

# NMOS Fabrication Process Description

Modified by Alex Chediak on March 2000.

Modified by TAs team (Eric Hobbs, Paul Hung, Paul Friedberg, Min She) in Fall semester, 2002. Updated by Wei-Chang Li, Fall 2013, Spring 2014, Fall 2014, Spring 2015.

Modified by Shiqian Shao, Fall 2015. Modified/updated by Mark Hettick, Fall 2016.

## Part 1: A checklist

### What do you need in EE143 lab and NanoLab?

At the beginning of the semester, the TAs team in the current semester should check the following stuff to make sure they are in EE143 lab or NanoLab.

#### 1) General stuff:

Item	Usage purpose	Quantity	Comments
Long Teflon wafer handler	Hold 3" wafer during chemical etching	6	Need RCA cleaning
Metal tweezer	Hold and Transfer wafer	6	
Teflon tweezer	Hold wafer	3	Need RCA cleaning. If wafer must be kept clean, (for example, before gate oxidation) you should use Teflon tweezer. <b>No metal tweezer!</b>
HF burn paste		2	Use it if you contact HF

#### 2) Oxidation (sintering) process module

Item	Usage	Quantity	Comments
Clean 3" quartz boat	Field oxidation growth in NanoLab	1	Kept in NanoLab. Need RCA cleaning.
Clean 3" quartz boat	Gate oxidation growth	1	In EE43 lab, need RCA cleaning.
3" quartz boat	Intermediate oxide growth and sintering	1	in EE143 lab, need RCA cleaning.
Cylindrical carrier	Carry boat	1	Need HF cleaning in NanoLab
Thermal couple	Measure temperature	1	
Long glass thermometer	Measure temperature	3	Each furnace has one
Thick cotton gloves	Hold hot stuff	Several pairs	
Brick	Hold the hot end cap	1	
End cap	Seal the furnace	3	Each furnace have one
Glass bubbler	Supply vapor during wet oxidation	1	Connected to center furnace tube
Heater for glass bubbler	Heating water into vapor	1	

Spin-on-glass liquid	Dope S/D	1 bottles	Kept in the refrigerator. Expire in 6 months
Blue wafer transfer box	Transfer wafer between NanoLab and EE143 lab	1	Need RCA cleaning and always put into a plastic bag.
3" white Teflon cassettes	Hold wafer in the blue wafer transfer box	1	Kept in the blue box and need RCA cleaning
Oxygen gas	Oxidation	1 bottle	
Nitrogen gas	Annealing	1 bottle	
Forming gas	sintering	1 bottle	

### **3) Chemical Cleaning and Etching module**

Item	Usage	Quantity	Comments
Yellow acid resistance gloves	Put it on when dealing with chemicals	6 pairs	Kept in plastic bag after being used.
Beaker	Piranha cleaning	1	Each beaker should be labeled and should not mixed. You need to place the beakers in the acid holder fixture available at the sinktop to avoid accidental spillage.
	Piranha rinsing	2	
	5:1BHF	1	
	10:1BHF	1	
	HF rinsing	2	
	At etching	1	
	Si etching	1	
	General rinsing	2	
Glass heating bath	Al etching process	1	Keep water temp at 50°C
Heating oven	Heat the glass bath		During Al etching
Tall Teflon Bath	RCA cleaning	3	
White Teflon Cassettes	Wafer cleaning and spindrying	1	Kept in Msink6 drawer, NanoLab, need RCA cleaning
		2	In EE143 lab
Cassettes handler	Handle the cassettes	1	In Msink6 drawer, NanoLab
Thermometer	Measure temperature	1	

### **4) Photoresist Developing and Acetone Stripping Module**

Item	Usage	Quantity	Comments
Beakers	Develop photoresist	1	
	PR rinsing	2	
	Acetone	1	Strip PR
	Acetone rinsing	2	
Blue wafer transfer box	Transfer wafer	2	

Small bottles and droplets	Container for photoresist	3	PR should be obtained from NanoLab
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### **Aluminum Evaporations Module (Turbo Pump System)**

Al targets	Al source	One bag (>50 piece)	
Tungsten coil	Heating the Al targets	One bag (>20 piece)	

### **5) Chemical Material in EE143 lab**

Chemicals	Purpose	Quantity	Comments
Sulfuric acid	Wafer cleaning	2	
Hydrogen peroxide	Wafer cleaning	2	
5:1 BHF	Etch oxide	2	
10:1 BHF	Etch oxide	2	
Si etchant	Etching polysilicon	2	Ask NanoLab at least 48 hours before you need it.
Al etchant	Etching Al	2	
Ammonium Hydroxide	RCA cleaning purpose	2	
2-Propanol	Cleaning dirty stuff	2	
OCG825 Photoresist		2	Use small bottles to get PR from NanoLab
OCG934 developer OPD4262	Developing PR	2	OPD4262 is cheaper and somehow has better results
Acetone	Strip PR	2	

#### **Note:**

- 1) The 3" boat and cassettes, handler kept in NanoLab is for NanoLab usage only. Please don't take them back to EE143 lab or take any stuff from EE143 into NanoLab, to prevent contamination.
  - 2) RCA cleaning procedure: All of the clean stuff needs to be RCA cleaned. First, put the stuff into one of the white tall Teflon bath, then pour 5 part of DI water, 1 part of Ammonium Hydroxide, then 1 part of H<sub>2</sub>O<sub>2</sub>. RCA liquid should be aspirated after RCA cleaning is done.
  - 3) At the beginning of the semester, the TAs should check the beaker in the following way: put a wafer handler with 3" wafer into the beaker, fill the beaker with DI water till the water immerse the 3" wafer completely, mark the water level. Then in future, you can always fill the BHF, HF, poly etchant and so on to this level.
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## Part 2: Process Flow (Process Overview)

[Week 1](#): Starting Materials

[Week 2](#): Initial Oxidation – 4500 Å (done by TA in NanoLab), Active Area Photolithography

[Week 3](#): Gate Oxidation – 800 Å

[Week 4a](#): Poly-Si Deposition – target 4000 Å (done by TA in NanoLab), Gate Photolithography

[Week 5a](#): Source-Drain Deposition (N+)

[Week 5b](#): Source-Drain (N+) Drive and Intermediate Oxidation

[Week 6](#): Contact Cut

[Week 7](#): Metallization

[Week 8](#): Metal Definition

### Week 1: Starting Materials. (No lab this week.)

#### 1. Wafers

- 1) 3" p-type silicon wafers with a resistivity of 14-16 ohm-cm and <100> crystal orientation. In addition to work wafers to each student group, each section will receive one wafer to be used as a control during week #4. And each session should have one to two TA wafers.
- 2) Blanket Implant:  $6.0 \times 10^{12}$  /cm<sup>2</sup>, B11, 60 KeV (This part is arranged by NanoLab staff, Jeff clarkson).
- 3) Uniquely identify each of the wafers Label wafers with diamond scribe. Label using small letters near the flat. Do not scribe off the edge of the wafer as this will cause the wafer to break. DO NOT LABEL YOUR WAFER ACROSS THE CENTER AS IT WILL DESTROY YOUR DEVICES.
- 4) Divide Wafers into lab sections.
- 5) Measure resistivity on one control wafer. Resistivity to be reported to students in week 3

