[MUSIC PLAYING]

PROFESSOR: Hello, everyone. Today we'll be taking a look at how light interacts with the surface of a solar cell. Right now I'm standing next to a solar module made up of individual silicon solar cells. If you look closely, these cells actually appear black. And they appear black for a very important reason. Solar engineers work very hard to make their solar cells as efficient as possible. Reflected light is lost energy, so good engineers will want to minimize the total amount of reflected light.

To make solar cells absorb as much light as possible, and appear black, solar engineers do two things. First, they grow this very thin film of a dielectric layer on the surface. This layer is aptly called an anti-reflection coating. Second, they texture the wafer. And today we'll demonstrate how texturing is performed, and quantify its enhancement for reducing light reflection.

Silicon wafers don't start out black. In fact, they appear gray. Polished wafers even look mirror-like, and reflect quite a bit of light. Here we see a polished wafer, which reflects around 1/3 of the light off its surface. And to create the rough surface that reflects less light, solar engineers immerse their silicon wafers into a hot, wet chemical bath, which helps create tiny surface features. In this example, we use a solution of potassium hydroxide, or KOH, which is heated to around 80 degrees Celsius. This violent reaction is actually etching into the silicon, and carving out little tiny pyramids on the surface. And the result is a wafer that loses its shiny appearance, and appears to have a dull finish.

The textured wafer is left with a surface that is covered with microscopic pyramids, whose base is around a micron, or about 1/50 of the width of a human hair. It turns out that this wafer only reflects about 1/3 as much light as it previously did. The reason this KOH which bath work so well at texturing the silicon surface is due to the fact that these silicon wafers are large crystals, which in this case means that the atoms are formed in an ordered, repeating pattern.

I have a model of the silicon crystal structure right here. On our model, I've highlighted the surface in red. Note that each silicon atom below the surface is actually bonded to four other silicon atoms, with four covalent bonds. Note that the surface atoms are only bonded to two other silicon atoms, and it has two bonds that are unbonded. The alkaline etch is able to remove silicon atoms more rapidly, when they have fewer bonds holding to the lattice. Hence, a solution quickly removes atoms on the surface.

Now if I were acting as the KOH solution, I would remove all the atoms that only have two covalent bonds. Let's remove a few atoms. So this one only has two covalent bonds. It gets removed. These three atoms on the surface only have two covalent bonds holding them, so I'll remove them as well. Let's go ahead.

Now we can see that after we have removed a few atoms, we have created some atoms below our original surface that only have two covalent bonds holding to the lattice. These atoms will also get removed by the KOH. Now if we continue this process, it would look something like this.

So what we're going to do is measure the reflectivity of both a flat and a textured wafer. First, we'll measure the flat wafer, and use a laser pointer as a light source to simulate sunlight coming from very far away point. We'll shine light down on the surface, and measure the amount of light that gets reflected or bounced back away from the surface, which we'll label as R.

So I'm standing next to our first experiment, which I just outlined in the previous sketch. We'll be using this laser pointer, shining it onto this silicon wafer, and into our photodiode. For those of you who don't know what a photodiode is, it is a tool that can measure the amount of light hitting its surface. The current that's read off of this ammeter will be proportional to the amount of light hitting our photodiode. To help visualize the beam path, we're going to use some steam.

Now if we turn on our laser pointer, hits our photodiode, and we can get a good reading. And right now we see that it's reading around 0.9 milliamps. But how does this compare to a textured wafer? Let's find out.

Now it's hard to measure the reflectivity of a textured wafer with a laser pointer, because it bounces the light off at several different angles, and we can't measure the entire beam with a photodiode alone. However, we can simulate what this would be like. Let's go to our sketch board to show how we can approximate this measurement.

To measure the reflectivity of a textured surface, we'll create a 10,000 to one scale model. We'll approximate our textured surface using two pieces of silicon. Again, we use a laser pointer as our light source, and shine it on one side of the pyramid. It'll bounce off that next surface, and off the adjacent side, and then we'll measure the amount of light reflected. Let's go to our experimental setup.

So let's clarify our set up. The two angled lines in our drawing, the adjacent sides, on our atomic models, and the two angled, non-textured wafers in our set up, are all representing the pyramid structure of a textured wafer, just like the one visible in our scanning electron microscope image. Let's use some steam to visualize the beam path.

Now that the steam has settled, we can get an accurate reading of the reflectivity of our modeled silicon surface. And I turn on our laser pointer. So now we can see that our photodiode is reading around 0.33 milliamps. This corresponds to around a 9% reflectivity, which is quite a huge reduction from what we had before, by about a factor of 3.

So in summary, today we learned how silicon is etched using a KOH solution, and how the resultant pyramids increase the efficiency of our solar cells, by reducing the amount of reflective losses by a factor of 3. If you found this interesting, please watch our other solar demos to learn more about how these exciting devices work. I'm Joe Sullivan from MIT, and thanks for watching. I'm out of here.

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