Fundamentals of Micro and Nanofabrication

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Lecture - 59

Lab demo: Silicon Nitride cantilever fabrication-1

This lecture is on a demo of the Fabrication of Silicon Nitride cantilever process. We will understand how a device is fabricated and what are all the individual unit processes required to achieve the desired device. All the processes involved in the fabrication is carried out in a cleanroom.

As the name suggests, the cleanroom is clean, with a controlled number of particles, temperature, and humidity. Hence, it is a controlled environment. The cleanrooms are classified as a class hundred, class thousand, class one, class ten; number indicating the number of particles that can be found in a cubic field. So, this is one metric used to classify clean room levels and the cleanliness level of any cleanroom.

Most of the devices fabricated are either a micrometer scale or nanometer scale. So, when the device shrinked down, even the smallest of the dust particle on the device can either short a device or create open circuit or undesirable functionality issues. To avoid this, the particles are controlled by filtering and creating a controlled environment. To operate in the controlled environment, humans are required, who is one of the main sources of particles; coming out of skin, breathe, hair, and clothing. To avoid this, an elaborate procedure is followed to enter a clean room and process.

The procedure to enter a cleanroom is called a gowning procedure.

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The slide shows the national nanofabrication centre (NNFC) located at the Indian Institute of Science Bangalore. To enter this, one should make sure that one's biometric is authenticated.

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Only authorized personnel are allowed to enter the premises. To enter the facility following procedures need to be followed.

1. Foot cover: Remove the footwear or wear overall footwear depending on clean rooms. At the NNFC facility, the footwear is removed and an intermediate

transport slipper with overalls' is used. This zone allows acts as a buffer region to reduce any kind of contamination that can be transferred into the clean room.

2. Air shower: to remove the entire loose particle that is sitting on cloth and skin. Here a forced air is used to remove all these particles. After air shower Gowning procedure is followed
3. Face mask: The first step in gowning process is to cover the mouth using facemask.
4. Hair net: to avoid particle coming off from head.
5. Bunny suit, to covers the overall body.
6. Shoes: shoes of appropriate size are used to avoid any difficulty in walking.
7. Gloves: To protect hand that is not covered by bunny suit.

Once we make sure gowning is properly done, and the gown is comfortable, we enter the cleanroom premises and then enter the bay for individual processes. This lecture demonstrates a simple example of fabrication of a cantilever beam using silicon nitride as the cantilever material on silicon substrate.

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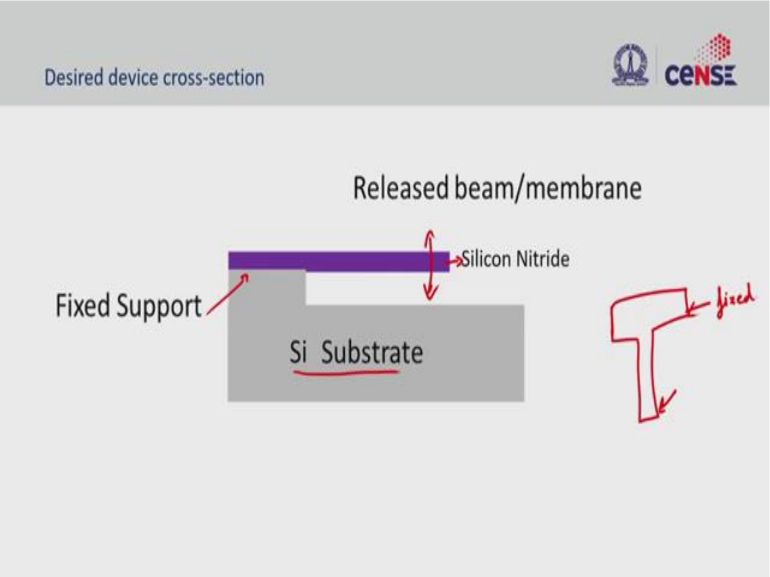

Desired device cross-section

Released beam/membrane

Silicon Nitride

Fixed Support

Si Substrate

fixed

The above slide shows the desired device cross-sectional image. The device has a released beam or the membrane of a silicon nitride, fixed at one end to a silicon substrate and free-standing at the other side, to freely move. To fabricate this device, involves multiple processes.