#### 2. Check Masks and Clean the Mask (4" x 4" Chrome Plates)

- 1) ACTV = Defines the Active Area (Dark Field)
- 2) POLY = Defines the Gate (Clear Field)
- 3) CONT = Defines the Contacts (Dark Field)
- 4) METL = Defines the Metal (Clear Field)
- 5) Mask Cleaning Procedure:
  - 6) At sinks douse chrome side with Acetone. If necessary one may lightly use a mask scrubber to remove any residual resist (Exercise extreme caution if you choose to use the scrubber so that the mask is not damaged).
  - 7) While Acetone is still pooled on mask, use IPA (2-Isopropanol) to rinse Acetone off. Do not use water! Blow mask dry using N<sub>2</sub> gun.

## Week 2a: Initial Oxidation – 4500 Å. (Performed by TA in the NanoLab.)

**Checklist:** a 3” white Teflon cassettes and cassettes handler in Msink6 drawer in NanoLab. An RCA cleaned 3” quartz boat.

- Standard clean your work wafer in Msink6 in NanoLab (Piranha clean + short HF dip) as notes below: (Please refer to the Msink6 operation manual in NanoLab homepage for more detailed information)

Pre-Furnace Clean (Required):

- Transfer 3” wafers into the clean 3” Teflon cassettes kept in the drawer marked as EE143 next to Msink6. Slide the cassettes handler over the slit to hold the cassette.
- Add 100ml H<sub>2</sub>O<sub>2</sub> into one of the Piranha bath at Msink6. Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes to wash off the wafers.
- Rinse the wafers off in the quick dump rinse (QDR) station at Msink6. The QDR cycles can be invoked from a special keypad mounted on the face of the station. Three successive dump/rinse cycles will thoroughly wash off the acid from wafers/cassette. At the beginning the cassettes may be too hot to directly get plunged into a DI filled dump rinse station. You can dump the water, and then place the wafers in the tank. Start the program to slowly fill up the tank and automatically cycle through the dump- rinse steps. Make sure to also rinse the cassettes handler to get rid of any possible piranha acid left behind on the handle from previous step (use DI deck hose). After the 3 dump/rinse cycle resistivity meter should read above 10 ohm-cm.
- Dip the cassette/wafers in 10:1 BHF tank for 20 seconds, then immediately place it in dump quick dump rinse station to cycle through DI rinse as per defined in the step 3 above. This "HF dip" removes the native oxide.
- Repeat QDR rinse cycles noted in step3 above. This time it is recommended that you start with the QDR tank filled with DI water, as the HF tank is kept at room temperature and the DI dip will stop HF working on your wafers.
- Take the cassettes out and use N<sub>2</sub> gun to dry the wafers piece by piece. Only Teflon tweezer or clean wand is allowed to hold the wafer post piranha/HF clean.

- Oxidize wafers at 1000 °C for 5-85-5 minutes (dry-wet-dry) O<sub>2</sub> in a MOS clean furnace (tystar2) with recipe “2WETOXA”. DO NOT USE Tystar3 or 4 which is not clean enough for this application. Ask process staff for another furnace, if Tystar3 is down. Before wet oxidation, please ask NanoLab staff to help you to put the 3” quartz boat into the furnace. (The boats are in the dedicated drawer for EE143 near sink6)

*\* Comment: Tystar2 gave 4400 Å and 4900 Å for 80 and 95 minutes at 1000°C (Fall'13)*

*\* Comment: Tystar2 gave 4700 Å for 90 minutes at 1000°C (Fall'14)*

- After oxidation is done, wait for at least 10 minutes at the unloading step for the wafers to cool down after you open the furnace. Then you can unload the wafer directly into 3” wafer box or tray. Otherwise the hot wafers may melt the plastic wafer box or tray. Make sure to only use vacuum wands to unload your wafers with a face shields on your face.
- Measure oxide thickness on Nanospec. It should be approximately 4500–4800 Å.

## Week 2b: Active Area Photolithography

### 7. Standard photoresist (PR) coating

- 1) If practical, spin wafers immediately after high temperature treatment. Otherwise dehydrate the wafers in an oven for 20 minutes at 120 °C.
- 2) Place wafers in HMDS vapor for 2 minutes or more minutes. HMDS promotes adhesion between oxides (e.g., native silicon dioxide) and photoresist.
- 3) Lift the black lever directly under the front of the spinner.
- 4) Verify the spinner is set to the right spin speed and time by loading and spinning a dummy wafer. The wafer should spin at 3000 RPM for 30 seconds.
- 5) To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
- 6) Get a bottle of OCG 825 photoresist from the refrigerator beneath the spinner.
- 7) Dispense one eye dropper of resist on the wafer and start a spin cycle.
- 8) Return the bottle of OCG 825 photoresist to the refrigerator beneath the spinner.
- 9) Soft bake at 90 °C for 1 minute on the hot plate. Soft baking evaporates most of the solvent in the PR so that it is not sticky.
  - a) Turn on the hot plate vacuum (black knob)
  - b) Place the wafer on the hot plate.
  - c) After 1 minute, turn off the vacuum knob, and place wafer on the metal rest piece for 10 seconds for cooling.

### 8. Standard photomasking: Mask #1 (ACTV)

- 1) Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3 to 10 seconds. Shorter times are needed when the lamp is newer and for more-reflective substrates such as aluminum. Make sure the **yellow lights** are ON for all spaces.

**Note: ~0.9-1 second with new lamp (Spring'16)**

- 2) Pour 1000 ml of OPD4262 developer solution into a beaker.
- 3) Develop and tell students that developing should only be done in yellow light. The yellow filters filter out shorter, more energetic wavelengths of light (e.g. green, blue, violet, and UV), which could cause exposure of the entire wafer.
- 4) Dip the exposed wafer into the developer for typically 60-80 seconds (ask the TA for the current optimal exposure time; it takes more time if the developer has been used more) and agitate slowly. Observe the reddish liquid forming near the wafer. It is the dissolved photoresist.

**Note: 45 seconds for first set, 50-55s after is good - +5 second at most (Spring 2016)**

- 5) Rinse in DI water for 1 minutes in each of 3 dedicated rinse beakers successively, then spray rinse.

**NOTE:** DO NOT use the same set of 3 rinse beakers for more than one kind of rinse. For example, do not use the developer rinse beakers for rinsing after an HF etch. Instead prepare another set of 3 dedicated rinsing beakers.

