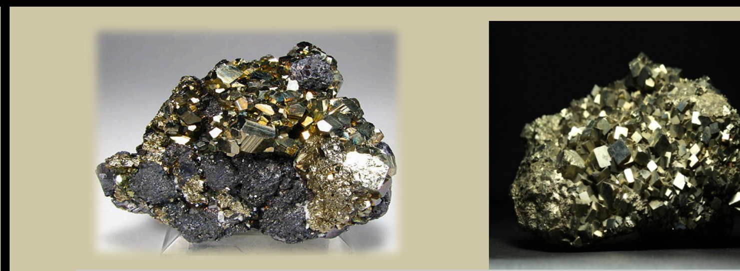
Ivy Chang Hamilton High

INVESTIGATION OF THE ELECTRICAL PROPERTIES OF METAL/PYRITE (FeS_2) JUNCTIONS



Arizona USA

Abstract

The nontoxic semiconductor pyrite FeS2 appeals to us as a good candidate for solar cells because it has a small bandgap (0.95 eV) and is made from inexpensive materials. The electrical properties of the variety of metals (Au, Ni, Cr, Al, Fe) deposited on pyrite (FeS_2) were investigated for future application in pyrite photovoltaic technology. From the first set of data collected, Cr, Al, and Fe pyrite junctions exhibit rectifying behavior that were Schottky barriers. The electrostatic potential barrier of the Schottky barrier depletion region creates an internal electric field which separates electron hole pairs by light. Au and Ni pyrite junctions have linear non-rectifying current-voltage (I-V) characteristics (ohmic). Our next step was to test Cr, Al, and Fe junctions with a layer of indium (In) pressed upon the surface to serve as an Ohmic contact. Fe showed ideal characteristics of a Schottky barrier; however, the small barrier height and the large series resistance did not facilitate the determination of an accurate barrier height at room temperature. Low temperature measurements will be carried out so that more ideal Schottky barrier characteristics can be obtained; since the current transport through the depletion region of the Schottky barrier falls exponentially while series resistance falls much slower when the temperature is lowered.

Background Information

As one of the earth's abundant materials, the small bandgap, nontoxic semiconductor (0.95 eV) pyrite FeS2, appeals to us as a good candidate for solar cells. The integrated absorption coefficient for the spectrum of wavelength values between 300 and 750 nm is almost the same as the visible light range, making it ideal for photovoltaic application. Unlike silicon (Si), pyrite is easily obtainable at a very low cost (Wadia et al 2009:2568). Out of 23 promising semiconducting materials, twelve materials were found to meet or exceed the annual worldwide electricity consumption. Further elimination allowed only nine possible candidates for their potential for a significant cost reduction. Extraction cost was a factor and the unconventional solar cell candidates included: FeS2, CuO, and Zn3P2 (Wadia et al 2009:2702). For high volume production of solar panels, cheaper material for commercial use will be a huge factor to drive research advancement.

Procedures

In previous studies [Newman], the clean condition of the surface proved to be independent of the barrier height. However, to ensure all factors are well controlled, the samples will be cleaned and polished as best as possible for consistent results. There are five metals (Ni, Au, Cr, Fe, Al) will be investigated.

The experiment procedures are as below:

- Using the dicing saw (Fig.1), correctly place the sample so there will be a parallel cut.
- Polishing step must be executed thoroughly with the right processes. Using (in order) 240 grit, 400 grit, 800 micron, 9 micron, 6 micron, 3micron, and 1 micron pads interchangeably (Fig.2), a shiny, flat surface is achieved with tedious examination under a microscope.
- The completed sample will then be cleaned with water, soap, acetone, and ethanol.
- The sample will be taken to the Denton Vacuum. Placing the mask carefully over the sample, clips will be used to fasten it in place (Fig.3,4).
- Vacuum will be pumped down so that no air contaminants will cause any damage during evaporation.
- I-V measurements will be taken from all the samples with evaporated metals.
- Nitrogen gas (N_2) will be used to dry the surface of any miniscule particles.
- Wearing gloves place the probes on two different dots of the deposited metal and pressed down further to penetrate the oxide layer (Fig.5).
- The light should be turned off, and the lid should be closed to leave the sample in complete darkness. Measurements will be taken.

