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.

Part 1) A checklist: what do you need in EE143 lab and microlab?

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 microlab.

1) General stuff:

stuff	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. **No metal tweezer!**
HF burn paste		2	Use it if you contact HF

2**) Oxidation (sintering) process module**

stuff	Usage	quantity	Comments
Clean 3" quartz boat	Field oxidation growth in microlab	1	Kept in microlab. 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 microlab
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 microlab 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

stuff	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.
	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^oC
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 sink6 drawer, microlab, need RCA cleaning
		2	In EE143 lab
Cassettes handler	Handle the cassettes	1	In sink6 drawer, microlab
Thermometer	Measure temperature	1	

4) Photoresist Developing and Acetone Stripping Module

stuff	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 microlab

5) Aluminum Evaporations Module

Cherry bomb Container	Liquid N2 inside	1	
cart	For cherry bomb	1	
funnel	Pour liquid N2	1	
Al targets	Al source	One bag (>50 piece)	
Tungsten coil	Heating the Al targets	One bag (>20 piece)	

6) 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 microlab 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 microlab
OCG934 developer	Developing PR	2	
Acetone	Strip PR	2	

Note:
1) The 3" boat and cassettes, handler kept in microlab is for microlab usage only. Please don't take them back to EE143 lab or take any stuff from EE143 into microlab, 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_2O_2 . RCA liquid should be aspirated after RCA cleaning is done.
3) In Fall semester, 2002, the small beakers used in the previous years have been replaced with larger beakers. 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.

Part 2: Process Flow (Process Overview)

Week 1: Starting Materials
Week 2: Initial Oxidation - 5200 Å
Week 3: Active Area Photolithography
Week 4: Gate Oxidation - 800 Å
Week 5: Poly-Si Deposition - In Microlab
Week 6: Gate Photolithography
Week 7: Source-Drain Deposition (N+)
Week 7: Source-Drain (N+) Drive and Intermediate Oxidation
Week 8: Contact Cut
Week 9: Metallization
Week 10: Metal Definition

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

- **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: $3.0\text{x}10^{12}$ /cm^2, B11, 60 KeV.
  3. Uniquely identify each of the wafers Label wafers with diamond scribe. Label using small letters near the flat. Do not scrib 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
- **Check Masks and Clean the Mask** (4" x 4" Chrome Plates)

1. ACTV = Defines the Active Area (Dark Field)
2. POLY = Defines the Gate (Light Field)
3. CONT = Defines the Contacts (Dark Field)
4. METL = Defines the Metal (Light Field)
5. Mask Cleaning Procedure
    - 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).
    - While Acetone is still pooled on mask, use IPA (2-Isopropanol) to rinse Acetone off. Do not use water! Blow mask dry using N_2 gun.

Week 2: Initial Oxidation - 5200 Å. (Performed by TA in microlab.)

Checklist: a 3” white Teflon cassettes and cassettes handler in sink6 drawer in microlab.
A RCA cleaned 3” quartz boat

6. Standard clean your work wafer in sink6 in microlab (please refer to the sink operation manual in microlab homepage)

1. Put the 3” wafer into the clean 3” wafer cassettes, slide the cassettes handler to hold the cassettes.

2. Add 100ml H_2O_2 into one of the Piranha bath. 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 60 seconds in each of 3 dedicated tanks successively. At the beginning, the cassettes may be too hot to fit into the tank. After a few seconds, it should be Ok. Also rinse the cassettes handler to get rid of the piranha acid before HF etching.

4. After the resistivity meter in the last tank indicator turns from red to green, Dip in 10:1 BHF for 20 seconds. This "HF dip" removes the native oxide.

5. Rinse in DI water for 60 seconds in each of 3 dedicated rinse beakers successively, till the resistivity meter in the last tank turns from red to green and stay at green for 20 seconds.

6. Take cassettes out and use N_2 gun to dry the wafer piece by piece. Only Teflon tweezer or clean wand is allowed to hold the wafer after Piranha cleaning.

7. Oxidize wafers at 1050 °C for 5-70-5 minutes (dry-wet-dry) O_2 in NON-MOS clean furnace (tystar4) with recipe “4WETOXA”. Before wet oxidation, please ask microlab staff to help you to put the 3” quartz boat into the furnace.
8. 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.
9. Measure oxide thickness. It should be approximately 5200 Å.

