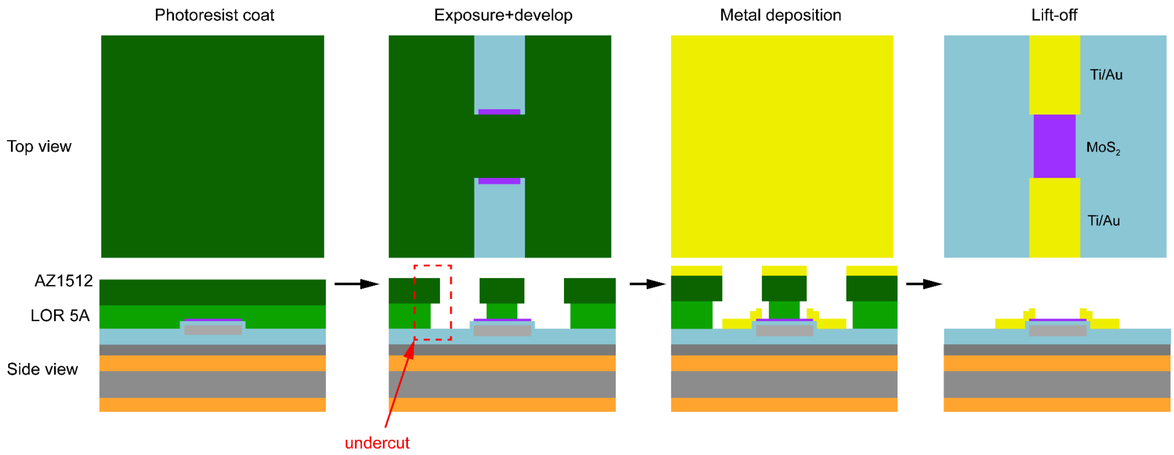


Figure 2. Overview of the process for patterned contact deposition.

The resist exposure and development step will be followed my metal deposition and lift-off, Figure 2. In order to facilitate lift-off, we will be using here the bilayer resist technique, meaning that instead of a single resist layer, we will be coating the wafer with two different photoresists, first LOR 5A, followed by AZ1512. In cases where bilayers are used, the one on the bottom requires a lower exposure dose than the one on top. When we expose this stack of resists at the dose which is optimal for the top resist, the one on the will be slightly overexposed, meaning that the patterns in this layer will be a little bigger than those in the top layer, resulting in an undercut (Figure 2, second panel from the left). In this particular case, LOR is not photosensitive but it gets removed during the development step through the windows opened in the AZ1512 film, resulting in an undercut. Once the metal film is evaporated, because of the presence of the undercut, the metal film forming the contacts will not come into contact with the resist. This will result in smoother contact edges and much easier lift-off.

For the actual evaporation step, we will use an electron-beam evaporator, with the schematic shown in Figure 3. It is based on a vacuum chamber and is typically pumped down to the $<10^{-5}$ mbar or range of pressure. On the bottom of the chamber is a material source in the form of a water-cooled copper base with a conical perforation into which we place a crucible (made of a high-melting point material such as graphite, BN, tungsten etc) containing the metal to be evaporated. The material is molten using a stream of electrons emitted from a heated filament and with a trajectory that is bent using a magnetic field. The metal is heated to its boiling point and starts to evaporate, resulting in a stream of metal atoms which condenses on the substrate. The stream of evaporating atoms can be interrupted using a moveable shutter. Substrates are placed upside-down, in order to minimize possible contamination from falling particles. The sample holder is rotated using a motor in order to assure uniformity of deposition. The thickness of the deposited metal is precisely measured using a quartz thickness monitor (QCM). It consists of a crystal of quartz, a piezoelectric material, oscillating under an application of an AC voltage. Shifts in its resonant frequency are related to the mass of the oscillator, allowing us to determine the thickness of the deposited film.

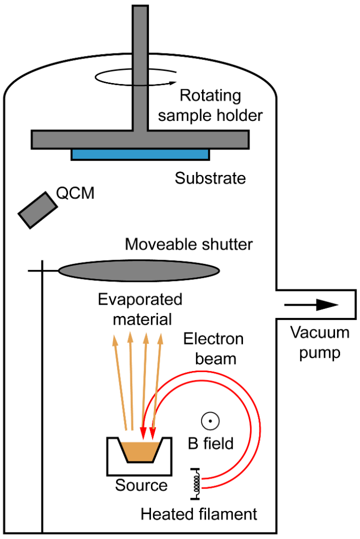
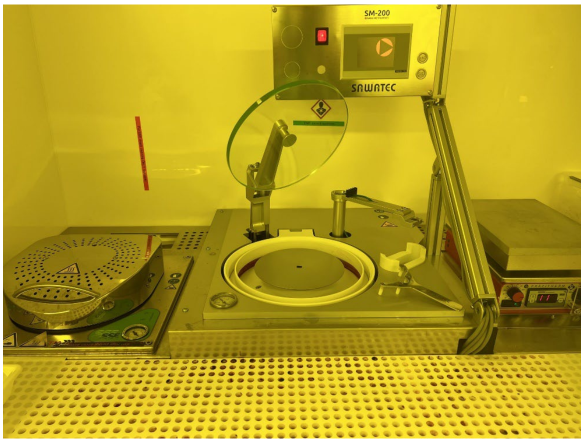