Fig. 1: Dicing Saw

Fig. 2: Polishing Materials

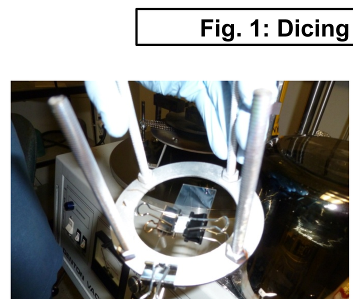


Fig. 3: Before the Denton

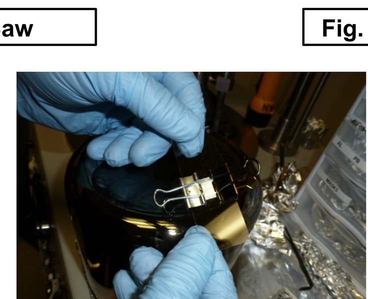


Fig. 4: Mask and Pyrite

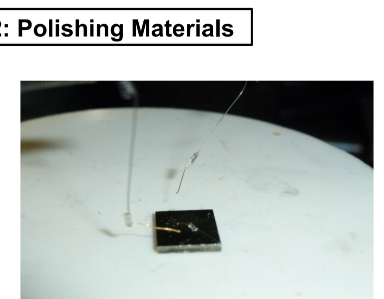
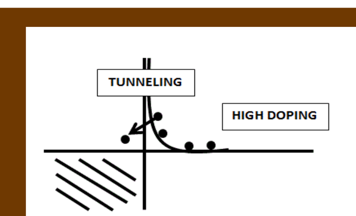


Fig. 5: Pyrite with Probes

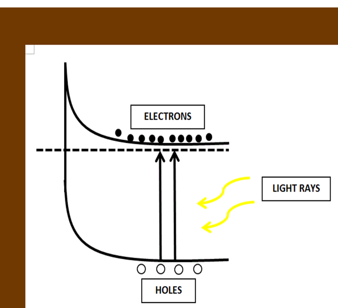
Photos taken by myself

How do the different metal-semiconductor junctions' electrical properties allow further understanding for future development of pyrite solar cells?

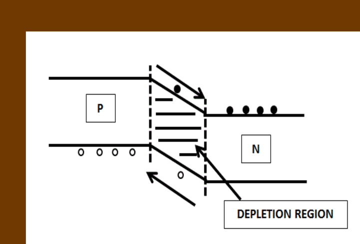
Data/Analysis

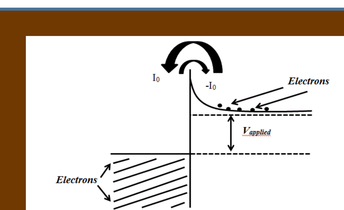


Although it may seem like every metal and semiconductor produces a Schottky barrier, metals like gold and nickel (at room temperature) were ohmic. This can be explained through tunneling, where the electrons "sneak" into the metal. At lower temperatures, more Schottky barriers may be seen from these particular metals.

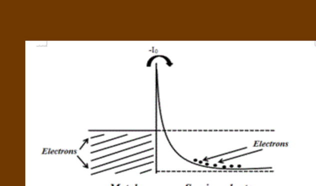


Why are we interested in Schottky barriers? Schottky barriers, unlike the behavior of ohmic contacts, produce depletion regions. These regions are where light rays enter and produce electron hole pairs that separate to create current which is commonly known as the photovoltaic effect. Holes travel upward (soap bubbles) and electrons roll downward (rocks down a hill). It is in our best interest to find a metal that produces a Schottky barrier so it can be applicable to possible development in solar cells.

