Study on cost reduction of thin-film amorphous silicon PV modules in Thailand with in-house TCO glass coating using PVD method

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Abstract

This paper describes the study on the possibility to reduce the cost of Transparent Conductive Oxide (TCO) glass using as the superstrate of the glass-to-glass thin-film a-Si PV modules with lower cost in-house produced TCO glass using Physical Vapor Deposition (PVD) method. Most commercial TCO glass used today by thin-film a-Si PV module manufacturers is produced in a few large float glass plants in with the Atmospheric Pressure Chemical Vapour Deposition (APCVD) process. For the in-house production of TCO glass in this study, a TCO glass coating facility using PVD coating method was added to the glass preparation area at the beginning of the production process in the existing thin-film a-Si PV module factory in Thailand.

Key Words: *Amorphous Silicon, In-house TCO glass coating, Physical vapor deposition (PVD)*

1. Introduction

Photovoltaic is a key technology option to the shift of conventional to renewable energy. The current solar cell technologies are well established and provide a reliable product, with sufficient efficiency and energy output for at least 20 years of life time. During the past few years, the growth of this industry has been in average above 30% per year. This extremely high annual growth is significant upside potential of both crystalline silicon and thin-film PV modules production [1].

More than 95% of the PV modules produced and installed today are made from silicon, the same silicon used in semi-conductor industry. Both semi-conductor and PV industry grows at the same pace and same period and pushes for higher demands ultra-high purity (UHP) silicon materials. Consequently the UHP-silicon materials become scarce and much more expensive. Many existing PV module manufacturers as well as the new investors are shifting their targets towards thin-film silicon PV technology which use much less silicon, cheaper to produce and has clear path for both efficiency as well as cost improvement in the near future. It is anticipated that thin-film silicon PV will account up to 10 % of the total PV market in 2010 and will then take at least one-third of the total PV market by year 2030 [2,3].

1.1 Thin-film Silicon

Thin-film a-Si silicon cells are mainly deposited by typical Plasma Enhanced Chemical Vapor Deposition (PECVD) method using ultra high purity silane gas, hydrogen gas and other dopants such as phosphorus and Boron. The solar cells made from these materials tend to have lower energy conversion efficiency than crystalline silicon, but are much less expensive to produce. This study will only focus on the TCO glass for glass-to-glass thin-film a-Si pv modules with the cell structures as shown on Figure 1.

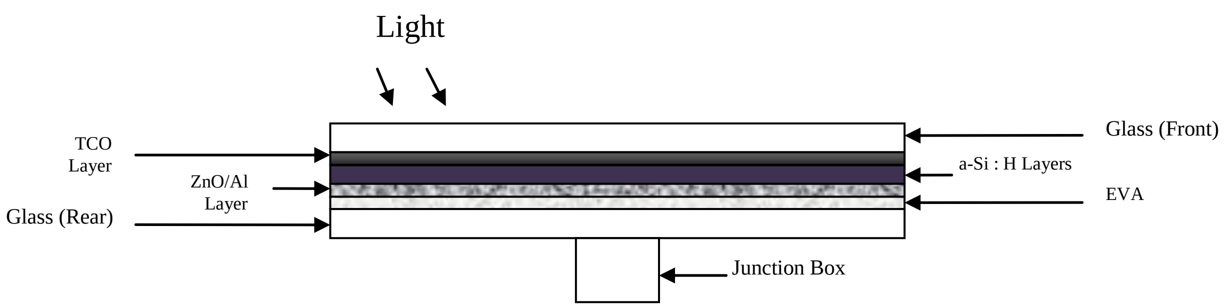

Figure 1: Structure of thin-film a-Si PV module

1.2 TCO Glass

TCO glass behaves as the front part of the thin-film a-Si PV module where sunlight hit its surface and shall serve as front contacts of the PV cell, have high electrical conductivity, high optical transmission and good adhesion property.

