Solar Cell LAB MANUAL

2009

Solar Cell
LAB MANUAL

This manual was designed for use with the Montana Microfabrication Facility at Montana State University. The intention of the manual is to provide lab users and MSU students with a complete description of the methods used to fabricate Solar Cells on 4-inch silicon substrates.

Special Thanks to:
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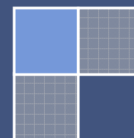


SUPPLIERS

University of Minnesota Nano Fabrication Center (NFC): Photomasks
www.nfc.unm.edu

Virginia Semiconductor: Silicon Substrates
www.virginiasemi.com

EL-CAT Inc.: Silicon Substrates
www.el-cat.com

JT Baker: Chemical Supplies
www.mallbaker.com/default.asp

Technical Glass Products Inc: Quartz-ware
www.technicalglass.com

Kurt J Lesker Company: Evaporation Filaments
www.lesker.com

MSU Chem-store: Labware/Chemical Supplies
www.chemistry.montana.edu/chemstores

Sigma-Aldrich: Chemical Supplies
www.sigmaaldrich.com

SPI Supplies: Wafer Tweezers
http://www.2spi.com/spihome.html

Gases Plus: Pressurized Gas Tanks
www.gasesplus.com (406)388-9109

The suggested high temperature process steps for use in Solar Cell EE 580 lab are listed here.

P+ diffusion	950°C	50 min
N+ diffusion	850°C	50 min
Dry oxidation	1000°C	80 min

How to use this manual…

The manual is broken up into laboratory segments containing multiple sections: *Goals, Equipment*, *Parameters*, *Methods* and *Results*. Each lab a set of process goals is presented to the user along with a list of equipment and the methods used to achieve those goals. The parameters segment is devoted to process dependent parameters specific to the fabrication methods used that week. The parameters are color coded to correspond to a specific process method. The methods section describes the processes used within that lab to achieve the desired goals. The methods are numbered to correspond to a process goal. The result section is left blank for users to record the results of that lab's processes.

10-Lab Overview

Introduction & P+ Rear Diffusion (Cobleigh)	Lab 1
Measure Sheet Resistivity & N+ Front Diffusion (Cobleigh)	Lab 2
Thermal Oxidation (AR coating) (Cobleigh)	Lab 3
Photolithography & Vias Oxide Etch (Front and Back) (EPS)	Lab 4
Cleaning & Aluminum Evaporation (Front) (Cobleigh)	Lab 5
Photolithography & Aluminum Contact Etch (Front) (EPS)	Lab 6
Cleaning & Aluminum Evaporation (Back) (Cobleigh)	Lab 7
Initial Characterization & Annealing (Cobleigh)	Lab 8
Post-Anneal Characterization (Cobleigh)	Lab 9
Experiments (Cobleigh)	Lab 10

Introduction& P+ Rear Diffusion Lab 1

GOALS:

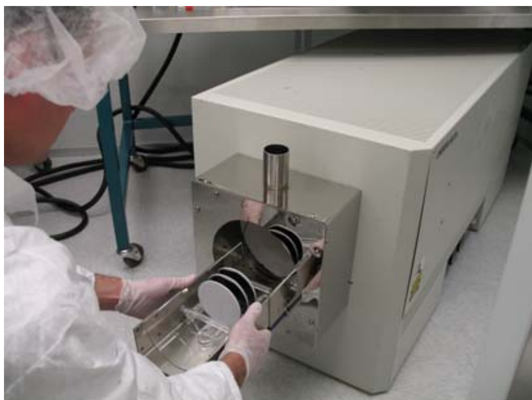
1. Familiarize students with the cleanroom layout, equipment, safety and procedure.
2. Present an overview of the solar cell fabrication process and various processing techniques (i.e. photolithography, etching, etc)
3. ID individual wafers
4. P+ Diffusion

EQUIPMENT:

- Wafer Scribe
- Boron Diffusion Furnace
- BORONPLUS GS139 Boron Sources

PARAMETERS

Boron Diffusion Parameters (Back Contact)			
Boron Source	Temperature (°C)	Time (minutes)	N_2 Flow
BORONPLUS GS-139	950	50	7



Methods:

1. Clean Room Etiquette

The lab employs many hazardous chemicals and processes. The safety of the lab students and users is the number one priority when participating in the lab. Follow all gowning and safety procedures outlined by the lab Teaching Assistant (TA).

To maintain the integrity of the wafers and the equipment, adhere to the process descriptions and details provided by the lab TA.

The most common reason a wafer will not make it to the end of the fabrication sequence, is poor handling. The wafer should be handled with the wafer-tweezers and with great attention. Limit the handling of the wafer with gloved hands to the edges and only during necessary circumstances. Never touch the wafer with a bare hand and never touch the center of the wafer, even with gloved hands.

When processing in the cleanroom, sources of contamination are another factor which may inhibit the success of the fabrication. Therefore, do not talk next to the wafers, keep the lid to the wafer box closed and lastly, do not hastily move about the clean room and do not get in a hurry to finish a process. When a lab student gets in a hurry it creates a situation with a greater likely hood of breaking a wafer or damaging a piece of equipment.

Follow proper gowning procedure and remember the clothing you where is to protect your wafer from you **not** to protect you from dangerous chemicals.

Methods:

2. Process Overview:

These solar cells are fabricated using a combination of thin film deposition and etching techniques. The sequence is a simple set of repeating steps including oxidation, etching, diffusion, cleaning and patterning. An overview of the sequence is shown to the right (**Figure 1**). The fabrication portion of the lab should take roughly eight labs to complete and the two additional labs devoted to characterization and testing.

Document everything seen and done in the clean room. Record all measureable quantities and procedures and any deviations. It is important to record every detail which may help explain device failures or anomalies.

3. Wafer Characterization and ID:

Semiconductor substrates, referred to as wafers, can easily be ordered through retailers and customized for specific applications. The wafers used for the lab are *100mm in diameter, 525±25 µm thick, <100>, single-side polished, single-crystal silicon, doped with boron (P-type) to a resistivity of 1-10 Ω-cm*.

A simple test to determine if the substrate is P-type or N-type silicon is known as the “Hot Probe Test.” Using a Digital Multi Meter (DMM) and a soldering iron, heat the positive probe of the DMM for several minutes with the soldering iron. Make sure the DMM is set to measure “mV.” Place both probe tips, positive and negative(ground) to the wafer surface. If the DMM indicates a positive voltage the substrate is N-type, if the voltage is negative the substrate is P-type. This test should be accurate up to a resistivity of 1000 Ω-cm.

Figure 2 Figure showing determination of silicon substrate type.

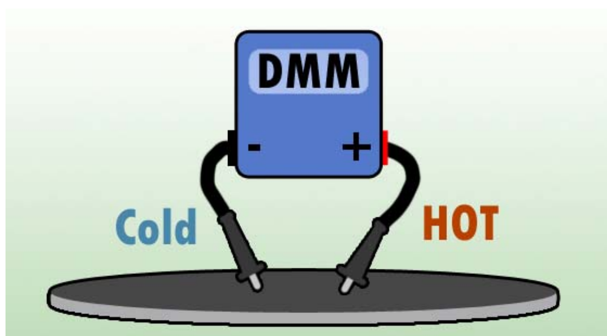


Figure 1 Overview of the fabrication sequence.

3. Wafer Characterization and ID:

Continued…

To keep track of individual wafers, a scribe can be used to mark the **back** of the wafer with an identification mark, typically a number or letter (**Figure 3**).

Proceed by lightly pressing the tip of the scribe against the surface of the wafer and with as few strokes as possible 'scribe' a section number and wafer number. Scribing should be done as close to the edge as possible and opposite of the flat to limit the effect on fabricated devices.

4. Boron Diffusion:

<u>(Check *Parameters* section for details)</u>

The goal of the boron diffusion is to create highly doped P-type silicon that will improve the contact between the silicon and the metal on the back of the cell.

To diffuse P-type (Boron) material, ramp the *Lindberg Blue Boron Diffusion Furnace* to 600°C and set the nitrogen flow. Remove the quartz boat with the solid, white, *BORONPLUS GS-139 sources* already in place. Load the silicon wafers next to the sources with the **<u>back</u>** side facing a source **(Figure 4).** Insert the quartz boat to the center of the furnace and ramp the furnace to the desired temperature **(Figure 5).** When the desired temperature is reached start the timer. After the allotted time, ramp the furnace down to 600°C (or 0°C if finished with furnace), pull the quartz boat and remove the wafers and set them aside to cool. When the temperature drops below 400°C the nitrogen can be turned off.

Figure 5 Inserting the boat into the Boron Diffusion Furnace.

Figure 3 Scribing the surface of a wafer using a steel-tipped scribe.

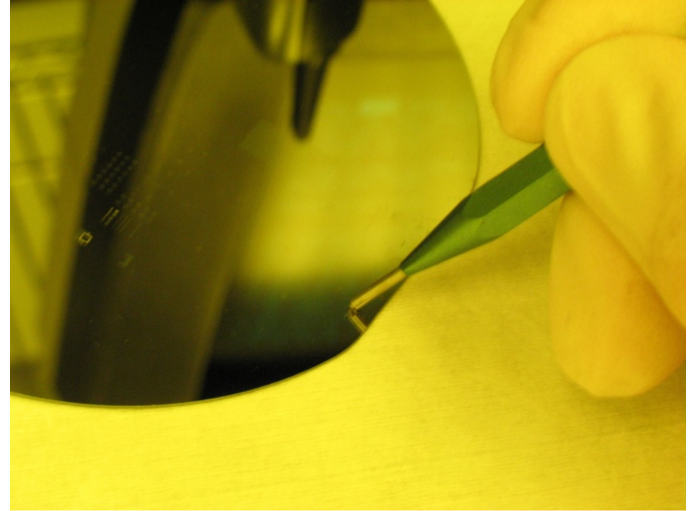
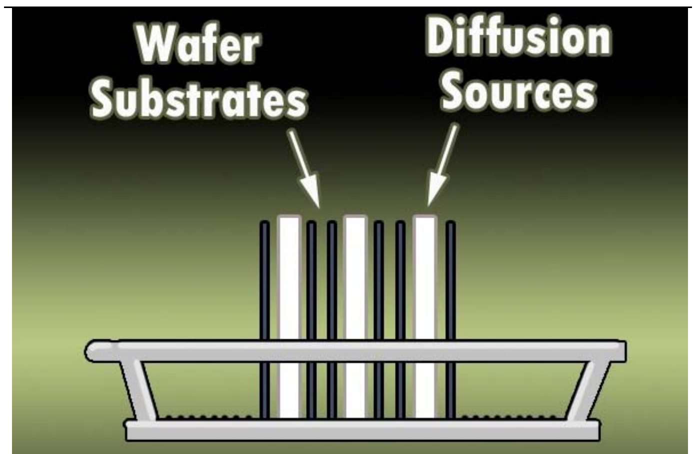


Figure 4 An illustration of how the wafers are loaded into the quartz boat next to the diffusion sources.