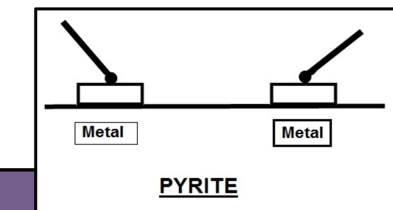




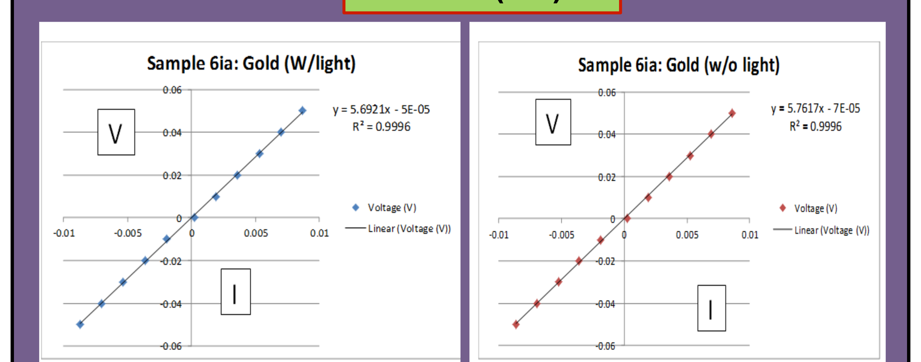
Rectifying behavior can be explained through how voltage affects the electron flow from the semiconductor into the metal and vice versa. When voltage is applied (bias), this raises the Fermi level (quasi Fermi level) and enables electrons to pass over the barrier into the metal easier. Therefore, on the graph, this side of the graph would have more amount of current.

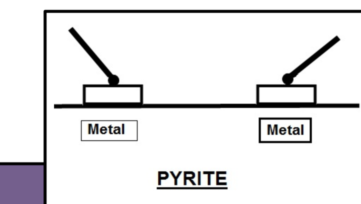


However, when the voltage is applied so that the quasi Fermi level is lowered, the energy of the electron isn't high enough to go over the barrier. Therefore, on the graph, this side of the graph would have less amount of current.

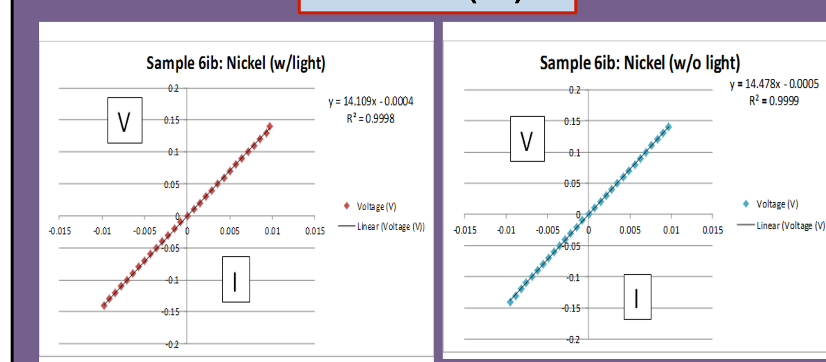


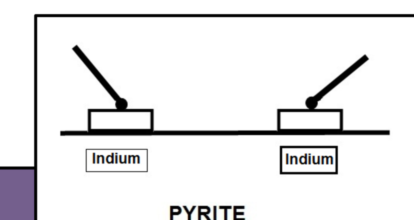
Gold (Au)



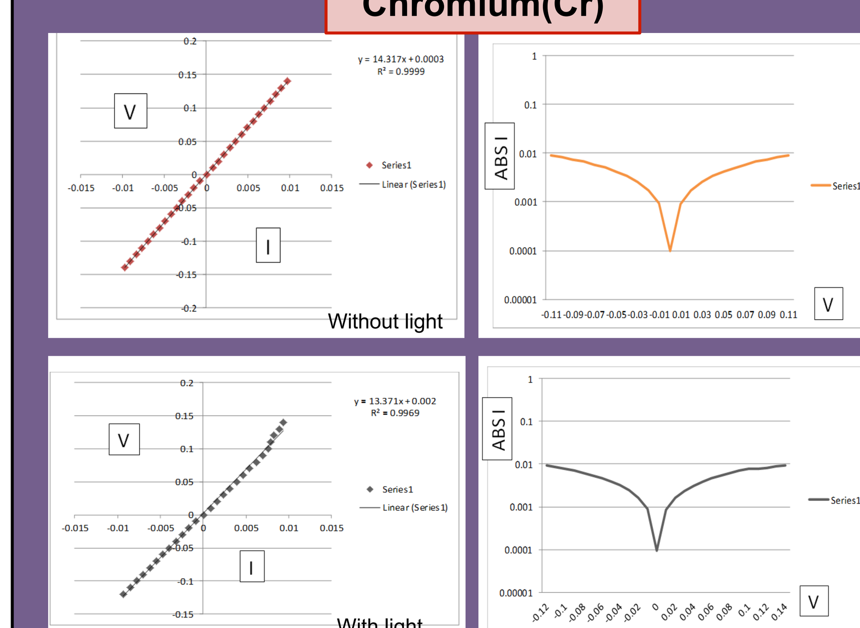


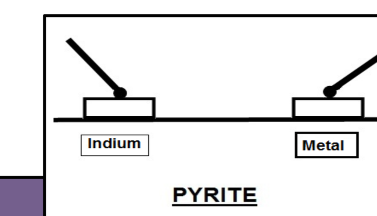
Nickel (Ni)



