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Technical Paper

Photovoltaic Glass

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Abstract: For generations we as a community have struggled to find a sustainable solution to the energy crisis. Oil prices are rising, wars are raging, and resources are running out. The global community has placed great emphasis on renewable energy. However, many forms of energy production have shown to be inefficient or difficult in managing cost. Up to this point solar energy has proved to be the most successful and widely known form of renewable energy, with a primary downside of taking too much space to be profitable. Solar photovoltaic (PV) glass generates electricity, and negates this major issue. This product is applicable in the use of glass windows available to the public. For example, the auto manufacturer Audi has made investments to incorporate this product into their vehicles in an attempt to be self sufficient. Photovoltaic glass is an important stepping stone towards a society no longer dependent on crude fossil fuels, and allows everyone access to clean renewable energy without the worry of another energy crisis.

Keywords: Amorphous, Photovoltaic, Renewable energy, Semiconductor, Solar energy, Transparent

1. Introduction

Photovoltaic glass brings a new concept to solar technology today by introducing solar cells. Photovoltaic cells are made from the process of converting light in the form of photons to electricity using semiconductors, known as the PV effect.[1] Edmund Bequerel, a French physicist, discovered the PV effect in 1839. He found that certain conductive materials produce small amounts of electric current when exposed to sunlight. Later, Bell Laboratories in New Jersey successfully created the first solar cell in 1954 out of silicon, but it was too expensive to produce for mass public use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through space programs like NASA, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space related applications and eventually public use.[2] There are many types of renewable energy that have been experimented with and tried in an attempt to halt the use of primitive and harmful fossil fuels. Even with these multiple sources of wind, endothermic, and hydroelectric energy, solar energy seems to be the most widely known and prevalent for consumer use. Traditionally, solar energy has taken the form of large panels placed on rooftops or in large farms designed for that specific purpose. It has always been a hindrance and an eyesore to see solar energy in the works. So what is holding us back from making multipurpose solar cells? That is where photovoltaic glass comes in. In this paper we review the description, types of photovoltaic glass, application, benefits and drawbacks of this technology.

2. Description

2.1. Silicon Solar Cells

To understand the importance of photovoltaic glass, we must start with the current choice for solar energy, which are silicon structures within panels. The main issues challenging photovoltaics are efficiency, cost, and space. Silicon is the typical material used to create PV cells due to its high efficiency. It is a semiconductor that is the second most abundant element on the Earth's crust.[3] Semiconductors have a thickness of about one-hundredth of a centimeter or less and can absorb all visible light. Silicon forms ranges from amorphous to polycrystalline to monocrystalline structures. Monocrystalline structures are the most efficient type because it has the most perfect structure, therefore reducing space since it has the highest conversion rate from light into electricity at most 20% efficiency. The typical cost per watt for monocrystalline is around $5 and it is usually opaque blue or black. Polycrystalline is the next most efficient at around $4 per watt and 13-16% efficiency. Finally, the least most efficient form is amorphous, which has no crystalline structure and requires the most amount of space yet is the most common type. It costs around $3 per watt and has an efficiency of 7-13%.[4] However, due to the high cost of silicon, the market requires new materials and processes that can give an equivalent efficiency, while at the same time reducing costs. Therefore, researchers came up with thin film PV cells. Thin films reduce the amount of semiconducting material used to manufacture amorphous solar cells, which reduces the cost by more than half.[5]

2.2. How Photovoltaics Work

Solar energy is the main component behind the photovoltaic cells. Unlike energy generators, PV cells do not need any moving parts to gain energy. Instead, the solar cells convert light from the sun in the form of photons into electrical energy that can be distributed to users.[3] In a solar cell, the semiconducting crystalline structures have 2 layers sandwiched between 2 electrodes, making a p-n junction with potential difference. The n side, or negative side, hosts extra electrons while the p, or positive side has "holes" for the electron from the n side to fill. Photons knock the electrons out from the p side with enough energy to move them out of place, drawing them into a flowing circuit as illustrated in Figure 1.[6] The semiconductors are topped by a reflect-proof film that minimizes the loss of light by reflection. It effectively traps the light falling on the solar cell by promoting its transmission to the semiconductor below.[3] The semiconductors are typically metal and have to be as thin as possible to not reflect as much light.