RESULTS:

Wafer Number:

NOTES/CHANGES:

N+ Front Diffusion Lab 2

GOALS:

1. Strip the Borosilicate Glass
2. Measure Sheet Resistivity
3. Phosphorus Diffusion

EQUIPMENT:

- 6:1 BOE
- Teflon Dish
- JANDEL 4-point Probe Station
- Phosphorous Diffusion Furnace
- PHOSPLUS TP-250 Phosphorous Sources

PARAMETERS:

SiO_2 Etch Parameters*			
BOE concentration	SiO_2 Etch Rate (Å/min)	Approx. Etch Time (minutes)	Etch Mask
6:1	900	5*	none
Phosphorous Diffusion Parameters (N+)			
Phosphorous Source	Temperature (°C)	Time (minutes)	N_2 Flow
PHOSPLUS TP-250	850	50	7

Methods:

1. Etching the SiO_2:

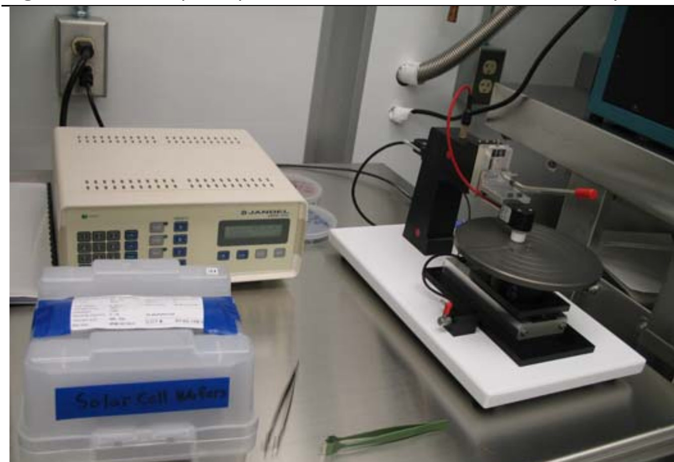
(Check *Parameters* section for details)

There is a layer of borosilicate glass on the surface of the wafer that needs to be removed before the wafers can go into the diffusion furnace. This step should be carried out with extreme care. Begin by pouring enough 6:1 BOE into a *Teflon or plastic dish*. Submerge the wafer in the *6:1 BOE* for the appropriate amount of time or until the exposed SiO_2 is completely removed. Rinse in DI water and dry with the nitrogen gun.

2. Sheet Resistivity Measurements:

The back of the wafer now has a higher conducting layer on the surface. To characterize the doping the sheet resistivity is measured. Use the *JANDEL 4-point probe* **(Figure 6)** to measure the sheet resistivity of the diffusion. Start by raising the probe arm, uncapping the tip and placing the wafer on the stage. Align the probes over the rear of the wafer opposite of the flat, then lower the probe arm to make contact with the wafer. Set the current to 1uA (press '1' and 'uA') Press 'FWD' The unit is now passing a current through the sample. It should be giving a positive voltage reading. If the voltage reading is negative or less than a millivolt, increase the current by an order of magnitude until you get a voltage reading of greater than one millivolt. Record the voltage value. Press 'REV' The unit is now passing a current through the sample in the reverse direction. It should be giving a negative voltage reading about the same magnitude as the FWD measurement. Record the value.

Figure 6 The four-point probe used to measure sheet resistivity



Increase the current by another order of magnitude but do not exceed 100 mA, the voltage should also increase by an order of magnitude. Record the value Press 'FWD' Record the value for the new forward current, it should be an order of magnitude larger than the previously recorded value. Press 'Ω/□'. This is the sheet resistivity measurement.

3. Phosphorous Diffusion:

(Check *Parameters* section for details)

The goal of the phosphorous diffusion is to create highly doped N-type silicon to create the pn junction of the solar cell.

To diffuse N-type (Phosphorous) material, ramp the *MODULAB Phosphorous Diffusion Furnace* to 600°C and set the nitrogen flow. Remove the quartz boat with the solid, white, *PHOSPLUS TP-250 sources* already in place. Load the silicon wafers next to the sources with the patterned side facing a source. Insert the quartz boat to the center of the furnace and ramp the furnace to the desired temperature. When the desired temperature is reached start the timer. After the allotted time, ramp the furnace down to 600°C (or 0°C if finished with furnace), pull the quartz boat and remove the wafers and set them aside to cool. When the temperature drops below 400°C the nitrogen can be turned off.

Figure 7 Placing the boat tray on the front of the Phosphorus Diffusion Furnace .

RESULTS:

Rear Sheet Resistivity (#1):

NOTES/CHANGES:

Antireflection Oxidation Lab 3

GOALS:

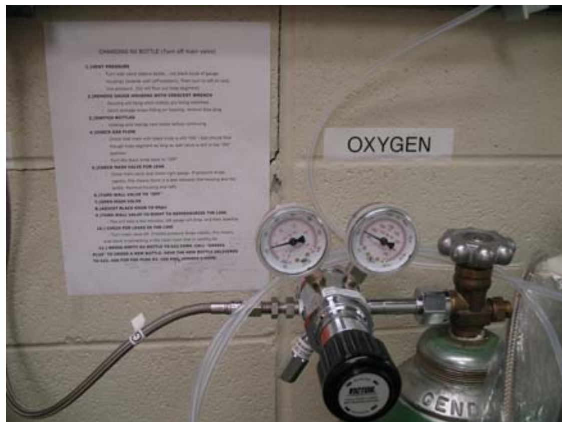
1. Strip the phosphosilicate glass (PSG)
2. Measure Sheet Resistivity
3. Dry Oxidation

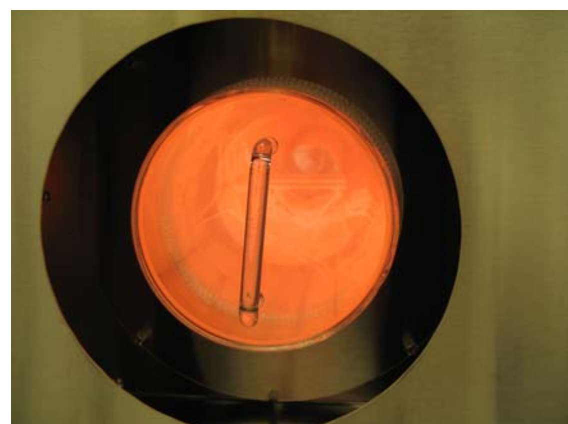
EQUIPMENT:

- 6:1 BOE
- Teflon Dish
- JANDEL 4-point Probe Station
- MODULAB Oxidation Furnace

PARAMETERS:

Oxidation Parameters				
Temperature (°C)	Time (minutes)	Type (wet or dry)	N_2/O_2 Flow	Bubbler Setting
1000	80	Dry	7/9	off





Methods:

1. Etching the SiO_2:

(Check *Parameters* section for details)

There is a layer of phosphosilicate glass on the surface of the wafer that needs to be removed before the wafers can go into the oxidation furnace. This step should be carried out with extreme care. Begin by pouring enough 6:1 BOE into a *Teflon or plastic dish*. Submerge the wafer in the *6:1 BOE* for the appropriate amount of time or until the exposed SiO_2 is completely removed.

2. Sheet Resistivity Measurements:

REPEAT: The front of the wafer now has a higher conducting layer on the surface. To characterize the doping the sheet resistivity is measured. Use the *JANDEL 4-point probe* to measure the sheet resistivity of the diffusion. Start by raising the probe arm, uncapping the tip and placing the wafer on the stage. Align the probes over the rear of the wafer opposite of the flat, then lower the probe arm to make contact with the wafer. Set the current to 1uA (press '1' and 'uA') Press 'FWD' The unit is now passing a current through the sample. It should be giving a positive voltage reading. If the voltage reading is negative or less than a millivolt, increase the current by an order of magnitude until you get a voltage reading of greater than one millivolt. Record the voltage value. Press 'REV' The unit is now passing a current through the sample in the reverse direction. It should be giving a negative voltage reading about the same magnitude as the FWD measurement. Record the value. Increase the current by another order of magnitude but do not exceed 100 mA, the voltage should also increase by an order of magnitude. Record the value Press 'FWD' Record the value for the new forward current, it should be an order of magnitude larger than the previously recorded value. Press 'Ω/□'. This is the sheet resistivity measurement.

The thermal processing will cause the dopants to move farther into the substrate changing the sheet resistivity each time, remeasure the sheet resistivity of the back and compare to the initial measurement.

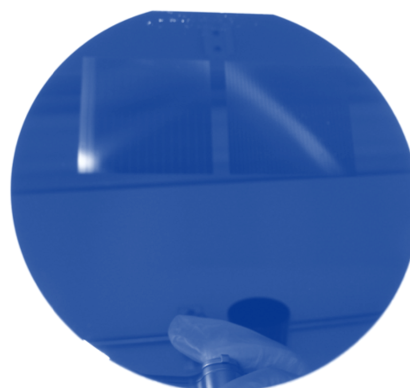
3. Dry Oxidation: Growing SiO_2

(Check *Parameters* section for details)

The goal of this oxidation run is to grow the antireflective coating. The oxide thickness should be approximately 1300Å thick, which is approximately a quarter of a wavelength at the peak of the solar spectrum. This oxide will be grown in an oxygen environment with no water vapor so it is called dry oxidation.