Week 3: Active Area Photolithography

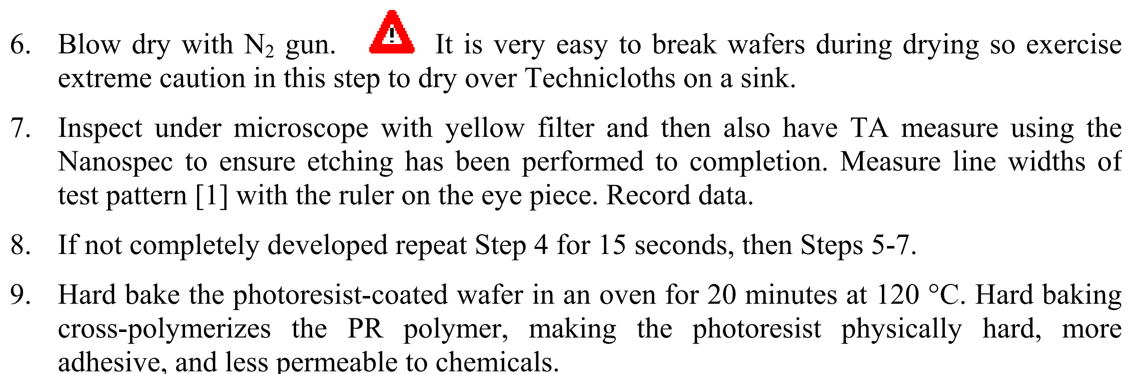
10. Standard photoresist (PR) coating

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. TA: Check to ensure HMDS liquid is in the small beakers in the blue bin. If not, fill small beaker to ~75% capacity and replace.
3. Lift the black lever directly under the front of the spinner.
4. Make sure the vacuum on the hot plate is not being used because it shares the same vacuum line with the spinner. If it is then wait until the vacuum is turned off. Using the spinner when the hot plate vacuum is being used can cause the wafer to fly off the spinner and **break**!
5. 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.
6. To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
7. Get a bottle of OCG 825 G-line, positive photoresist from the refrigerator below the spinner.
8. Dispense one eye dropper of resist on the wafer and start a spin cycle. Be sure to use enough photoresist (one full eye dropper) to cover the entire wafer. Incomplete wafer coverage will require stripping the PR on the wafer and repeating the 20 minute dehydration bake.
9. After the whole lab session finish PR coating, 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. We should completely ELIMINATE any usage of the vacuum on the hot plate before the whole lab session finish the PR coating. It's too difficult to have a class of students constantly switching the vacuum from hotplate to spinner, etc. If there's a lag in communication, wafers will get broken on the spinner.
10. Turn on the hot plate vacuum (black lever) **if** the spinner is not being used.
    1. Place the wafer on the hot plate.
    2. After the wafer is sucked down to the hot plate, turn OFF the hot-plate vacuum so that the spinner may be used.
    3. Center the wafer on the hot plate with a metal tweezer. (Placing the wafer on the hot plate without the vacuum on will cause the wafer to slide all over the hot plate. If the wafer slides off the wafer may break.)

11. 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.
2. Pour 500 ml of premixed OCG 934 2:1 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.
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_2 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 15 seconds, then Steps 5-7.
9. 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.

12. 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 500 ml of buffered 5:1 HF (BHF) into a **plastic** beaker. Buffered HF is a mixture of NH_4F (ammonium fluoride) and HF 5:1. Its etch rate of thermal SiO_2 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 (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.

13. Do the standard resist strip

1. Dip wafer in acetone 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 [1] with the ruler on the eyepiece in microscope. And measure the field oxide thickness on your wafer.

Week 4: Gate Oxidation - 800 Å

Gate oxidation is done in tube #3 (bottom) at 1100 °C following a TCA ($C_2H_3Cl_3$) clean. Gases used are N_2 and O_2.