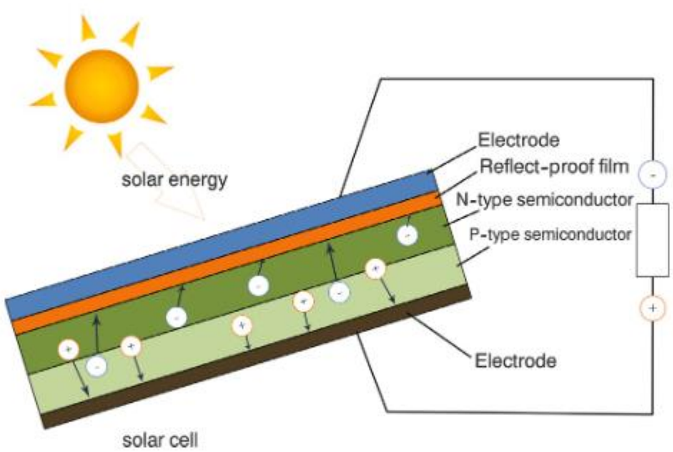

Figure 1. Schematic operating principle of a PV solar cell.[7]

2.3. Photovoltaic Glass

Photovoltaic glass utilizes amorphous solar cells due to its flexibility, thin nature, and transparency. The basic form of the glass is made up of solar cells that are embedded between two glass panes filled with a special transparent resin using a casting process.[8] The resin used also has sound absorbing properties which double as sound proof for the structure. Polyvinyl butyral is a type of clear, strong resin that is the choice for high impact glass. The top sheet consists of a highly transparent, white sheet of glass and the bottom sheet is made of conventional glass that meets the requirements of the desired location, whether it be on a facade of a building, in a transparent roof, or on the ground.[9] Figure 2 lays out how basic photovoltaic glass is structured.

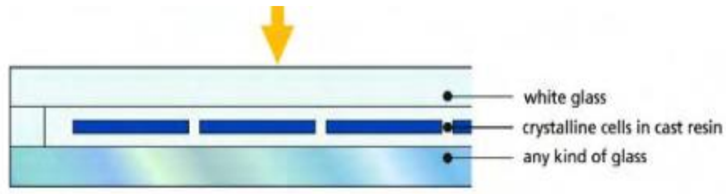

Figure 2: A diagram of the casting process of solar cells within resin into photovoltaic glass.[9]

3. Application

3.1. General Application

Solar energy is traditionally used in large commercial quantities located on plots of open field or on a small scale on top of residential homes. Solar panels have a limitation to their application because they are a hindrance with the amount of surface area required and how much area that takes. However, photovoltaic glass alleviates that issue with the ability to be placed in more subtle locations while still providing solar energy production.

Traditional solar energy production had demands that are not always feasible. Often these traditional solar panels are found in large solar farms leaving the land incapable for reuse. These solar fields, while efficient, take up large plots of usable property. In India, the Kurnool Ultra Mega Solar Park spans twenty-three square kilometers.[3] The Longyangxia Dam Solar Park in China encompasses over twenty-five square kilometers and houses four million solar panels.[3] Also, in India a new project will encompass over fifty-two square kilometers over five villages in order to be efficient.[3] The creation of these massive solar farms could be avoided with the application of photovoltaic glass.

3.2. Types of Photovoltaic Technology

There are several different types of transparent photovoltaic solar cells in the midst of research and development. All are varying in transparency, materials, and efficiency. This leads to the potential for increasing applications. Some of the types of transparent photovoltaic solar cells include the following: screen printing dye synthesized solar cell, near-infrared, polymer solar cell, transparent luminescent solar concentrator, perovskite, tandem semi-transparent perovskite, electrophoretic technique, dip-coater, and quantum dot solar cell.[5] Each of these takes a different approach to solar technology applications and levels of transparency which is shown in Table 1. With there being a variety of studies and trials into different photovoltaic technologies, the result is a wide range of efficiencies and uses. Companies like Onyx Solar have already begun to utilize this variety in efficiency versus transparency into their projects as seen in Table 2.[10] With the four different transparency levels that Onyx presents ranging from none to high, there are more applications available for consumers.

