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Ultrathin Glass for the Photovoltaic Applications

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Chemically strengthened ultrathin glass with a thickness of less than 1 mm has many advantages, such as flexibility, smooth surface, good transmittance, excellent gas and water barrier, much higher toughened in relations to thermally tempered glass, higher impact resistance, increased corrosion resistance and much higher abrasion rate. Chemical strengthening process is a process where an ion exchange occurs by diffusion between the glass panes and the brine solution bath. The deeper penetration of the glass surface by ions contained in the brine bath contributes to the hardness of the glass sheets, which reduces the occurrence of surface defects that cause reflections. From the point of view of photovoltaic applications ultrathin glass significantly reduces the weight of the whole photovoltaic panel structure with respect to known solutions. Furthermore, the reduction of the glass thickness increases the transmission of solar energy in the visible range directly through the glass. In addition, chemical tempered glass has a lower reflectance of light from the surface than the thermally tempered glass. What is more, ultrathin glass is perfect substrate for deposition of nanomaterials, i.e. conductive films or quantum dots. In this work we demonstrate that chemically strengthened ultrathin glass is a perfect material for the photovoltaic applications, i.e. as a substrate for deposition of thin layers and for the design of photovoltaic modules of reduced weight.

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1. Introduction

In recent years, development of electronics-related products which are i.e. solar cells has continued apace, and development of products with higher performance and higher functionality is being demanded. Ultrathin glass with a thickness below 1 mm is one of the most popular substrate material for conventional displays and devices. This type of glass has outstanding characteristics in terms of flexibility, transparency, corrosion, and abrasion resistance, surface smoothness, and gas barrier capability, so it is used as a substrate for manufacturing various devices requiring these characteristics. It is known that if the thickness of a glass is more than a dozen or so μm, its permeability of gases will be close to "0" (i.e., completely gas barrier characteristics), and its performance as a gas barrier will be sufficient. However, as an innate weak point concerning glass (namely, an inorganic substance), its brittleness means it is easy to break. Although a glass with thickness below 1 mm becomes more flexible compared to standard 3 mm glass, its weakness is higher breakability. The composition of glass and surface modification of glass have been studied, and strengthened ultrathin glasses have been commercialized [1, 2]. For these reasons chemical strengthening of ultrathin glass seems to be the appropriate way to achieve the desired properties of the materials.

Ultrathin glass subjected to the chemical strengthening process gain hardness, good flexibility, excellent transmittance of light, better resistance to corrosion and abrasion. Glass strengthening by ion exchange, called "chemical" tempering, is a process where the original glasses are immersed into a molten alkali salt at a temperature below the glass transition. During the time of immersion, the alkali ions from the glass that are close enough to the surface are exchanged for those from the molten salt [3, 4]. From the point of view of photovoltaic applications this type of glass is very popular as a substrate for the production of CdTe solar cells [5–7], CIGS solar cells [8] or perovskite based solar cells [9].

Ultrathin glass is also very useful material for deposition of thin layer with the use of atomic layer deposition (ALD) techniques [10] or spin- and spray-coating [11]. One alternative concept for the flexible solar cells is based on the introduction of polymer foils as a substrate instead of glass [12–15] but ultrathin glass after chemical strengthening is better material for building integrated photovoltaic (BIPV) sector through their transparency and hardness. A lot of organic polymer films have disadvantage like poor gas–barrier (water vapor, oxygen) and the resulting degradation of performance due to oxidation of the device components fabricated on a flexible substrate has become a big problem [1, 16].

It is worth to note that ultrathin glass usage in photovoltaic (PV) modules significantly reduces the weight of the whole photovoltaic panel structure with respect to known solutions and thus reduces the load on the building structure. So, PV modules with ultrathin glass have to be installed on wider variety of buildings than to date and limited load-bearing capacity of the roof would no longer issue.

This work demonstrates that chemically strengthened ultrathin glass is very well substrate for the photovoltaic applications, i.e. as a substrate for deposition of thin layers and for the design of PV modules of reduced weight.

