Schottky Diode – Procedure

Purpose

Diodes are one of the fundamental solid-state electronics devices. They can be found in most electronic circuits and are useful for their rectifying properties among other things. A common introductory lab activity in solid-state electronics is to show the rectifying properties of a simple diode. The current trend in nanotechnology involves many processes, one of which is to fabricate electronics at the nano scale. Diodes, and making them small, are of particular interest in the field of nanotechnology.

While commercially available diodes are cheap and readily available, the process of making one in the classroom is outside the realm of possibility for most, if not all, high school science labs. However, one type of diode that has many practical electronics applications can be fabricated in most standard high school science labs. This activity details the process for making a Schottky diode. This would be appropriate in a Physics, AP Physics, or Electronics course at the secondary level.

Background & Theory

Diodes exhibit the characteristic property of conducting electricity when voltage is applied in one direction and not conducting when electricity is applied in the reverse direction.

Semiconductors

Pure silicon is not a good conductor. It can be made to conduct by introducing certain impurities like phosphorous or boron atoms (a process called “doping”). Silicon is element 14 and has 4 valence electrons. Pure Silicon will arrange into a crystal structure where each Si atom will share electrons with its neighbors. Every electron is part of a bond so there will be no “free” electrons available to move. When a few Phosphorous atoms (which are similar in size to Silicon, but have 5 valence electrons) are added to Silicon, the Phosphorous atoms will replace a few of the Silicon atoms and there will be extra “free” electrons that can move and therefore conduct electricity. In this case, the charge carriers are the negative electrons and the Silicon is n-type. On the other hand, when a few Boron atoms are added to the Silicon, the reverse phenomenon occurs. Boron is also similar in size to Silicon but has only 3 valence electrons. Replacing some Silicon atoms with Boron will create some places that would normally contain electrons but now are missing, creating “holes” in the crystal structure. These “holes” act as positive charge. As electrons rearrange to fill them, these holes move. The charge carriers are now considered to be positive and the Silicon is said to be p-type.

Diodes

A diode is formed when n-type and p-type semiconducting material is brought into contact. A certain amount of mobile charge moves across the barrier until equilibrium is established. When a voltage is applied across the semiconductors, charge will flow in one direction and the device will exhibit ohmic properties. That is, as the potential increases, the current will increase linearly. When the voltage is reversed, no charge will flow for a certain range of voltages. The diode acts somewhat like a check valve in plumbing. Water flows in one direction under pressure, but when the direction of the pressure is reversed, the check valve prevents the flow of water in the reverse direction. When a circuit element allows current flow in one direction but not in the reverse it is said to exhibit rectifying properties.

Schottky Diodes

A Schottky diode is a type of diode that is also known as a barrier diode. Instead of forming a p-n junction, a Schottky diode is formed when two metal contacts are formed on a semiconductor surface. One contact becomes an ohmic connection and the other contact forms a barrier that exhibits diode properties. An ohmic

contact is one that has little resistance and allows charge carrier flow in either direction between the metal and semiconductor. Schottky diodes can be formed using either n-type or p-type semiconductors. If n-type Silicon is used for the semiconductor, Aluminum and Gold would be a good choice for the two metals. Aluminum has a work function less than Silicon and Gold has a work function greater than Silicon. In this case, the Gold forms the ohmic connection with the Silicon and the Aluminum forms the Schottky barrier. At the interface between the Aluminum and the Silicon, some mobile negative charge carriers (electrons) in the n-type Silicon will spontaneously migrate to the Aluminum to a lower energy (they move toward the lower work function). This will leave a region in the Silicon that is depleted of negative mobile charge carriers and therefore positive in charge. Further movement of electrons is slowed by Coulomb repulsion. Electrons will flow into the Aluminum until equilibrium is reached.

As a positive potential is applied to the metal, a smaller potential drop across the semiconductor will result. More electrons will diffuse toward the metal than into the semiconductor and current will flow through the junction. As a negative voltage (reverse bias) is applied, the potential across the barrier now increases, yielding a larger depletion region. The barrier restricts the electrons to the metal and there is no current. The Aluminum-semiconductor junction exhibits rectifying behavior. A large current exists under forward bias, while almost no current exists under reverse bias.

