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Using blackbody structure to improve the efficiency of solar cell

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Abstract

Today solar power is the most promising new energy source, it is safe, cheap, and abundant. Its total power on the earth reaches 1.22 X 10^{17}W per year, and we human only need 1.33 X 10^{12}W per year. Solar cell is an essential device that can convert the energy from the sunlight into electricity; however, current solar cell reflects too much sunlight shone thereon, and this is a major factor that lowers its conversion efficiency, which is only about 20~30% on average. Blackbody is material that can only absorb but never reflect electromagnetic radiation, in nature it is hard to find blackbody material, but a large cavity with only a small hole can be approximately equivalent to a blackbody, and such structure is also applicable to reduce the reflection of current solar cell, using it to modify the anti-reflective layer of a solar cell. By substituting multilayer "non-head" pyramid structures for the "inverted" pyramid structures in the anti-reflective layer of a current solar cell, the reflection can be reduced since the lights shone into the multilayer "non-head" pyramids through their entrances need to be reflected for many times before going out again. This can improve the conversion efficiency of current solar cells a lot.

Introduction: Solar Power

Solar power is rich, the full power of solar energy our earth can receive each year can reach $\mathbf{1.22x10^{17}W}$, this is ten thousand times of current requirements by the human, which is only about $\mathbf{1.33x10^{12}W}$ per year. As Figure 1 shows, the majority of solar power that reaches the earth would be absorbed by the ground, a part would be reflected back into the space by the atmosphere or the ground. the parts of solar power that are not utilized on the earth are much larger than 0.01%, at least 30% of the total solar power to the earth is reflected, and among the part which is not reflected, only 30% of that reaches the lands,[1,2] the part in sea should be what caused tornado and typhoon, method therefore our demand for energy can be totally satisfied as long as we can develop these parts of solar energy effectively, and this can also convert many catastrophes into our useful energy, lower the entropy of the earth and probably have no bad influence to the biosphere as long as we managed it well. There is also greenhouse effect that causes climate change, the earth absorbed too much heat from sunlight, it can both satisfy people's demands for energy and alleviate climate change to convert this part of solar power into electricity or any other useful work, we could use thermal voltaic cell[1] to accumulate this part of energy to be useful electric power as well. Plant can absorb $\boldsymbol{CO_2}$ and sunlight and convert them into carbohydrate which stores energy in large capacity and mobile form, if we can store the energy from solar power in such form, the solar power can be same available as any other fossil fuels as well, and it is necessary for our energy storage to be safe. The amount of solar power that is redundant to the earth's environment is enough to meet human's demand for energy, and we can also develop solar power in space in the future if those on earth were not enough anymore.

Solar power is also safe and free, abundant and should not be bad to the environment if we utilize it properly, and solar power is much more abundant in space than that on the earth. In fact, fossil fuels are solar power stored in the earth hundreds of millions of

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years ago, could replace fossil fuels if we can save them in same way safely.

Sun is a natural controlled nuclear fusion reactor, it has 600 million tons of hydrogen fusing together per second, the energy released from the fusion balanced the gravity, the sun and the earth both have an age of about 5 billion years, and they still have another 5 billion years of lives (at this respect our sun and earth is more likely to be relics designed by prehistory civilizations which may be our ancestors), we can utilize such tremendous solar power before our earth died which could be caused by the sun turning to a red giant in 5 billion years. According to quantum mechanics, energy is probabilistic but not always conserved, the time-energy uncertainty principle suggests that energy can be created probabilistically under some conditions, therefore there possibly are methods to create a sun from vacuum in some ways like planting a tree using some seeds, we human must get the hang of such science and technology so that we can create a new solar system and immigrate to the new solar systems by ourselves before the death of our sun or earth. The ultimate development of nuclear power should be one with solar power, we need develop solar power to satisfy our needs for energy in future before the fossil fuels were used up and nuclear power to be same safe, cheap, and abundant as our sun in the future, it would be better that our nuclear power technology is renewable, i.e., we could create a sun or a mini sun from vacuum, if we could create new sun, we can live on new earth around it where the condition is habitable.

