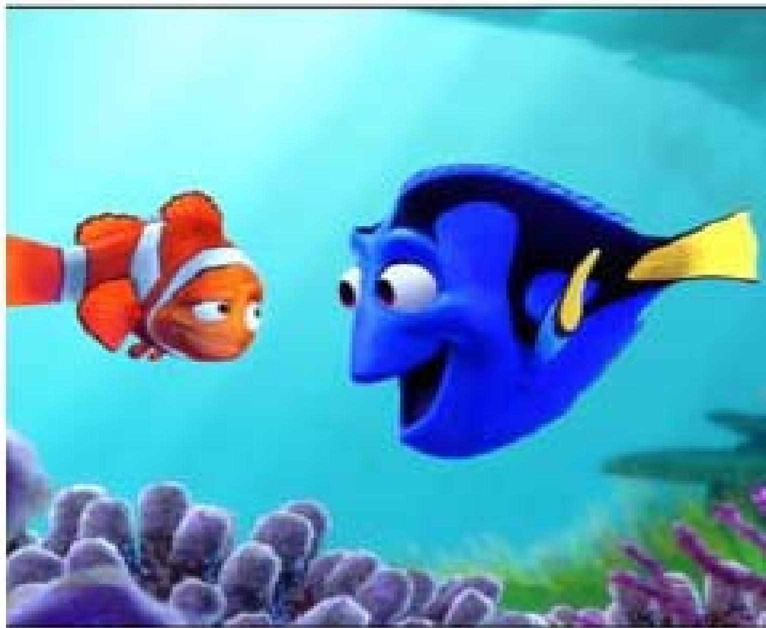
ECEn 452 Labs #2-7

Semiconductors/ Metals/Oxides



3/3/04

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OBJECTIVE

Ultimately, these first six labs serve as tutorials and preparation for our culminating project of the semester – the MOSFET. Although introductory, these labs do include a final goal/project. By the end of lab 7, we should hopefully have a wafer with a color and clear picture from *Finding Nemo*. If all goes well, it should be a satisfying conclusion before moving to the MOSFET.

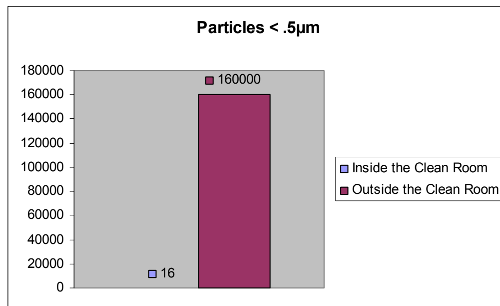
WRITE-UP OUTLINE

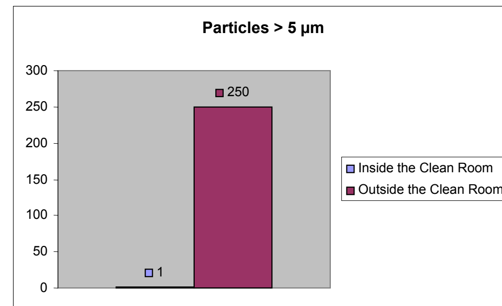
This write-up will briefly review the goals, procedures, results, observations, and highlights from each of the labs. Reconciliation for any inconsistencies or failures shall be attempted. A final conclusion will summarize.

LAB #2 – INTRO TO THE CLEANROOM AND METAL DEPOSITION

Goals: As a necessary beginning to semiconductor processing, a basic tutorial in the more fundamental processes and concepts was needed. Important lessons from this lab include cleanroom specifications, metal evaporation using e-beam and thermal evaporators, vacuums, resistivity, and observing the results on a wafer.

Procedure: A good portion of this lab was observation. The first demonstration pertained to cleanroom particles. Using the particle counter, the amount of particles both in and out of the cleanroom was compared. The results were astonishing. See the figures below:

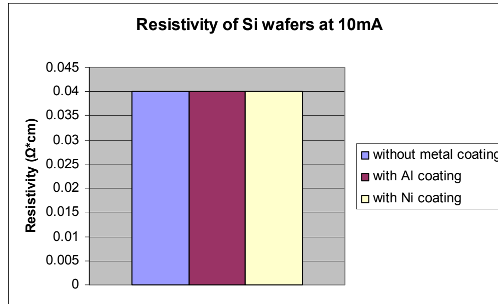




Next, Phil demonstrated using the e-beam and thermal evaporators and depositing particular metals onto wafers. It was sufficient for conceptual understanding, though the actual procedure was very brief and quick. While the metals deposited, Phil also gave a brief lecture about various vacuum styles. Afterwards, the four-point probe was used to measure each wafer's resistivity. A voltage potential is placed across each pair of points and the measured current enables the resistance (V/I) to be found. Finally, the high-power microscope allows direct visual observation of any particles or imperfections in the wafers.