To oxidize, insert the wafers into oxidation furnace using the quartz rod and quartz boat. There should be two dummy wafers, one at the front of the boat and another at the rear, to maintain uniformity across the boat. Ramp the furnace to 600°C before the removing the quartz boat and loading the wafers. Prior to the temperature reaching 400°C, turn on the nitrogen to purge the furnace. Load the wafers and insert the quartz boat to the center of the furnace and ramp the furnace to the desired temperature. When the desired temperature is reached start the timer, stop the nitrogen flow and turn on the oxygen. After the allotted time, turn off the oxygen and turn on the nitrogen and ramp the furnace down to 600°C (or 0°C if finished with furnace), pull the boat, remove the wafers, and set them aside to cool.

Figure 8 After oxidation the wafer will appear blue .



RESULTS: Lab 3

Front Sheet Resistivity (#1):

Rear Sheet Resistivity (#2):

NOTES/CHANGES:

Photolithography & Vias Oxide Etch   Lab 4

GOALS:

1. Measure the thickness of the SiO_2 layer with the ellipsometer
2. Photolithography (PV Mask 4 Backside Contacts)
3. Hardbake
4. Photolithography (PV Mask 2 SiO_2 Etch)
5. Hardbake
6. Oxide Etch

EQUIPMENT:

- Ellipsometer
- BREWER Spin-coater & Hotplate
- SHIPLEY 1813 Positive Photoresist
- ABM Contact Mask Aligner
- MF 319 Developer
- 6:1 BOE
- Teflon Cassette

PARAMETERS:

Spin-coat & Soft-bake Parameters

Spin Program	Speed (RPM)	Time (seconds)	Ramp (RPM/s)	Dispense Type (automatic or manual)	Soft-bake Program	Temperature (°C)	Time (minutes)
#9	5250	30	20000	Manual (static)	#9	115	1

Exposure & Development Parameters (MASK #4)

Mask Orientation (writing toward or away from user)	Wafer Orientation (flat to the left or the right)	UV Intensity Channel B (mW/cm^2)	UV Dose (J/cm^2)	Exposure Time (seconds)	Development Time (seconds)
Toward	Left	30	~135	4.5	30-60

Hard-bake Parameters

Hard-bake Program	Temperature (°C)	Time (minutes)
#9	115	1

Exposure & Development Parameters (MASK #2)

Mask Orientation (writing toward or away from user)	Wafer Orientation (flat to the left or the right)	UV Intensity Channel B (mW/cm^2)	UV Dose (J/cm^2)	Exposure Time (seconds)	Development Time (seconds)
Toward	Left	30	~135	4.5	30-60

Hard-bake Parameters

Hard-bake Program	Temperature (°C)	Time (minutes)
#9	115	1

SiO_2 Etch Parameters* *for 1,200-1,300Å thick SiO_2 layer*

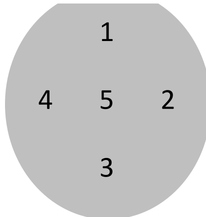
BOE concentration	Dry SiO_2 Etch Rate (Å/min)	Approx. Etch Time (minutes)	Etch Mask
6:1	150	10*	Shipley 1813 Photoresist

Methods:

1. Measuring the SiO_2 thickness:

Measure the thickness of the silicon dioxide at the points shown on the wafer using the *ellipsometer,* **Figure 9**. For reference, the ellipsometer prompts for measuring SiO_2 thickness estimate and index they are:

Thickness	***1300 Å***
Index	***1.46***



2. Photolithography with Mask #4 (Backside Contacts):

Spin-coating & Soft-baking

(Check *Parameters* section for details)

The fourth mask contains the features of the backside contact via etch. The vias are holes in the SiO_2 which allow the rear aluminum electrode to contact the diffused silicon surface.

Begin by using the *BREWER spin-coater* to spin a thin film of *SHIPLEY 1813* photoresist onto the backside of the wafer. Next, transfer the wafer to the adjacent hotplate and soft-bake to remove solvents and harden the resist. A good coating of photoresist will be barely visible to the naked eye and have a minimal number of streaks or blotches (**see Figure 10**). If there are a large number of defects, solvent clean, dehydrate, and try re-spinning the photoresist a second time.

Figure 9 The oxide thickness is measured using the ellipsometer. It measures the light intensity as a function of polarization reflected off the surfaces on the wafer

3. Photolithography with Mask #4 (Backside Contacts):

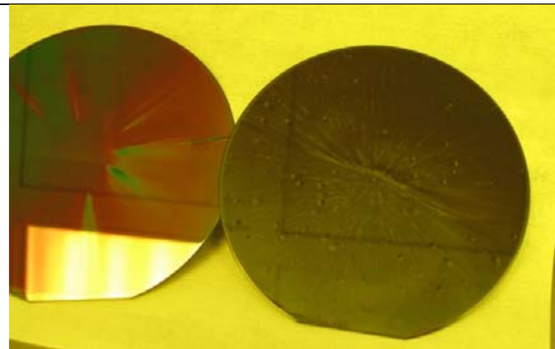
Exposure & Development

(Check *Parameters* section for details)

Proceed by patterning the photoresist with Mask #4.

Load the mask onto the *ABM contact-aligner* mask stage. Turn the mask-vac on and raise the mask stage. Carefully, load the wafer onto the substrate chuck backside up and orient it such that the <110> plane (wafer flat) is to the left and running straight up and down. Turn on the substrate-vac to lock the wafer in place and lower the chuck to avoid hitting the contact mask. Next, lower the mask stage and raise the substrate chuck up to meet the mask, fringe lines will become visible as the wafer and mask come into contact. Align the mask to the wafer using the markers on the sides of the wafer. Turn on the contact-vac to remove any air gap between mask and wafer. Adjust the exposure time and channel setting then expose. Remove the wafer by turning off the contact-vac, lowering the substrate chuck, raising the mask frame, and turning off the substrate-vac. Transfer the wafer to a dish of *MF319 developer* (a faint outline of the features can be seen at this point), submerge the wafer in MF319 and gently swirl for 30-60 seconds until the exposed resist is completely dissolved. If done correctly there should be no photoresist left in the exposed regions. If there is, resubmerge the wafer in the MF319 developer for additional time. If unsuccessful, use a solvent clean to strip the photoresist, dehydrate and re-spin again. When finished, pour the used MF319 into the MF319 waste container located under the solvent bench next to the photoresist.

Figure 10 Wafers that have been spun with photoresist and exhibit signs of a poor coating i.e. streaking, blotchiness and color gradients



Methods:

4. Hard-baking:

(Check *Parameters* section for details)

It has been observed, that without hard-baking, the photoresist exhibits adhesion problems and frequently delaminates from the surface during etching. Hard-baking is very similar to soft-baking and follows the same procedure. Load a wafer onto a hotplate for a set time at the appropriate temperature.

5. Photolithography with Mask #2 *(SiO$_2$ Etch)*: Spin-coating & Soft-baking

(Check *Parameters* section for details)

The PV Mask #2 contains the features of the front side oxide contact etch. The oxide is removed which allows the aluminum fingers to contact the doped silicon surface.

REPEAT: Begin by using the *BREWER spin-coater* to spin a thin film of *SHIPLEY 1813* photoresist onto the topside of the wafer. Next, transfer the wafer to the adjacent hotplate and soft-bake to remove solvents and harden the resist. A good coating of photoresist will be barely visible to the naked eye and have a minimal number of streaks or blotches (**see Figure 9**). If there are a large number of defects, solvent clean, dehydrate, and try re-spinning more photoresist.

6. Photolithography with Mask #2 *(SiO$_2$ Etch)*: Exposure & Development

(Check *Parameters* section for details)

Proceed by patterning the photoresist with Mask #2.

REPEAT: Load the mask onto the *ABM contact-aligner* mask stage. Turn the mask-vac on and raise the mask stage. Carefully, load the wafer onto the substrate chuck top surface up and orient it such that the <110> plane (wafer flat) is to the left and running straight up and down. Turn on the substrate-vac to lock the wafer in place and lower the chuck to avoid hitting the contact mask.

Next, lower the mask stage and raise the substrate chuck up to meet the mask, fringe lines will become visible as the wafer and mask come into contact. Align the mask to the wafer using the markers on the sides of the wafer. Turn on the contact-vac to remove any air gap between mask and wafer. Adjust the exposure time and channel setting then expose. Remove the wafer by turning off the contact-vac, lowering the substrate chuck, raising the mask frame, and turning off the substrate-vac. Transfer the wafer to a dish of *MF319 developer* (a faint outline of the features can be seen at this point), submerge the wafer in MF319 and gently swirl for 30-60 seconds until the exposed resist is completely dissolved. If done correctly there should be no photoresist left in the diffusion contact regions (**see Figure 10**). If there is, resubmerge the wafer in the MF319 developer for additional time. If unsuccessful, use a solvent clean to strip the photoresist, dehydrate and re-spin again. When finished, pour the used MF319 into the MF319 waste container located under the solvent bench next to the photoresist.

