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A Review of Electromagnetic Radiation Impacts on Heterojunction Intrinsic Thin Layer Solar Cells

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Abstract— Heterojunction Intrinsic Thin Layer solar cells (HIT cells) are a fascinating variant of the solar cell, which has its development centered with the special "thin" intrinsic layer. These solar cells are relatively modern compared to those first created. Despite such solar cells, their relationships to electromagnetic radiation have yet to be fully specified. This review will focus on the Photoelectric Effect, Diffraction and Interference, Absorption and Emission, and Ionization of electromagnetic radiation on these specific cells. Furthermore, mathematical representations of energy with and without gratings will be referred to. Although HIT cells respond similarly to electromagnetic radiation as general solar cells, their design and novel developments have led to a few differences in structure and thus efficiency. In general, HIT cells function via the photoelectric effect with diffraction gratings or metal gratings using light's wave properties to improve efficiency. Depending on the wavelength of electromagnetic radiation, light is absorbed—the intrinsic layer aids in increased open-circuit voltage.

***Index Terms*— Physics, Solar Cells, Electromagnetic Radiation, HIT Cell**

I. INTRODUCTION

Heterojunction Intrinsic Thin Solar Cells (Fig. 1) were a novel development by Sanyo in the 80s. They have a particular diagram with an intrinsic layer of i-Si which surrounds (on both ends of) either n-type or p-type c-Si or crystalline silicon layer in the middle (each of these types exists for use or demonstration purposes) [5]. Functioning based on similar principles to regular solar cells, there is only a difference in the band diagram (Fig. 2). With amorphous n-type doped layers on top and p-type doped layers on the bottom, the p-type crystalline silicon serves as the primary electron and hole source, easily obtained as the n-type Si on the top layer enables visible light, notably from the sun, to penetrate the middle layer. The band diagram demonstrates a curved center with a curved edge on the right (relatively thin, the intrinsic layer) and a thick block. The opposite side is asymmetrically similar (as opposites/reciprocals). The result is the hole not enabled to jump bandgaps into the n-type while the electrons cannot enter the p-type layer, forcing them to go to the p-type and n-type, respectively. From such ends, Ag's wires will be collected on top, sometimes with ITO (indium-tin-oxide) as a conductive oxide to not absorb photons meant for the solar cell. With more conductivity, such materials aid the HIT cell. As stated by Nainani, electrons can flow through the wires from the n-type to the p-type and power electronic devices. The existence of solar cells enables the capturing of solar energy in light for usage as electricity for modern electronic devices. This process involves diffraction gratings for increased efficiency through light's wave properties, and visible light through the photoelectric effect ultimately enables electricity harnessing. Visible light is used by the HIT cell as well [10].

II. GENERAL SOLAR CELL FUNCTION

Solar cells use materials that can absorb light to receive energy from photons and thus get holes and electrons through the effect known as the photovoltaic effect. The photovoltaic effect helps to make electricity from photons in light through the medium of solar panels. Solar cells are constituents of solar panels. Visible light from the sun can be considered the energy that can lead to electrons having their energy levels increased and eventually exiting from their bonds when impacting a solar cell. The cell has a nice setup, leading to a voltage difference in two different sections, which can then be used, through a circuit, to power electricity-using objects [6]. Solar cells have n-type and p-type layers of silicon. N-type silicon has extra electrons while p-type has “holes” for the extra electrons to go to. These two layers are separate. Light it like a stream of photons in this case where the photon will be able to excite an electron out of the silicon bond of the n-type semiconductor. This will in turn, free up a hole to move to the p-type and the electron to get collected by metal. This metal will then be routed through an electronic device to power it before the electrons go to the p-type layer and rejoin with their “hole.”

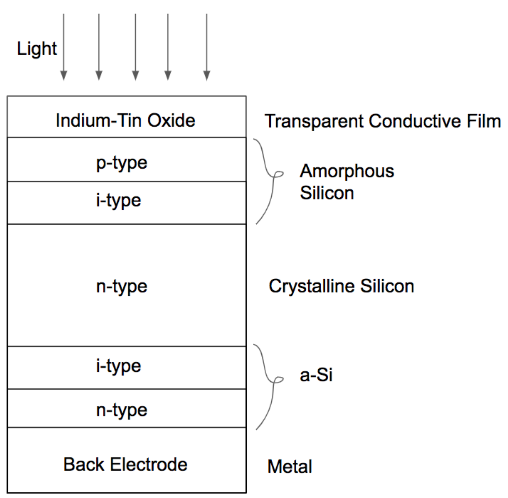

Figure 1: Layout of the HIT Cell as a Cross-Section. You can see the ITO (indium-tin-oxide) layer on top, followed by HIT solar cells' usual set up layers. Please note that the c-Si in some research is that of p-type.