Results: The only real measurable results from this lab were the resistivities, as shown:

Normal Si	Aluminum Deposit	Nickel Deposit
.04 Ω*cm	.04 Ω*cm	.04 Ω*cm



Interestingly enough, the four-point probe was also measuring .04 Ω*cm without any wafer. Needless to say, the four-point probe appeared to be functioning improperly.

Observations: Honestly, there was some disappointment in the lack of hands-on applications during this lab. Nobody felt confident in using either of the evaporators or understanding the vacuum systems completely. Fortunately, this show-and-tell approach is only for this lab and much hands-on experience will be included in the future labs.

Highlights: The highlight of this lab was playing with the particle counter. It's amazing how much dust comes from simply flipping through a lab book or rubbing clothing. When it came time to estimate how many particles would be measured out in the hallway, nobody came even close to the right amount! Everybody was orders of magnitudes wrong!

<u>LAB #3 – LITHOGRAPHY</u>

Goals: To develop a lithography "recipe" that will be used in future labs. The "recipe" will include photoresist amount, exposure time, and developing time.

Procedure: The easiest way to summarize the approach: trial and error. With a few pointers from Phil (who obviously didn't want to spend all Friday evening in the cleanroom), several trial runs were made, each with a slightly different lithography procedure. For example, photoresist amount (in drops) began at 25 drops and was incrementally increased until a sufficient value of 36 drops was decided. Exposure times were also incrementally altered. One final procedure to be learned was removing the photoresist from the wafers.

Results: The easiest way to summarize is in the following table:

CANON		PERKIN-ELMER	
Exposure Time (s)	*Result*	*Exposure Speed (cm/s)*	*Result*
10	Underexposed	275	Underexposed
20	Pretty Good	225	Less Underexposed
30	Still Good	175	Pretty Good
40	Overexposed	125	Overexposed

The final recipe is as follows:

Photoresist – 36 drops
Canon Time – 20-30 seconds
Perkin-Elmer Speed – 175cm/s

Observations: In contrast to the previous lab, there was a great deal of hands-on experience here. Though the ideas of underexposure and overexposure had been discussed in class, the actual effects proved to be much more satisfying. In addition, this lab provided future motivation for cleanroom production and techniques. In short, the group really began to become excited and attached to the work and lessons being taught.

Highlights: The most enlightening part, as mentioned before, was seeing the harm and results of over/underexposure. Lithography came to life as each step became crucial – from adding the correct amount of photoresist to aligning correctly and so forth. Hopefully, the final recipe will prove successful in future projects.

LAB #4 – WET ETCHING/ANNEALING

Goals: To develop a "recipe" for etching/annealing that will be used in future labs. The "recipe" will include etching time, annealing temperature, and annealing environment.

Procedure: Again, the basic approach was through trial and error. Phil provided starting points (for some reason, he still didn't want to be in the cleanroom on Friday), and trial runs were examined for best results. Each of the two wafers was etched (Al in BHF, Ni in HNO_3). Each wafer was "cleaved" with a diamond-point pin for the various annealing conditions. The following variables were included in the trials: etching times for aluminum and nickel, annealing temperatures of 350°C, 400°C, or 450°C and annealing environment of H_2N_2 or N_2. A scotch tape test provided a quick assessment of the annealing effectiveness.

Results: The etching results were somewhat incomplete, whereas the etching times were not varied since there was only one wafer of each metal. The etching times are:

Aluminum: 3 min. 49 sec. Nickel: 4 min. 50 sec.

Both of these etch times proved to be much too long. (In future labs, the etching time was considerably reduced with better results.)