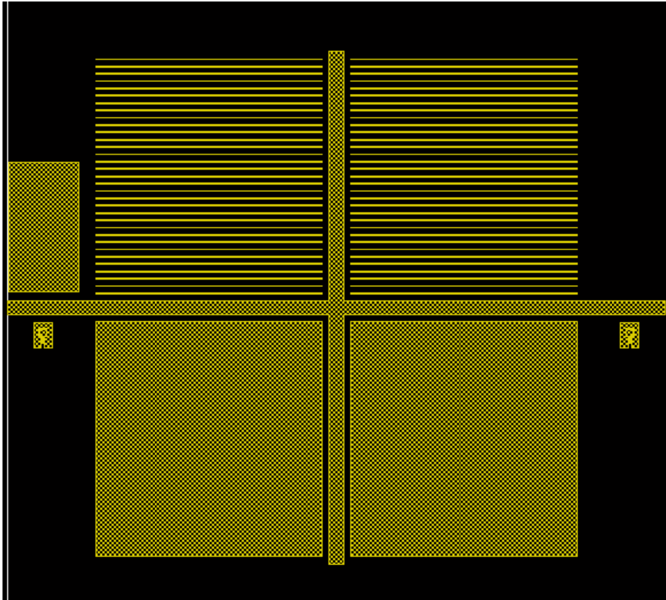
7. Etching the SiO$_2$:

(Check *Parameters* section for details)

This step should be carried out by the lab TA for safety reasons. Begin by loading the wafers into a *Teflon cassette* with equal spacing between wafers. Using the handle, submerge the cassette in *6:1 BOE* for the appropriate amount of time or until the exposed SiO$_2$ is completely removed. To determine if the SiO$_2$ is completely removed, check the regions for color (**see Figure 11**) and hydrophobicity. When the silicon dioxide etch is complete, remove the cassette. Place the cassette in the rinse sink then run the rinse cycle, and then dry the wafers with the nitrogen gun when completed.

Masks:

Front silicon dioxide etch to expose the silicon for metal contacts.



The metal etch creates the electrical contacts and wording on the surface.

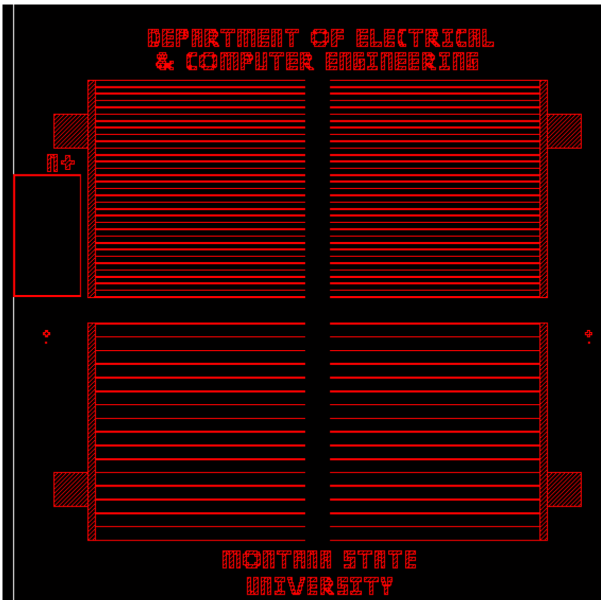
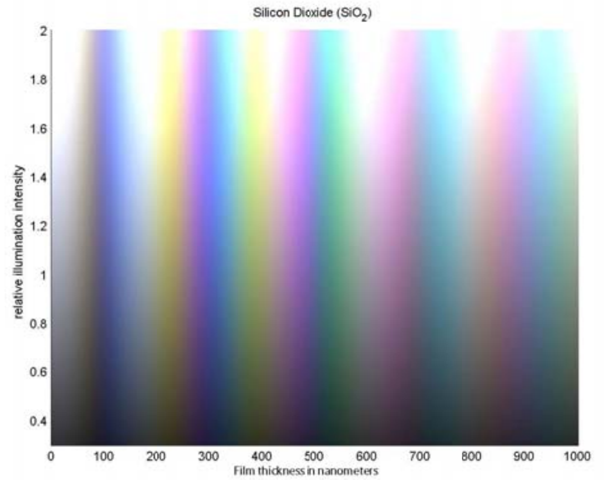


Figure 11. Wafers that have oxide will have a characteristic color depending on the thickness of the oxide.



SiO_2 Thickness (Å):

NOTES/CHANGES:

Cleaning & Al Evaporation (Front) Lab 5

GOALS:

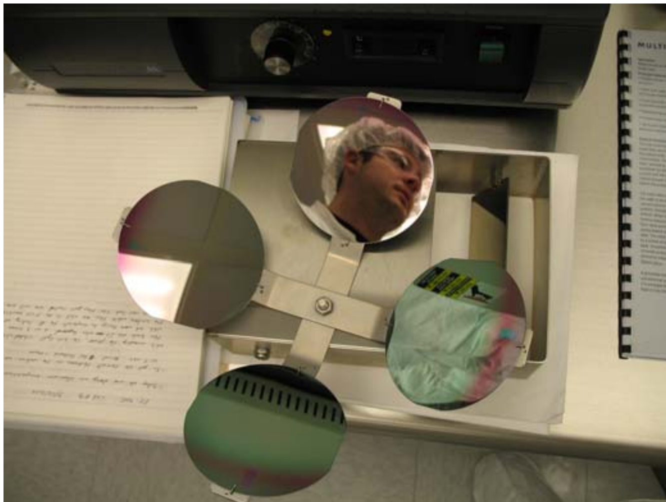
1. Solvent Clean
2. Aluminum PVD
3. Measure Sheet Resistivity

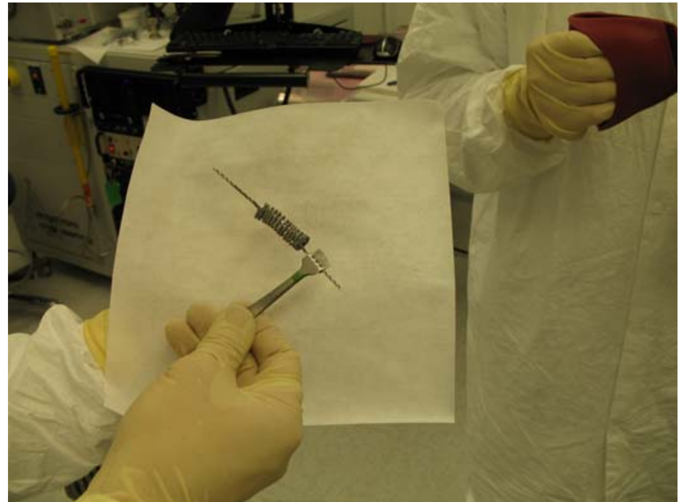
EQUIPMENT:

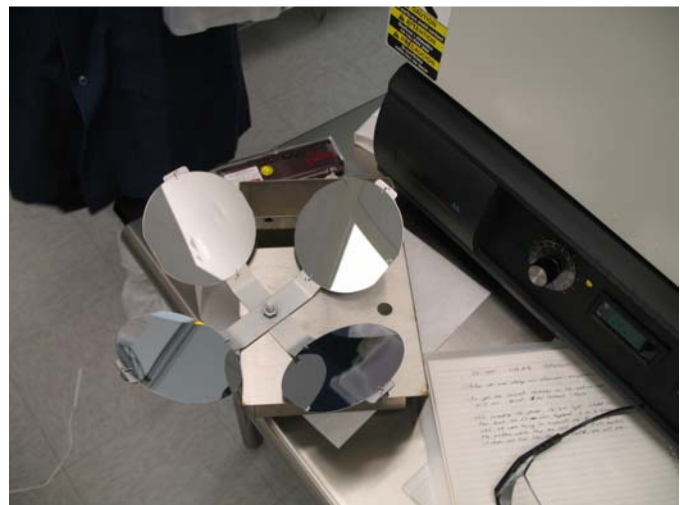
- Acetone, Methanol, Isopropyl
- MODULAB Physical Vapor Deposition System
- JANDEL 4-point Probe Station

PARAMETERS:

Aluminum Deposit Parameters* *for 3000-4000Å thick Aluminum layer*			
Al Foil Area (cm^2)	Al Foil Thickness (μ)	Filament to Wafer Distance (cm)	Power Level
30	40	13.5	40%







Methods:

1. Solvent Clean:

To remove the photoresist a solvent clean is performed. Rinse the wafer with *acetone* using the squirt bottle, and follow with *isopropyl* and *methanol.* Rinse the wafers in DI water.

Place the wafers in the acid bath cassette and clean them in the nanostrip bath. After the allotted time spray rinse the cassette and place it in the Semitool rinser and dryer. Run the cleaning program.

Figure 12 Use a three solvent clean to remove the photoresist from the wafer.

2. Aluminum PVD:

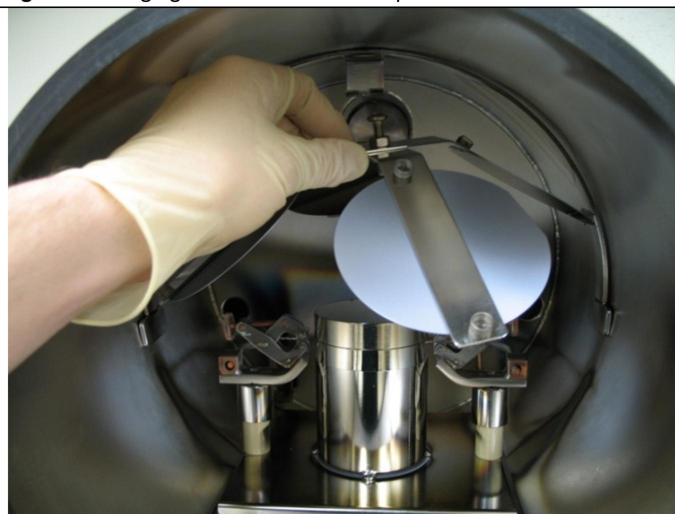
The goal of the aluminum evaporation is to create a thin film of aluminum on the topside of the wafer. The aluminum will be patterned with Mask #3 (Metal 1) to create electrical contact pads for characterizing the finished devices. The evaporation is accomplished with the *MODULAB PVD system*. See the *MODULAB PVD* operations manual for more information.

Approximately 30-40 cm^2 of aluminum should be evaporated. This will provide roughly 0.5-0.7µm of aluminum on the wafer surface. If sufficient coverage is not obtained the wafers can be rotated in the holder and a second coat of aluminum can be evaporated over the first coating.