A Schottky diode can be made using p-type Silicon as well. However, the Aluminum will now serve as the ohmic connection and the Gold-Silicon junction is the barrier. Better results are achieved using n-type Silicon.

Materials

- 1 – 2” Silicon wafer (n-type or p-type: See Procedure to test the Si wafer for dopant type below)
- 1 small square (~4 mm^2) each of Aluminum and Gold foil
- Gas burner (Meker-type or propane)
- Ring stand and ring
- Ceramic Pipe triangle
- 2 – Scissors (1 for each metal)
- 2 – Tweezers (1 for each metal)
- 2 – Metal spatulas with long handles (~8”) (1 for each metal)

Materials to test dopant type:

- soldering iron - fine sharp tip is best
- DMM - with ability to measure current
- pointed probe for voltmeter to contact wafer surface
- bare alligator clip (no insulation because it will get hot) for voltmeter to attach to soldering iron

Materials to test diode:

- 9 Volt battery
- Miniature bulb (2V, 0.06A) and holder
- Wires with alligator clips
- 2 T-pins

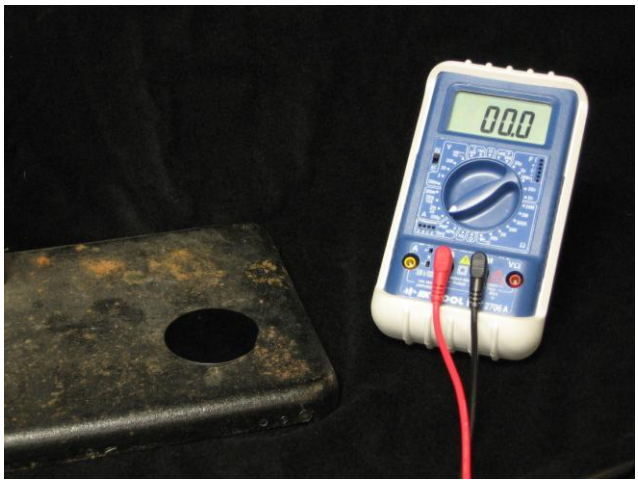
Safety

This procedure involves heating an object to very high temperature. Safety precautions should be taken to prevent accidents. Procedures should be supervised by an adult. BE SURE TO WEAR SAFETY GOGGLES WHENEVER WORKING NEAR FLAME

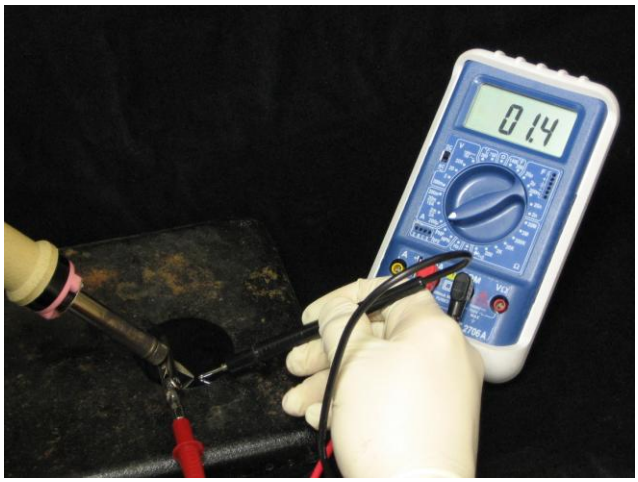
Test Silicon Wafer for Dopant Type

N-type Silicon is preferred for this activity. It is helpful to know the dopant type of the Silicon wafer in order to properly test the diode. If the type of Silicon you are using is uncertain, then perform the following procedure to determine the dopant type.

1. Configure the DMM as an ammeter to read the lowest possible current.
2. Connect alligator clip to one of the DMM leads. Plug that lead into the (+)/A terminal. Plug the other DMM lead into the (-)/ground/COM terminal.
3. Attach alligator clip to soldering iron tip. Turn on soldering iron (the actual temperature is not important, just let it heat up).



4. Once up to temperature, touch the tip of the soldering iron (the one with the alligator clip attached) to the surface of the wafer.
5. Touch the other DMM probe to the surface of the wafer (get as close to soldering tip as possible without touching).
6. The polarity of the current reading determines type: (-) is p-type, (+) is n-type (The magnitude is not important).