Annealing results are best seen in table format, shown here:

Process #	Temp (°C)	Gas	Scotch (Al)	Scotch (Ni)	Remarks
1	350	N_2	Pass	Pass	Al – Pinholes
2	350	H_2N_2	Pass	Fail	
3	400	H_2N_2	Pass	Fail	Ni – Gold color
4	400	N_2	Pass	Fail	Ni – Gold color
5	450	N_2	Pass	Fail	Ni – Dark, dark gold
6	450	H_2N_2	Pass	Fail	Ni – Dark, dark gold

The final recipe is as follows:

Aluminum: 450°C in H_2N_2 for five minutes

Nickel: 350°C in N_2 for five minutes

Observations: Overetching proved to be the greatest challenge of this lab. As will be seen in the next lab, this overetching created challenges in measuring the contact resistance (since many of the pads were etched away). It would have been helpful to have a little more guidance in the etching procedures and times. It turns out that we had enough problems in the next lab even without the overetching issue.

Highlights: Dressing in acid gear proved to be quite entertaining to all involved (except the actual acid-person). In reality, observing the results of different annealing conditions so clearly (such as how Ni failed the scotch test almost every time) was very educating to see. No amount of classroom talk could compensate for actual results.

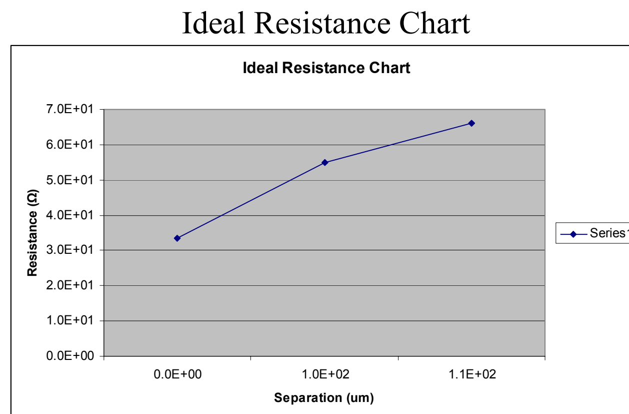
LAB #5 – CONTACT RESISTANCE

Goals: Determine the contact resistance for the various metals and annealments from the previous lab.

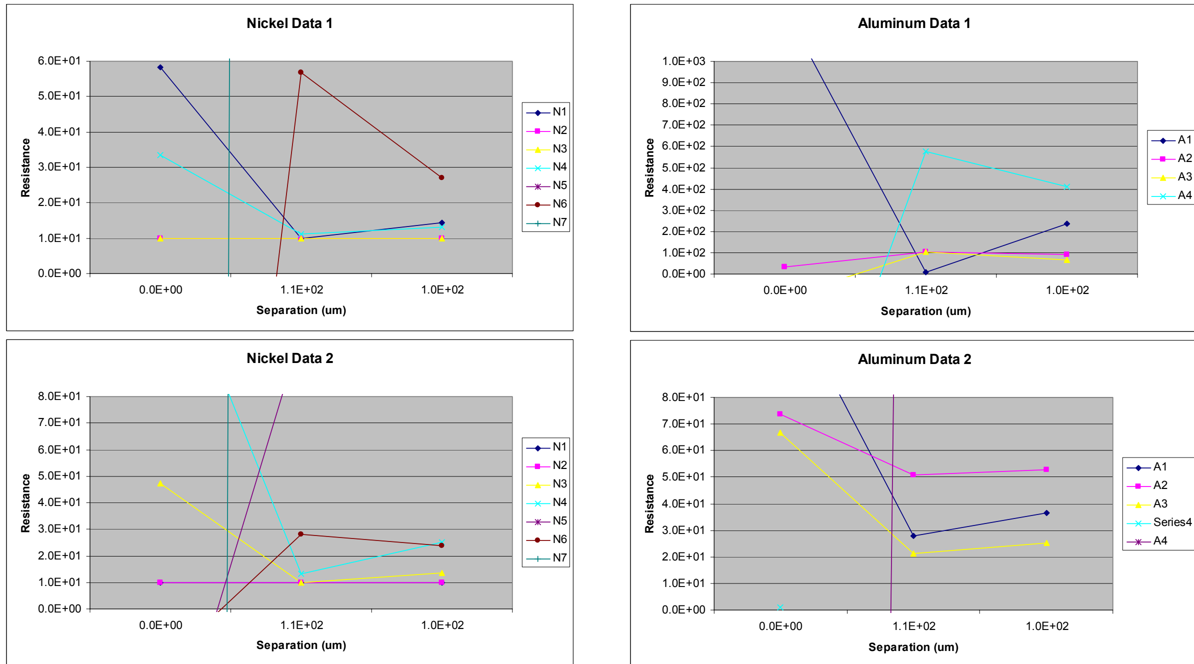
Procedure: The basic procedure for this lab is as follows: 1) Apply a test voltage from the parameter analyzer and obtain a resulting current between two pads on our wafers, 2) Calculate R_{PAD} using the measured values from step 1, and 3) Calculate R_C for the various annealments and metals. All of the calculations and data are easily stored in Excel.