- 6) Blow dry with N<sub>2</sub> gun. It is very easy to break wafers during drying so exercise extreme caution in this step to dry over Technicloths on a sink.

- 7) Inspect under microscope with yellow filter and then also have TA measure using the Nanospec to ensure etching has been performed to completion. Measure line widths of test pattern [1] with the ruler on the eye piece. Record data.
- 8) If not completely developed repeat Step 4 for 5 seconds, then Steps 5-7.
- 9) (Optional) Hard bake the photoresist-coated wafer in an oven for 20 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the photoresist physically hard, more adhesive, and less permeable to chemicals.

9. Oxide etching and inspection: measure the field oxide thickness in the active area (the field oxide will be etched away here) before etching. It's easy to focus on patterned wafer under the nanospec.

- 1) Pour buffered 5:1 HF (BHF) into a **plastic** beaker to the fill line. Buffered HF is a mixture of  $\text{NH}_4\text{F}$  (ammonium fluoride) and HF 5:1. Its etch rate of thermal  $\text{SiO}_2$  is  $\sim 1000 \text{ \AA}/\text{min}$ . at 25 °C. BHF is used rather than plain diluted HF because the buffer keeps the strength and thus the etch rate closer to constant.
- 2) Determine the etching time according to the oxide thickness (measured using Nanospec) to be etched plus a 15 % overetch. The overetch is performed for process latitude (i.e., the oxide thickness and the etch rate both may vary across a wafer and among wafers).
- 3) Dip wafers in water for at least 10 seconds (Rinse tank 1 is acceptable) to wet the surface. Because of the surface tension of BHF, air bubbles can sometimes get trapped on the wafer surface if the surface is completely dry, leading to localized areas where the oxide is not removed.
- 4) Dip wafer in buffered 5:1 HF for the length of time determined in Step 2. Etching is complete when the etchant "beads" on bare Si; (i.e., a hydrophobic backside surface is detected.)
- 5) Rinse in DI water for 10 seconds in each of 3 dedicated rinse beakers successively, then spray rinse only (no Polymetrics).
- 6) Spin dry.
- 7) Inspect etching for completion under microscope & with the Nanospec.

10. Do the standard resist strip (acetone)

- 1) Dip wafer in a 1000 ml acetone bath for 2 minutes.
- 2) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively
- 3) The acetone may not strip the photoresist (PR) completely. Some PR residue may be left. Dip in IPA for 20 seconds can remove the PR completely. (IPA sublime very quickly).
- 4) Blow Dry

Then Measure line widths of test pattern using microscope that is equipped with Micro-manger. Microscope (the one next to quartz tube): use 40× object lens, save picture using *Micro-manager 1.3*. Open the saved picture using *ImageJ* and measure features by directly drawing a box on the features and it will display the number of pixels in the main window. 1 pixel = 282.3 nanometers.

### Week 3: Gate Oxidation - 800 Å

Gate oxidation is done in tube #3 (bottom) at 1100 °C following a TCA (C<sub>2</sub>H<sub>3</sub>Cl<sub>3</sub>) clean. Gases used are N<sub>2</sub> and O<sub>2</sub>.

#### 11. TCA Clean Furnace. (*Performed by Staff*)

- 1) *When you arrive, the furnace will already be on and stabilized.*
- 2) *Confirm temperature controller is set to the required temperature. For 1100 °C the controllers should be about +30.0, 87.0, +00.0. The center value adjusts the temperature of the central zone of the furnace. The left and right values set the temperature of the load and gas-input zones relative to the center region.*
- 3) *Check the temperature in the "hot zone" using the thermo-couple.*
- 4) *Open the sliding exhaust (scavenger) door on the side of the loading vestibule. Close the others if they are not being used.*
- 5) *Remove the glass end cap from tube (holding it with an insulating glove) and place it on the fire brick on the counter.*
- 6) *Load an empty boat into the "hot zone". Push boat in no faster than 1" every 10 second. Pushing the boat in faster can cause the boat to crack due to thermal stress.*
- 7) *Replace the glass end cap. Make sure gas outlet is pointing towards the exhaust (scavenger) door.*
- 8) *Turn on O<sub>2</sub> flow at maximum rate (15+ cm, steel ball) for at least 10 minutes. This requires that the O<sub>2</sub> tank is turned on, the regulator is set to 10 psi (MAX), the postregulator valve is on, the valve on the flow meter is opened to read 15 cm+, and the O<sub>2</sub> valve at tube 3 is opened. \*\*\* This step is critical; if there is not sufficient oxygen in the tube when the TCA starts flowing, the TCA will not oxidize (burn) completely and will form soot inside the tube. \*\*\**
- 9) *Start the TCA bubbling by closing the N<sub>2</sub> valve at tube 3, opening the TCA valve at tube 3, opening the valve to the TCA bubbler, and opening the N<sub>2</sub>/TCA valve on the flow controller. Keep this to a low flow rate, say 1-2 on the scale. It is important to open valves starting at the tube end. Flowing gas into the bubbler vessel with the tube 3 TCA valve off will pressurize the bubbler vessel, causing it to explode. This would be very bad. Leaving the tube 3 N<sub>2</sub> valve on will cause N<sub>2</sub> gas to circumvent the bubbler vessel. If bright blue flames are visible at the tube inlet, decrease the N<sub>2</sub> flow rate. The flames are a result of too much free carbon in the tube, i.e. not enough O<sub>2</sub> to react with the incoming TCA. Too much TCA will cause a small explosion. (This has happened before. The other end of the tube was blown off.) If no bubbles are seen, check that the TCA level is above the frosted zone of the N<sub>2</sub> tube in the bubbler vessel.*
- 10) *TCA clean for 1 hour at 1100 °C. TCA removes heavy-metal contaminants by supplying the chlorine to form volatile chlorides:  $N_2 + 2 O_2 + C_2H_3Cl_3 \rightarrow 2 CO_2 + 3 HCl + N_2$ .*
- 11) *Turn off N<sub>2</sub>/TCA flow, and close TCA bubbler valve, and the tube 3 TCA valve. It is important to close valves starting at the flow meter, and working towards tube 3, thereby not pressurizing the TCA bubbler.*
- 12) *Wait 10 minutes after turning off TCA.*
- 13) *Switch gases to N<sub>2</sub> = 40 sccm and O<sub>2</sub> = 15 sccm for wafer loading. This is 90% N<sub>2</sub> and 10% O<sub>2</sub>.*



12. Standard Clean process wafers and one implanted control wafer from Week 1. Label the control wafer "OCR DATE", where OCR stands for Oxide Control Wafer, and DATE is the current date. . **This SAME control wafer will be used throughout the processing during thermal steps. Be sure to keep it with the wafers for the current lab section.** Make sure not to HF dip for more than 20 seconds.