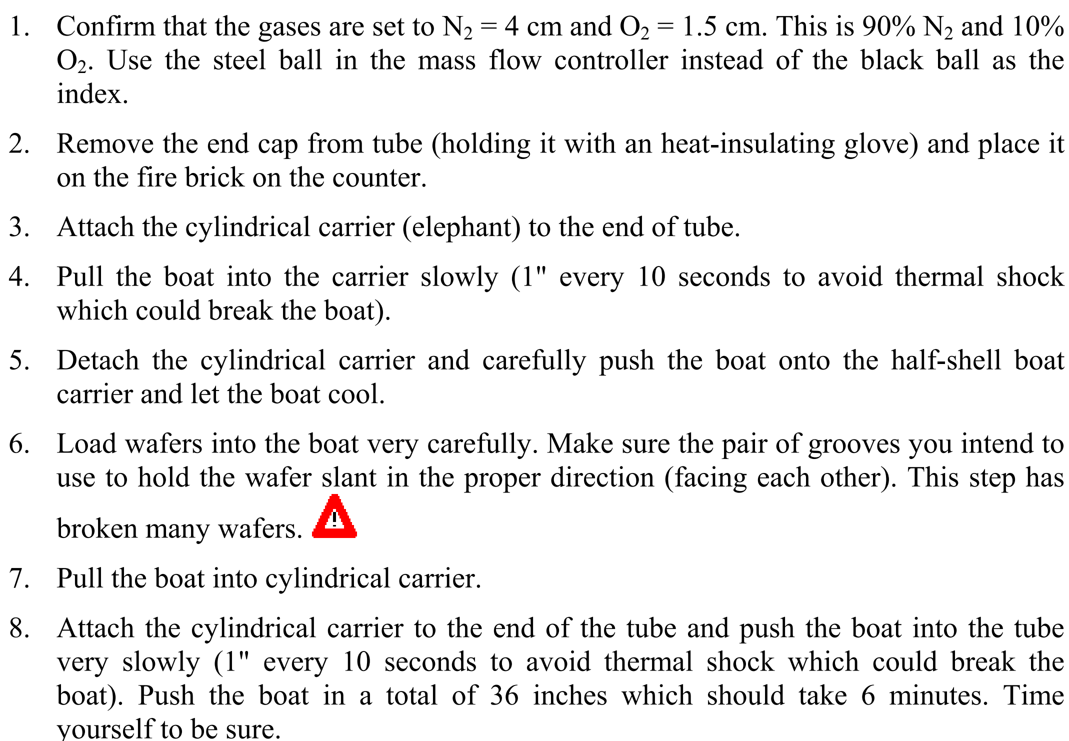
14 TCA Clean Furnace. (***Performed by TA***.)