Figure 3. Schematic of an electron-beam evaporator.

For the case of the evaporator used for this exercise, the entire deposition process is computer controlled and requires minimal input from an operator.

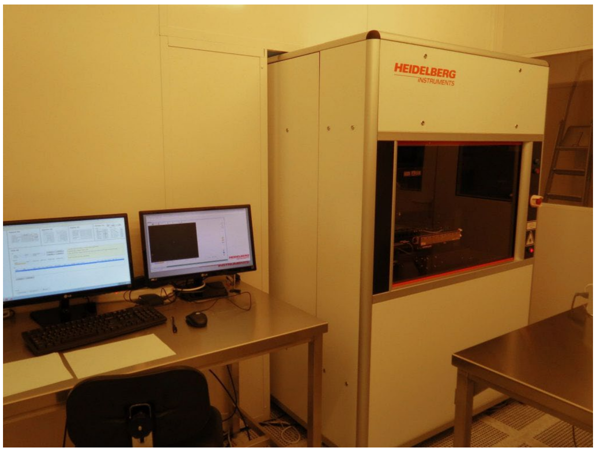
2.1. Description of the equipment used

Sawatec SM-200



Sawatec SM-200 is a manual spin coater. Once the sample loaded by the user on the chuck, it follows the steps of the recipe chosen, varying rotation speed and ramps. Typically, a wafer spin coating starts with a slow step so that resist is evenly spread across the wafer before thinning it down to the desired thickness. For chips, it ends with a short faster step in order to reduce the corner effects.

MLA150



MLA150 is mask-less aligner, a laser writer that makes it possible to write a pattern directly into a photoresist layer, without having to produce a photomask first. This is done by scanning the sample directly under the laser beam. The resolution is limited by the photoresist (length of the molecular chains in the polymer used), light wavelength and numerical aperture of the optics, resulting in a typical resolution of around 1 µm.

LAB600 evaporator

Figure 4. Left: Lab600 evaporator. Middle: e-beam evaporation source. The material is placed in the circular crucible in the middle and heated using an electron beam. Right: boat for evaporation via Joule heating.

The evaporator model Lab600 made by company Leybold Optics is piece of equipment allowing us to deposit metallic or insulating thin films on substrates placed above a material source heated by an electron beam. Evaporation is carried out in high vacuum (on the order of 10^{-6} mbar or better), in order to minimize the collisions between gas molecules and the stream of evaporating materials as well as possible chemical reactions (mostly oxidation). Multiple materials can be loaded in the same time, allowing the deposition of different films in a single evaporation run which is controlled by a computer and carried out automatically.

The special feature of the Lab600 is a very large distance between the source and the deposition substrate, on the order of 1 m. This results in a near perpendicular angle of deposition, high uniformity of the deposition over the surface of the wafer and a low substrate temperature, making it especially suitable for deposition of metal films for lift-off.

For this device fabrication step, we deposit a contact stack consisting of a 2 nm thick Ti film acting as an adhesion layer and first contact layer to MoS_2, followed by a 50 nm think Au film. We know from experience that such films reliably result in good electrical contacts to MoS_2.

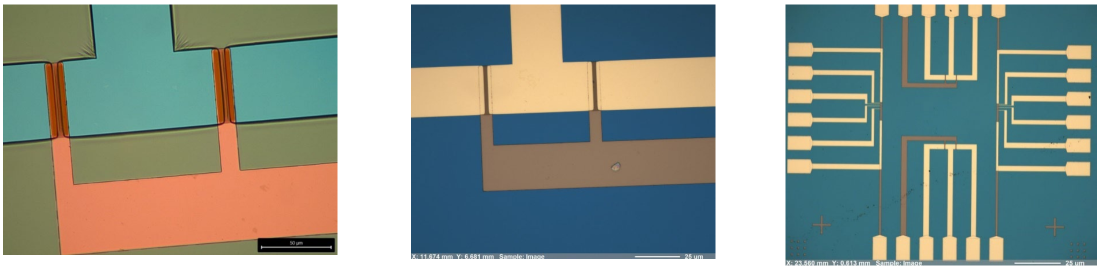


Figure 5. Optical micrographs of the device during different phases of fabrication. Left: after exposure and development. Center and right: after evaporation and lift-off.

