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CHALLENGES OF OXIDE GLASSES IN THE APPLICATIONS OF RENEWABLE ENERGY: A REVIEW

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ABSTRACT

Fossil fuel has been an energy source for decades which has been causing large emissions of CO_2 and consequently has negatively influenced the climate of earth. For this reason, there has been large demand for new resources of energy that are eco-friendly for the environment. Exchange the energy sources needs engineering materials that have ability to convert the energy from one image to another. Oxide glasses are considered inorganic materials. They gain an interest for wide range of engineering applications of energy like in solar panels because They appear strength and good resistance for environmental conditions; in addition to good thermal stability and feasibility of shaping and processing. However, there still are challenges of implementing glass in energy applications. This short review will highlight the main challenges of oxide glasses and will present some ideas for them.

Keywords: glass; sealing glass; solar panel; PV cell; power plant.

1. INTRODUCTION

Global warming as a results of CO_2 emissions has been big challenge for humanity. According to the European Environment Agency (EEA), the heat of the earth has rose in June 2024 by 1.5 °C [Allen et al., 2018]. Therefore, there is a global demand for new energy sources to reach zero CO_2 emissions. The common natural sources of energy are wind, sunlight and water. Sunlight is considered the most unlimited freely available energy resource. It can be transformed into electricity using solar panels which trap it inside after chemical and physical reactions to generate what is called solar power. The resulting power in this way depends on the amount of sunlight which, in turn, varies based on location and time. The surface of solar panels must be protected against harsh environmental conditions using glass that it has the ability to transport light efficiently. According to the literature, glass makes around 67 – 76% of the total weight of solar panel [Zier et al., 2021].

Among wide range of glass, oxide glasses are widely used in the renewable power plants to achieve different functions as seen in Figure 1. This glass is considered cheap in comparison to other kinds of glasses. They are used in power storage and solid electrolyte besides other functions. Some power plants use mirrors from oxide glasses to concentrate sunlight in concentrator stations. Such a power plant can supply annually about 800 GWh [Pretorius et al., 2006, Onyango et al., 2006]. High mechanical strength of glass can be reached by shaping glass as fibers of few microns in diameter. Lightweight and strong

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blades of wind rotors (turbines) are made of glass fiber reinforced polymer composites [Xu et al., 2024].

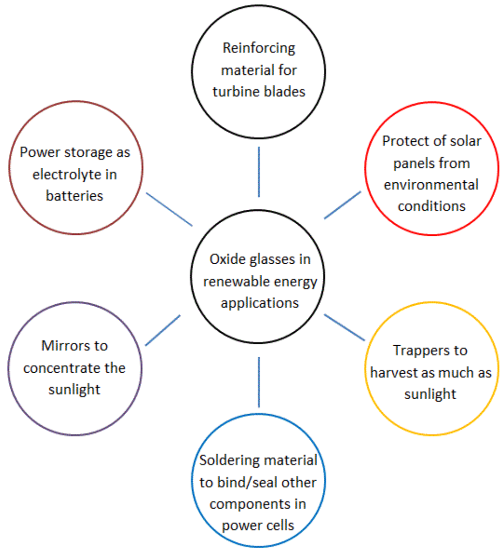

Figure 1: Functions of oxide glasses in renewable energy suppliers.

The physical and chemical properties of glass can be modified by adjusting the chemical composition and changing the surface features of glass. However, the weight of glass which considered critical for solar panels supplied for moveable objects. Most important is the optical properties of glass and the light transmission inside glass. This short review aims at addressing the most important challenges of oxide glasses for using as an engineering material for clean energy. In addition to suggest some perspectives for developing glass.

2. Role of oxide glasses in renewable power plants

Oxide glasses play an important role in renewable power plants. The main functions of glass in clean-energy suppliers can be divided according to the glass position on the units of power plants:

2.1 Protection

Solar panels comprise many layers. The top one is glass layer (see Figure 2). It is commonly mounted on one side of the solar panel to minimize the weight of the panel. The main part of the solar panel is the photovoltaic (PV) cell. This effect has been discovered in 1983 [Becquere 1839; Echeverry et al., 2018]. The principle of PV work depends on semiconductors (electron-hole) working principle which can be summarized in electron-hole pairs generation upon light illumination. As a result a photocurrent generated along the direction of the built-in electric field. It was reported that the performance of photovoltaic panels is around 80% corresponds an average output power of 1 to 25 MWp [Bansal et al., 2021]. Basically, silicon as semiconductor is used as one- or polycrystals with an acceptable efficiency (upto 25%) and affordable price [Raimundo et al., 2021].