3.3. Future Application Ability

Photovoltaic glass is expected to see massive growth over the next several years with many anticipated applications. With photovoltaic technology's energy production predicted to increase to 345 GW by the year 2020 and 1081 GW by 2030, there are great outlooks.[5] Corporations like Audi are taking advantage of this growing energy producing technology by applying it to their vehicles.[11] With transparency being key to the design of these solar cells an occupant of the vehicle would not have obstructive vision through a sunroof. Photovoltaic transparent glass on a vehicle has the potential to run multiple systems like heating, air conditioning, and towards recharging the battery of electric cars.[11]

Table 1. Comparison of Different Types of Transparent Photovoltaic Technology.[4]

comparisons between different TPV based on process.

Name of Solar Cell	Year	T%[a] (%)	J_{sc}[b] (mA cm^{-2})	V_{oc}[c] (V)	FF[d]	η%[e] (%)
Screen printing DSSC [102]	2007	60%	16.25	0.779	0.73	9.2%
Near-Infrared OPV [106]	2011	55 ± 3%	4.7 ± 0.3	0.62 ± 0.02	0.55 ± 0.03	1.7 ± 0.1%.
Polymer Solar cell [108]	2012	66%	9.3	0.77	56.2	4.02%
Transparent luminescent solar **concentrator (TLSC)** [111]	2014	86 ± 1%	1.2 ± 0.1	0.5 ± 0.01	0.66 ± 0.02	0.4 ± 0.03%
Perovskite [112]	2014	30%	10.30	1.074	57.9	6.4%
Tandem Semi-transparent Perovskite [117]	2014	77% peak[f]	17.5	1.025	0.71	12.7%
Electrophoretic Technique [124]	2015	55%	14.83	0.68	0.71	7.1%
Dip-coater [142]	2015	~70%	16.17	0.738	0.688	8.22%
Quantum Dot Solar cell [150]	2016	22.74%	12.83	0.58	0.52	3.88%
Quantum Dot Solar cell [151]	2016	24%	0.56	18.2	0.53	5.4%

[a] Transmission rate percentage of the light through the solar cell.
[b] Current short circuit in one cm^2 active area of the solar cell.
[c] Voltage open circuit in one cm^2 active area of solar cell.
[d] Fill factor which equal to the maximum power divided by the theoretical power.
[e] The efficiency percentage of the solar cell.

4. Benefits

Photovoltaic energy overall is non-polluting, silent, long-lasting, and reduces the dependency on other fuels. In comparison to regular solar panels and solar energy, photovoltaic glass energy has many benefits including the fact that as it being glass it has more usage that typical thermal panels.

One of these benefits include a safer, long-term investment. Though solar PV has a higher capital cost than

Table 2. Differences in Transparency Levels.[2]

TECHNICAL DATASHEET

	no transparency		low transparency		medium transparency		high transparency	
Glass lites	2	3	2	3	2	3	2	3
Max. Power IEC 60904-1	57.6 Wp/sqm		40 Wp/sqm		34 Wp/sqm		28 Wp/sqm	
Visible Light Transmittance UNE-EN 410:1998	0.2%	0.0%	10.8%	10.1%	17.3%	16.3%	28.4%	26.7%
SHGC UNE-EN 410:1998	22% 5%*	23% 5%*	29% 12%*	29% 10%*	34% 15%*	32% 12%*	41% 21%*	37% 17%*
U - Value (W/m²K)	5.7 1.2*	5.2 1.2*	5.7 1.2*	5.2 1.2*	5.7 1.2*	5.2 1.2*	5.7 1.2*	5.2 1.2*
UV Transmittance UNE-EN 410:1998	0.0%	0.0%	1.5%	0.1%	1.5%	0.3%	4.7%	0.4%
Exterior reflectance UNE-EN 410:1998	7.6%	7.3%	8.3%	7.3%	7.6%	7%	8.2%	7.1%
Acoustic insulation UNE-EN 12578:2002	32(-1;-3) 37(-1;-5)*	34(-1;-3) 37(-1;-5)*	32(-1;-3) 37(-1;-5)*	34(-1;-3) 37(-1;-5)*	32(-1;-3) 37(-1;-5)*	34(-1;-3) 37(-1;-5)*	32(-1;-3) 37(-1;-5)*	34(-1;-3) 37(-1;-5)*