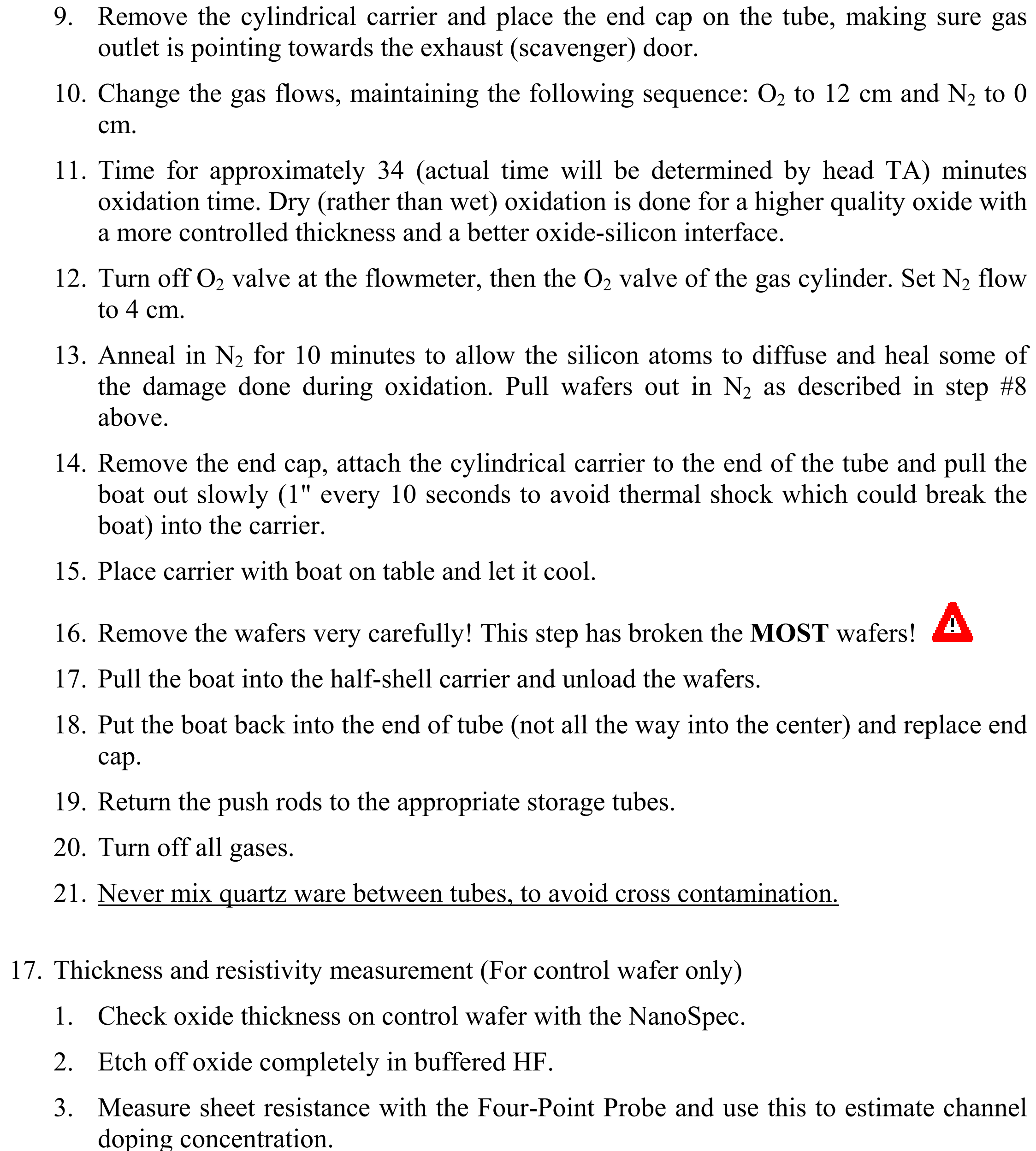
1. *When you arrive, the furnace will already be on and stabilized.*
2. *Confirm temperature controller is set to the required temperature. For 1100 °C the controllers should be about +30.0, 87.0, +00.0. The center value adjusts the temperature of the central zone of the furnace. The left and right values 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_2 flow at maximum rate (15+ cm, steel ball) for at least 10 minutes. This requires that the O_2 tank is turned on, the regulator is set to 10 psi (MAX), the post-regulator valve is on, the valve on the flow meter is opened to read 15 cm+, and the O_2 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_2 valve at tube 3, opening the TCA valve at tube 3, opening the valve to the TCA bubbler, and opening the N_2/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_2 valve on will cause N_2 gas to circumvent the bubbler vessel. If bright blue flames are visible at the tube inlet, decrease the N_2 flow rate. The flames are a result of too much free carbon in the tube, i.e. not enough O_2 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_2 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_2/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_2 = 4 cm and O_2 = 1.5 cm for wafer loading. This is 90% N_2 and 10% O_2.*

15. Standard Clean process wafers and one implanted control wafer from Week 1. Label the control wafer "OCR DATE", were 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.)
    1. Measure out 10 parts of H_2SO_4 in **Pyrex** beaker
    2. 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 minutes seconds 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.
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.
8. Spin dry.

16 wafer Loading and Oxidation

1. Confirm that the gases are set to N_2 = 4 cm and O_2 = 1.5 cm. This is 90% N_2 and 10% 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. Make sure the pair of grooves you intend to use to hold the wafer slant in the proper direction (facing each other). 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 total of 36 inches which should take 6 minutes. Time yourself to be sure.

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_2 to 12 cm and N_2 to 0 cm.
11. Time for approximately 34 (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.
12. Turn off O_2 valve at the flowmeter, then the O_2 valve of the gas cylinder. Set N_2 flow to 4 cm.
13. Anneal in N_2 for 10 minutes to allow the silicon atoms to diffuse and heal some of the damage done during oxidation. Pull wafers out in N_2 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.

17. 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 5 Poly-Si Deposition. (Performed by TA in Microlab.)

18. Standard clean wafers in sink6 in the microlab.

1. Put the 3” wafer into the clean 3” wafer cassettes, slide the cassettes handler to hold the cassettes.

2. Add 100ml H_2O_2 into one of the Piranha bath. 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 60 seconds in each of 3 dedicated tanks successively. At the beginning, the cassettes may be too hot to fit into the tank. After a few seconds, it should be Ok. Also rinse the cassettes handler to get rid of the piranha acid .

5. Rinse in DI water for 60 seconds in each of 3 dedicated rinse beakers successively, till the resistivity meter in the last tank turns from red to green and stay at green for 20 seconds.