Solar Cell

Solar cell is the essential device for utilizing solar power, it uses

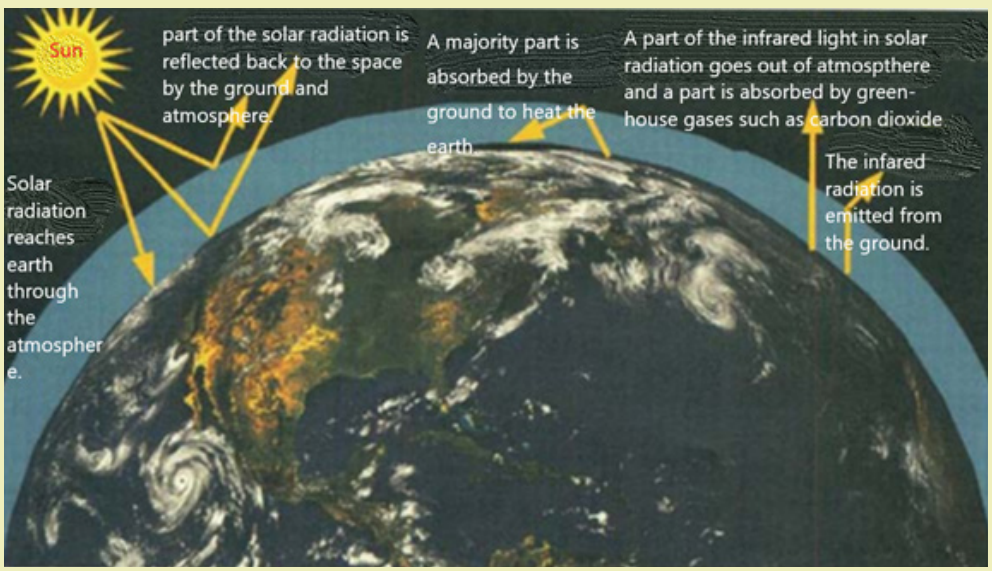

Figure 1: The solar power that reaches the earth, a part of them was reflected, a part became heat on the earth, a part is emitted as infrared radiation which is partly absorbed by the greenhouse gas and partly goes out of the atmosphere.

a ***p-n*** junction to absorb the energy from sunlight and convert the energy flow into the electromotive between the two sides of the junction, the direct current by connecting the two sides can do useful work. However, as the solar power is intermittent, it is better to store the large amount of energy from our solar power in similar way with fossil fuels and use them to motivate the power plants we currently have, must have absolutely no risk to human, can also use them to do anything needs fossil fuels, some materials that can store electricity with large capacities and fast rate of charging safely is also available.

As shown in Figure 2, in an intrinsic silicon semiconductor, the thermal agitation of the molecules excited the electrons in valance band to conduction band and left same number of holes in the valance band, electron can move to other places in the conduction band, and holes can move to other places in the valance band. Applying ***p***-type doping into intrinsic silicon semiconductor, acceptor impurity atoms, such as boron atoms, will replace some silicon atoms in the semiconductor crystal while the structure of the crystal doesn't change, they will bond with other silicon atoms in same way as how a silicon atom bonds with other silicon atoms, i.e., each boron atom will still bond with four other silicon atoms in the diamond-structure of the intrinsic silicon crystal, a boron atom bonding to its four neighboring silicon atoms will donate a hole in the ***p*** doped semiconductor, which is equivalent to a positron and can carry electricity in the valance band. ***n***-type doping is similar to ***p***-type doping, just substitute "donor" for the "acceptor", an arsenic atom is a donor atom, when it was doped into the semiconductor, the structure of the semiconductor crystal doesn't change, and it will donate an electron into the conduction band when it is bonding with other silicon atoms, and bonding is still in the diamond-structure of the intrinsic silicon crystal. Apply ***p***-type (or n-type) doping into an ***n***-type (or a ***p***-type) semiconductor, a ***p-n*** junction could be formed. Figure 3 shows such a ***p-n*** junction, the electrons and holes donated by the donor and acceptor atoms in the semiconductor, which are non-equilibrium carriers in ***p*** and

n region will diffuse into the opposite regions and recombine with each other, leaving the regions with no non-equilibrium carriers, and the doping atoms are therefore charged, this region is called space charge region.[3-8]

There is an electric field between ***p*** and ***n*** region because of the charged atoms, from positive charged donor atoms to the negative charged acceptor atoms, this is the built-in electric field. As the diffusion force makes the carriers diffuse into the opposite region,

Table 1: Conversion efficiency of current solar cells, the average efficiency of cells are about 20% to 30%.[9]