2. Experimental

Ultrathin glass sheets with the thickness of 0.85 mm (ESG glass — tempered glass, Ger. Einscheiben Sicherheitsglas) and standard 3 mm glass (FLOAT type — type of glass made by floating molten glass on a bed of molten metal) were washed with distilled water and ethylene/propylene alcohol every time before usage. Hardness and abrasion resistance were performed with the use of sanding test and visualized by optical profilometer measurements. Infrared and visible–ultraviolet absorption spectra were respectively measured by UV–VIS–NIR JASCO V–670 spectrometer. Indentation measurements were performed by iNano Mechanics system in LABNATEC company. Deposition of transparent conductive oxide (TCO) layers were performed with the use of ALD technique. SEM measurements of obtained active layers were performed using scanning electron microscope.

3. Results and discussion

Sanding test were performed to check hardness and abrasion resistance for the ultrathin 0.85 mm and standard 3 mm glasses. Optical profilometer visualisations of these results are depicted in Figs. 1, 2.

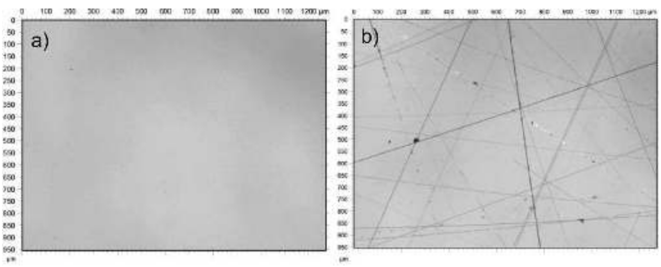

Fig. 1. Ultrathin glass (0.85 mm) before (a) and after (b) sanding test.

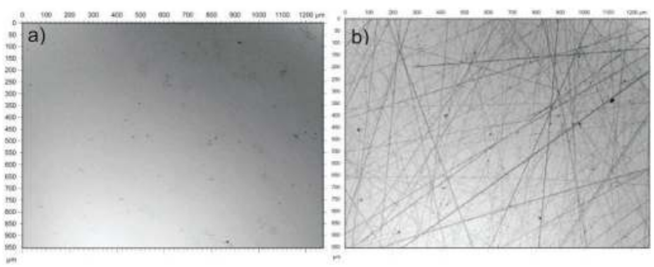

Fig. 2. Standard glass (3 mm float type) before (a) and after (b) sanding test.

Sanding tests show that thin glass is more resistant to scratching than standard glass of greater thickness. Chemical strengthening process caused that ultrathin glass gained greater hardness (eight times higher hardness compared to float type glass). This is very important advantage of thin glass from the point of view of applications in the PV modules directly exposed to the atmospheric factors. In order to check how chemical strengthening process influences to the strength of thin glass, indentation measurements (dynamic measurements of hardness) were also performed. Nanoindentation is a robust technique for determination of hardness tests of thin film for which conventional testing are not feasible. Advantages of this technique are: wide dynamic range (50 μm), low time constant (20 μs), noise floor below 0.2 nm, ease of use, high accuracy of measurements. Results of nanoindentation servey were collected in Table I.

TABLE I

Results of indentation measurement for ultrathin glass before (A) and after (B) chemical strengthening process.

Glass	A	B
target measurement strength [mN]	45	45
max. measurement strength [mN]	44.9602	44.9498
target measurement deep [nm]	5000	5000
max. measurement deep [nm]	649.2	624.9
average hardness value [GPa]	7.03	8.11
variation (CV) [%]	1.20	1.25
average of reduced module [GPa]	79.43	80.21
variation (CV) [%]	0.57	0.74

Table I shows that the chemical strengthening of glass increases the hardness of this material, which makes it better from the standpoint of photovoltaic applications.

Another important feature is transparency of the glass. Transmittance parameter was measured using UV–VIS–NIR spectrometer. These measurement results are provided in Fig. 3.