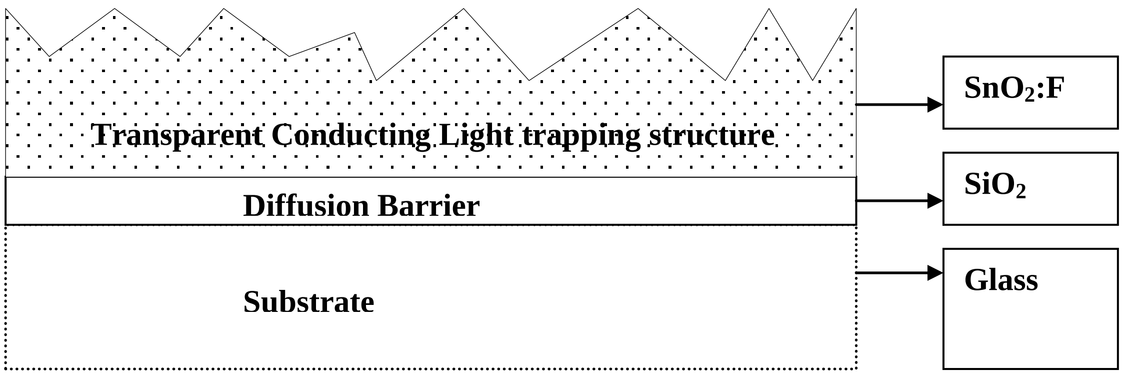

Figure 2: Microscopic structure of TCO glass

a) Property of TCO glass

Important properties of commercial TCO glass are 10-15 ohm/square on sheet resistant, can transmit more than 80% of light, with thickness variation less than 10% and haze more than 10% [4,5].

b) Structure of TCO glass

Commercial TCO glass used as the superstrate for glass-glass thin-film a-Si PV module is made from a thin soda lime glass sheet with thin layer of SiO_2 and SnO_2 integrated on one side. The thickness of glass can be from 3-6 mm. depending on the design. Thickness of SiO_2 and SnO_2 layers as shown in Figure 2 deposited on the glass surface by the APCVD method are approximately 100 nanometers and 500 nanometers respectively.

2. Production Process of Thin-film a-Si PV and Role of TCO Glass

2.1 Production Process of Thin-film a-Si PV Modules

In the production process of thin-film a-Si PV modules shown below, commercial TCO glass purchased from the float glass factories is used as one of key raw materials.

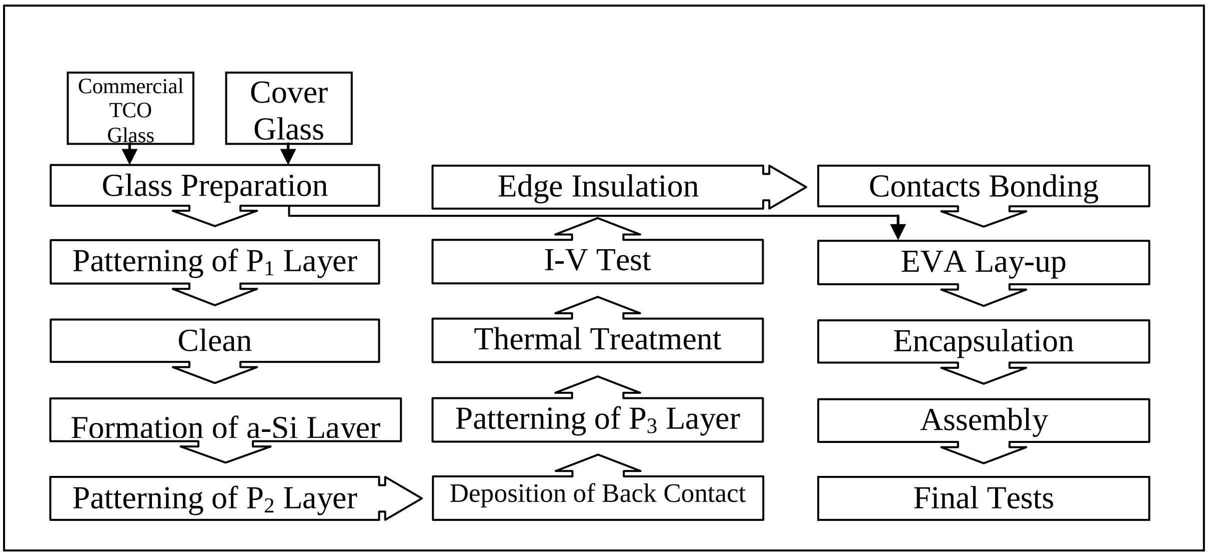

Figure 3: Production process steps of thin-film a-Si PV modules

2.2 Role of TCO Glass

Key raw materials required for manufacturing of thin-film a-Si PV modules are: TCO glass, cover glass, process gasses i.e. Silane, Phosphene, TMB, Hydrogen, Nitrogen etc., metallic targets i.e. ZnO and Al, EVA (Ethylene Vinyl Acetate) sheet, metallic foil, silicone compounds, junction box, cables etc. From manufacturing experience of the above thin-film a-Si PV modules in Thailand, the direct material cost structure of a module can be summarized as Table 1. The table shows that TCO glass serves more than 50 percent of the total direct material costs.