PV Technology		Conversion Efficiency	
		Cell	Module
Crystalline	Monocrystalline silicon (Si)	27.60%	24.40%
	Multicrystalline Si	23.30%	20.40%
	Multi-junction Gallium arsenide (GaAs)	47.60%	38.90%
Thin Film	Cadmium telluride (CdTe)	22.30%	19.50%
	CIGS	23.60%	19.20%
Emerging	Perovskite/Si tandem	33.70%	-
	Perovskite	26.00%	17.90%
	Organic	19.20%	13.10%

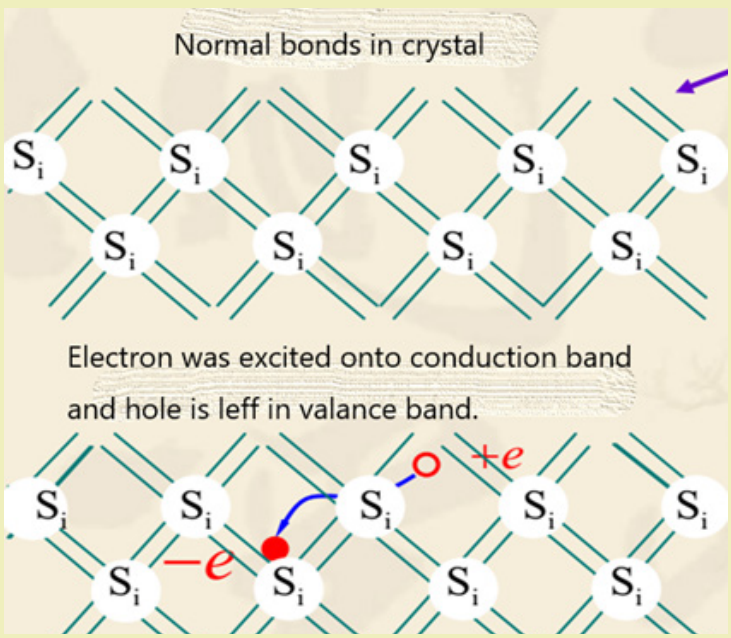

Figure 2: Intrinsic silicon semiconductor and its intrinsic excitation, thermal agitation will create a pair of electron and hole which can be carriers, moving freely in the semiconductor.

this built-in electric field exerts opposite force to the diffusion forces and balances the diffusion, it makes the carriers drift in opposite directions to their diffusion. As the diffusion continues, the built-in electric field will be stronger and stronger and finally stop the diffusion. The diffusion force is related to the density gradient of the carriers, while the strength of the built-in electric field is related to the number of charged atoms in the two sides of the depletion region (space charge region). When there is photon with enough high energy shone into the ***p-n*** junction, it will split the combined electron-hole pairs, then the single electrons and holes will move apart under the force of the built-in electric field without diffusion force before they went out of the depletion region. Such process can be in a dynamic equilibrium with the diffusion if it is continuous, when there are continuous photons with enough high energy shone into the semiconductor and split the electron-hole pairs in the depletion region, and this narrows the space charge region, weakening the built-in electric field, the diffusion unbalanced by the built-in electric field can be a potential to produce electricity, it is the electromotive induced by the incident photons. There are just a part of non-equilibrium carriers outside the depletion region, electrons outside the ***p*** region and holes outside the n region, wanting to recombine with each other and their diffusion force

are not balanced by the built-in electric field, the incident photons with enough high frequency and the built-in electric field continues splitting electron-hole pairs apart and pushing them back to the regions where they were majority non-equilibrium carries, and the built-in electric field will be weakend and can't balance the diffusion anymore, the equilibrium between diffusion and drift changed from static one to dynamic one, and the diffusion force unbalanced by the built-in electric field produces an electromotive between p and n region, this is the so-called photon-induced electromotive, and we can convert the solar power to be our useful power using this electromotive.

Blackbody And Possible Improvement to Solar Cell

Solar cell have to absorb the energy from sunlight to produce electricity using the photon-induced electromotive introduced above, but currently the conversion efficiencies of solar cells averagely are only about 20% to 30%, as shown in Table 1. There is a highest one has conversion efficiency about 50%, it is ***GaAs***, ***GaAs*** but is much rarer than ***Si***, and is toxic. Only silicon is friendly to human body, its highest conversion efficiency is only about 30% and is monocrystalline silicon which is more expensive than the multicrystaline silicon with only a conversion efficiency of 23.3%. The main cause of energy loss in solar cell is reflection, the conversion efficiency can be improved if there is less reflection.