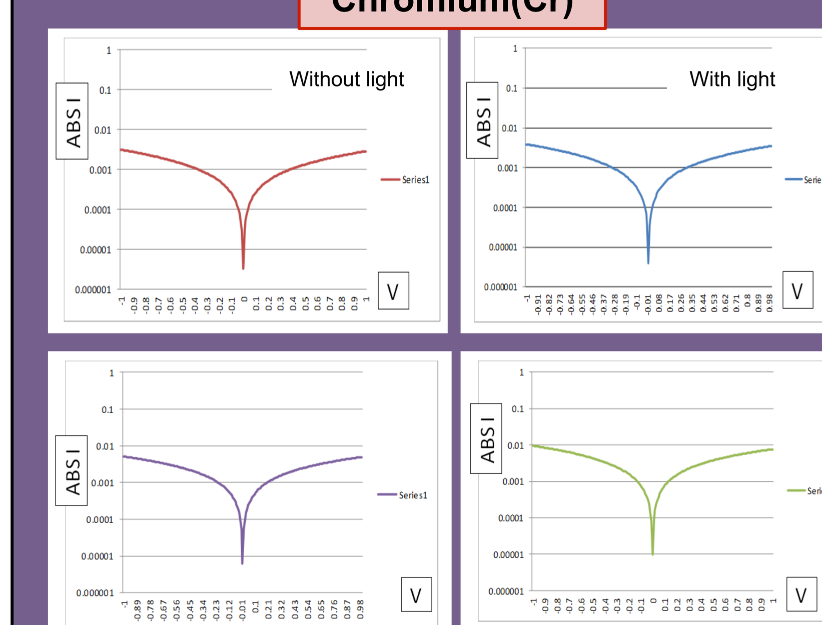


Chromium(Cr)

