ND*nano* Undergraduate Research Fellowship (NURF)
2012 Project Summary

1) Student name: Jung Whan (Stephen) Kim

2) Faculty mentor name: Dr. Patrick Fay

3) Project title: High-Performance Solar Cell Fabrication

4) Briefly describe any new skills you acquired during your summer research:
Through this summer research, I learned and practiced the whole etching process of a solar cell from cleaning the wafer to taking the SEM images of the etched sample. The following list is a brief summary of what I have learned for this summer.

1. Mounting a small solar cell sample on a SiO_2 wafer - I used a thermal grease to fix the sample on a SiO_2 wafer for the efficient temperature control.
2. Oerlikon ICP, Alcatel ICP – These etchers are used to make the etching patterns on a small solar cell sample.
3. Ellipsometer – This equipment measures the thickness of a SiO_2 mask at the top of a small solar cell sample before we etch the sample.
4. SEM (Scanning Electron Microscope) – This microscope checks the etching patterns on a solar cell sample. I took the images to calculate the etch rate and selectivity of each etching recipe.

5) Please briefly share a practical application/end use of your research:
For my summer research, I focused on finding the etching recipe that can produce the clear etching patterns for a backside contact solar cell. Unlike a traditional solar cell, a backside contact solar cell puts the metals only on the back side. As a result, this backside contact solar cell can reduce the shadowing loss by the metals on the front side. My research contributes to the development of a backside contact solar cell because it needs a clear etching through the multi-junction structure for the current flow.

Project summary:
A solar cell is a device that converts the sunlight into electricity. A traditional solar cell has metals both on the front and back of the cell. We can increase the efficiency of a solar cell by using a backside contact solar cell. To make a backside contact solar cell, we need to develop the etching technique so that we can make the smooth and vertical etching patterns. Then, these patterns are filled with the metals for the current flow within a solar cell. My project has been focusing on testing the various combinations of chemical gases to find the best recipe for the solar cell etching.

For the first 8 weeks of this 10 week project, I focused on adjusting the ratios of three different gases, BCl_3, Cl_2, and H_2. I found the ratio that produces etching patterns with a vertical sidewall, smooth sidewall and bottom surface, and no undercut on the edge. However, the problems were the low etch rate and selectivity, which are the crucial factors of the etching process; if the etch rate and selectivity are too low, it takes too much time to finish the etching and we cannot etch the sample long enough because the SiO_2 mask is etched too quickly compared to the multi-junction solar cell, respectively.

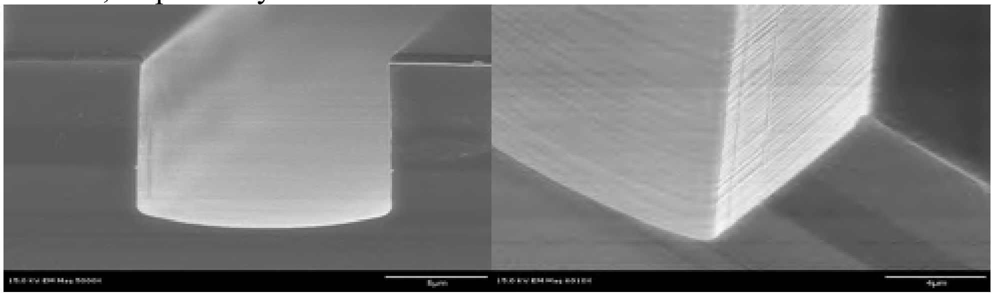

Figure1. Front Image and Sidewall-Bottom Image of $SiCl_4$ and Ar Etching.

For the last two weeks, I began to use the new gas combination, $SiCl_4$ and Ar. The result shows that the etch rate and selectivity values of the new method are much better than the previous recipes. However, we still need more etching tests to verify this result because it was the first trial and there have been some technical difficulties. I will pursue the further research on this new gas combination if the opportunity is given in the fall semester. For more detailed information, the readers can refer to my research paper below.