3. Sheet Resistivity Measurements:

REPEAT: The aluminum layer on the wafer creates a higher conducting layer on the surface. To characterize the aluminum layer the sheet resistivity is measured. Use the *JANDEL 4-point probe* **(Figure 6)** to measure the sheet resistivity of the aluminum. Start by raising the probe arm, uncapping the tip and placing the wafer on the stage. Align the probes over the rear of the wafer opposite of the flat, then lower the probe arm to make contact with the wafer. Set the current to 1uA (press '1' and 'uA') Press 'FWD' The unit is now passing a current through the sample. It should be giving a positive voltage reading. If the voltage reading is less than a millivolt, increase the current by an order of magnitude until you get a voltage reading of greater than one millivolt. Record the value. Press 'REV' The unit is now passing a current through the sample in the reverse direction. It should be giving a negative voltage reading about the same magnitude as the FWD measurement. Record the value. Increase the current by another order of magnitude but do not exceed 100 mA, the voltage should also increase by an order of magnitude. Record the value Press 'FWD' Record the value for the new forward current, it should be an order of magnitude larger than the previously recorded value. Press 'Ω/□'. This is the sheet resistivity measurement.

Figure 13 Hanging the Wafers in the Evaporator.



RESULTS: Lab 5

Front Aluminum Sheet Resistance (Ω/□):

NOTES/CHANGES:

Photolithography & Al Contact Etch   Lab 6

GOALS:

1. Photolithography (PV Mask #3 Metal 1)
2. Hardbake
3. Aluminum Etch
4. Measure Aluminum thickness

EQUIPMENT:

- BREWER spin-coater and hotplate
- SHIPLEY 1813 positive photoresist
- ABM Contact Mask Aligner
- MF 319 developer
- PAN Etch
- Wafer Glassware
- AMBIOS Profilometer

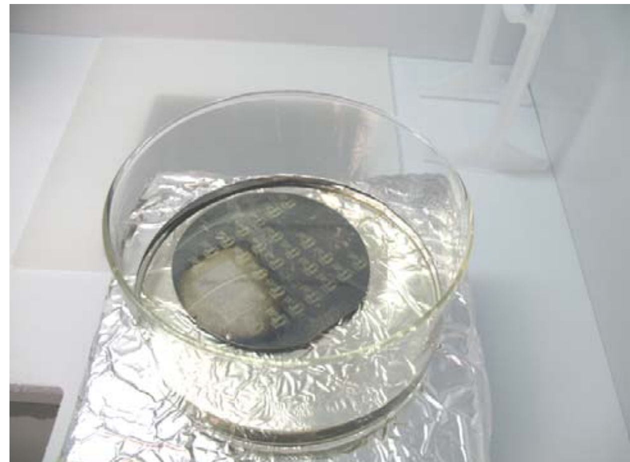
PARAMETERS:

Spin-coat & Soft-bake Parameters							
Spin Program	Speed (RPM)	Time (seconds)	Ramp (RPM/s)	Dispense Type (automatic or manual)	Softbake Program	Temperature (°C)	Time (minutes)
#9	5250	30	20000	Manual (static)	#2	115	2

Exposure & Development Parameters (MASK #3)					
Mask Orientation (writing toward or away from user)	Wafer Orientation (flat to the left or the right)	UV Intensity Channel B (mW/cm^2)	UV Dose (J/cm^2)	Exposure Time (seconds)	Development Time (seconds)
Away	Left	30	~135	4.5	30-60

Hard-bake Parameters		
Hardbake Program	Temperature (°C)	Time (minutes)
#2	115	2

Aluminum Etch Parameters ** for 0.5-1um thick aluminum layer*			
Etchant	Approx. Etch Rate (Å /min)	Approx. Etch Time (minutes)	Etch Mask
PAE	350	15* (Room Temperature)	Shipley 1813 Photoresist



Methods:

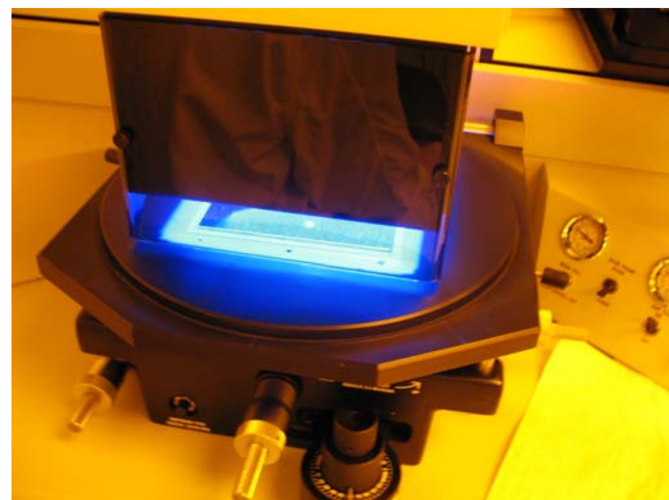
1. Photolithography with Mask #3 (Metal 1): Spin-coating & Soft-baking

(Check *Parameters* section for details)

The third mask contains the features for the top side metal contacts.

REPEAT: Begin by using the *BREWER spin-coater* to spin a thin film of *SHIPLEY 1813* photoresist onto the topside of the wafer. Next, transfer the wafer to the adjacent hotplate and soft-bake to remove solvents and harden the resist. A good coating of photoresist will be barely visible to the naked eye and have a minimal number of streaks or blotches (**see Figure 7**). If there are a large number of defects, solvent clean, dehydrate, and try re-spinning more photoresist.

Figure 14 A student using the ABM mask aligner to align Mask #3 and exposing.



2. Photolithography with Mask #3 (Metal 1): Exposure & Development

(Check *Parameters* section for details)

Proceed by patterning the photoresist with Mask #3.

REPEAT: Load the mask onto the *ABM contact-aligner* mask stage. Turn the mask-vac on and raise the mask stage. Carefully, load the wafer onto the substrate chuck and orient it such that the <110> plane (wafer flat) is to the left and running straight up and down. Turn on the substrate-vac to lock the wafer in place and lower the chuck to avoid hitting the contact mask. Next, lower the mask stage and raise the substrate chuck up to meet the mask, fringe lines will become visible as the wafer and mask come into contact. Align the mask to the wafer using the markers on the sides of the wafer. Turn on the contact-vac to remove any air gap between mask and wafer. Adjust the exposure time and channel setting then expose. Remove the wafer by turning off the contact-vac, lowering the substrate chuck, raising the mask frame, and turning off the substrate-vac. Transfer the wafer to a dish of *MF319 developer* (a faint outline of the features can be seen at this point), submerge the wafer in MF319 and gently swirl for 30-60 seconds until the exposed resist is completely dissolved. If done correctly there should be no photoresist left in the diffusion contact regions (**see Figure 8**). If there is, resubmerge the wafer in the MF319 developer for additional time. If unsuccessful, use a solvent clean to strip the photoresist, dehydrate and re-spin again. When finished, pour the used MF319 into the MF319 waste container located under the solvent bench next to the photoresist.

2. Hard-baking:

(Check *Parameters* section for details)

REPEAT: It has been observed, that without hard-baking, the photoresist exhibits adhesion problems and frequently delaminates from the surface during etching. Hard-baking is very similar to soft-baking and follows the same procedure. Load a wafer onto a hotplate for a set time at the appropriate temperature.

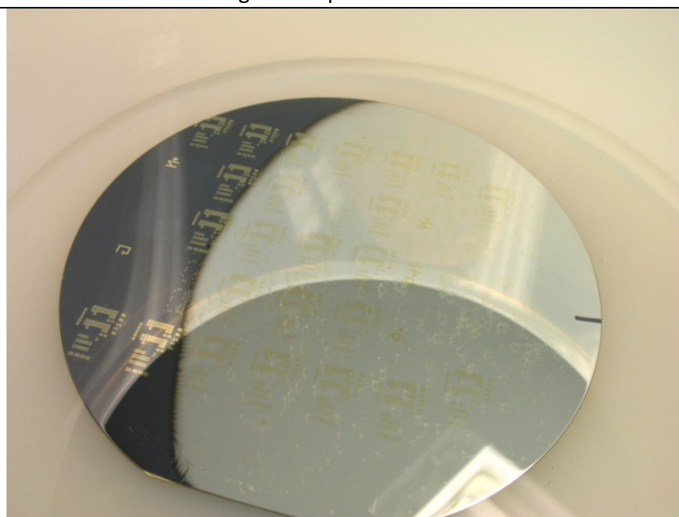
3. Etching Aluminum:

(Check *Parameters* section for details)

The exposed aluminum is removed in a PAN Acid Etch (PAE) one wafer at a time. The PAN contains three acids: phosphoric, acetic, and nitric. It etches aluminum at approximately 350Å/min and is highly selective to aluminum compared to photoresist.

Begin by pouring a small amount of PAE into a pyrex or Teflon evaporating dish. Submerge a wafer and gently swirl until the exposed aluminum has been etched. A visible etch front will move across the wafer as the aluminum is removed (see **Figure 15**). The etch will take between 10-15 minutes to complete. The etch rate increases with temperature. The evaporating dish can be placed on a hot plate and heated to 70°C to increase the etch rate. The complete etch will then only take several minutes.

Figure 15 Aluminum being etched in PAE. Note the etch front moving from left to right. This is a result of a varying thickness in the aluminum created during the evaporation.



3. Solvent Clean:

REPEAT: To remove the photoresist a solvent clean is performed. Rinse the wafer with *acetone* using the squirt bottle, and follow with *isopropyl* and *methanol.* Rinse the wafers in DI water.

Place the wafers in the acid bath cassette and clean them in the nanostrip bath. After the allotted time spray rinse the cassette and place it in the Semitool rinser and dryer. Run the rinsing program.

4. Aluminum Thickness Measurements:

Measure the thickness of the patterned aluminum film with the *AMBIOS Stylus Profilometer,* **Figure 16***.* Begin by loading a wafer onto the stage. Using the XP2 software move the stage and wafer beneath the stylus. Adjust the stylus height and stage position over a patterned feature. Scan the feature with an appropriate scan length, speed, and force. Consult the AMBIOS operations manual for more details. The results should resemble the following figure, **Figure 17**.

Figure 16 The Stylus Profilometer is used to measure steps in thin films.