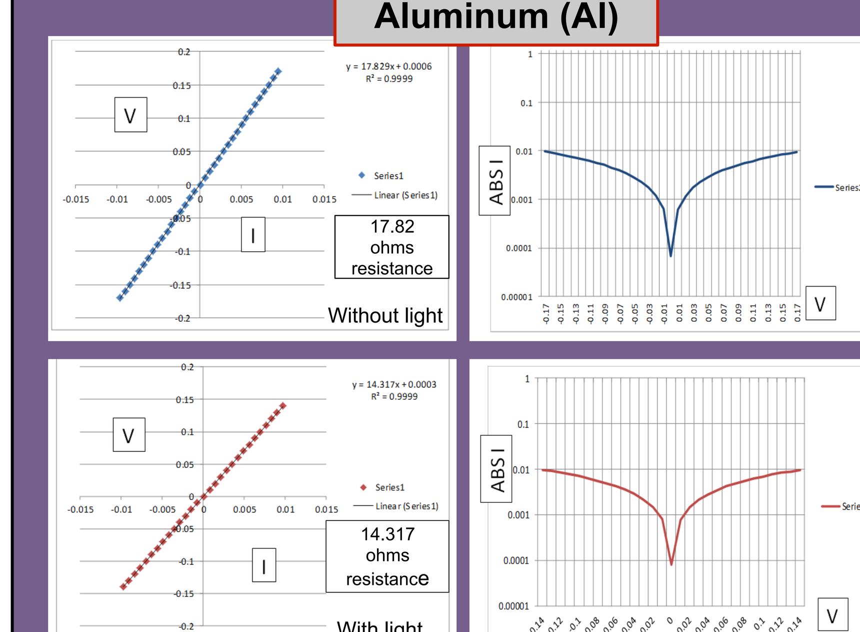




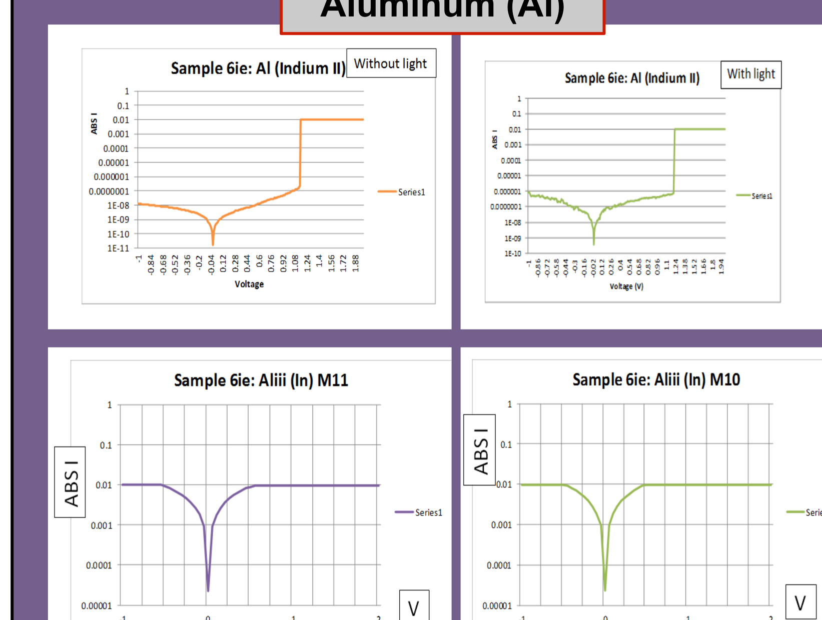
Chromium(Cr)



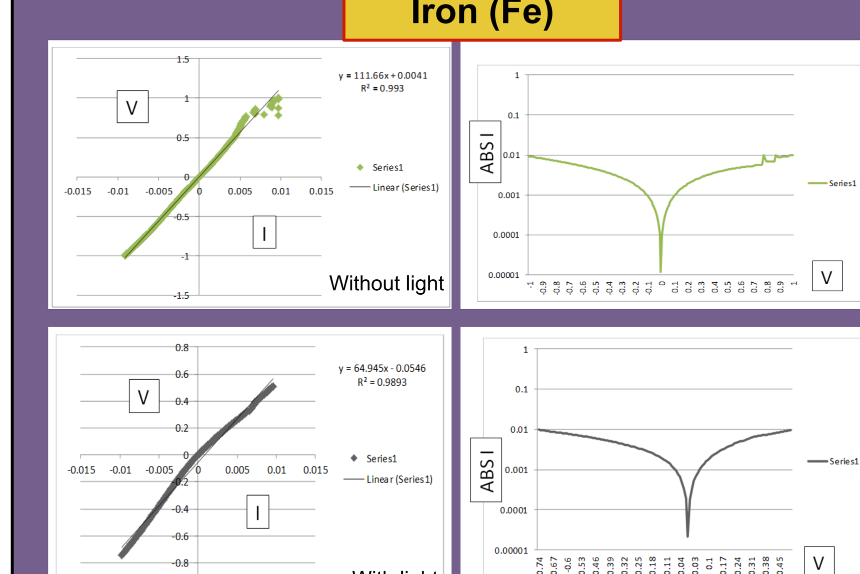
Aluminum (Al)



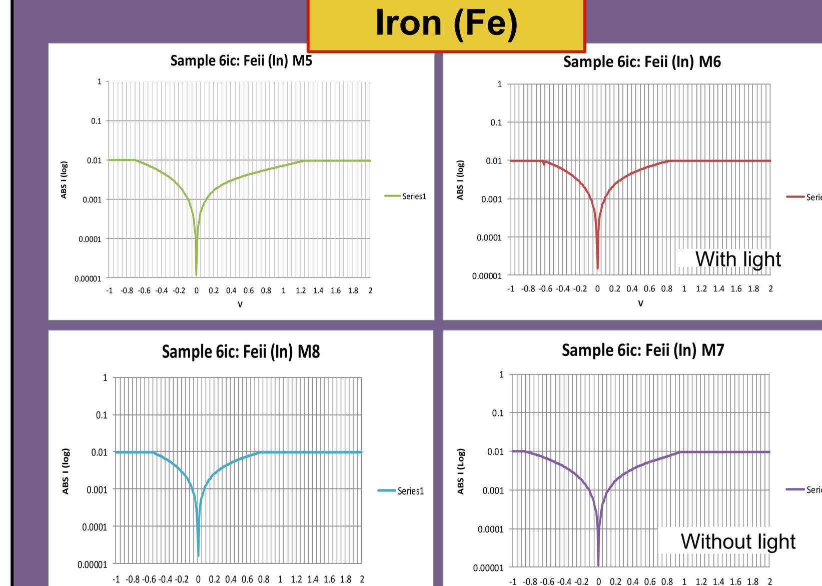
Aluminum (Al)