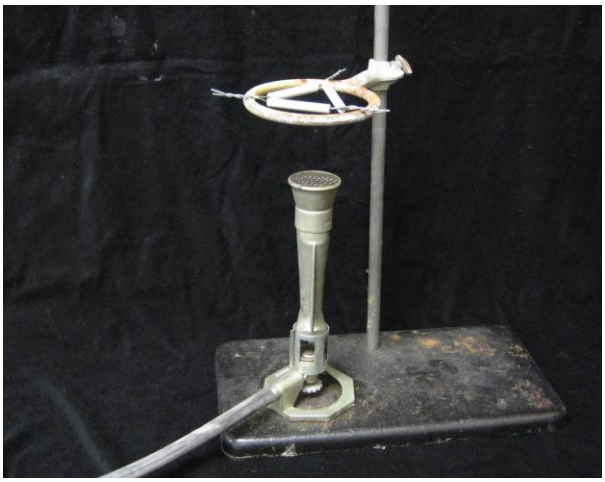
7. Switch connections to DMM (alligator clip to (-)/ground, pointed probe to (+)). Repeat the measurement. The polarity of the current measured by the DMM should be opposite to that read in step 7 (this is a sanity check to make sure it is working properly and that the DMM can actually measure low enough)

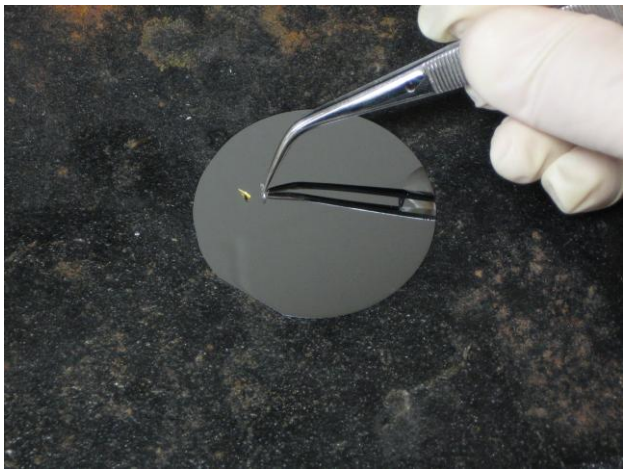
Explanation:

Charge carriers behave similarly to gases. When a gas is heated, the gas molecules gain energy and the gas expands. There is a net movement of the gas from hot to cold. When the soldering iron tip is in contact with the wafer, the majority charge carriers will move away from the hot tip. The cold tip collects the charge. This movement of charge is current, which can be detected by a DMM in ammeter mode. The polarity is dependent on the majority carrier type (and dependent upon which terminal the hot probe is connected to on the DMM).

Prepare the Diode

It is important to prevent contamination of the gold and aluminum foils. Scissors, spatulas, and tweezers should be designated for one metal. Also wear latex gloves when handling the wafer and foils to prevent skin oil contamination.