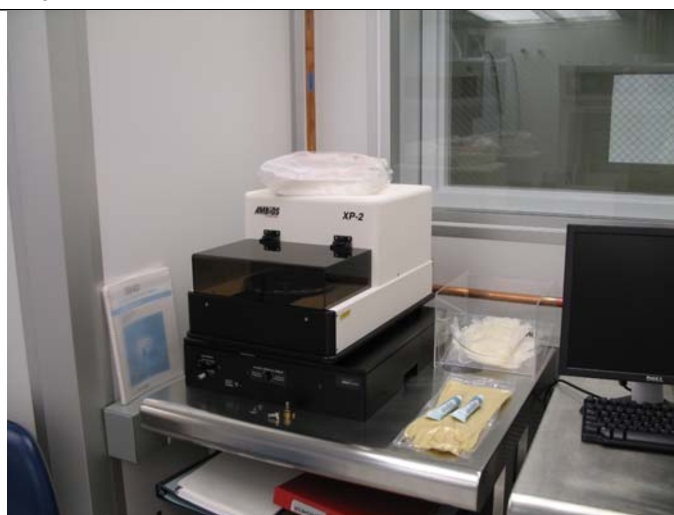
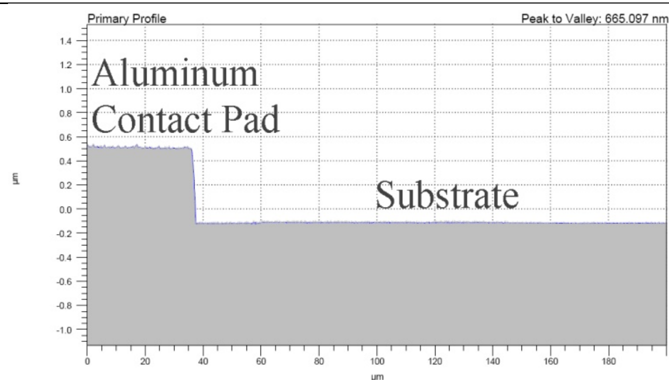


Figure 17 Profilometer data of an aluminum pad. The data reveals the thickness of the aluminum film.



RESULTS:

Aluminum Thickness (Ắ):

NOTES/CHANGES:

Cleaning & Al Evaporation (Back) Lab 7

GOALS:

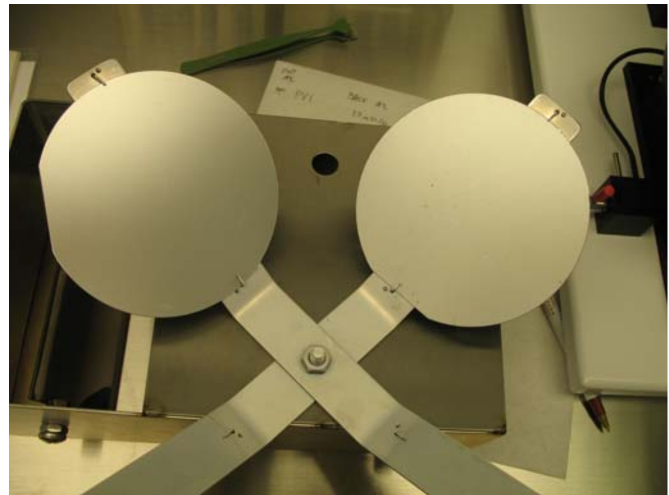
1. Solvent Clean
2. Aluminum PVD
3. Measure Sheet Resistivity

EQUIPMENT:

- Acetone, Methanol, Isopropyl
- MODULAB Physical Vapor Deposition System
- JANDEL 4-point Probe Station

PARAMETERS:

Aluminum Deposit Parameters ** for 3000-4000Å thick Aluminum layer*			
Al Foil Area (cm^2)	Al Foil Thickness (μ)	Filament to Wafer Distance (cm)	Power Level
30	40	13.5	40%



Methods:

1. Solvent Clean:

REPEAT: To remove the photoresist a solvent clean is performed. Rinse the wafer with *acetone* using the squirt bottle, and follow with *methanol* and *isopropyl.* Rinse the wafers in DI water.

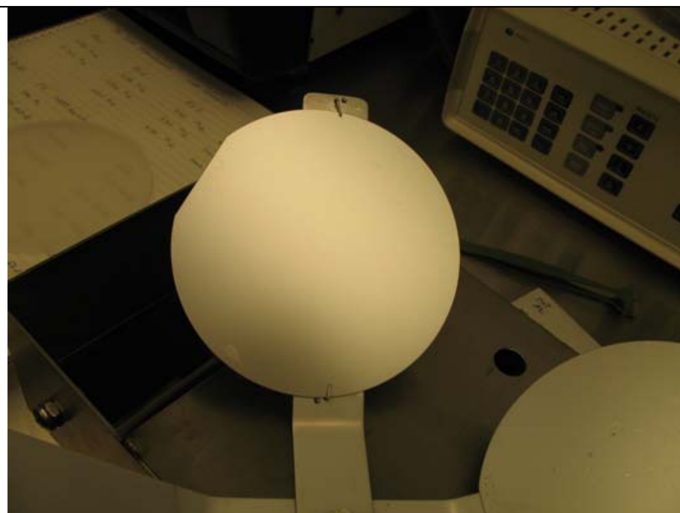
Place the wafers in the acid bath cassette and clean them in the nanostrip bath. After the allotted time spray rinse the cassette and place it in the Semitool rinser and dryer. Run the cleaning program.

2. Aluminum PVD:

REPEAT: The goal of this aluminum evaporation is to create a thin film of aluminum on the backside of the wafer. The aluminum will not be patterned. The evaporation is accomplished with the *MODULAB PVD system*. See the *MODULAB PVD* operations manual for more information.

Approximately 40-50 cm^2 of aluminum should be evaporated. This will provide roughly 0.5-0.7µm of aluminum on the wafer surface. If sufficient coverage is not obtained the wafers can be rotated in the holder and a second coat of aluminum can be evaporated over the first coating.

Figure 18 The backside of the wafer should be entirely covered with aluminum.



3. Sheet Resistivity Measurements:

The aluminum layer on the wafer creates a higher conducting layer on the surface. To characterize the aluminum layer the sheet resistivity is measured. Use the *JANDEL 4-point probe* **(Figure 6)** to measure the sheet resistivity of the aluminum. Start by raising the probe arm, uncapping the tip and placing the wafer on the stage. Align the probes over the rear of the wafer opposite of the flat, then lower the probe arm to make contact with the wafer. Set the current to 1uA (press '1' and 'uA') Press 'FWD' The unit is now passing a current through the sample. It should be giving a positive voltage reading. If the voltage reading is less than a millivolt, increase the current by an order of magnitude until you get a voltage reading of greater than one millivolt. Record the value. Press 'REV' The unit is now passing a current through the sample in the reverse direction. It should be giving a negative voltage reading about the same magnitude as the FWD measurement. Record the value. Increase the current by another order of magnitude but do not exceed 100 mA, the voltage should also increase by an order of magnitude. Record the value Press 'FWD' Record the value for the new forward current, it should be an order of magnitude larger than the previously recorded value. Press 'Ω/□'. This is the sheet resistivity measurement.

Figure 19 The sheet resistivity measurement is taken by pressing the 'Ω/□' button.

RESULTS: Lab 7

Rear Aluminum Sheet Resistance (Ω/□):

NOTES/CHANGES:

Initial Characterization & Annealing Lab 8

GOALS:

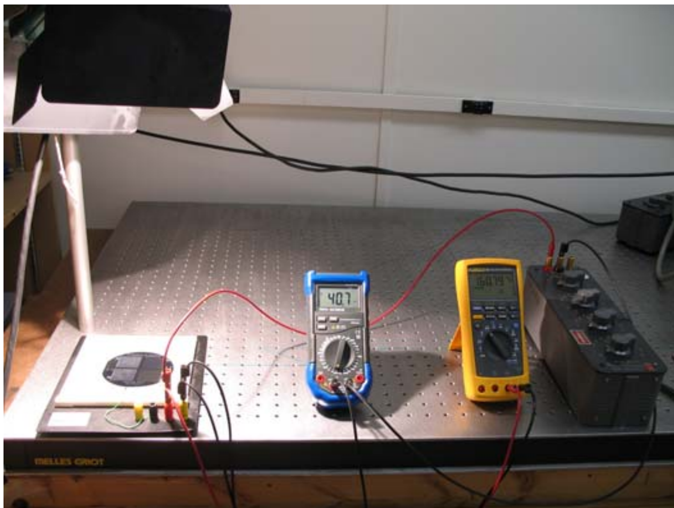
1. Measure the short circuit current and the open circuit voltage
2. Anneal the wafer to improve the electrical contact between the metal and semiconductor.

EQUIPMENT:

- Digital Multi-Meter (2)
- Flood Light
- Programmable Hot-Plate

PARAMETERS:

Aluminum Anneal	
Hot Plate Temperature (°C)	Time (minutes)
400	30



Methods:

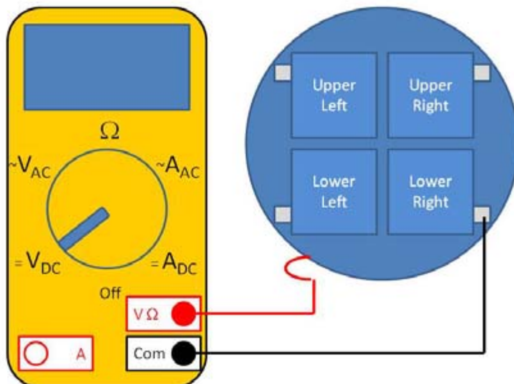
1. Characterization:

The two measurements that gives an indication of the performance of the solar cell are the Open Circuit Voltage (V_{oc}) and the Short Circuit Current (I_{sc}). Both are measured by placing a Digital Multimeter (DMM) across the contacts of the solar cell.