6. Take cassettes out and use N_2 gun to dry the wafer piece by piece. Only Teflon tweezer or clean wand is allowed to hold the wafer after Piranha cleaning.

19. Deposit 3500 Å Phosphorus-doped polysilicon in tylan16 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 tylan16. 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_2 on them.

    Comments: in Fall semester 2002, the deposition rate is 25A/min with recipe “16DOPLYB”.

20. Measure poly-Si thickness with the NanoSpec.

Week 6: Gate Photolithography

21. 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. Make sure the vacuum on the hot plate is not being used. If it is then wait until the vacuum is turned off. Using the spinner when the hot plate vacuum is being used can cause the wafer to fly off the spinner and **break**!
5. 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.
6. To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
7. Get a bottle of OCG 825 photoresist from the refrigerator beneath the spinner.
8. Dispense one eye dropper of resist on the wafer and start a spin cycle.
9. Return the bottle of OCG 825 photoresist to the refrigerator beneath the spinner.
10. 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. We should completely ELIMINATE any usage of the vacuum on the hot plate before the whole lab session finish the PR coating. It's too difficult to have a class of students constantly switching the vacuum from hotplate to spinner, etc. If there's a lag in communication, wafers will get broken on the spinner.
11.
    1. Turn on the hot plate vacuum (black lever) **if** the spinner is not being used.
    2. Place the wafer on the hot plate.
    3. After the wafer is sucked down to the hot plate, turn OFF the hot-plate vacuum so that the spinner may be used.
    4. Center the wafer on the hot plate with a metal tweezer. (Placing the wafer on the hot plate without the vacuum on will cause the wafer to slide all over the hot plate. If the wafer slides off the wafer may break.)

22. Standard photomasking: Mask #2 (POLY) SEE CHANGES IN PREVIOUSE LITHOGRAPHY MODULE

1. Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3-10 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.
2. Pour 500 ml of premixed OCG 934 2:1 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 40-60 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.
5. Rinse in DI water for 1 minute 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. Spray rinse and blow dry.
7. Inspect under microscope with yellow filter. 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 15 seconds, then Steps 5-7.
9. Hard bake the photoresist-coated wafer in an oven for 20 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the the photoresist physically hard, more adhesive, and less permeable to chemicals.

23. Etch poly-Si

1. Pour 10:1 BHF into a **plastic** beaker Up to the fill line
2. Pour 500 ml of a premixed silicon etchant, obtained from the Microlab, into a Plastic beaker. Etch rate: ~2200 Å/min. Composition: 64% HNO_3 / 33% H_2O / 3% NH_4F.
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.

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

1. Pour 500 ml of buffered 5:1 HF (BHF) into a **plastic** beaker. Buffered HF is a mixture of NH_4F (ammonium fluoride) and HF 5:1. Its etch rate of thermal SiO_2 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.

25. Do the standard resist strip

1. Dip wafer in acetone for 2 minutes.
2. Rinse in DI water for 1 minute in each of 3 dedicated rinse beakers successively. If the acetone didn't remove the photoresist completely, Dip in IPA for 20 sec
3. Spray rinse and blow dry

Week 7a: Source-Drain Deposition (N+)

26. Standard clean wafers **without HF dip**.

1. Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
    1. Measure out 10 parts of H_2SO_4 in **Pyrex** beaker
    2. 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. 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

27. Bake the wafers in the oven for 5 minutes at 200°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 coated on the wafer uniformly.
28. Turn on bubbler heater to 98 °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**
29. Spin Filmtronics Phosphorosilica spin-on-glass at 3000 RPM for 20 seconds including p-type test wafer from week 4, step 4. 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.
30. Bake at 200 °C for 15 minutes in bake oven.

    NOTE: Do Not use a Teflon holder for the wafers in the 200 °C oven! The Teflon boats will flow at this temperature. Place the wafers on glass slides in the furnace.
31. N+ pre-diffusion is done at 1050 °C in furnace tube #2 (center). Set O_2 flowmeter to 1.5 cm and N_2 to 4 cm. (This corresponds to 10% O_2 and 90% N_2.) The setting is constant during push, deposition and pull.
32. Push in wafers at 1 inch/10 seconds.
33. Hold 5 minutes in hot zone.
34. Pull out at 1 inch/10 seconds.
35. Phosphorus glass removal: dip wafers in 10:1 BHF for amount of time determined from annealed PSG rate (4700 Å/min). Note that wafer may not be hydrophobic due to film left by Spin-On Glass. Piranha cleaning will remove this film.
36. Rinse in D.I. water for 1 minute seconds in each of 3 beakers successively, then spray rinse.
37. Spin dry.
38. Measure resistivity on the control wafer with the Four-Point Probe.