Glass layers protect the solar cells against the environmental conditions i.e. dust, rain, and dirt in addition to storm debris. The thickness of the glass panels must be kept as thin as possible in order to lower the overall solar panel weight. Chakraborty et.al. reported that the thickness front glass is between 2.8 and 4 mm [Chakraborty et.al., 2020]. The protecting glass can be used as plain ordinary glass or as strengthened glass. This kind of glass produced after a suitable heat treatment of the ordinary glass. It is affordable and stands on thermal stability in addition to higher strength which gives preference against hail and strong wind [Hu et al., 2021, Pablos et al., 2020]. Glass in such case provides acceptable resistance against impact of debris.

Beside the protection, the front glass layer may achieve additional functions once the glass surface has modified. It has been reported that modifying the glass surface texture can increase the resulting power of solar cells to 4% by decreasing the reflection of sunlight [Raut et al., 2011].

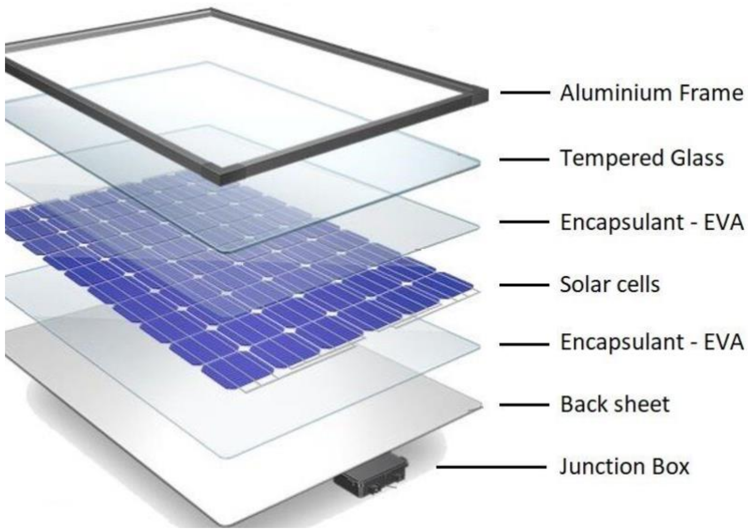

Figure 2: Sketch of the PV principle work.

Coating of glass surface can also help to provide stable optical performance for the lifetime of the solar panel mission by preventing solarization and discoloration of the glass [El Amrani et al., 2014]. Moreover, applying anti-reflective coatings on glass surface can increase the sun irradiance transformed by over 2.5%.

2.2 Sealing material

Sealing is a process of joining of different materials using different soldering materials. Glass is one of soldering materials. It can be used to join glass-glass and glass-metal. Glass-to-metal seal has been a research trend for decades to solve crucial problems of joints. These joints have been used in many applications of energy in the field of electronic packaging [Chern et al., 2007]. The glass properties must be adjusted to strict certain values in order to be used in a particular system. These properties depend on the nature of the terminals to be sealed, the design of the joints, additional functionalities that the seal must perform, and the system working conditions [Winkler et al., 2019].

A hermetic encapsulation is a part of sealing process which implies preventing gases and moisture from getting in or out of a device. It is an important step for production special kinds of solar cells called dye solar cells (DSCs) and perovskite solar cells (PSCs) [Emami et.al., 2019]. They are prone to degrade due to losing the electrolyte by evaporation and leakage [Capitao et.al., 2023: Martins et.al., 2020]. Glass is impermeable to organic solvents, water, and oxygen, high thermal and mechanical stability, and is inert to electrolyte compounds [Capitao et.al., 2023].

The stability of DSCs like other kinds of solar cells is an important aspect for their commercialization. However, the evaluation of the lifetime of solar cells is a difficult task as it depends on the specific degradation mechanisms [Ashgar et.al., 2009].

2.3. Energy storage

Oxide glasses are good material for thermal energy storage. Special compositions are used for this application. The selection criteria for thermal storage media are: (1) Low viscosity over a wide temperature range, (2) High heat capacity, (3) Thermal stability, (4) Low cost, and (5) Low toxicity [Elkin et.al., 2014]. The viscosity of Glass fluid must be low enough to be transferred in an heat exchanger.

Glasses have a high potential to be applied in new devices for energy production, energy transfer, energy storage, and efficient energy usage. For example, glasses are expected to be innovative materials for the next generation of all solid-state Li^+/Na^+ secondary batteries In fact, the compositional versatility of glasses allows them to be tailored with different properties. For economic reasons, the search for glasses with specific properties and a low melting temperature is also of scientific and technological interest. Ion transition is the mechanism of electrical conductivity in glass. It is a good candidate to being part of futuristic batteries. Consequently, such oxide-based systems have received great attention. Among various oxide materials, sodium superionic conductor [Mandal et.al, 2021] oxide-based phosphate materials exhibit high ionic conductivity, thus researchers have been studying them extensively in the last decade for battery applications.