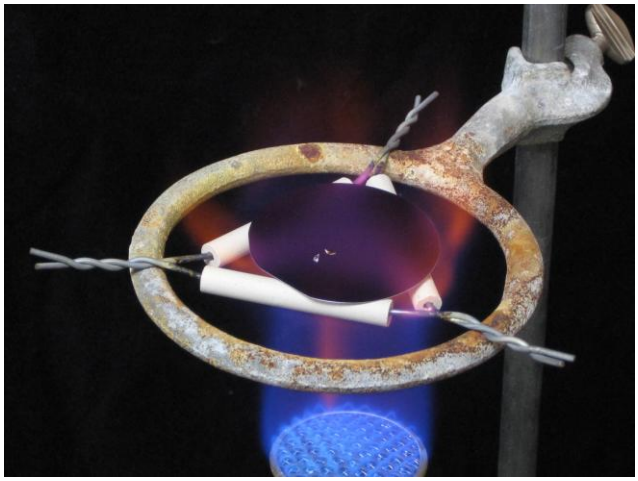


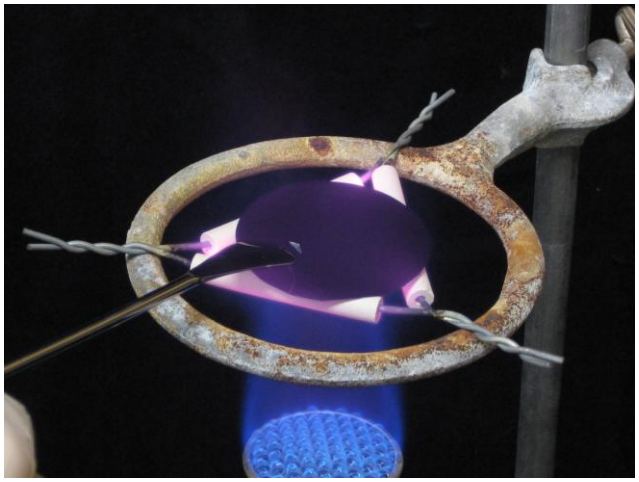


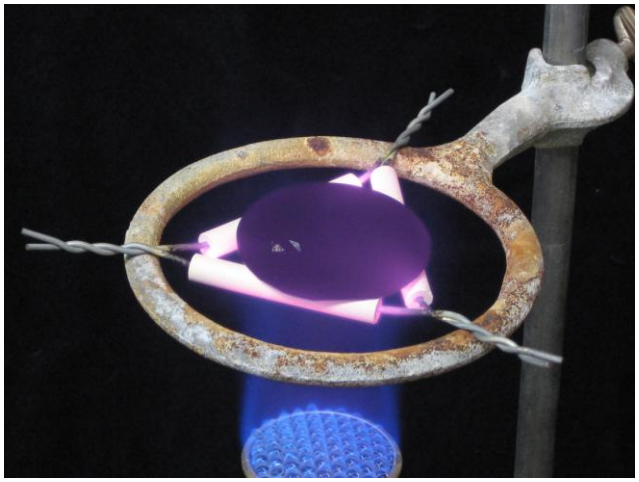
1. Set up the ring stand and Meker-type burner. Place the iron ring so that the hottest part of the flame will be at the ring. Place the ceramic pipe triangle on the ring. The triangle serves as the platform for the wafer.

2. Prior to lighting the burner, prepare the Silicon wafer (preferably n-type) by snipping off a small piece (~2mm^2) of gold and aluminum foils onto the wafer. The foil pieces should be placed within a few millimeters of each other, but not touching. Carefully place the wafer on the triangle so that it is well supported.

3. Once the burner is lit, it can be helpful to dim the lights. The wafer will begin to glow in a short time and it will be easier to see with the lights dim. All objects glow a reddish orange when they reach about 600°C. This is significant, because 577°C is the temperature necessary for the Aluminum and Silicon to form a eutectic. Aluminum melts at 660°C, but when it is in contact with Silicon, a eutectic forms with a lower melting point. The eutectic point of Gold and Silicon is at a much lower 360°C, so high temperature is for the Aluminum. The orange/red glow of the wafer is a visual cue that the correct temperature has been reached.







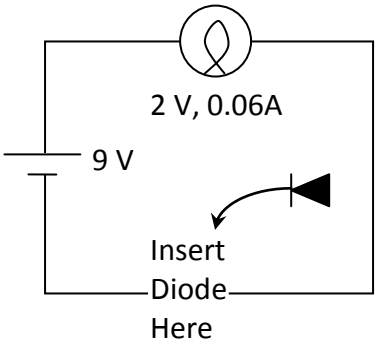
4. Once the wafer is glowing, try and make good contact between the foils and the wafer by carefully using the edge of the designated spatula to press down on the gold and aluminum foils. Contamination will ruin the diode, so be sure to use the appropriate tool for each metal. Also, BE VERY CAREFUL not to press too hard or you will shatter the wafer and hot pieces may fly out. It is also possible that the foil pieces will adhere to the spatula. It may work best if you use the edge of the spatula as opposed to the flat area. In any case, do not leave the spatula in the flame too long. Metal tends to be a good conductor of heat. Also, be aware that after the spatula is removed from the heat it will remain very hot.