Publications (papers/posters/presentations):

UNIVERSITY OF NOTRE DAME
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2012 NURF Summer Research: ICP Etching on a Solar Cell

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My summer project involves the study of the various gas combinations to produce the etched patterns on a backside contact solar cell sample. The etched patterns should have a smooth sidewall and bottom surface and a vertical sidewall without the undercut on the edge. I primarily used five different gases: BCl_3, $SiCl_4$, Cl_2, H_2, and Ar. Throughout the summer, I worked with Yuning Zhao, a graduate assistant at Notre Dame, to adjust and test the various gas ratios and check the results on the SEM image. The results suggest that $SiCl_4$ based gas combinations have the best etch rate and selectivity, but the further research is necessary because we succeeded the $SiCl_4$ based gas etching only once and there are technical difficulties in controlling the gas flow.

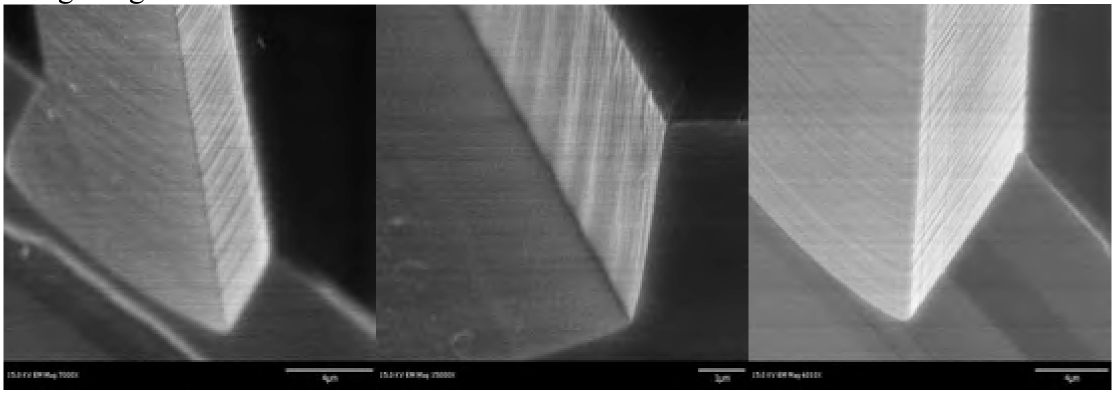
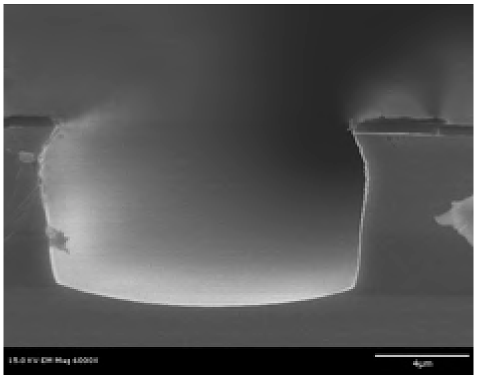


Figure1. SEM images of the etching patterns from the left: Sample #5 (BCl_3:12/Cl_2:5), Sample #6 (BCl_3:15/Cl_2:2/H_2:2), Sample #4 ($SiCl_4$:7.5/Ar:7.5)

As the images of the Figure1 demonstrate, all of the gas combinations of BCl_3/Cl_2, $BCl_3/Cl_2/H_2$, and $SiCl_4$/Ar produce the smoothly etched surfaces. However, the SEM images show the sidewall undercut for the BCl_3/Cl_2 based gas combination. According to the reference, we can solve this sidewall undercut problem by adding gaseous H_2 because it reacts with Cl_2 to reduce the number of radical ions used in the chemical etching. The reduction of the radical ions prevents the excessive chemical etching, the process responsible for the sidewall undercut.