- 1) Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
  - a) Measure out 10 parts of  $\text{H}_2\text{SO}_4$  in **Pyrex** beaker (or a chemical resist plastic beaker)
  - b) Very slowly add 1 part of  $\text{H}_2\text{O}_2$ . Note: This mixture is self heating. When cool it may be refreshed by very slowly adding 1 part of  $\text{H}_2\text{O}_2$ .
- 2) Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes.
- 3) Pour 10:1 BHF into a plastic beaker to fill line.
- 4) Rinse the wafers of in DI water for 1 minute in each of 3 dedicated rinse beakers successively, then spray rinse.
- 5) Dip in 10:1 BHF for 20 seconds. This "HF dip" removes the native oxide.
- 6) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively, spray rinse. Then put all of the wafers into the 3" white Teflon cassettes, and put cassettes in a clean blue box and rinse again under goose hose with running water for ~3 mins.
- 7) Place the cassettes in Vertex spin dryer until resistivity meter indicates 10-15 M (not installed as Fa'14) or for 10 minutes. Note: Clean, bare silicon is hydrophobic and metallic in appearance.

13. Wafer Loading and Oxidation

- 1) Confirm that the gases are set to  $\text{N}_2 = 40$  sccm and  $\text{O}_2 = 15$  sccm. This is 90%  $\text{N}_2$  and 10%  $\text{O}_2$ . Use the steel ball in the mass flow controller instead of the black ball as the index.
- 2) Remove the end cap from tube (holding it with an heat-insulating glove) and place it on the fire brick on the counter.
- 3) Attach the cylindrical carrier (elephant) to the end of tube.
- 4) Pull the boat into the carrier slowly (1" every 10 seconds to avoid thermal shock which could break the boat).
- 5) Detach the cylindrical carrier and carefully push the boat onto the half-shell boat carrier and let the boat cool.
- 6) Load wafers into the boat very carefully using vacuum wand. Make sure the pair of grooves you intend to use to hold the wafer slant in the proper direction (facing each other). Make sure wafers are sitting loosely in the slots. This step has broken many wafers.
- 7) Pull the boat into cylindrical carrier.
- 8) Attach the cylindrical carrier to the end of the tube and push the boat into the tube very slowly (1" every 10 seconds to avoid thermal shock which could break the boat). Push the boat in a pre-determined depth (by TA's) used for the entire class.
- 9) Remove the cylindrical carrier and place the end cap on the tube, making sure gas outlet is pointing towards the exhaust (scavenger) door.

- 10) Change the gas flows, maintaining the following sequence: O<sub>2</sub> to 120 sccm and N<sub>2</sub> to 0 sccm.
- 11) Time for approximately 45 (actual time will be determined by head TA) minutes oxidation time. Dry (rather than wet) oxidation is done for a higher quality oxide with a more controlled thickness and a better oxide-silicon interface.

***Note: 865 Å, 782 Å, 730 Å, 697 Å, 646 Å in the first five slots (Fa'13)***

- 12) Turn off O<sub>2</sub> valve at the flowmeter, then the O<sub>2</sub> valve of the gas cylinder. Set N<sub>2</sub> flow to 40 sccm.
- 13) Anneal in N<sub>2</sub> for 10 minutes to allow the silicon atoms to diffuse and heal some of the damage done during oxidation. Pull wafers out in N<sub>2</sub> as described in step #8 above.
- 14) Remove the end cap, attach the cylindrical carrier to the end of the tube and pull the boat out slowly (1" every 10 seconds to avoid thermal shock which could break the boat) into the carrier.
- 15) Place carrier with boat on table and let it cool.
- 16) Remove the wafers very carefully! This step has broken the MOST wafers!
- 17) Pull the boat into the half-shell carrier and unload the wafers.
- 18) Put the boat back into the end of tube (not all the way into the center) and replace end cap.
- 19) Return the push rods to the appropriate storage tubes.
- 20) Turn off all gases.
- 21) Never mix quartz ware between tubes, to avoid cross contamination.

14. Thickness and resistivity measurement (For control wafer only)
  - 1) Check oxide thickness on control wafer with the NanoSpec.
  - 2) Etch off oxide completely in buffered HF.
  - 3) Measure sheet resistance with the Four-Point Probe and use this to estimate channel doping concentration.

## Week 4a Poly-Si Deposition. (Performed by TA in NanoLab.)

Standard clean wafers in Msink6 in the NanoLab. Three inch closed boats are available for this process.

### Pre-Furnace Clean (Required):

- 1) Transfer 3" wafers into the clean 3" Teflon cassettes kept in the drawer marked as EE143 next to Msink6. Slide the cassettes handler over the slit to hold the cassette.
- 2) Add 100ml H<sub>2</sub>O<sub>2</sub> into one of the Piranha bath at Msink6. Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes to wash off the wafers.
- 3) Rinse the wafers off in the quick dump rinse (QDR) station at Msink6. The QDR cycles can be invoked from a special keypad mounted on the face of the station. Three successive dump/rinse cycles will thoroughly wash off the acid from wafers/cassette. At the beginning the cassettes may be too hot to directly get plunged into a DI filled dump rinse station. You can dump the water, and then place the wafers in the tank. Start the program to slowly fill up the tank and automatically cycle through the dump- rinse steps. Make sure to also rinse the cassettes handler to get rid of any possible piranha acid left behind on the handle from previous step (use DI deck hose). After the 3 dump/rinse cycle resistivity meter should read above 10 ohm-cm.
- 4) Dip the cassette/wafers in 10:1 BHF tank for 20 seconds, then immediately place it in dump quick dump rinse station to cycle through DI rinse as per defined in the step 3 above. This "HF dip" removes the native oxide.
- 5) Repeat QDR rinse cycles noted in step3 above. This time it is recommended that you start with the QDR tank filled with DI water, as the HF tank is kept at room temperature and the DI dip will stop HF working on your wafers.
- 6) Take the cassettes out and use N<sub>2</sub> gun to dry the wafers piece by piece. Only Teflon tweezer or clean wand is allowed to hold the wafer post piranha/HF clean.

15. Deposit 4000 Å Phosphorus-doped polysilicon in Tystar10 (T16 if T10 is down) using the standard recipe. The silane supplies the silicon, while the phosphine provides phosphorus for n-type doping. Wafers should be loaded in the center of the boat for Tystar10. Try to avoid the first and last two work position in the boat. Do not remove the 4" dummies and load the 3" wafers in the same slots. To load the 3" wafer efficiently, use the wand to suck the front side of the 3" wafers and then slide the 3" wafer into the slot with their backs against the 4" dummies. The 3" wafers stay nicely and they keep the vertical position during the deposition. Be sure to include a 3" process monitor on either side of the 3" work wafers. These control wafers should have a 1000 Å SiO<sub>2</sub> on them.