Results: The following tables and charts depict our measurements and calculations of Contact Resistance v. Separation distance in two types of metals, nickel and aluminum. Most obviously noted is the erroneous data we gathered due to improper readings given by the instrumentation. In the ideal case, we should have seen a graph such as this:

Ideal Resistance Chart



Actual Resistance Chart (Erroneous due to faulty instrumentation)



Observations: Oops. Again, a little extra guidance could have saved us a lot of trouble and error. Many of our values recorded are erroneous due to faulty maximum current reading. As a result, we produced negative resistances! In retrospect, this problem could have been easily fixed by simply turning down the voltage measurement below 1V. In addition, it would help to instruct the TAs in using the parameter analyzers before the lab so if anything does come up (as it did in our case), it can be easily fixed.

Highlights: Watching Dr. Hawkins threaten to beat the parameter analyzer. Nothing else, really.

LAB #6 – OXIDE GROWTH

Goals: Grow a specified amount of oxide on silicon wafers using both dry and wet oxide techniques.

Procedure: This lab required the growing of two different widths of oxides. The first wafer (aiming for 1000Å oxide thickness) was processed using dry oxidation for 45 minutes. This wafer provided a basis for measuring thicknesses through three different techniques: color chart, ellipsometer, and the nanospec. The second set of wafers (aiming for 5200Å oxide thickness) was processed using 10 minutes of dry oxidation and 52 minutes of wet oxidation. After measuring the actual thicknesses, the <111> wafers should be etched to the desired thickness, if necessary. Our procedural flowchart is as follows:

Results: Using the three measurement techniques, we found the actual thickness of our dummy wafer to be:

Color Chart: 3250Å
Ellipsometer: 3526Å
Nanospec: 3500Å

Obviously, we missed our 1000Å mark, but Phil said that he was prepping the furnace for the wet oxidation process, and may have interfered with our dummy wafer.

For the second set of wafers, we measured:

<100> wafers: 5549Å
<111> wafers: 6788Å

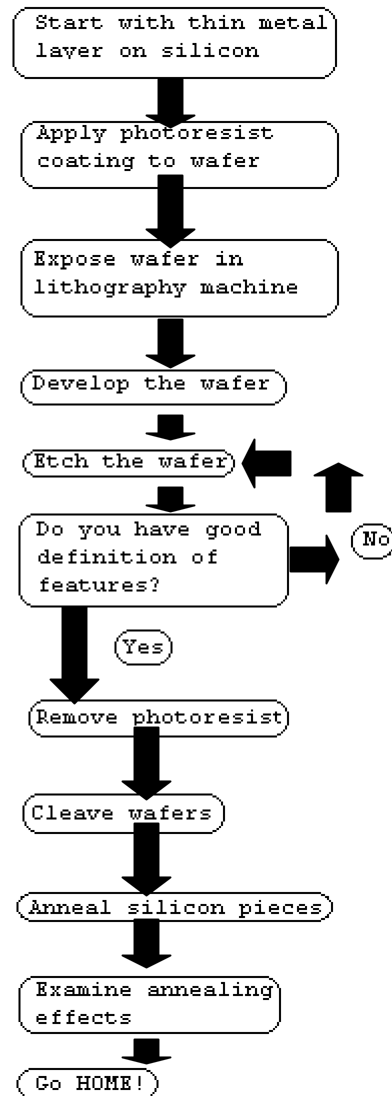
After etching the <111> wafers, the new thickness was measured to be:

<111> wafers [etched]: 5603Å and 5895Å

Although not ideal, they provided the proper color for the green base of the next lab.

Observations: It immediately became apparent that our "ideal" time calculations are reasonable estimates. In addition, it's better to err on the side of too thick an oxide layer as opposed to too thin. Thankfully, having too little oxide was one problem we didn't have to deal with. As far as the techniques for measuring thickness, they all proved fairly consistent and reliable. Needless to say, we favored the nanospec due to its simplicity (especially compared to the ellipsometer) and accuracy (as compared to the color charts).