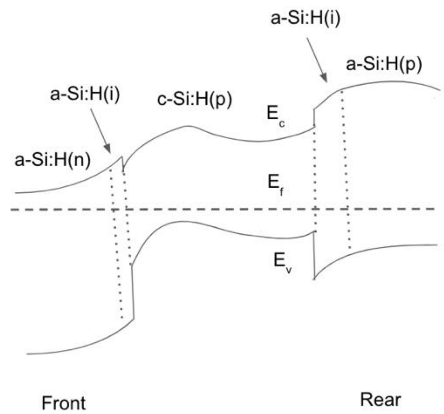

Figure 2: Band Diagram of the HIT Cell, labeled. You can see the sloping up section directly under the a-Si:H(i) to be the intrinsic layer, with this specific side enabling easier tunneling for electrons while the other end blocks holes.

VI. PHOTOELECTRIC EFFECT

The photoelectric effect enables only light of the wavelength of visible light (no lower in frequency or no higher the wavelength since “speed” of the waves is higher when the frequency is high and thus wavelength is low) to ionize the electrons. This is since the wavelengths of no less than visible light will be absorbed by electrons. For solar cells, visible light is enough to be absorbed by the electrons. Next, electrons turn into photoelectrons that are emitted and can get collected in the n-type doped layer of silicon while the positive charges collect at the p-type. Thus, all a solar cell is doing is providing a means of getting and harvesting this newfound photoelectron energy. By routing the electrons through a circuit, work can be done [6].

Similar research has been done on absorption coefficients of Si QDs/SiC MLs, yielding graphs for the visible light spectrum. Corroborating research previously accomplished, this publication proves that absorption occurs for wavelengths of visible light with varying degrees dependent on thickness and size. The sizes of Si QD deeply impacted photovoltaic performances, although they produced similar-pathed

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graphs. Towards 800nm there is a decrease of the coefficient although it never reaches zero, signifying the photoelectric effect in that any photons of energy higher than the threshold (typically situated at the visual light range) can be absorbed. As described by Borlace in a future paragraph, the decrease is likely contributed by the design and harmful effects of higher frequency electromagnetic radiation [1].

III. WAVE PROPERTIES: DIFFRACTION AND INTERFERENCE

The diffraction grating (Fig. 3) is used in solar cells to maximize efficiency by channeling light into specific solar cells' particular areas. Grating geometries are studied to aid in this process—for instance, backside grating using quadrilateral geometries aid in light distribution and thus increased efficiency. Light passes through these quadrilaterals and, via the wave properties of diffraction and interference, get distributed and lead to both negative and positive interference. In simplified terms, they can add or cancel each other. These are in turn reflected for use for energy purposes. In this case, visible light enters, diffracts, interferes, and gets reflected to be more evenly distributed than a concentrated beam and thus usefully ionizes (or excites electrons with so much energy that they leave their orbital) silicon atoms in the crystalline layer. The path difference for constructively interfering light must be $n\lambda$ while destructively interfering light's path difference is $(n+0.5)\lambda$. Thus, it is possible to visualize a spread of light as it passes through slits where diffraction occurs. Because light diffracts (spreads out) when passing through a slit instead of making a solid line as expected if light were a particle, we know that light has wave properties as well. This is further supported by interference, leading to numerous blobs of light formed from the original one (with the spots from constructive interference while destructive interference is responsible for dark areas in between). As we can visualize waves to have crests and troughs, the orientation of such to be aligned (constructive) or flipped forms of each other (destructive) aid work due to light's wave descriptions. Light interference patterns also aid in this solar cell design process for diffraction gratings. As compared to non-diffraction grating solar cells (Fig. 4 and Fig. 6 formula), the diffraction grating cells are massively more efficient [9]. Tying this back into wave theory, we know that the faster the wave's speed, the higher the frequency and lower the wavelength. The faster the wave that enters, the faster the wave exits, which is a valid reason why visible light, alongside its plentiful sources, is more useful than lower frequency, higher wavelength, and slower waves (ex. radio waves).

Separate research on metal gratings is based in part because nanowires destructively interfere with light reflected from sapphire substrates. This forms a suppressed reflection of the zeroth-order. Experiments were conducted on resonantly scattered light of λ = 650nm with a supercell structure to backlight scatter in the 30-75 degree range. The use of such metal grating geometries enabled red light scattering appearances with lower reflection rates. Quantum efficiency only dropped in the scattering spectral band. In other research, we see similar trends, corroborating that diffraction and interference via diffraction gratings or metal gratings aids in solar cell efficiency [7].