Week 7b: Source-Drain (N+) Drive and Intermediate Oxidation

38. This step is done at 1050 °C in tube #2. Check gas connection to allow for steam oxidation, dry O_2 and N_2 flow. Set dry O_2 to 6.5 cm on flowmeter. Set N_2 to 0 cm (OFF).
39. Fill bubbler with D.I. water if needed. Use a clean, well rinsed beaker to fill bubbler.
40. Standard clean wafers, including control wafer used in step 7a.

1. Mix piranha solution as follows: (Piranha is used to remove metals and organics.)
    1. Measure out 10 parts of H_2SO_4 in Pyrex beaker
    2. 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. Rinse the wafers off in DI water for 10 seconds in each of 3 dedicated rinse beakers successively, then spray rinse.
4. Spin dry.

41. When the water is boiling in the bubbler (approximately 20 minutes) push wafers into furnace in dry O_2 (O_2 should already be on to 6.5 cm). N_2 should be OFF.
42. Set O_2 flowmeter to 2.5 cm and switch valves to wet O_2. 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.
43. Turn off wet O_2 and turn on N_2 to 4 cm on scale.
44. Anneal for 25 minutes in N_2.
45. Pull wafers out in N_2. Pull out at 1 inch/10 seconds.
46. 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 8: Contact Cut

47. 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. TA ~ Check that HMDS is present in small beakers in blue canister.
3. Lift the black lever directly under the front of the spinner.
4. Make sure the vacuum on the hot plate is not being used. If it is then wait until the vacuum is turned off. Using the spinner when the hot plate vacuum is being used can cause the wafer to fly off the spinner and **break**!
5. 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.
6. To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal to stop the spinner.
7. Dispense one eye dropper of resist on the wafer and start a spin cycle.
8. 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. We should completely ELIMINATE any usage of the vacuum on the hot plate before the whole lab session finished the PR coating. It's too difficult to have a class of students constantly switching the vacuum from hotplate to spinner, etc. If there's a lag in communication, wafers will get broken on the spinner.
9.
    1. Turn on the hot plate vacuum (black lever) **if** the spinner is not being used.
    2. Place the wafer on the hot plate.
    3. After the wafer is sucked down to the hot plate, turn OFF the hot-plate vacuum so that the spinner may be used.
    4. Center the wafer on the hot plate with a metal tweezer. (Placing the wafer on the hot

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

1. Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3-10 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.

   Comments: In this week, you can overexpose the wafer a little if the alignment is good. Overexposure will give big contact holes and won't ruin devices, while underexposure will.
2. Pour 500 ml of premixed OCG 934 2:1 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.
5. Rinse in DI water for 1 minute 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. Spray rinse and blow dry. The wafer may fall off the wafer handler. So be careful!
7. Inspect under microscope with yellow filter. Measure line widths of test pattern [1] with the ruler of the eye piece. Record data.
8. If not completely developed repeat Step 4 for 15 seconds, then Steps 5-7.
9. Hard bake the photoresist in an oven for 20 minutes at 120 °C. Hard baking drives off the rest of the polymer, making the photoresist physically hard, more adhesive, and less permeable to chemicals.

49. 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 500 ml of buffered 5:1 HF (BHF) into a **plastic** beaker. Buffered HF is a mixture of NH_4F (ammonium fluoride) and HF 5:1. Its etch rate of thermal SiO_2 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 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 surface is detected.)
5. Rinse in DI water for 1 minutes in each of 3 dedicated rinse beakers successively, then spray rinse only (no Polymetrics).
6. Spin dry.
7. Inspect etching for completion under microscope.

50. 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.

1. Dip wafer in acetone for 2 minutes.
2. Rinse in DI water for 10 seconds in each of 3 dedicated rinse beakers successively, then spray rinse.
3. Dip in IPA for 20 seconds if the acetone didn't remove the photoresisit completely.
4. Spray rinse and blow Dry.

51. Strip oxide from the control wafer and measure its sheet resistance using the Four-Point Probe.

Week 9: Metallization

52. 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.)
   1. Measure out 10 parts of H_2SO_4 in **Pyrex** beaker
   2. 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 500 ml of 10:1 BHF into a **plastic** beaker.
4. Rinse the wafers off 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. 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
7. Place 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.