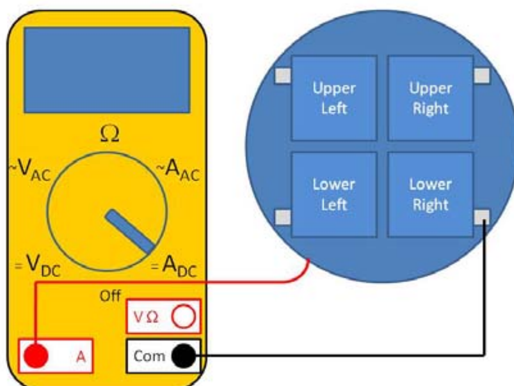
Place your wafer in the test bed be sure that contact is made to one solar cell front pads and the rear aluminum of the wafer. Connect the front side contact to the common terminal of the DDM and the rear contact to the Voltage terminal. Illuminate the solar cell and set the DDM to measure DC voltage. Record the Open Circuit Voltage (Figure 20). Move the Rear contact to the Current Terminal and set the DDM to measure DC current. Record the Short Circuit Current.

Figure 20 Set up to measure the Open Circuit Voltage and the Short Circuit Current of the solar cell.

Open Circuit Voltage



Short Circuit Current



2. Annealing:

Typically the results of the characterization measurements are poor. This is because there is not a good electrical contact between the deposited aluminum and the silicon. This contact can be improved by the inter-diffusion of the aluminum and silicon during the annealing of the wafer. The annealing is done by placing the wafer on a hot plate and heating the wafer.

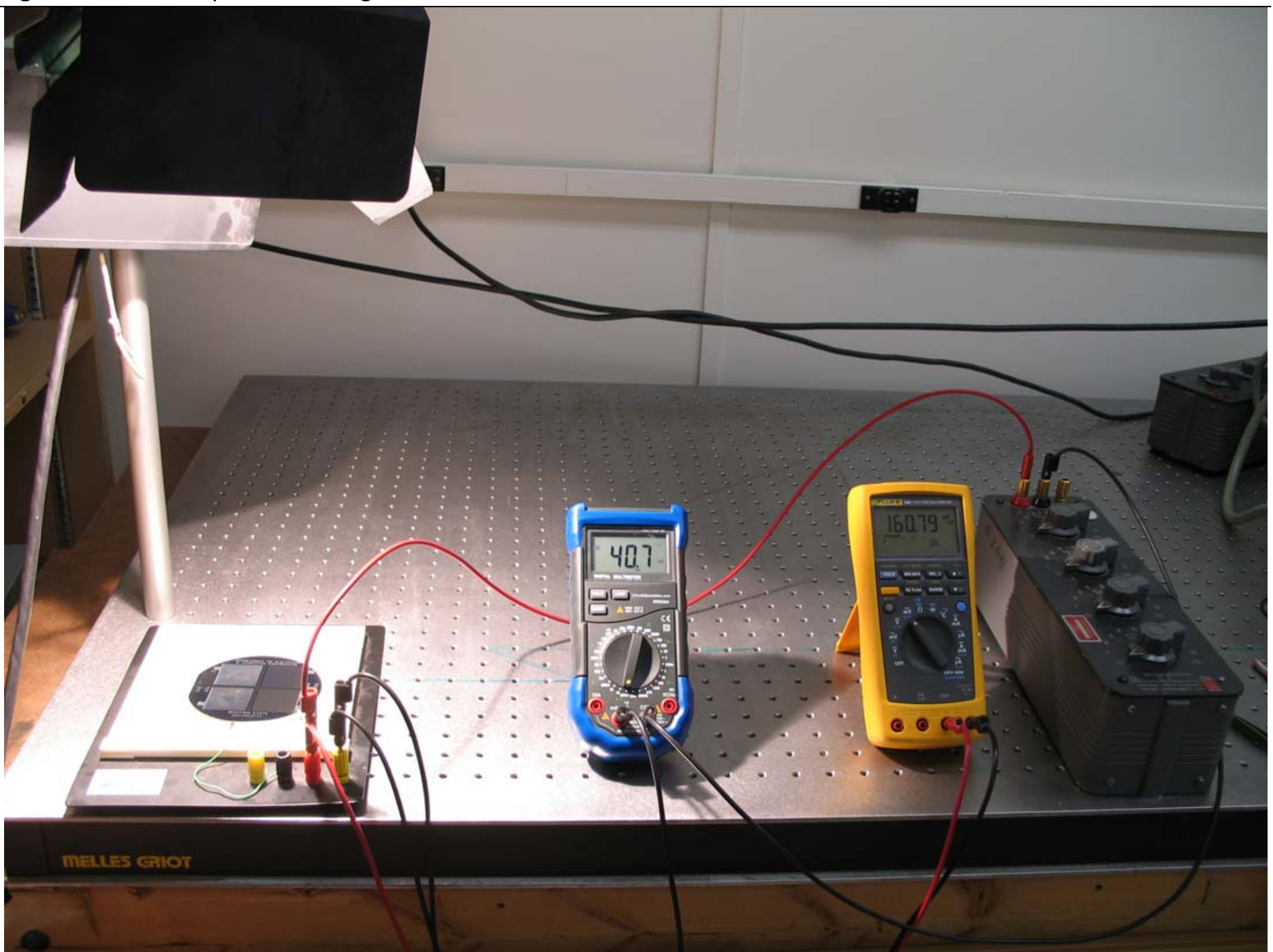
Figure 21 Annealing the solar cell wafer on a hot plate.

Post-Anneal Characterization Lab 9

GOALS:	EQUIPMENT:
1. Create current – voltage plots for each of your four solar cells.	• Flood Light • Contact station • Digital Multi Meter (2) • Decade Resistor Box

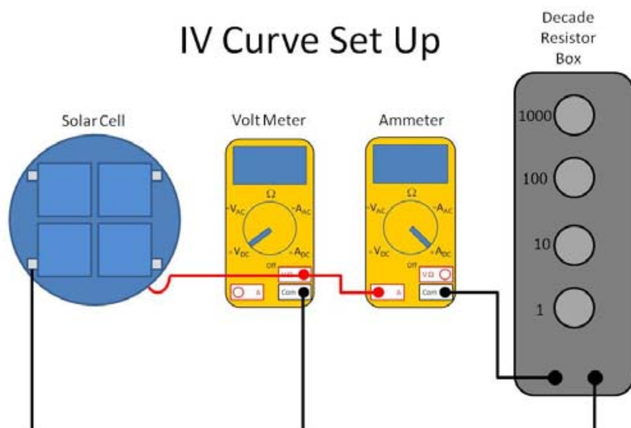
PARAMETERS:

Figure 22 Test set up with flood light as source.



Methods:

Figure 23 Schematic of the Voltage – Current Measurement System



Place your wafer in the test bed. Be sure that contacts are made to one solar cell front pads and the rear aluminum of the wafer. Connect the front side contact to the common terminal of the DMM and the rear contact to the Voltage terminal, turn the knob such that the DMM is acting as a voltmeter (V_{DC}). Connect a second DMM Current terminal to the Voltage terminal of the first DMM and the common terminal to a decade resistor box and turn the knob on the DMM to measure DC current (A_{DC}). Connect the other terminal of the decade resistor box to the common terminal of the first DMM that is acting as a voltmeter. The set up should be ready to measure the voltage and current output of the solar cell as the load resistance is varied as shown in **Figure 23**.

Illuminate the solar cell with the flood light and record the voltage and current readings as the load resistance is varied. Fill out the following results sheet for each of your four solar cells. Record your wafer marking, the fabrication dates, which solar cell you are testing (top left, top right, bottom left, or bottom right) the date you tested your solar cell, the final sheet resistivities and the thermal processing times and temperatures in the places provided. You will be turning in a copy of these sheets for each of your solar cells. They will be used to monitor the process results with the possibility of improving the process in future offerings of the class.

At short circuit, the solar cell produces electric current but not voltage. At open circuit, the solar cell produces voltage but no current. Electric power is defined as the product of the current and the voltage. Somewhere between these points where zero power is produced a maximum power operating point exists.

Place the data in a spreadsheet or graphing program with one column recording the voltage another column recording the current and a third column that records the product of the voltage and the current, which is the power generated. Plot the IV curve with the current on the vertical or y-axis and voltage on the horizontal or x-axis. Plot the power in the vertical axis (use the right axis or plot a second graph) and the voltage on the horizontal axis. Find the maximum power on the curve and find the corrsponding voltage and current. This is the maximum power your solar cell can produce under this illumination condition.

Repeat these two plots for each of your solar cells. Discuss the differences in the four solar cells and their corresponding IV curves and power plots.

Calculate the fill factor, $FF = Pmax/(I_{sc}V_{oc})$. For a good cell this should be 0.7 or greater. It is a measure of how “square” the IV characterization curve is.