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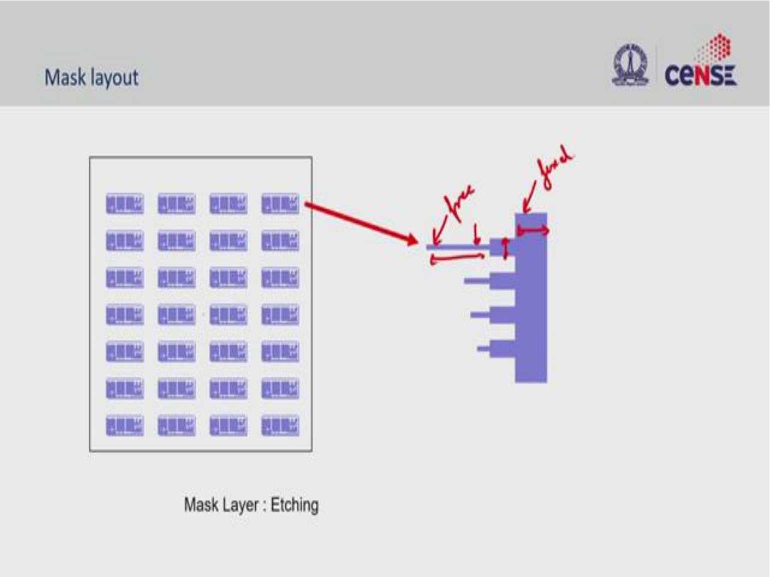

Mask layout

Mask Layer : Etching

The first step is to design a photomask for lithography. The above slide shows a group of cantilever designs on the left and a zoomed-in image of one design on the right. The design consists of a fixed side and hanging side of particular width and length. After designing mask plate is developed.

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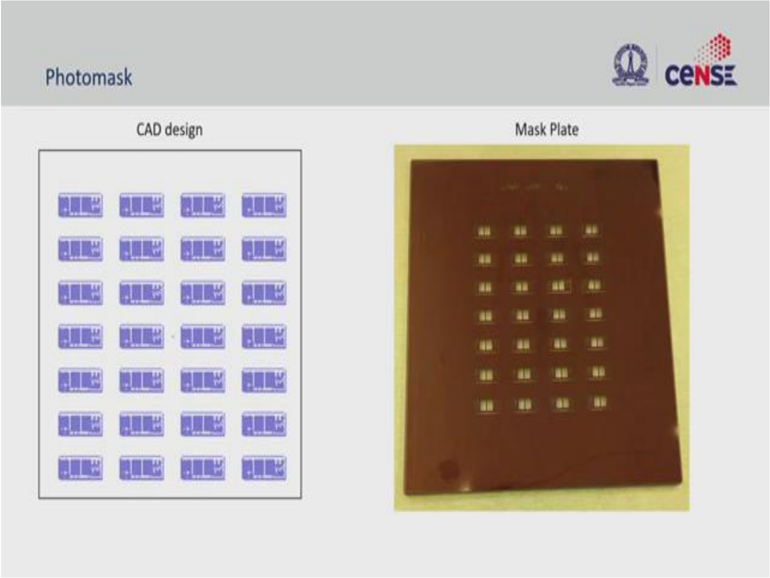
Photomask

The required device is designed using a cad tool and transferred to a mask plate. The Mask plate consists of the opaque chromium region and the open regions. The open regions are the places where light would go through. Once the mask plate is ready, we can start the fabrication process.

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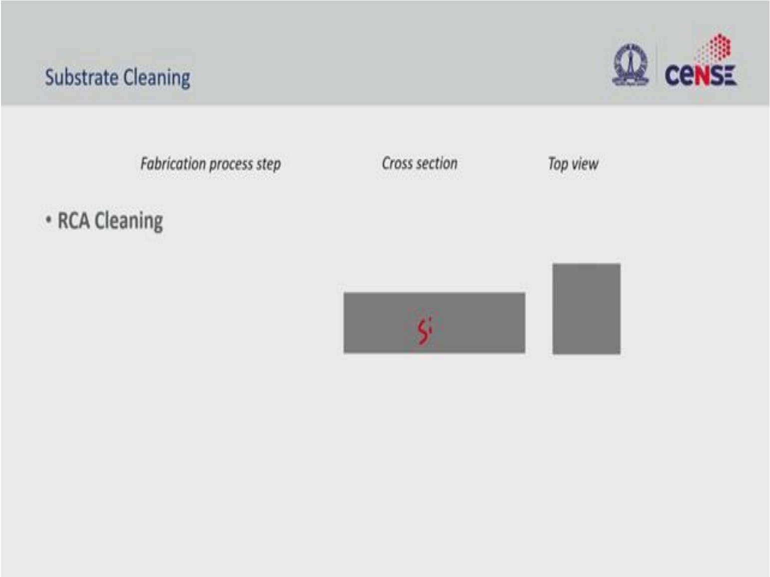
Substrate Cleaning

- RCA Cleaning

The first step in fabrication is substrate cleaning. Here we use a wet process, RCA, to clean the silicon wafer to remove any contamination on the surface.