***\*Note: 4300Å – 4800 Å for 3 hours 30 minutes, 5000Å – 5800 Å for 4 hours, in Tystar10 (Fa'13)***

16. Measure poly-Si thickness with the NanoSpec (poly on oxide program).

## Week 4b: Gate Photolithography

17. Apply standard resist coating (same procedure as that in week3)

- 1) If practical, spin wafers immediately after high temperature treatment. Otherwise dehydrate the wafers in an oven for 20 minutes at 120 °C.
- 2) Place wafers in HMDS vapor for 2 minutes or more minutes. HMDS promotes adhesion between oxides (e.g., native silicon dioxide) and photoresist.
- 3) Lift the black lever directly under the front of the spinner.
- 4) Verify the spinner is set to the right spin speed and time by loading and spinning a dummy wafer. The wafer should spin at 3000 RPM for 30 seconds.
- 5) To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
- 6) Get a bottle of OCG 825 photoresist from the refrigerator beneath the spinner.
- 7) Dispense one eye dropper of resist on the wafer and start a spin cycle.
- 8) Return the bottle of OCG 825 photoresist to the refrigerator beneath the spinner.
- 9) Soft bake at 90 °C for 1 minute on the hot plate. Soft baking evaporates most of the solvent in the PR so that it is not sticky.
  - a) Turn on the hot plate vacuum (black knob)
  - b) Place the wafer on the hot plate.
  - c) After 1 minute, turn off the vacuum knob, and place wafer on the metal rest piece for 10 seconds for cooling.

21. Standard photomasking: Mask #2 (POLY) SEE CHANGES IN PREVIOUS LITHOGRAPHY MODULE

- 1) Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3 to 10 seconds. Shorter times are needed when the lamp is newer and for more-reflective substrates such as aluminum. Make sure the **yellow lights** are ON for all spaces.

*Note: 0.9-1 second with new lamp (Spring'16)*

- 2) Pour 1000 ml of OPD4262 developer solution into a beaker.
- 3) Develop and tell students that developing should only be done in yellow light. The yellow filters filter out shorter, more energetic wavelengths of light (e.g. green, blue, violet, and UV), which could cause exposure of the entire wafer.
- 4) Dip the exposed wafer into the developer for typically 60-80 seconds (ask the TA for the current optimal exposure time; it takes more time if the developer has been used more) and agitate slowly. Observe the reddish liquid forming near the wafer. It is the dissolved photoresist.

*Note: 45 seconds for first set, 50-55s after is good - +5 second at most (Spring 2015)*

- 5) Rinse in DI water for 1 minutes in each of 3 dedicated rinse beakers successively, then spray rinse.

**NOTE:** DO NOT use the same set of 3 rinse beakers for more than one kind of rinse. For example, do not use the developer rinse beakers for rinsing after an HF etch. Instead prepare another set of 3 dedicated rinsing beakers.

- 6) Blow dry with N<sub>2</sub> gun. It is very easy to break wafers during drying so exercise extreme caution in this step to dry over Technicloths on a sink.
- 7) Inspect under microscope with yellow filter and then also have TA measure using the Nanospec to ensure etching has been performed to completion. Measure line widths of test pattern [1] with the ruler on the eye piece. Record data.
- 8) If not completely developed repeat Step 4 for 5 seconds, then Steps 5-7.
- 9) **IMPORTANT:** Hard bake the photoresist-coated wafer in an oven for 40 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the photoresist physically hard, more adhesive, and less permeable to chemicals.

#### 18. Etch poly-Si

- 1) Pour 10:1 BHF into a plastic beaker up to the fill line
- 2) Pour a premixed silicon etchant, obtained from the NanoLab, into a Plastic beaker up to the fill line. Etch rate: ~2200 Å/min. Composition: 64% HNO<sub>3</sub> / 33% H<sub>2</sub>O / 3% NH<sub>4</sub>F.  
*Comment: Etch polysilicon in pre-mixed etchant, watch for color change. Etch time = 2.5 min initially for a 5000 Å film but increases to 5-12 min (max) after 3 days exposed to air. (Sp'16)*
- 3) Determine necessary etch time based on polysilicon thickness and add a 15% overetch.
- 4) Dip wafers in water (Rinse tank 1 is acceptable) to wet the surface. Because of the surface tension of BHF, air bubbles can sometimes get trapped on the wafer surface if the surface is completely dry, leading to localized areas where the oxide is not removed.
- 5) Dip the wafer into the BHF solution for 20 seconds to remove any native oxide, which is etched more slowly than polysilicon. Rinse the wafers for 1 minutes in DI water in each of 3 dedicated rinse beakers successively.
- 6) Immerse wafers in the silicon etchant for the determined etch time. Watch the color changes as the silicon is etched. When the color has stopped changing COMPLETELY the etch is done. Do not terminate the etch before this time.
- 7) Rinse the wafers for 1 minute in DI water in each of 3 dedicated rinse beakers successively.
- 8) Spin dry or continue to etch.
- 9) Inspect etching for completion under microscope.

#### 19. Etch oxide in active area until clear (~1 minute) in BHF.

- 1) Pour buffered 5:1 HF (BHF) into a plastic beaker to the fill line. Buffered HF is a mixture of NH<sub>4</sub>F (ammonium fluoride) and HF 5:1. Its etch rate of thermal SiO<sub>2</sub> is ~1000 Å/min. at 25 °C. BHF is used rather than plain diluted HF because the buffer keeps the strength and thus the etch rate closer to constant.
- 2) Determine the etching time according to the oxide thickness to be etched plus a 20 % overetch. The overetch is performed for process latitude (i.e., the oxide thickness and the etch rate both may vary across a wafer and among wafers).
- 3) Dip wafers in water (Rinse tank 1 is acceptable) to wet the surface. Because of the surface tension of BHF, air bubbles can sometimes get trapped on the wafer surface if the surface is completely dry, leading to localized areas where the oxide is not removed.
- 4) Dip wafer in buffered 5:1 HF for the length of time determined in Step 2. Etching is complete when the etchant "beads" on bare Si; (i.e., a hydrophobic surface is detected.)
- 5) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively, then spray rinse only (no Polymetrics).

- 6) Spin dry.
- 7) Inspect etching for completion under microscope.

20. Do the standard resist strip (PRS3000)

- 1) Dip wafer in a 1000 ml PRS3000 bath for 5 minutes.
- 2) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively 3)
- 3) Blow Dry

**NOTE (Spring '16): Ensure you do not use acetone for this step, or other hard baked resist strip steps. Acetone will not fully strip the crosslinked resist, and it will contaminate further processes.**

## Week 5a: Source-Drain Deposition (N+)

### 21. Standard clean wafers **without HF dip**.

- 1) Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
  - a) Measure out 10 parts of  $\text{H}_2\text{SO}_4$  in Pyrex beaker (or a chemical resist plastic beaker)
  - b) Very slowly add 1 part of  $\text{H}_2\text{O}_2$ . Note: This mixture is self heating. When cool it may be refreshed by very slowly adding 1 part of  $\text{H}_2\text{O}_2$ .
- 2) Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes.
- 3) Rinse the wafers off in DI water for 1 minute in each of 3 dedicated rinse beakers successively, then spray rinse.
- 4) Spin dry.