RESULTS: Lab 9

Wafer:

Fab Dates:

Device: Top Left Top Right Bot Left Bot Right

Test Date:

Isc: Voc:

R (Ohms)	I (mA)	V (mV)
	Isc=	0
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		
200		
300		
400		
500		
600		
700		
800		
900		
1000		
2000		
10000		
∞	0	Voc=

p+ Sheet Resistivity

n+ Sheet Resistivity

Front Al Sheet Resistivity

Back Al Sheet Resistivity

Forward Resistance

Reverse Resistance

N+ Diffusion Time Temperature

P+ Diffusion Time Temperature

Oxidation Time Temperature

RESULTS: Lab 9

Wafer:

Fab Dates:

Device:	Top Left	Top Right	Bot Left	Bot Right

Test Date:

Isc: Voc:

R (Ohms)	I (mA)	V (mV)
	Isc=	0
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		
200		
300		
400		
500		
600		
700		
800		
900		
1000		
2000		
10000		
∞	0	Voc=

p+ Sheet Resistivity

n+ Sheet Resistivity

Front Al Sheet Resistivity

Back Al Sheet Resistivity

Forward Resistance

Reverse Resistance

N+ Diffusion	Time	Temperature
P+ Diffusion	Time	Temperature
Oxidation	Time	Temperature

RESULTS: Lab 9

Wafer:

Fab Dates:

Device: Top Left | Top Right | Bot Left | Bot Right

Test Date:

Isc: Voc:

R (Ohms)	I (mA)	V (mV)
	Isc=	0
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		
200		
300		
400		
500		
600		
700		
800		
900		
1000		
2000		
10000		
∞	0	Voc=

p+ Sheet Resistivity

n+ Sheet Resistivity

Front Al Sheet Resistivity

Back Al Sheet Resistivity

Forward Resistance

Reverse Resistance

N+ Diffusion	Time	Temperature
P+ Diffusion	Time	Temperature
Oxidation	Time	Temperature

RESULTS: Lab 9

Wafer:

Fab Dates:

Device: Top Left | Top Right | Bot Left | Bot Right

Test Date:

Isc: Voc:

R (Ohms)	I (mA)	V (mV)
	Isc=	0
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
20		
30		
40		
50		
60		
70		
80		
90		
100		
200		
300		
400		
500		
600		
700		
800		
900		
1000		
2000		
10000		
∞	0	Voc=

p+ Sheet Resistivity

n+ Sheet Resistivity

Front Al Sheet Resistivity

Back Al Sheet Resistivity

Forward Resistance

Reverse Resistance

N+ Diffusion	Time	Temperature
P+ Diffusion	Time	Temperature
Oxidation	Time	Temperature

Experiments Lab 10

GOALS:

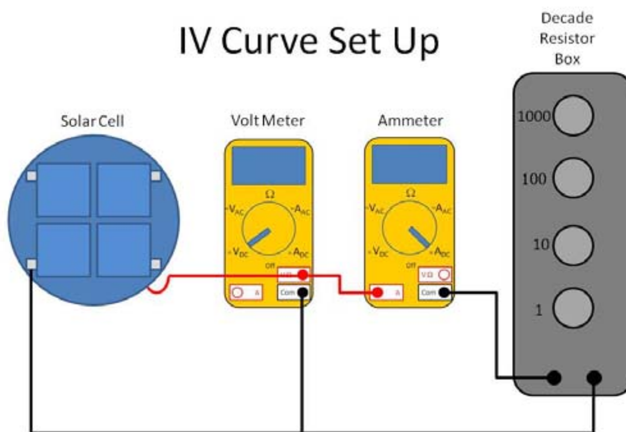
1. **1.** Conduct angle experiments on your solar cell
2. **2.** Other questions and possible experiments

EQUIPMENT:

- Flood Light
- Contact station
- Digital Multi Meter (2)
- Decade Resistor Box

Methods:

Figure 23 Schematic of the Voltage – Current Measurement System



Place your wafer in the test bed be sure that contact is made to one solar cell front pads and the rear aluminum of the wafer. Set the resistance to the optimum power point. Place the solar cell at 0° where the solar cell is directly facing the light source. Measure the voltage and the current using the multimeters. Record the values in a table. Calculate the power by mulitiplying the voltage by the corresponding current record this calculation. Now change the angle of the solar cell and repeat the measurements of the voltage, current and power. Step the angle $\pm 10^o$ increments filling in the table from $+90^o$ to 0° to -90°

Lambert's Law of Illlumination states that the illumination of a surface is proportional to the cosine of the angle between the incident light rays and the normal to the surface.

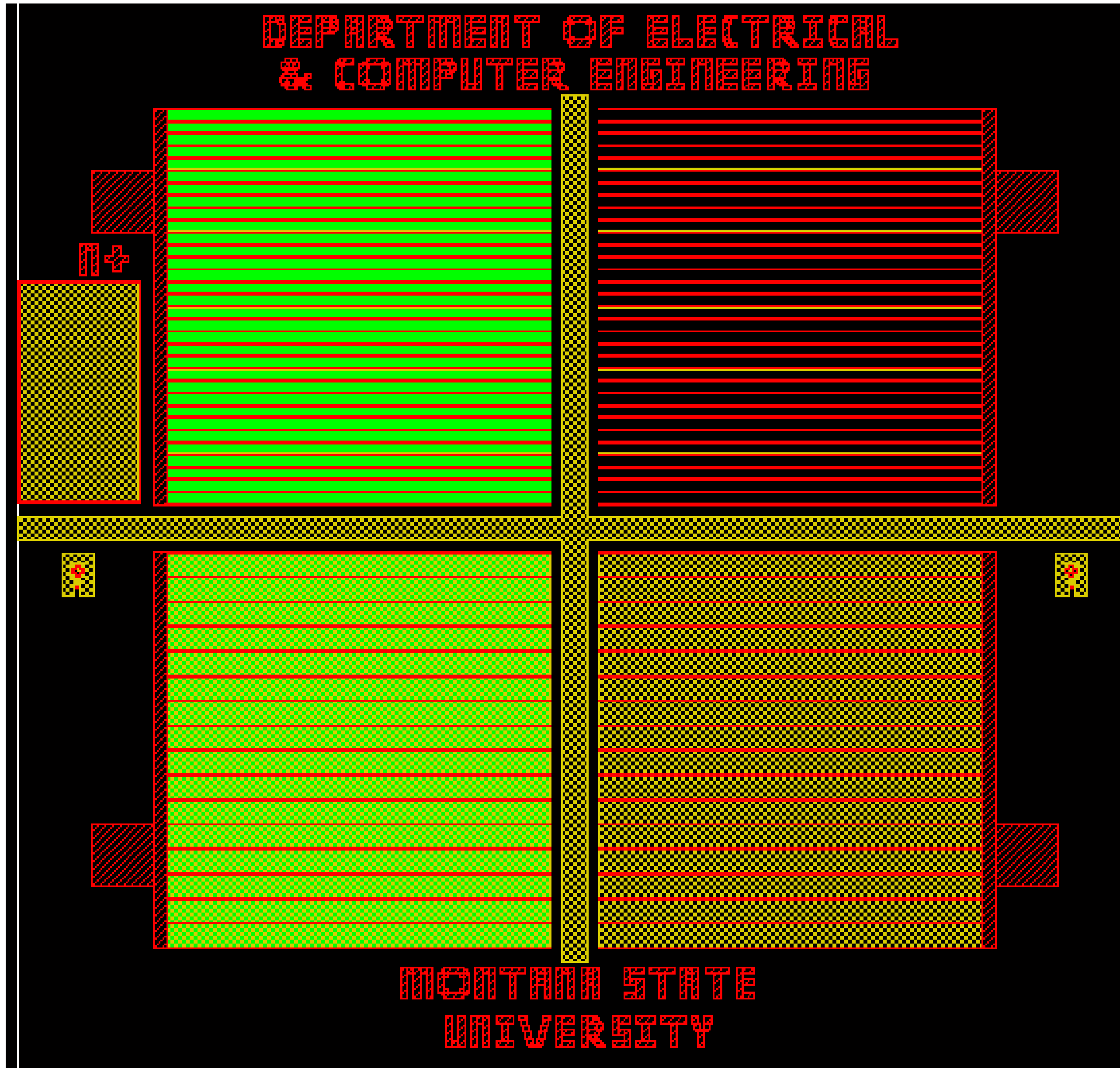
$$P = A\cos\theta$$

P is the power obtained, A is a product of the incoming intensity of the light, area of the solar cell and its efficiency (the power attained when the light is perpendicular to the cell) and θ is the angle of the light to the normal.

Plot the experimental power obtained on the vertical y-axis and the angle on the horizontal x-axis. Superimpose a plot of the cosine function with an amplitude (A) equal to the peak power obtained. See how well the two plots match and discuss the discrepancies.

Wafer Layout

The following image is of the wafer layout. Each wafer contains 4 devices as well as a test structure.



Wafer:

Fab Dates:

Device: **Top Left** **Top Right** **Bot Left** **Bot Right**

Test Date:

Isc: **Voc:**

R (Ohms)	I (mA)	V (mV)
	Isc=	0
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
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600		
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900		
1000		
2000		
3000		
4000		
5000		
6000		
7000		
∞	0	Voc=

p+ Sheet Resistivity

n+ Sheet Resistivity

Front Al Sheet Resistivity

Back Al Sheet Resistivity

Forward Resistance

Reverse Resistance

N+ Diffusion Time Temperature

P+ Diffusion Time Temperature

Oxidation Time Temperature

Question 1: How does the voltage change when the distance between a bright light and a solar cell is varied?

Measure the distance from the center of a bulb to the face of the solar cell and record the voltage.

Distance	10cm	20cm	30cm	40cm	50cm	60cm	70cm	80cm	90cm	100cm
Voltage (V)										

$$V \propto \frac{1}{d^2}$$

Question 2: How does the current change when the distance between a bright light and a solar cell is varied?

Measure the distance from the center of a bulb to the face of the solar cell and record the voltage.

Distance	10cm	20cm	30cm	40cm	50cm	60cm	70cm	80cm	90cm	100cm
Current (mA)										

$$I \propto \frac{1}{d^2}$$

Question 3: How does the power change when the angle between the light and the solar cell is varied?

Measure the angle from the center of a bulb to the normal of the face of the solar cell and record the voltage, current, and power.

Angle	0	±10	±20	±30	±40	±50	±60	±70	±80	±90
power(mW)										

Question 4: Does the color of the light affect the voltage and current of the solar cell?

Filter the light reaching the solar cell by placing colored cellophane over the solar cell.

Color:	Clear	Purple	Blue	Green	Yellow	Orange	Red
Voltage (V)							
Current (mA)							

Question 5: Does the area illuminated affect the voltage and current of the solar cell?

Use the cardboard to cover fractions of the solar cell and record the voltage and current.

Coverage	0%	25%	50%	75%	100%
Voltage (V)					
Current (mA)					

Question 6: Does the position where the light strikes the solar cell impact the voltage and current of the solar cell?

Cut a hole smaller than the solar cell in a piece of cardboard. Record the voltage and current as the hole is moved to different positions on the solar cell. Does the shape of the hole matter? Does the size of the hole matter?

Other Questions:

Affects of temperature
Glass over the solar cell
Water on the solar cell
Reflected light versus direct light
Polarization