* Values of photovoltaic glass with isolated glass units (IGU) composed of 12 mm argon chamber and low emissive interior glass. The isolated glass units (IGU) are customized in all cases according to the requirements of the project and can reach U values of up to 0.7 W/m²K. Visit the thermal transmittance calculation tool available on our website.

solar thermal, the government has offset this with initiatives such as the Feed-In-Tariffs, which has made them an attractive long-term investment.[12] As shown in Figure 3, PV is also more beneficial as it generates electricity compared to regular solar which is used to generally heat water and air, which ultimately is one of the largest advantages.[13]

As depicted in Figure 4, companies and investors are also more interested in PV rather than concentrated solar power. CSP is very reliant on irradiance, access to water and large scale deployments.[14] Another benefit of PV glass is that the maintenance and operating costs are lower than that of other renewable energies. PV energy is also silent when operating and not to mention, it is super efficient in installing. The design of this product allows for no interference in residential lifestyle.

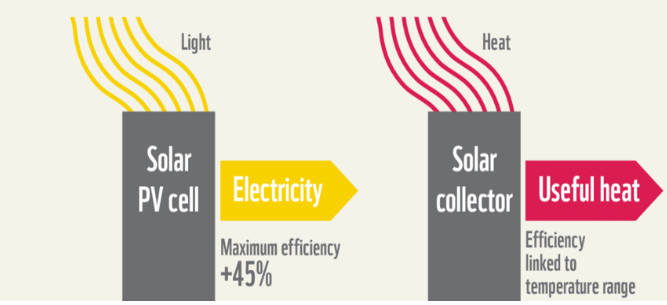

Figure 3. Difference between how PV and thermal energy works.[13]

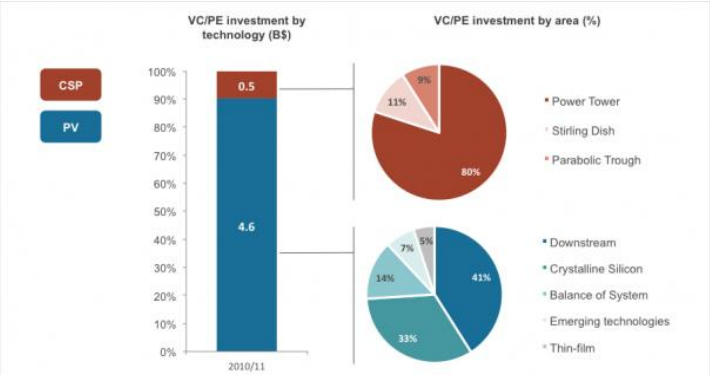

Figure 4. Investments in PV vs CSP.[14]

5. Drawbacks

Although PV is highly beneficial, there are some drawbacks of using this newer technology. As previously stated, this is new technology, so it is still developing and is not in high demand at the moment. For example, there is a higher manufacturing start-up cost compared to that of thermal. Even though the prices are higher at the moment, the prices are continuing to decrease as it becomes more popular and is in higher demand. Also the cost of PV glass maintenance and operating are lower than that of other renewable energies. Another disadvantage of using PV energy is that there are toxic chemicals, such as cadmium and arsenic, in the production. Though, this conflict can be solved through recycling and correct disposal. In the quantum dot solar cell for PV, the dots are inorganic and low transmission.[15]

6. Summary

In conclusion, photovoltaic cells transfer solar energy into electrical energy using semiconductors and p-n junctions. The main difference between photovoltaic glass and its predecessors is the fact that the transparency of the glass allows for dual usage. However, the more transparent the material, the less solar energy it absorbs. PV is more beneficial compared to thermal cells and becoming more popular. The glass can be used to make up a building's surface material instead of being an unattractive and bulky addition to a structure's roof, or taking up land space. By introducing transparent solar cells, PV technology presents a whole new, and clear, concept.

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