3. Kinds of oxide glasses in energy applications

Four kinds of oxide-based glasses are mainly implemented in power plant components which are silicate glass, borate glass, phosphate glass. Silicate-based glasses are interesting for many applications spatially in power suppliers. It provides mechanical, chemical and weather protection for solar cells [Belançon 2023, [Muniz et al., 2021]. These cells are responsible for around 3% of the electrical power produced around the world [Davidsson et al., 2017]. Three essential silicate compositions are used in this field: soda-lime glass, borosilicate glass, lead glass or lead-crystal glass. They can be easily formed in different shapes to satisfy different functions like plates to cover the solar cells and tubes for thermal concentrators applications [Neuroth et al., 1987]. Adding metal ions like Na^+, K^+, Ca^{2+}…etc. to the base oxide form causes structural changes leading to enhance the properties of these glasses. They can be used as sealing material to seal metal-metal and metal-ceramic terminals. They are attractive soldering materials because some kinds of them have comparable thermal expansion coefficient (TEC) to that of some super metals alloy for advanced applications. For instance TEC of borosilicate glass is 5.15 x 10^{-6} K^{-1} which matches that of kovar alloy 5.3 x 10^{-6} K^{-1} [Chern et al., 2007 and Singh et al., 2021].

Soda-lime glass is basically used in the PV panels. It is costly effective. This glass has lower optical properties as it has iron oxide in its chemical composition which act as light dissipaters [Coyle et al., 1980]. The regular SLG contains upto 1% Fe_2O_3. Regular SLG is inconvenient for solar panels because Fe_2O_3 scatters the incident light and lowers the light transmittance. Ultra-white or ultra-clear soda-lime glass is produced by lowering the content of iron oxide (<0.01wt) to improves its optical characteristics. It helps to raise the efficiency of a solar panel >15% than those use regular SLG [Qu et al., 2024]. Borosilicate glass is another composition of silicate glass and is also applied for the solar panels. This kind of glass shows relatively higher optical properties than soda-lime glass. In addition it has more thermal stability which can better serve in hot regions. Lead glass or lead-crystal glass is another kind of oxide glass used in the structure of high quality solar cells because it has chemical durability and high optical performance (Belancon et. al., 2023). In this glass, the lead units is part of the main silica units of the glass structure. Special solar panels use it because it is expensive. This glass is higher in density than the others because of lead in its composition.

B_2O_3 is the former oxide of borate glasses. They are preferred over silicate glasses in sealing applications as silica has affinity against media that contain lithium and sodium like in liquid electrolytes of lithium batteries [Bengisu et al., 2016]. They can vitrify over a wide range of compositions with hosting rare earth oxides such as La_2O_3, Pr_6O_{11}, Nd_2O_3, and Sm_2O_3 [Bengisu et al., 2016; Terashima 1997]. They characterize by having low melting temperatures which makes them very interesting for encapsulating materials. The following compositions $PbO.B_2O_3.SiO_2$ or $PbO.ZnO.B_2O_3$ represent glasses that are the choice for most commercial joints. Their long working range without make them interesting for many enegineering applications [Moreno et al., 1998].

Phosphate-based glasses are other kind of glass used in energy applications. It has interesting properties compared to silicate and borate glasses. They offered low glass transition temperatures and high refractive index for optical applications [Brow 2000]. The structure–property relationship of phosphate glasses can be controlled by choosing suitable additives. Phosphate sealing glasses was specially developed for hermetic-sealing applications [Hudgens et al., 1998]. They have low sealing temperatures and high thermal expansion coefficients (to match desirable pin materials like copper). The drawbacks of this kind of glasses represented by their reactivity to water. Besides they having high-expansion coefficient which limit their applications. Therefore, precautions must be taken when producing this kind of glass at following the traditional methods. The chemical durability of phosphate glass can be risen by introducing modifying ions like Al^{3+}, B^{3+}, and Ln^{3+}. This will make the structure of phosphate glass more reliable against OH-groups, which cause breaking the fundamental bonds and eventually depolymerizing of phosphate network.

For instance, introducing 15 mol% of Al_2O_3 to $Na_2O.P_2O_5$ glass will improve the water resistance by forming AlPO4 network bridges [Peng et al., 1991; Chong et al. 2024]. This kind of glass shows fluorescent optical properties to absorb sunlight in luminescent solar concentrators (LSC) [Gallagher et al., 2007; Gallagher et al., 2007; Reda et al., 2008]. Table 1 shows the main properties of oxide glasses.