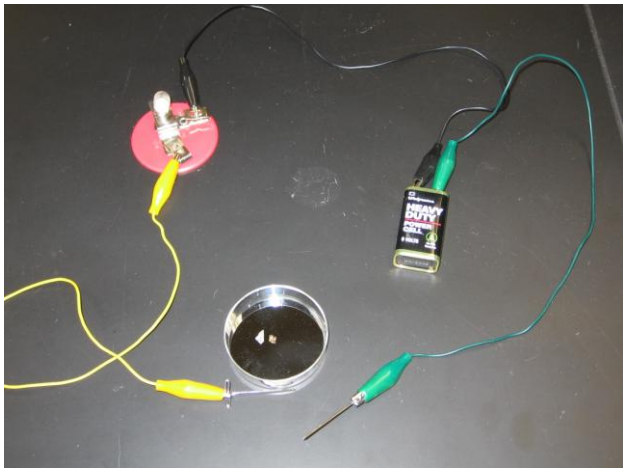
5. The whole process may not take more than a minute depending on how close the wafer is to the hottest part of the flame. It is important to not overheat the wafer because the barriers may not form properly and there may be no diode properties.

6. Once the foils have adhered to the wafer, remove the heat and allow the wafer to cool. The wafer can be carefully removed from the triangle with tweezers. It will cool within a minute or two when no longer in contact with the triangle. Before handling, be sure it has completely cooled. You can gently place the wafer on the table top for a few seconds and the remaining thermal energy will be deposited in the table top. After this, it can be handled with your hands. Now you are ready to test your diode.

Test the Diode

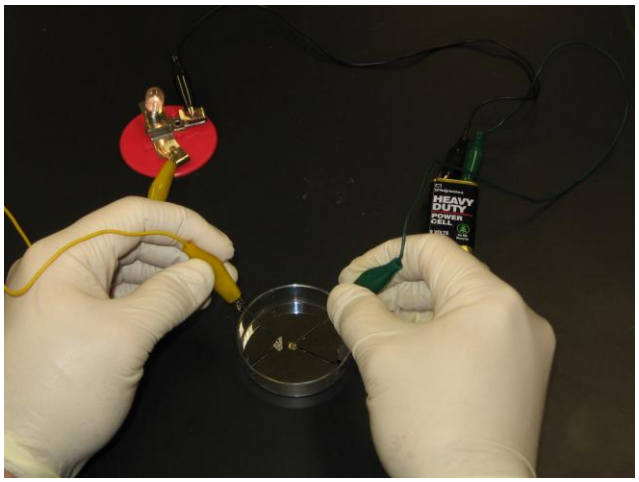
Because the diode making process is not very well controlled, the results will be spotty. The age of the wafer and potential for contamination can make it difficult to observe the rectifying property of your diode.

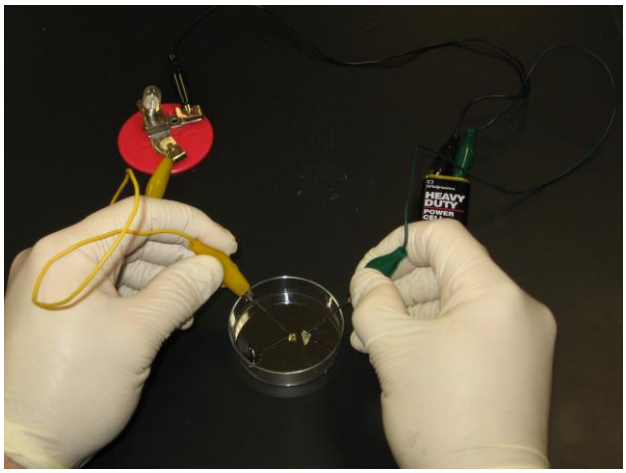




1. Set up the testing circuit by following the schematic shown above.

2. Attach T-pins to the free ends of the wire.





3. Touch one pin to the gold foil and the other to the aluminum foil. Observe the bulb.

4. Switch the position of the pins so they contact the other foil and observe the bulb.

5. When using n-type Silicon, a positive voltage at the Aluminum should conduct and cause the bulb to light.

6. When using p-type Silicon, a positive voltage at the Gold should conduct and cause the bulb to light.

7. Add an ammeter to measure the current.

8. Add a potentiometer to vary the voltage.