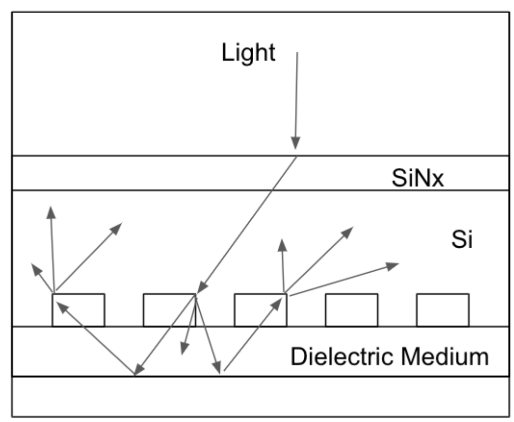

Figure 3: Diffraction Use in Solar Cells via Diffraction Gratings. You can see the rectangular objects as aids for diffraction gratings, which diffract light for higher efficient capturing.

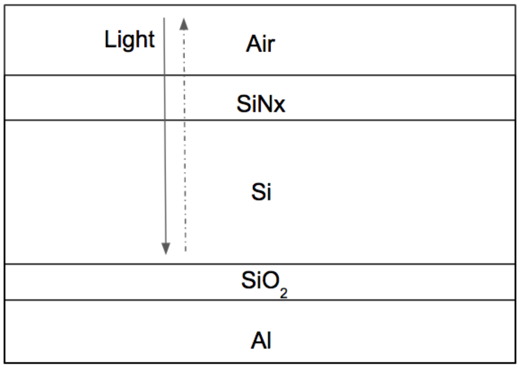

Figure 4: Non-diffraction Grating Solar Cells. There are no geometries for diffraction, leading to less efficiency as light (the arrow) reaches the cell.

VII. ABSORBTION AND EMISSION

Silicon is a semiconductor helping this to function. The top layer is doped with phosphorus making an n-type or negative type layer (Fig 5). UV, X-ray, and Gamma-ray waves (shorter wavelengths that are associated with cancer sometimes) are of thus higher frequency and energy, which leads to them being quite harmful to solar cells, and therefore the cell is made not to allow it to penetrate the surface of the solar cell and the Infrared or Radio waves (with longer wavelengths that tend to be associated with heat) either bounce off or passes through the solar cells. These are not absorbed since photoelectrons will only occur with higher frequency light that can adequately be absorbed for enough energy to overcome the energy well with minimal effect initially from intensity shows that lights are also particles since waves, in this case, would instead make changes based on power. Visible light wavelengths are absorbed. Thus, this can come to the middle layer and kick out an electron creating a hole (an effective positive charge which is not an actual hole but basically a symbol of losing an electron) and free the electron from a silicon bond. The freed-up electrons will go to the n-type silicon while the holes (results of the ionization of electrons) migrate to the bottom layer or, in other words, to the p-type (doped usually with boron). On top of the phosphorus has Ag, and the bottom is on top of an Al plate where wires connected will create an electrical circuit as long as sunlight impacts it as stated by Borlace.

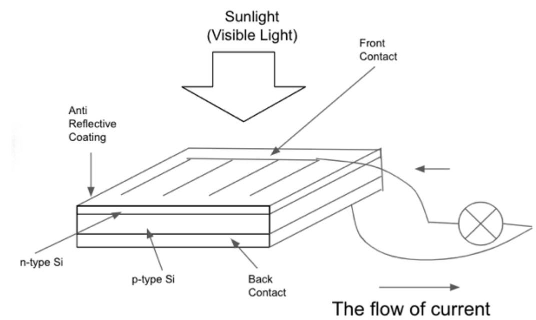

Figure 5: General Solar Cell Diagram. Here, we see the n and p-type layers near to each other although many models also add a c-Si layer in between. These layers help electrons and holes stay where there is a build-up and electricity harnessing ability when connecting the contacts to an electronic device and back towards the section with positively charged holes.