53. Aluminum Evaporation (refer to the ATE module section 9: operations)

1. Turn knob on front of evaporator to "STARTUP". This starts the roughing pump, evacuates the foreline, and starts the diffusion pump. No valves should be open in this setting. Make sure to add liquid nitrogen to cold trap after the diffusion pump has warmed up for 20 min.
2. Vent the chamber by turning the knob to "VENT". All the valves should be closed and N_2 is vented into the chamber.
3. After chamber reaches atmospheric pressure, the jar will lift from the steel base. Lift the jar up and turn the switch back to "STARTUP".
4. Lift stainless steel wafer holder out of the inner glass cylinder ("chimney") and place it on the table covered with lint-free paper.
5. Loading the sample and supporting accessories.
    1. Place a clean glass slide in stand inside chimney for a clear window.
    2. Hang 2 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).
    3. Turn shutter knob so that the shutter is covering the charges.
    4. Place wafer facing down on top of wafer holder.
6. Place wafer holder back inside the chimney.
7. Wipe stainless steel base and bottom of bell jar with lint free paper soaked with 2-propanol.
8. 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 diffusion pump.
9. Switch to Pirani pressure gauge by hitting the "GAUGE" button when the pressure falls below $5x10^{-4}$.
10. Pump down to $2\text{-}5x10^{-6}$ 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.
11. 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.
12. 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.
13. 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.
14. Remove wafers in the same way they were loaded (Steps 2-7 above).
15. 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.
16. When all wafers are coated, turn knob to I am not sure that we actually do this . See processing module Paul Hung is writing

Week 10: Metal Definition

54. 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. Make sure the vacuum on the hot plate is not being used. If it is then wait until the vacuum is turned off. Using the spinner when the hot plate vacuum is being used can cause the wafer to fly off the spinner and **break**!
5. 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.
6. To **start** the spinner, use the **large button** on the foot pedal. To **stop** the spinner, use the **small button** on the foot pedal.
7. Dispense one eye dropper of resist on the wafer and start a spin cycle.
8. 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. We should completely ELIMINATE any usage of the vacuum on the hot plate before the whole lab session finish the PR coating. It's too difficult to have a class of students constantly switching the vacuum from hotplate to spinner, etc. If there's a lag in communication, wafers will get broken on the spinner.
    1. Turn on the hot plate vacuum (black lever) **if** the spinner is not being used.
    2. Place the wafer on the hot plate.
    3. After the wafer is sucked down to the hot plate, turn OFF the hot-plate vacuum so that the spinner may be used.
    4. Center the wafer on the hot plate with a metal tweezer. (Placing the wafer on the hot plate without the vacuum on will cause the wafer to slide all over the hot plate. If the wafer slides off the wafer may break.)

55. Standard photomasking: Mask #4 (METL)

1. Following Quintel Aligner Instructions, align wafers to mask and expose. Typical exposure times are 3-6 seconds. Shorter times are needed when the lamp is newer and for more-reflective substrates such as aluminum. Pour 500 ml of premixed OCG 934 2:1 developer solution into a beaker. Make sure the **yellow light** is on in all spaces!
2. 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.
3. 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.
4. Rinse in DI water for 1 minute 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.
5. Spray rinse and blow dry
6. Inspect under microscope with yellow filter. Measure line widths of test pattern [1] with the ruler of the eye piece. Record data.
7. If not completely developed repeat Step 4 for 15 seconds, then Steps 5-7.
8. Hard bake the photoresist in an oven for 20 minutes at 120 °C. Hard baking cross-polymerizes the PR polymer, making the the photoresist physically hard, more adhesive, and less permeable to chemicals.

56. Metal Etch:
    1. Pour 500 ml of Al etchant into glass beaker; heat in water bath (for constant temperature) on hot plate to 50 °C.
    2. Immerse wafer in water for at least 10 seconds to wet.
    3. Place wafer in aluminum etchant at 50 °C. Al etchant has a composition of (approximately) 80% Phosphoric acid, 10% H_2, 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 your wafer moving 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.
57. Remove resist in acetone (no piranha, which attacks aluminum), dip in IPA, blow dry.
58. 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_2, 10% H_2) for 20 minutes. Gas flow is set to 4 cm. 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.

The fabrication process is now completed and the devices are ready for characterization!