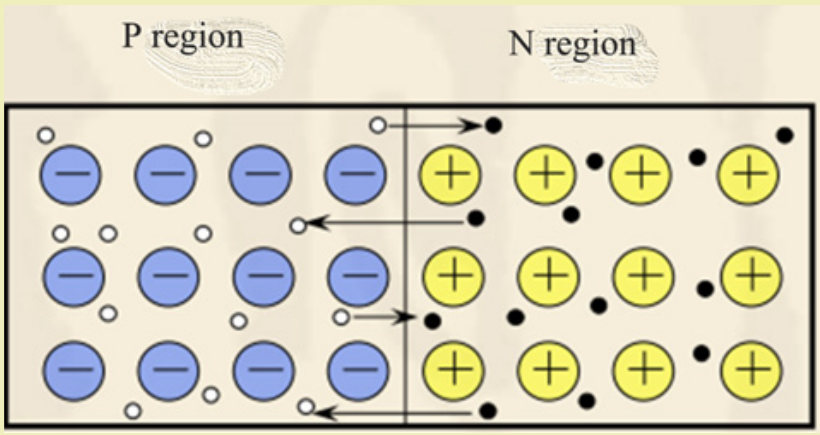

Figure 3: p-n junction, the left is p region doped with donor atoms and the right is n region doped with acceptor atoms. The donor atoms contribute electrons in p region and the acceptor atoms contribute holes in n region, they both are non-equilibrium carriers that can move freely in the material. Once the p-n junction forms, they will diffuse into each other's region under the diffusion force produced by the junction, recombining with each other, and leave a space charge region (depletion region) with no non-equilibrium carrier and electric field balances the diffusion force.

Blackbody is a material that has no ability to reflect any radiation luminated thereon. Though in reality it is hard to find an ideal blackbody material, we can use a structure to make an approximate blackbody, as figure 4 shows, a large cavity with only a small hole, the hole can be approximately equivalent to a blackbody since almost all incident lights will be reflected for many times inside before they can get out of the cavity through the hole again, so that the majority of the energy can be absorbed before they exit the cavity, only a tiny part of their energy could be reflected out at last, this almost is same to no reflection. Such structure was once used to study blackbody radiation, where Planck used the hypothesis that the energy of radiation can only be transmitted in wave packet that contains energy $\Sigma=h\nu$, and ν is the frequency of the radiation wave, to derive the correct formula of blackbody radiation which is consistent with the experimental data, and it should also be feasible to be applied to improve conversion efficiency of the solar cell to make a solar cell "blacker".

As Figure 5 shows, we could consider inverting the "inverted" pyramid in the anti-reflective layer of current solar cells to make this, as the green lines at the center of the solar cell in the figure, a "inverted" pyramid of original solar cell are inverted again and its head was cut to make an entrance into its empty inside; thereby, the lights (red lines in the figure) went into the pyramid through the entrance need to be reflected on the substance for more times before going out through the entrance again. Many such "non-head" pyramid structures are also made to be multilayer structures in the solar cell, as shown by the green lines in the figure, to make more area that has such function to absorb the incident lights and make them be reflected for many times on the substance before going out.

The more times a beam hit onto the substance, the more it will be absorbed by the solar cell, and more electron-hole pairs will be split to produce the electromotive between ***p*** and ***n*** sides,the proportion of energy that is absorbed at each hit should be same. Such structure makes the light be reflected onto the substrate for more times to be absorbed more, and its entrance can be covered with transparent flat surface that prevents dust or any other

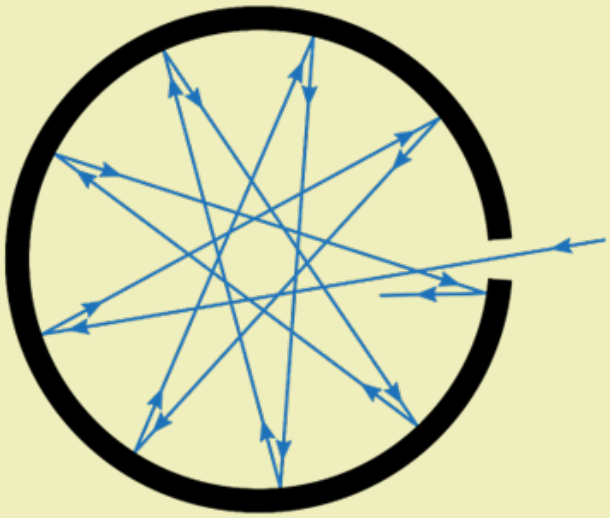

Figure 4: A large cavity with only a small hole is approximately equivalent to black body, light shone into it can hardly be reflected out because it probably needs be reflected for many times before going out through the hole again, the more times it was reflected, the more absorption it got, the possibility of being reflected or absorbed for a photon when it hit on to the substrate should be same at each time, there should be a certain proportion of energy be absorbed at each reflection.