4. Discussion

The above information have shown the importance of oxide glasses in the field of renewable energy. The roles of glass has varied from protection and soldering to energy storage. Formulation the chemical composition of glasses is a key factor that makes glass an interesting engineering material for energy applications. The review exhibits that soda-lime glass is most popular and cheapest one. It contains iron oxide to lower the green color. However, 1 wt% of this oxide scatters the incident light and lowers the light transmittance through the glass. Lowering Fe_2O_3 yields, what is called, ultra-white or ultra-clear soda-lime glass. It contains iron oxide < 1% wt to improve its optical characteristics. It helps to raise the efficiency of a solar panel >15% than those use regular SLG [Qu et al., 2024]. Combining high optical characteristics of glass with low weight is favorable for the power plants. This leads to make thin glass sheets, hence, lower the total weight of solar panels.

Beside the chemical composition, engineering of glass surface helps to improve the performance of solar glasses. Yang et al. have reported that glass surface with inverted pyramid patterns enhances the light reflection inside the solar panel [Tas et al., 2023]. Keeping the PV cells out of dust and fogs ensures constant power supplying. The economic data has shown that glass defects can cost 8.5 €/kWp/year while those because of the installing failures coat 13 €/kWp/year [Tao et al. 2015, Yao et al 2019]. On the other side, coating of glass surfaces with special material enhances the optical characteristics and maintenance of solar glass plants. For instance, copper indium germanium selenide Cu(In,-Ga)Se_2 and cadmium telluride (CdTe) are common which implemented in this application. However, the cost of rare elements is considered a challenge of using such materials [McEvoy et al., 2012; Miles et al., 2007; Bagher et al., 2015; Wright et al., 2012]. Moreover, limited crystallinity of the thin films can reduce the PV cell efficiency [Wright et al., 2012].

Glass is the promising material for energy storage batteries. Instated of the liquid electrolyte, solid glass electrolyte is a good candidate. Glass-based materials are assumed to be promising as a solid electrolyte material in battery applications owing to their isotropic ionic conduction, good machinability and easy fabrication. However, achieving high ionic conductivity at room temperature from glass-based solid electrolyte materials is still challenging for the scientific community [Mandal et.al., 2021]. Sodium-ion batteries with their associated low costs and abundant sodium reserves have attracted significant attention as promising next-generation large-scale energy storage systems to replace lithium-ion batteries (Tsuji2021).

Other studies exhibit that manipulating glass composition allows glass to absorb the resulting radiation either by heavy elements [Sheng et al., 2001]. In construction, glass in walls is used as part of the energy-saving technologies. The heat capacity, density and thermal conductivity of glass/air system are all parameters which affect the thermal response [Dhifaoui et al., 2007].

Glass has shown that it is a good material for sealing technologies. Special attention must be paid to the difference in thermal expansion coefficient between glass and the base material [Moser et al., 2017]. Otherwise, failure of joints will occur. This can be controlled by careful choosing of chemical composition in addition to the design of the joint. Moreover, low sealing temperatures save energy and more important keeps glass stable during and after sealing.

5. Recommendations

This reviewing has shown that oxide glasses are still challenging for energy applications. According to the author's literature survey, there are few literature that deal with oxide glasses for solar power plants. This short review has shown that glass is very important part of the energy-sources conversion to face the climate change. In light of above mentioned challenges, the following points summarize some perspectives:

- Discovering new functions for oxide glasses by formulation their chemical composition.
- The chemical durability of the hearmatic seals against water is another demand that ensures reliable joints.
- The surface of glass sheets can be engineered to optimize light reflection at the glass-air interface. Methods like chemical etching and plasma etching are considered effective and cheap to gain textured glass surfaces.
- Glass is prone to fracture as a results of debris. Therefore, investigation repair methods would be effective to lower the cost of running the solar cells.
- Develop special coatings for self-cleaning glass surfaces (rebel moisture and dust) or for increasing light harvesting to maximize the powder of solar plants.
- Oxide glasses are basically characterized as weak electrolyte materials which necessitates increasing their ionic conductivity by increasing the concentration of charge carriers.

6. Conclusions

This short review has shown that oxide glasses have play big role in supporting renewable energy generation from natural sources. Understanding the working principles of glass open wide range of application to the next generations of engineers. The yield power is directly proportion to the area of the PV cells. Thus, thin glass sheets would be important to lower the total weight of solar panels. Chemical composition and surface engineering of glass can be engineered together for ultimate performance. This urges more investments in glass developing to optimize the yield power.

Conflicts of interest

There are no conflicts to declare.

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