Fiure2. SEM images of the etched 10um trench with the undercut: Sample #1 (BCl_3:15/Cl_2:2)

After I solved this undercut issue, I focused on the etch rate and selectivity, the crucial factors in the etching process. If the etch rate and selectivity are low, it takes too much time to create the etched patterns on a solar cell and SiO_2 mask at the top of a solar cell is etched too fast, respectively. Generally, the selectivity value below 10 is not acceptable. It is also important to note that the addition of H_2 decreases the etch rate and selectivity because of the less number of radical ions responsible for the chemical etching.

The two tables below summarize the characteristics of the etched solar cells that have smoothly etched surfaces. The first table lists the type of gases used, etching time, temperature, pressure, RIE and ICP power, and DC Voltage I measured from the Oerlikon ICP. The second table has the etch rate and selectivity values based on the initial height of the SiO_2 mask measured from the ellipsometer, the etched depth of the SiO_2 mask and the depth of the multi-junction 10um width trench measured from the SEM.

Sample Number	BCl_3	$SiCl_4$	Cl_2	H_2	Ar	Etching Time (min)	Temp. (C)	Pres. (mT)	RIE	ICP	DC Voltage (V)
1	15		2			10	180	2.4	100	300	152
2	15		2	2		8	180	2.4	100	300	131
3	12		5			4	50	2.4	100	300	141
4		7.5			7.5	10	180	2.4	100	300	138
5	15		2	2		8	180	2.4	100	300	140
6	15		2	2		8	180	2.4	100	400	152

Table1. The characteristics of the etched samples

Sample Number	Initial Height of SiO_2(Mask) (um)	SiO_2(Mask) Height after Etching (nm)	Semiconductor Etched Depth (um)	Etch Rate (um/min)	Selectivity
1	1.210 ± 0.050	452.04 ± 9.041	7.696 ± 0.3	0.770 ± 0.030	10.154 ± 1.287
2	1.210 ± 0.050	646.67 ± 12.933	4.169 ± 0.3	0.521 ± 0.038	7.365 ± 1.478
3	1.210 ± 0.050	923.44 ± 18.469	1.6355 ± 0.3	0.409 ± 0.075	5.707 ± 0.417
4	1.210 ± 0.050	655.07 ± 13.101	11.074 ± 0.3	1.107 ± 0.030	19.956 ± 1.946
5	1.210 ± 0.050	547.79 ± 10.956	4.170 ± 0.3	0.521 ± 0.038	6.297 ± 0.140
6	1.210 ± 0.050	534.43 ± 10.869	4.190 ± 0.3	0.524 ± 0.038	6.202 ± 0.126

Table2. The characteristics of the 10 um trench patterns of the 6 etched Samples. The magnification was fixed at 7000 for all the SEM measurements.

Based on the values in the Table 2, it is clear that the $SiCl_4$/Ar gas combination (Sample #4) has the best etch rate and selectivity value. On the other hand, other samples have a slower etch rate and low selectivity. There are several reasons for these low values. First, the low temperature in the sample #3 decreases the etch rate because of the micro-masking of a less volatile compound resulting from the low temperature etching. For the Sample #2 and #6, the addition of hydrogen gas affected the etch rate. There are less radical ions for the etching because the gaseous Cl_2 react with the gaseous H_2 in the chemical etching. For the Sample #5, we decreased the ICP power from 400 to 300 to compare the etch rate and selectivity with the values of the Sample #6. This lower ICP power should have a lower etch rate. However, for this case, the etch rate of the Sample #6 and Sample #5 are almost same because the change of the ICP power was not as significant as I expected.

In summary, the $SiCl_4$/Ar gas combination etching gives the best etch rate and selectivity. However, we need to work on adjusting the two gas ratio to verify the efficiency of this new gas combination and to maximize the etch rate and selectivity. If the opportunity is given in the fall semester, I will continue my research on this new gas recipe.