HAVE TA'S REFER TO THE PROCESSING MODULE HERE THAT WE HAVE WRITTEN FOR THE FURNACES

22. Bake the wafers in the oven for 5 minutes at  $200^\circ\text{C}$ . Some water bubble may be trapped in the wafers. This baking step will remove the water bubble completely. Otherwise the spin-on-glass may not coat on the wafer uniformly.
23. Turn on bubbler heater to  $98^\circ\text{C}$ . Turn on heater tape. Check water level. **The water level should fall close to, but below, the opening in the bubbler apparatus which admits steam into the gas flow to the furnace. Make sure the release valve (cap) on the bubbler is loosely capped, or open the cap in case the steam pressure built up in the bubbler might push water into the furnace.**
24. Spin Filmtronics Phosphorosilica spin-on-glass at 3000 RPM for 20 seconds including a p-type test wafer (bare wafer). Less than half of a pipette-full of SOG is needed. Check the manufacturing date beforehand. SOG expired after six months due to increased viscosity. It will hinder the development later.
25. Bake at  $200^\circ\text{C}$  for 15 minutes in bake oven.
26. NOTE: Do Not use a Teflon holder for the wafers in the  $200^\circ\text{C}$  oven! The Teflon boats will flow at this temperature. Place the wafers on glass slides in the furnace.
27. Load wafers into the boat very carefully using vacuum wand. Make sure the pair of grooves you intend to use to hold the wafer slant in the proper direction (facing each other). Make sure wafers are sitting loosely in the slots. This step has broken many wafers.
28. N+ pre-diffusion is done at  $1050^\circ\text{C}$  in furnace tube #2 (center). Set  $\text{O}_2$  flowmeter to 15 sccm and  $\text{N}_2$  to 40 sccm. (This corresponds to 10%  $\text{O}_2$  and 90%  $\text{N}_2$ .) The setting is constant during push, deposition and pull.
29. Push in wafers at 1 inch/10 seconds.
30. Hold 10 minutes in hot zone.
31. Pull out at 1 inch/10 seconds.
32. Phosphorus glass removal: after wafers are cooled, dip wafers in 10:1 BHF for amount of time determined from annealed PSG rate ( $4700 \text{ \AA}/\text{min}$ ). Note that wafer may not be hydrophobic due to film left by Spin-On Glass. Piranha cleaning will remove this film.  
***Comment: hard to determine if PSG is removed since most of the area is covered by field oxide. 2.5mins in BHF should do it. Ensure that you use 10:1 BHF, 5:1 is too fast. (Sp '16)***
33. Rinse in D.I. water for 1 minute in each of 3 beakers successively, then spray rinse.

34. Spin dry.
35. Measure resistivity on the control wafer with the Four-Point Probe.



## Week 5b: Source-Drain (N+) Drive and Intermediate Oxidation

36. This step is done at 1050 °C in tube #2. Check gas connection to allow for steam oxidation, dry O<sub>2</sub> and N<sub>2</sub> flow. Set dry O<sub>2</sub> to 65 sccm on flowmeter. Set N<sub>2</sub> to 0 cm (OFF).
37. Fill bubbler with D.I. water if needed. Use a clean, well rinsed beaker to fill bubbler.
38. Standard clean wafers, including control wafers from step 5a (bare Si wafer with PSG doped) and week 3 gate oxidation step (oxide removed). The two wafers will be used to monitor the S/D region and the channel resistivity, respectively.

- 1) Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
  - a) Measure out 10 parts of H<sub>2</sub>SO<sub>4</sub> in Pyrex beaker (or a chemical resist plastic beaker)
  - b) Very slowly add 1 part of H<sub>2</sub>O<sub>2</sub>. Note: This mixture is self heating. When cool it may be refreshed by very slowly adding 1 part of H<sub>2</sub>O<sub>2</sub>.
- 2) Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes.
- 3) Rinse the wafers off in DI water for 1 minute in each of 3 dedicated rinse beakers successively, then spray rinse.
- 4) Spin dry.

39. When the water is boiling in the bubbler (approximately 20 minutes) push wafers into furnace in dry O<sub>2</sub> (O<sub>2</sub> should already be on to 65 sccm). N<sub>2</sub> should be OFF.
40. Set O<sub>2</sub> flowmeter to 25 sccm and switch valves to wet O<sub>2</sub>. Two valves must be adjusted here. One allows the gas flow to enter the bubbler (first valve, green handle). The other chooses the gas flow path to be through the bubbler rather than around it (second valve, yellow handle). Again, consult the bubbler operation manual. Wet oxidation time is approximately 12 minutes (head TA will determine exact times). Wet oxidation (versus dry) is done because it grows oxide faster. Some of the single-crystal silicon of the source and drain and the polysilicon forming the gate are consumed during this oxidation.

***Comment: used 25 minutes in Fa'13 and thickness varied a lot, 750 Å–9000 Å from run to run.***

***Comment: (Fa'14) make sure the boiler lid is properly sealed. Otherwise, water vapor would leak out rather than flow into the tube.***

41. Turn off wet O<sub>2</sub> and turn on N<sub>2</sub> to 40 sccm on scale.
42. Anneal for 27 minutes in N<sub>2</sub>. (Adjust accordingly to make the overall oxidation and anneal times ~ 37 minutes)
43. Pull wafers out in N<sub>2</sub>. Pull out at 1 inch/10 seconds.
44. Check intermediate oxide thickness on control wafer, then etch oxide completely off in buffered HF and measure the sheet resistance with the Four-Point Probe.

## Week 6: Contact Cut

### 45. Apply standard resist coating

- 1) If practical, spin wafers immediately after high temperature treatment. Otherwise dehydrate the wafers in an oven for 20 minutes at 120 °C.
- 2) Place wafers in HMDS vapor for 2 minutes or more minutes. HMDS promotes adhesion between oxides (e.g., native silicon dioxide) and photoresist.
- 3) Lift the black lever directly under the front of the spinner.
- 4) Verify the spinner is set to the right spin speed and time by loading and spinning a dummy wafer. The wafer should spin at 3000 RPM for 30 seconds.
- 5) To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
- 6) Get a bottle of OCG 825 photoresist from the refrigerator beneath the spinner.
- 7) Dispense one eye dropper of resist on the wafer and start a spin cycle.
- 8) Return the bottle of OCG 825 photoresist to the refrigerator beneath the spinner.
- 9) Soft bake at 90 °C for 1 minute on the hot plate. Soft baking evaporates most of the solvent in the PR so that it is not sticky.
  - a) Turn on the hot plate vacuum (black knob)
  - b) Place the wafer on the hot plate.
  - c) After 1 minute, turn off the vacuum knob, and place wafer on the metal rest piece for 10 seconds for cooling.