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To carry out the wet process is to wear personal protective gear, protection from any chemical safety hazard. It includes safety sleeves to avoid any acid spill or splashes will fall on hands, then the apron to prevent any acid or any chemical spill onto the body. And the next is to protect the face and head using a face mask. Once completely dressed, we enter the wet bench, consisting of multiple benches for various wet processes.

The cleanroom facility has wet processing stages of metal contaminated and metal-free. Each stage has dedicated solvent and acid processing benches. Various processing stations are isolated to avoid any cross-contamination and for safety.

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We are going to do the cleaning process in the level one or front end process, with no metal and polymer contamination. Once we identify the level, each level will have dedicated carriers and Petri-dishes. The wafer need to be cleaned is kept in the carrier wafer and rinsed with deionised water. Then the carrier with wafer is kept inside the acid bath using the local protective gear. In this case acid bath contains RCA solution for cleaning. Once the wafer is inside the acid bath, the bath is closed with lid and start the process. The bath process automated, where the temperature of the bath is maintained at 75 degree Celsius, which is crucial and timer is set for 10 mins.

After completing the process, the wafer is taken out and all the acids sitting on the wafer and wafer carrier are removed. This is done in the rinser bath, where the carrier with wafer is kept in the bath, the handle is removed and the bath is closed. And once it is closed the bath is splashed with DI water to remove all the acid contamination sitting on the wafer. This again is an automated process where cleaning is monitored by looking at the conductivity of the deionized water as the pH and conductivity of the water will also change with acid content. The conductivity will start increasing with acid removal. Once all the acid is removed and the normal deionized water conductivity, 18 megaohms, is reached, we are assured that all the contamination is removed.

The indication light will blink showing process completion and then the wafer is taken out. To remove the water content present on the wafer, it is dried in the subsequent process.

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To dry the wafer, here spin-drying machine is used. The wafer is loaded with the wafer carrier inside the drying tool. The drying tool will spin the wafer and while spinning, the centrifugal forces will pull the water. And once it reaches the maximum spin speed all the waters content on the wafer is removed. The tool automatically indicates the process completion once the wafer is dry and the wafer is taken out. To ensure further removal of any water content, a dehydration bake is carried out if necessary. The cleaned wafer is then used for subsequent process.

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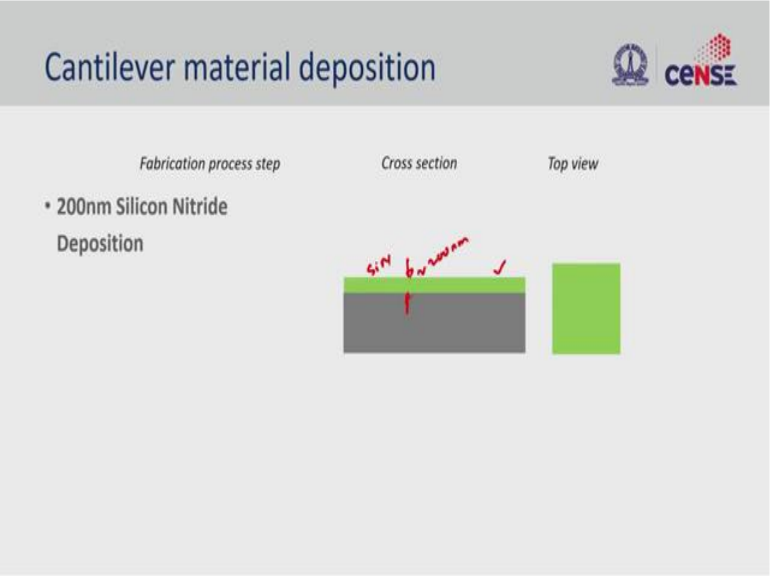

Cantilever material deposition

Fabrication process step | *Cross section* | *Top view*

- 200nm Silicon Nitride Deposition

The next process is cantilever material deposition. As mentioned earlier, we are using silicon nitride as the cantilever material of approximately 200 nanometres. The above slide shows the cross-section image of 200 nm silicon nitride on the silicon substrate, and the top view shows the uniform film as it is a blanket deposition. We are going to use low-pressure chemical wafer deposition, a high-temperature furnace process for silicon nitride deposition.