Iron (Fe)



Iron (Fe)



Conclusion

The sufficient amount of data revealed to us that Iron contacts produced a Schottky barrier with its rectifying behavior. The depletion region's internal electric field allowed photons to create electron-hole pairs that were separated and collected to generate electricity. However, the photovoltaic effect is not measurable because the sensitivity to the current produced from the light is deterred with the current produced from the dark. This is caused by the small Schottky barrier height produced by Iron contacts. Au and Ni showed definite ohmic results observed from the linear pattern. Cr sparked interest with its slightly exponential data. However, in the indium to indium trials, Cr proved to be ohmic. Al needs to be further studied to determine whether a Schottky barrier was present. These results contribute to photovoltaic application as the experimentation continues.

Discussion of Results

Five deposited metals were evaporated upon clean pyrite (FeS_2) surfaces. The aim for this experimentation was to explore the range of various work functions of metals to find Schottky barriers. Three sets of experiments were tested with I-V measurements. The results demonstrated that evidence of Schottky barriers could be found at room temperature.

Aluminum was rectifying. Unlike the other samples, it showed a barrier height large enough to be calculable. With no voltage, there was no current. The jump to .01 was a linear pattern that was seen in previous studies (Newman et al 1986: 1149). Aluminum's resistivity dropped from 17.829 Ω to 14.317 Ω when light was applied. This is expected for the photons are supposed to increase the current flow and therefore decrease resistivity. The previous experiments did not have either ends of the graph go to .01. However, the indium-to-indium contact was perfectly ohmic. Since the indium was already pressed on, these results were queer. After increasing the voltage from -1 V to 2V, the Schottky barrier was evident. Iron, like aluminum, was rectifying and tested three different times. The initial results did show bad contacts, however the interesting curve that appeared ohmic was going to be tested again. The resistance dropped significantly from 70.713 Ω to 35.741 Ω . Although the drop was predicted, the high resistance is questionable. Gold and Nickel produced non-rectifying results (linear) that was ohmic. Nickel might be measured again for repeatability for the data was not consistent. Chromium was rectifying from the first set of data. However, when the indium measurements were taken, it was ohmic (non-rectifying, linear).

During experimentation, errors could have occurred that might have deterred the results from becoming completely accurate. The cleanliness of the surface might have had contamination from the outside environment. The penetration of the oxide layer during experimentation might have not been able to contact the probe to the metal. Repeatability is a concern in some of the results. The probe contact to the surface of the pyrite could have not touched the metal, rather measured the pyrite. Examination of results might have overlooked the ohmic results and just assumed it as linear. Multiple trials will then firmly determine whether these results are accurate.

Future Research

The deposited metals (Au, Ni, Cr, Fe, Al) were tested at room temperature to have only found Fe showing evidence of a Schottky barrier. By cooling the experimentation environment to ~20 K, Al and other metals may prove to have rectifying behavior. This experimental set up will measure the resistance of the depletion region rather than the series resistance. The information obtained from the resistance will directly be able to determine the barrier height. Barrier height has a direct correlation with the area of the depletion region. Further research can also include expanding the study of the electrical properties of more metals (Ag, Mg, etc.). To fully understand the photovoltaic effect, use of "transparent" metals will increase the ability for light rays to reach the depletion region (Figure 1). Such metals that might be used are a thin gold layer, or indium tin oxide. Other metals might act inefficient as thin metals for measuring the Photovoltaic effect.

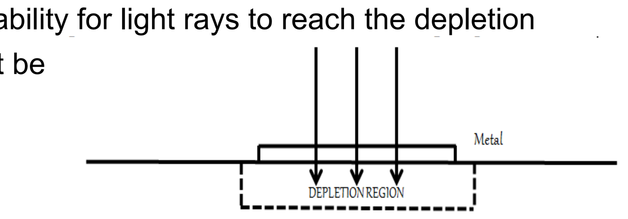


Figure 1: Light rays (arrows) pass through the metal and into the depletion region.

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