### 46. Standard photomasking: Mask #3 (CONT).

- 1) Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3 to 10 seconds. Shorter times are needed when the lamp is newer and for more-reflective substrates such as aluminum. Make sure the **yellow lights** are ON for all spaces.

***Comment: 0.9-1 second with new lamp (Spring'16)***

- 2) Pour 1000 ml of OPD4262 developer solution into a beaker.
- 3) Develop and tell students that developing should only be done in yellow light. The yellow filters filter out shorter, more energetic wavelengths of light (e.g. green, blue, violet, and UV), which could cause exposure of the entire wafer.
- 4) Dip the exposed wafer into the developer for typically 60-80 seconds (ask the TA for the current optimal exposure time; it takes more time if the developer has been used more) and agitate slowly. Observe the reddish liquid forming near the wafer. It is the dissolved photoresist.

***Note: 45 seconds for first set, 50-55s after is good - +5 second at most (Spring 2016)***

- 5) Rinse in DI water for 1 minutes in each of 3 dedicated rinse beakers successively, then spray rinse.

**NOTE:** DO NOT use the same set of 3 rinse beakers for more than one kind of rinse. For example, do not use the developer rinse beakers for rinsing after an HF etch. Instead prepare another set of 3 dedicated rinsing beakers.

- 6) Blow dry with N<sub>2</sub> gun. It is very easy to break wafers during drying so exercise extreme caution in this step to dry over Technicloths on a sink.

- 7) Inspect under microscope with yellow filter and then also have TA measure using the Nanospec to ensure etching has been performed to completion. Measure line widths of test pattern [1] with the ruler on the eye piece. Record data.
- 8) If not completely developed repeat Step 4 for 5 seconds, then Steps 5-7.
- 9) (Optional) Hard bake the photoresist-coated wafer in an oven for 20 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the photoresist physically hard, more adhesive, and less permeable to chemicals.

47. Do oxide etch for calculated time. The back side of the wafer should de-wet (metallic in color) indicating no oxide present. Inspect under microscope.

- 1) Pour buffered 5:1 HF (BHF) into a **plastic** beaker up to fill line. Buffered HF is a mixture of  $\text{NH}_4\text{F}$  (ammonium fluoride) and HF 5:1. Its etch rate of thermal  $\text{SiO}_2$  is  $\sim 1000 \text{ \AA}/\text{min}$ . at 25 °C. BHF is used rather than plain diluted HF because the buffer keeps the strength and thus the etch rate closer to constant.
- 2) Determine the etching time according to the oxide thickness (measured using Nanospec) to be etched plus a 15 % overetch. The overetch is performed for process latitude (i.e., the oxide thickness and the etch rate both may vary across a wafer and among wafers).  
  
Comments: If the alignment is good (for example, the contact hole is far away from the polysilicon gate and the field oxide), longer overetch (50% or even 100%) could be done to make sure the intermediate oxide across the whole wafer is completely etched away to make a good contact hole.
- 3) Dip wafers in water for at least 10 seconds (Rinse tank 1 is acceptable) to wet the surface. Because of the surface tension of BHF, air bubbles can sometimes get trapped on the wafer surface if the surface is completely dry, leading to localized areas where the oxide is not removed.
- 4) Dip wafer in buffered 5:1 HF for the length of time determined in Step 2. Etching is complete when the etchant "beads" on bare Si; (i.e., a hydrophobic backside surface is detected.)
- 5) Rinse in DI water for 10 seconds in each of 3 dedicated rinse beakers successively, then spray rinse only (no Polymetrics).
- 6) Spin dry.
- 7) Inspect etching for completion under microscope & with the Nanospec.

48. You may find it difficult to tell whether the etch is complete, therefore, remove resist and inspect wafer again. If the contacts are not clear, etch for an additional 15 seconds and check again. Contact holes over the silicon substrate (not the poly) appear white when cleared, and then perform the standard resist strip

- 1) Dip wafer in a 1000 ml acetone bath for 2 minutes.
- 2) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively
- 3) The acetone may not strip the photoresist (PR) completely. Some PR residue may be left. Dip in IPA for 20 seconds can remove the PR completely. (IPA sublime very quickly).
- 4) Blow Dry

**Note (Spring 2016): Acetone is okay here for PR stripping, because the hard bake is not usually performed. Use PRS3000 if the PR is hard baked.**

## Week 7: Metallization

49. Standard clean wafers. Do the last dip in 10:1 BHF just before wafer is ready to go into evaporator to minimize the native oxide at the aluminum-silicon interface. The Al evaporator can only accommodate 3 wafers each time.

- 1) Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
  - a) Measure out 10 parts of  $H_2SO_4$  in **Pyrex** beaker (or a chemical resist plastic beaker)
  - b) Very slowly add 1 part of  $H_2O_2$ . Note: This mixture is self heating. When cool it may be refreshed by very slowly adding 1 part of  $H_2O_2$ .
- 2) Immerse wafers in piranha solution for 10 minutes. Piranha removes organic contaminants by oxidizing (burning) them, and metals by forming soluble complexes.
- 3) Pour 10:1 BHF into a plastic beaker to fill line.
- 4) Rinse the wafers of in DI water for 1 minute in each of 3 dedicated rinse beakers successively, then spray rinse.
- 5) Dip in 10:1 BHF for 20 seconds. This "HF dip" removes the native oxide. This "HF dip" removes the native oxide. Please don't "HF dip" the wafers until it's ready to go into the Al evaporator. Otherwise the native oxide may grow after sometime.
- 6) Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively, spray rinse. Then put all of the wafers into the 3" white Teflon cassettes.
- 7) Place the cassettes in Vertex spin dryer until resistivity meter indicates 10-15 M or for 10 minutes. Note: Clean, bare silicon is hydrophobic and metallic in appearance.

50. Aluminum Evaporation

- 1) Make sure the turbo pump "Normal Operation" light is on; otherwise, press Start button on the turbo pump controller and the light will be on within a few minutes.
- 2) You can test the pump at this point by tuning the knob to "PUMP". The chamber pressure is decreased through the roughing valve. The system will cross over to high vacuum automatically. System will pump indefinitely in this mode.
- 3) Turn the knob to "VENT". All the valves should be closed and  $N_2$  is vented into the chamber.
- 4) After chamber reaches atmospheric pressure, the jar will lift from the steel base. Lift the jar up.
- 5) Lift stainless steel wafer holder out of the inner glass cylinder ("chimney") and place it on the table covered with lint-free paper.
- 6) Loading the sample and supporting accessories.
- 7) Place a clean glass slide in stand inside chimney for a clear window.
- 8) Hang 2-4 clean Al charges (staples) near the middle of the tungsten coil (centered below the chimney hole). This should result in about 8000 Å of Al (proper placement of the charges are necessary for good uniformity).
- 9) Turn shutter knob so that the shutter is covering the charges.
- 10) Place wafer facing down on top of wafer holder.
- 11) Place wafer holder back inside the chimney.
- 12) Wipe stainless steel base and bottom of bell jar with lint free paper soaked with 2propanol.