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Above slide shows horizontal low pressure chemical wafer deposition (LPCVD) furnace. Each material has dedicated tube for deposition. Here we see the silicon nitride deposition tube. The tube is made of quartz which can with stand high temperature. The gases for the deposition are injected using the cartridges (silane gas for silicon deposition). The wafer is loaded to the tube in a wafer boat and which is covered by a protective cassette. The cassette is removed carefully and the cleaned wafer is loaded. And then the wafer boat is transported into the furnace tube. The opening and closing of the tube is motorized, which are computer-controlled. A suitable program is used to control the speed of the movement of the holder, in and out. The temperature inside the tube is measured through the sensors.

Once the loading is done, we chose a specific recipe for silicon nitride deposition using the control program. All steps are pre-programmed, where the gas lines, the temperature elevance are controlled. Display on the control system shows the graphs of temperature with time, the initial increase in temperature, and then the temperature is maintained during deposition and reduction to a standby temperature after the deposition, to open the chamber and remove the wafers. Similar to temperature, various gas flows are shown in the graph with different colour traces.

And you can see here what is happening in different zones. A furnace tube consist of different zones; load zone, carrier zone and end zone. Load zone is the starting part of the tube, the central zone is the centre of the tube and the end zone is the end of the tube. The temperature should be maintained uniformly in all zones, in this case 700 ^{o}C. Each gas lines, dichlorosilane, ammonia and nitrogen, are connected to mass flow controllers (MFCs), whose flow(100 SCCM of nitrogen, 200 SCCM of dichlorosilane and 200 SCCM of ammonia) and pressure are controlled through the programme.

Once the deposition is done the feed gas is stopped and the tube starts cooling down. While cooling, nitrogen gas is purged to remove the residual precursor gasses present in the chamber in order to arrest any deposition during the ramp-down step. All the above information is loaded in the program and is updated.

Once the program is updated, the tool starts to deposit. During the deposition, the temperature, flow, and pressure are monitored using an interface.

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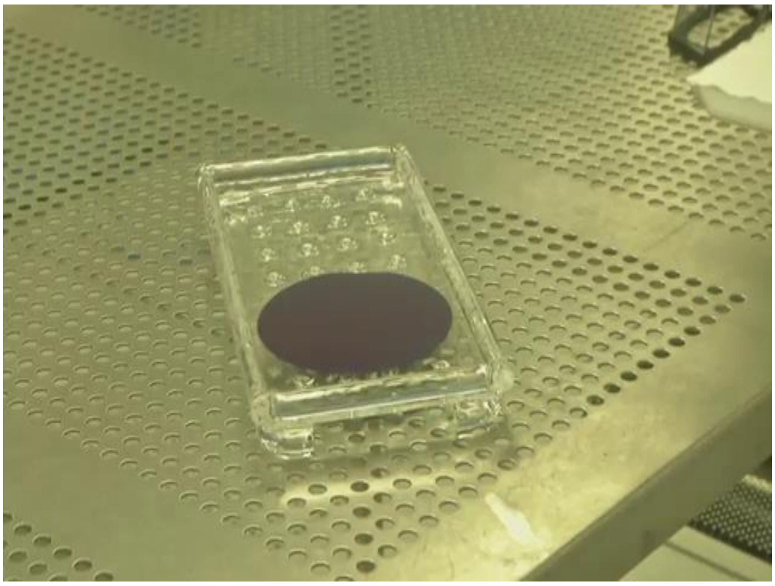

After deposition, the wafer is removed. The above image shows greyish or blackish silicon wafer has turned into a bluish tint because of the nitride film deposited on top of the silicon.

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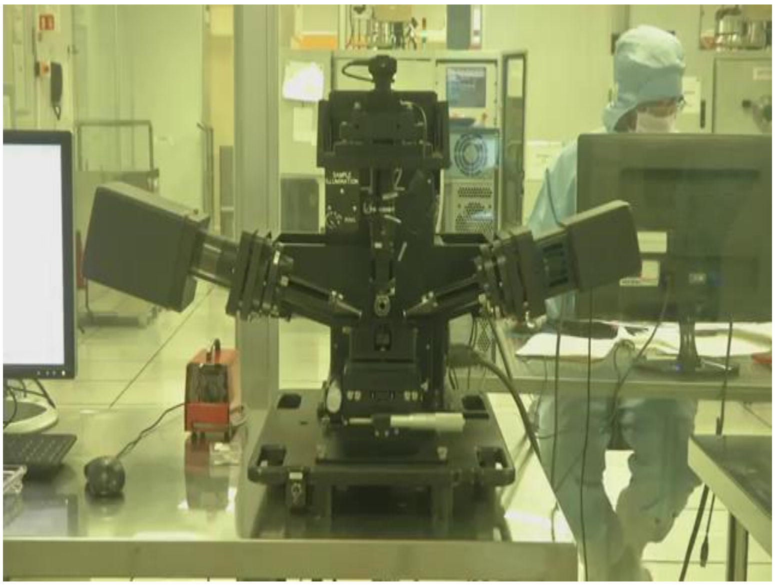