TLM Patterned Metal Flowchart



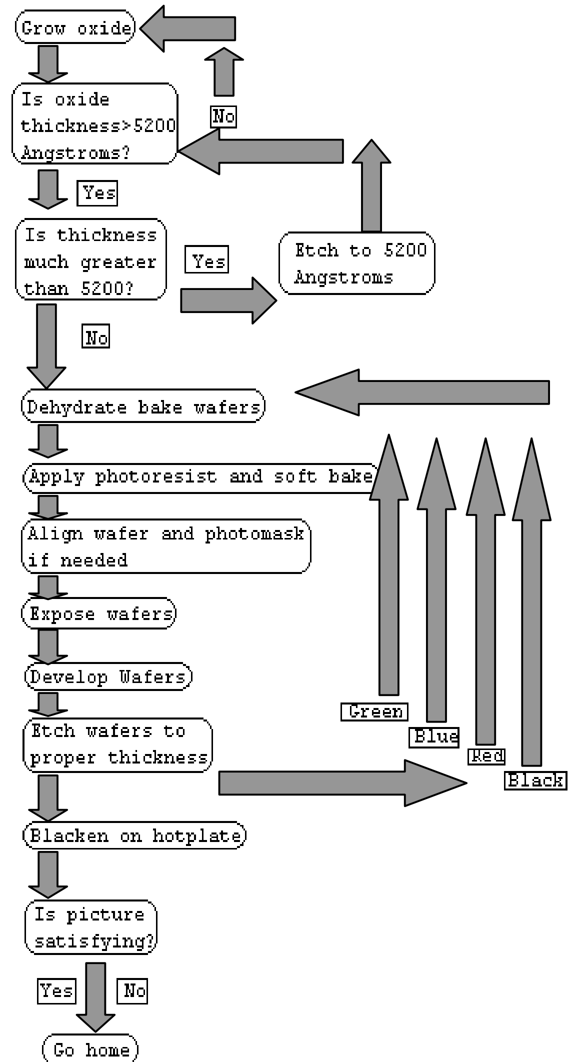
Highlights: It was interesting to see the ellipsometer technique for finding thickness, though it seemed like using an abacus compared to a computer. It was also great to have enough down-time to finish our lab report before the three-hour block ended. Unfortunately, we couldn't see much of the actual oxidation process since it all happened inside the furnace tubes.

LAB #7 – LEARNING PHOTOLITHOGRAPHY USING FULL COLOR DIELECTRIC PICTURES

Goals: Culminate the previous five labs in producing *Finding Nemo* color photo on our <111> silicon wafers. In addition, we will learn alignment techniques and about masks.

Procedure:
Refer to flowchart.

Finding Nemo Flowchart



Results: A very distorted, discolored version of the picture (although it was still apparent what the picture *should* have looked like). The following problems ruined our project:

1) Etch time. The lab write-up stated the BHF has a 1000Å/sec etch time. We took this literally. However, it should have been 1000Å/min, so instead of etching down to the 3100Å blue layer, we etched to the 4900Å blue layer and the 4650Å red-violet layer without realizing. This made it extremely difficult to see the alignment marks for the masks.

2) Alignment. As stated above, the alignment marks were nearly impossible to see (unless you are Dr. Hawkins). As a consequence, our masks were far from ideal, and the third mask we believe to have been aligned to the wrong set of marks.

3) Black Color. For the first wafer, we didn't realize that the hard-bake step comes BEFORE the development stage. As a result, we developed all the photoresist right off the wafer. For the second wafer, the misalignment mentioned above put the black coloring in all the wrong places.

Observations: Extensive processes such as this lab require great precision and careful procedure. Unfortunately, one little mistake at the beginning (etch time) cascaded into many greater and more visible mistakes. However, on the bright side, we're sure NOT to make a similar etch time mistake with our MOSFET.

Regardless of our lack of success, we enjoyed the process of learning from our mistakes. Most the previous labs were assimilated and used in the context of this lab. It sure would have been nice to have a picture we could have been proud of, though.

Highlights: Watching Dr. Hawkins get frustrated that none of us could see the alignment marks. All in all, this entire exercise was a highlight since we were creating something very visible and what should have been “a very satisfying color picture.”

CONCLUSION

Labs 2-7 were instrumental in preparing us for the creation of the MOSFET. The techniques we learned and mastered in these labs are critical to the correct development and execution of our MOSFET “recipe.” Learning from our mistakes, we are able to avoid the pitfalls of semiconductor processing. And, through these enjoyable exercises, we experienced our first hands-on exposure to the fundamental techniques of building semiconductor devices.