- 13) Lower bell jar and turn switch to "PUMP". Push bell jar cage down and close it all around until vacuum begins to hold it tight and cannot be lifted. The PUMP setting opens up the roughing valve to evacuate the chamber, and then switches over to the turbo pump.
- 14) Pump down to  $2-5 \times 10^{-6}$  torr. At this pressure, the flux of the residual gases (mostly  $H_2O$ ) is about 1% of the Al flux during deposition. Pumping should take ~30 minutes.
- 15) Turn off the Pirani ion gauge before starting the evaporation. Al will initially react with water vapor physisorbed to the chamber walls ( $2Al + 3 H_2O \rightarrow Al_2O_3 + 3 H_2$ ), causing the ion gauge to jump several decades if left on, which can cause damage to the thin W filament.
- 16) Switch evaporator (electrode) power to ON. Increase power by turning powerstat slowly clockwise. At ~40 Amps coil begins to glow, but the Al charges do not melt. This can be observed through the slide window. Let heat @ 40 Amps about 20 seconds to drive off water vapor.
- 17) Increase electrode power to ~60 Amps. The charges will evaporate suddenly and the slide will be coated with Al. As soon as this happens open the shutter and wait for 20 seconds. Slowly turn down powerstat and switch electrode power to OFF.
- 18) Remove wafers in the same way they were loaded (Steps 3-7 above).
- 19) When wafers are removed and "chimney" and other apparatus are returned to the chamber, push down the bell jar and turn knob to "PUMP" position. Hold the jar down until the vacuum pulls down enough to hold it down and the jar cannot be moved.

## Week 8: Metal Definition

### 51. Apply standard photoresist coating:

- 1) If practical, spin wafers immediately after high temperature treatment. Otherwise dehydrate the wafers in an oven for 20 minutes at 120 °C.
- 2) Place wafers in HMDS vapor for 2 minutes or more minutes. HMDS promotes adhesion between oxides (e.g., native silicon dioxide) and photoresist.
- 3) Lift the black lever directly under the front of the spinner.
- 4) Verify the spinner is set to the right spin speed and time by loading and spinning a dummy wafer. The wafer should spin at 3000 RPM for 30 seconds.
- 5) To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
- 6) Get a bottle of OCG 825 photoresist from the refrigerator beneath the spinner.
- 7) Dispense one eye dropper of resist on the wafer and start a spin cycle.
- 8) Return the bottle of OCG 825 photoresist to the refrigerator beneath the spinner.
- 9) Soft bake at 90 °C for 1 minute on the hot plate. Soft baking evaporates most of the solvent in the PR so that it is not sticky.
  - a) Turn on the hot plate vacuum (black knob)
  - b) Place the wafer on the hot plate.
  - c) After 1 minute, turn off the vacuum knob, and place wafer on the metal rest piece for 10 seconds for cooling.

### 52. Standard photomasking: Mask #4 (METL)

- 1) Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3 to 10 seconds. Shorter times are needed when the lamp is newer and for more-reflective substrates such as aluminum. Make sure the **yellow lights** are ON for all spaces.

***Comment: 0.9-1 seconds with new lamp (Spring 2016)***

- 2) Pour 1000 ml of premixed OPD4262 developer solution into a beaker.
- 3) Develop and tell students that developing should only be done in yellow light. The yellow filters filter out shorter, more energetic wavelengths of light (e.g. green, blue, violet, and UV), which could cause exposure of the entire wafer.
- 4) Dip the exposed wafer into the developer for typically 60-80 seconds (ask the TA for the current optimal exposure time; it takes more time if the developer has been used more) and agitate slowly. Observe the reddish liquid forming near the wafer. It is the dissolved photoresist.

***Comment: Better to use a bit longer (but not too much longer!) develop time 70–80 seconds as the undeveloped PR residue on Al is hard to see and might create short circuits and ruin the whole process after Al etch (Fall'13)***

- 5) Rinse in DI water for 1 minutes in each of 3 dedicated rinse beakers successively, then spray rinse.

**NOTE:** DO NOT use the same set of 3 rinse beakers for more than one kind of rinse. For example, do not use the developer rinse beakers for rinsing after an HF etch. Instead prepare another set of 3 dedicated rinsing beakers.

- 6) Blow dry with N<sub>2</sub> gun. It is very easy to break wafers during drying so exercise extreme caution in this step to dry over Technicloths on a sink.
- 7) Inspect under microscope with yellow filter and then also have TA measure using the Nanospec to ensure etching has been performed to completion. Measure line widths of test pattern [1] with the ruler on the eye piece. Record data.
- 8) If not completely developed repeat Step 4 for 5 seconds, then Steps 5-7.
- 9) **IMPORTANT:** Hard bake the photoresist-coated wafer in an oven for 40 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the photoresist physically hard, more adhesive, and less permeable to chemicals.

53. Metal Etch:

- 1) Pour ~1000 ml of Al etchant into glass beaker; heat in water bath (for constant temperature) on hot plate set at 115 °C for 10 minutes before use. Use stir bar for better circulation.
  - 2) Immerse wafer in water for at least 10 seconds to wet.
  - 3) Place wafer in aluminum etchant at 40–50 °C. Al etchant has a composition of (approximately) 80% Phosphoric acid, 10% H<sub>2</sub>, 5% acetic acid, and 5% nitric acid. Bubbles will form on the surface of the wafer as the etchant removes the metal. Be sure to keep agitating your wafers to replace chemical at the wafer's surface. Bubbling will subside as etch reaches completion. Etch rate of Al is ~100 Å/sec at 50°C; it is slower at lower temperature.
  - 4) Rinse wafer very well in DI water. Inspect.
54. Remove resist in **PRS 3000** (no piranha, which attacks aluminum), dip in IPA, blow dry.

**Note (Spring 2016): PRS 3000 must be used here because of the hard bake step. If resist residue remains, it can impede measurement after sintering. If this happens, further wafer cleaning may be necessary.**

55. Sintering: (Check the forming gas cylinder to make sure it is not empty!)

This step is done in furnace tube #1 (top) at 400 °C in forming gas (90% N<sub>2</sub>, 10% H<sub>2</sub>) for 20 minutes. Gas flow is set to 40 sccm. Slow push/pull is not necessary. Sintering does two things. It allows the aluminum and silicon to interdiffuse, forming a good contact. It also allows hydrogen atoms from the forming gas to diffuse into the silicon and tie up surface states at the oxide channel interface.

**Congratulations! The fabrication process is now completed and the devices are ready for testing!**