For visible light in general, specific trends are followed during the absorbing and emitting process. We will digress into visible light as it "provides" the energy source for our solar cells. At the atomic scale, we can see the light behaving as a particle and a wave. We can have the photons which are massless alongside atoms of silicon which are prevalent in the solar cell. Visible light in this case, can excite the electrons

In research, we learn that the design of CZTS (copper zinc tin sulfide) reflects principles of absorption. In particular, there is an optimum wavelength of approximately 500nm, as demonstrated on Sivathanu, Sharma, Thangavel, and Lenka's graph. Wavelengths contributing to absorbance are shown in the visible light spectrum [8]. Absorption in 350-degree celsius samples also increases if the bandgap increases. This is due to a decreased electrical recombination loss while enabling the cell to more efficiently absorb infrared radiation-which typically does not get absorbed due to lower energies than visible light. Although a few scientists have previously thought about decreased band gaps as a means of increased absorption, this unique setup and material selection with CZTS demonstrates that the bandgap increases lead to higher efficiencies.

Jarosz, Marczyński, and Signerski partially corroborate this work as they demonstrate that higher bandgaps have the opportunity to provide higher power efficiencies [4]. They showed that the power conversion efficiency limit of 1.8 EV is two times higher than that of 1.1 EV. This demonstrates that solar cells with higher band gaps in some instances may have higher efficiencies.

VIII. MATHEMATICS FOR PHOTON ABSORPTION BASED ON DIFFRACTION GRATINGS

$$A(\lambda) = (1 - R_f(\lambda)) \frac{(1 - e^{-\alpha(\lambda)d_{Si}})(1 + R_b(\lambda)e^{-\alpha(\lambda)d_{Si}}}{1 - R_f(\lambda)R_b(\lambda)e^{-2\alpha(\lambda)d_{Si}}}$$

Figure 6: Solar Cell With Silicon Dioxide Layer on Top of Al but Without Backside Grating Formula for Photon Absorption.

$$A = 1 - \left[\sum_m R_m + \sum_m T_m\right]$$

Figure 7: Solar Cell With Diffraction Grating Formula for Photon Absorption.

Above are two formulas used to find photon absorption for solar cells with and without diffraction gratings. In general, diffraction gratings aid by increasing photon absorption (via scattering of light, increasing the probability of the light ionizing a silicon atom successfully), leading to more efficient energy receiving.

IV. IONIZATION

Photons of visible light are absorbed, giving electrons energy to jump the band gap (and thus through the thin intrinsic layer) and having holes that go to the p-type. The crystalline silicon in this case, will be the one ionized, losing an electron from its usual four valenced ones in a bond with four other silicon atoms. This energy will not immediately be emitted but instead used for extraction as electricity. Thus, crystalline silicon atoms are ionized, which leads to the electron and hole sources [9]. It has been shown by research from Taguchi, Maruyama, and Terakawa that HIT cells, even with high temperatures, have a lower efficiency drop than that of conventional solar cells. This shows that, even though solar cells function in the sunlight and thus get exposed to high temperatures so as also to get energy from the photons for ionization, they still can function. Thus, the ionization effects are generally agreed upon by the science community.

V. THE INTRINSIC LAYER

HIT cells are unique in the sense of their intrinsic layer. These layers are designed as thin layers surrounding the c-Si and a-Si n, and p-type layers are above and below them. These thus serve a special property of allowing and blocking holes and electrons from entering n or p-type layers. Thus, their design includes low-width edges and high-width blocking areas. For the intrinsic layer next to the n-type silicon layer, the low-width "spike-like" edge is short and enables the electrons to pass through while the high-width block area does not let the holes pass. The opposite occurs on the other side where electrons are blocked and holes can enter the p-type layer. To pass through these low-width edges, tunneling transport happens [3].

This intrinsic layer is poor at conducting electricity as conveyed by Liu, Y., Pomaska, M., Duan, W., Qiu, D., Li, S., Lambertz, A., Gad, A., Breuer, U., Finger, F., Rau, U., and Ding, K. However, in experimentation, the intrinsic layer thickness directly impacts the effective minority carrier lifetime. This leads to higher open-circuit voltage. When the intrinsic layer is thinner, it has been shown to increase the fill factor as stated by Zhang, D., Swaaij, R., and Zeman, M.

IX. CONCLUSION

In conclusion, Heterojunction Intrinsic Thin layer solar cells follow similar responses to electromagnetic radiation as compared to general solar cells. The main difference is the intrinsic layer which, depending on thickness, can impact the minority carrier lifetime and lead to higher open-circuit voltage. When particularly visible light impacts the surfaces of such cells, responses include absorption and ionization. It is important to note that HIT cells differ in that they are capable of functioning more efficiently in higher temperatures. Finally, novel grating geometries have been developed and revised based on light's wave-like properties for obtaining increased energy. Available research has a consensus on such notions, with one disagreement being refuted by other researchers.

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