3. Description of experiments and tasks

Following is the overview of the tasks and operations to be carried out in this exercise. The main goal is to pattern a photoresist layer and use it for subsequent deposition of electrical contacts on predetermined locations on the MoS_2 film.

3.1. Photoresist coating (Location: Zone 13 – Sawatec SM-200 – Coating)

1. Mount the chip chuck, load the chip and activate the vacuum.
2. Coat the chip with 400 nm thick LOR5A (undercut layer) and 1 um of AZ1512HS by drop casting and launching the appropriate recipe.
3. Unload the chip and clean the chuck.

3.2. Photoresist exposure (Location: Zone 15, MLA150)

1. Load the chip.
2. Setup the job with the layout conversion and the alignment settings.
3. Perform alignment and expose the chip, with a dose of 50 mJ/cm^2, defocus 0.

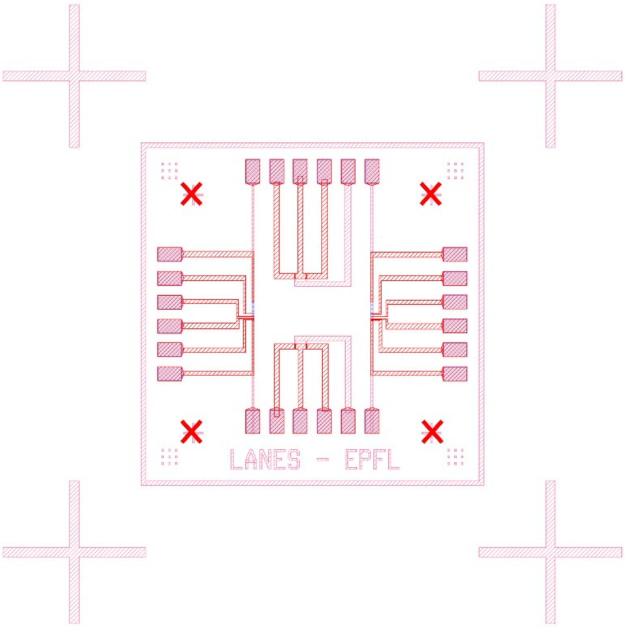


Figure 6. Alignment positions – Manual alignment in the crosses

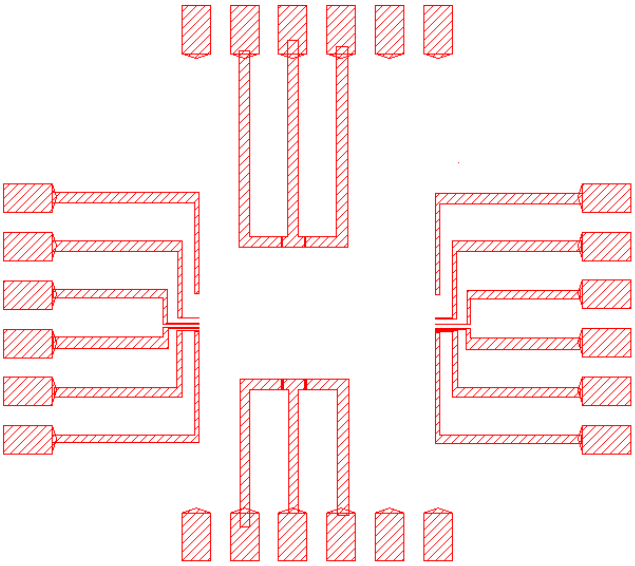


Figure 7. The pattern to be exposed – contacts

3.3. Development (Location: Zone 13, wet bench)

4. Develop the chip using AZ726MIF and rinsing with DI water.
5. Dry the chip using a nitrogen gun.

3.4. Sample inspection

Verify that the sample has been correctly exposed using one of the optical microscopes in CMI.

3.5. Evaporation (Location: Zone 4, Lab600)

1. Load wafer in LAB600
2. Select recipe 201: Ti/Au with 2nm Ti and 100nm Au.

3.6. Final inspection and resist stripping (LANES; done by the assistant)

1. Record the optical image of the chip using the microscope (Olympus BX51M).
2. Put the chip in an DMSO bath to lift-off the metal from chip.

4. Summary of experiments and tasks

1. Chip coating with the photoresist
2. Photoresist exposure and development
3. Contact deposition

5. Questions for the report

In the report, please show on the following:

1. Optical images of the sample after exposure and development