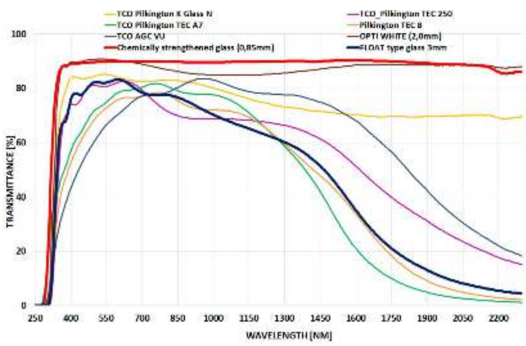

Fig. 3. Transmittance measurements for the different type of glass (the trade names of each type of glass are given in the chart).

The research shows that the transmittance of the glass thickness is less than 0.9 mm, undergone the chemical strengthening process, reaches 91–92% values in whole UV–VIS–NIR region. For comparison, results for a float type glass (3 mm) shows a value about 80% in UV–VIS radiation range and about 60% above 1000 nm. Transmission over 90% in a wide electromagnetic wavelength range allows for optimal work of different cell types. Ultrathin glass were tested as substrates for deposition of thin layers, i.e. transparent conductive oxides, quantum dots etc. SEM images (Fig. 4a and b) shows preliminary

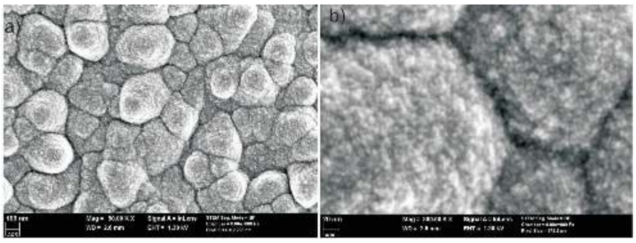

Fig. 4. SEM images of the conductive film (TCO) deposited on ultrathin glass.

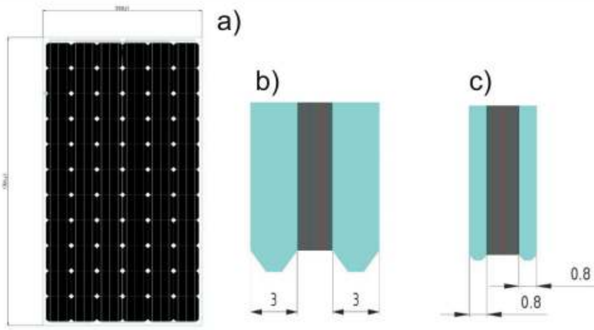

Fig. 5. (a) SUN MON 300 ULTRA GLASS MODULE designed in ML System Company, (b) weight reduction of photovoltaic panel with standard 3 mm glass from 27 kg (Fig. 5b) to 7 kg for 0.85 mm glass (Fig. 5c).

results of applying TCO layers by ALD technique on thin glass.

When it comes to practical usage of ultrathin glass in PV world, in ML System Company module based on ultrathin glass was prepared (Fig. 5a). This solution allows to reduce the weight of the whole structure from 27 to 7 kg (Fig. 5b,c).

4. Conclusions

Chemical strengthening process during that deeper penetration of the glass surface by ions contained in the brine bath takes place, contributes to the hardness of the glass sheets, which reduces the occurrence of surface defects that may cause reflections in ultrathin glass. This type of glass is perfect substrate for deposition of nanomaterials, i.e. conductive films. What is more, ultrathin glass significantly reduce the weight of the whole photovoltaic panel structure relative to the solutions currently common in photovoltaic. General conclusion is that thanks to good flexibility, smooth surface, good transmittance, excellent gas and water barrier, much higher toughened in relations to thermally tempered glass, higher impact resistance, increased corrosion resistance and much higher abrasion rate, ultrathin glass is ideal material in photovoltaic applications.

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