As the film doesn't have step height and it is uniform, blanket deposition spectroscopic ellipsometry is used to measure the film thickness. The above slide shows the ellipsometry tool with a broadband source in the left arm and a detector with an analyser in the right arm. The polarization change during the reflection of light is detected and given as a spectrum. The spectrum is fitted with a suitable model to extract the film thickness.

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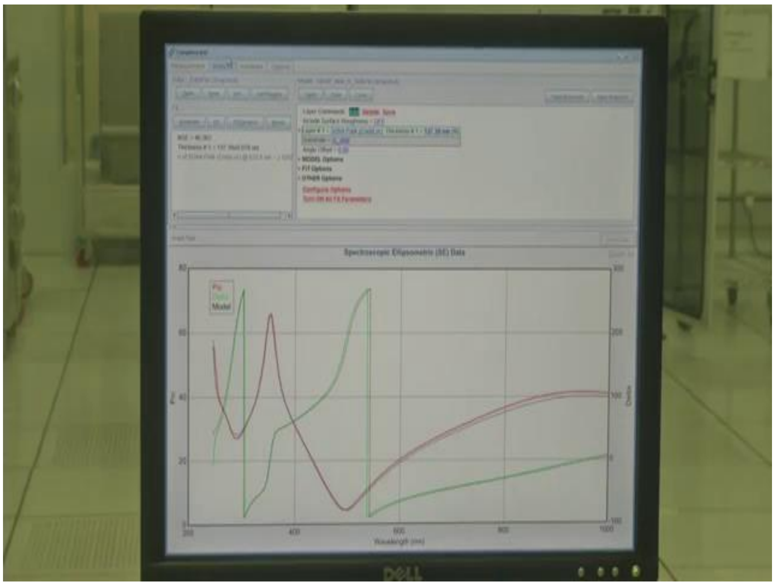

The above image shows the silicon nitride model used to fit the data. We see a reasonably good fit and the thickness measured is about 137 nanometres. The silicon nitride film is then taken for patterning.

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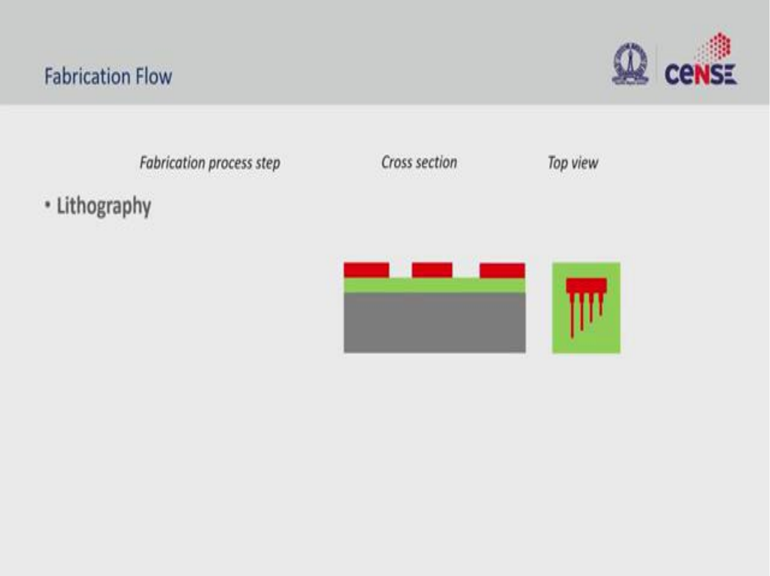

Fabrication Flow

Fabrication process step | *Cross section* | *Top view*

- Lithography

To pattern the film, we use lithography, where we coat a thin layer of photoresist. During this process, the pattern is transferred onto the photoresist and later on to the silicon nitride layer. The next steps for cantilever fabrication is explained in the next lecture.