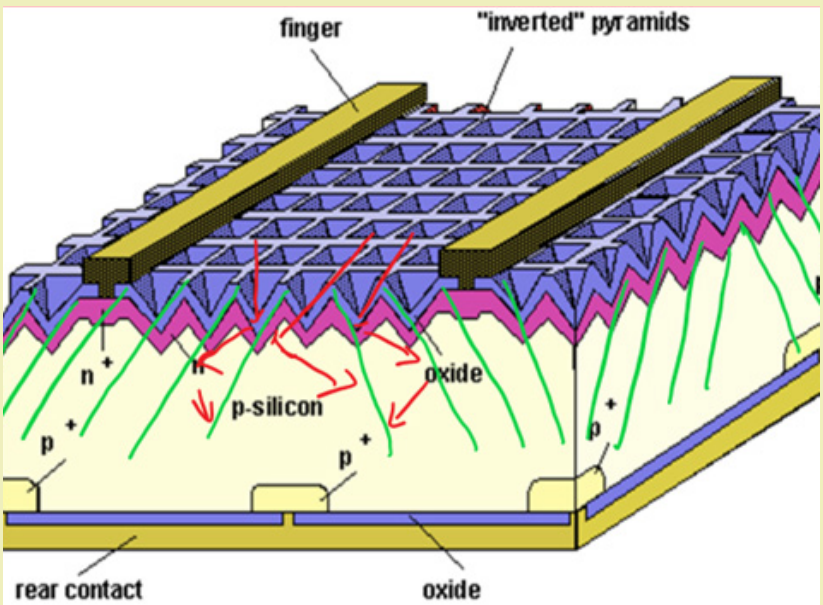

Figure 5: Application of blackbody structure to current solar cell, a modification to anti-reflective layer. The structure of the "inverted" pyramid is inverted again and the a part of its top is cut to make an entrance, as a "non-head" pyramid, and many such structures were made multilayer in the anti-reflective layer as the green lines described, as the entrance is much smaller than the inside, lights shone inside will be reflected for many times before going out through the entrance, thereby the energy absorption of the incident lights can be increased.The pyramid can also be cone.

material that covers light from entering the non-head pyramids, it is much easier to clean the dust on the flat surface than inside.

In fact, we can find the windows on our buildings are always much darker than the surface of the building, this is of same principle that is used by such structure; therefore, such structure probably can improve the conversion efficiency of solar cells a lot.

Conclusion

When studying about blackbody radiation, "alarge" cavity with

a small hole can be equivalent to a blackbody approximately, such structure that has small entrance with large inside can make the incident lights hard to be reflected out, since only when the incident light is in one line with its reflected beam can the light be directly reflected, otherwise the light needs to be reflected for many times before going out of the cavity through the hole again, the previous possibility of the direct reflection is much smaller than the later possibility, which is of the majority possibilities, when the incident light needs to be reflected for many times before going out of the cavity through the hole again.

The major cause to current low conversion efficiency of solar cell is reflection, if can make less lights to be reflected from the solar cell, the conversion efficiency can be improved. It is hard to make the material of a solar cell to be less reflective itself; however, applying the structure showed by Figure 4, which has only a small entrance with large inside, to replace the current anti-reflective structure of solar cells is promising to make the solar cells less reflective. Therefore, inverting the "inverted" pyramid in the anti-reflective layer of current solar cell and cut its head to make entrance into its inside to be a "non-head" pyramid, as shown in figure 5, can reduce the reflection of lights, which were shone into the entrance of the "non-head" pyramid, from the substance of the solar cell by increasing the times they need to be reflected on the substance before going out through the entrance again; moreover, making many such structures multilayer in the solar cell, as described by the green lines in Figure 5, can increase the area that has such function to reduce reflection by increasing the times that incident lights need to be reflected on the substance inside the "non-head" pyramids before going out again. Could expect such structures can improve the conversion efficiency of the solar cells a lot.

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Conflicts of Interest

Regarding the publication of this article, the author declares that he has no conflict of interest.

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