Table 1: Summarized of material cost structure

Material	**Ratio (%)**
1. Front glass superstrate or TCO glass	54
2. Rear cover glass	8
3. EVA sheet	12
4. Metal targets	6
5. Process gases	7
6. Junction box and cables	6
7. Miscellaneous parts	7
Total	**100**

3. Commercial and In-house TCO Glasses

TCO glass generally accounts only approx. 1-5% of total annual production of the float glass plant which normally produces TCO glass in a few large batches annually sufficient for at least a half-year or whole year supply [6,7]. Produced TCO glass is then cut to sizes and kept in the warehouse and later distributed to the customers on bi-weekly or monthly basis according to the advance orders from various thin-film a-Si PV module manufacturers all over the world. In the float glass production process, when the glass ribbon temperature in the annealing lehr reduced to approximately 650 °C and desired thickness obtained, Fluoride doped Tin Oxide (SnO_2:F) will be deposited with CVD method directly onto the glass surface.

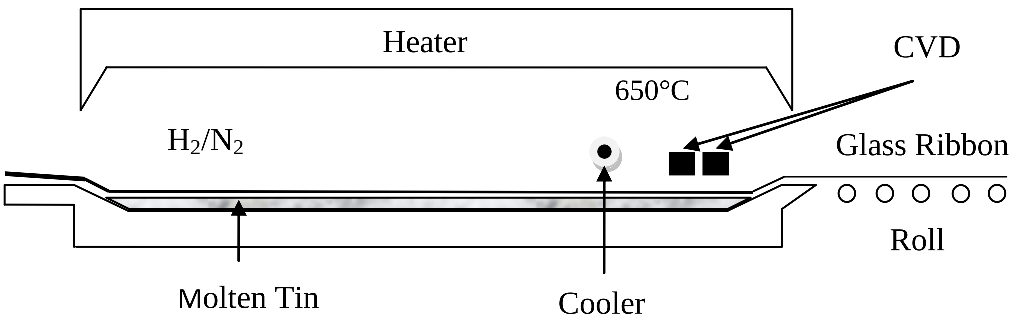

Figure 4: Deposition of SnO_2 layer with CVD method in the float glass plant

The on-line coating process as shown on Figure 4, TCO glass with thin layers integrated only on one side of the glass as shown in Figure 2 is produced. These layers; approximately 600 nanometers thick; are tin oxide (SnO_2) and an undercoat layer; silicon dioxide (SiO_2) which lies between the glass surface and SnO_2. This SiO_2 layer will help preventing SnO_2 layer from peeling of the glass surface. The price for locally produced 3.2 mm soda-lime float-glass sheet in Thai market is approx. Thai Baht (THB) 100 per square meter. The cost of producing the same glass in most float-glass plants worldwide shall be approximately at this level. After coating with SnO_2 layer, the cost of the TCO glass should not be higher than THB 200-240 per square meter, but due to market conditions, Bangkok Solar Co.,Ltd.: thin-film a-Si PV factory in Thailand has to pay as high as THB 600 (CIF Bangkok US$ 18.0) per square meter for imported commercial TCO glass. Since TCO glass account more than half of the PV module's direct material cost, it is therefore quite important to explore the possibility to reduce the production cost of thin-film a-Si PV modules with in-house TCO glass.

4. Pilot TCO Glass Coating Line in Thailand

Coating of metallic layer(s) on the surface of soda-lime glass can also be done off-line outside the float glass plant. There are several methods for depositing SnO_2 layer on glass surface to produce TCO glass such as APCVD Method and PVD or Sputtering Method. The thin-film a-Si factory in Thailand conducted the study on both methods and finally selected a TCO coating line with PVD method as a pilot in-house TCO glass line. This line is less complicated and furthermore the existing operators are already acquainted with the existing PVD system using for diffusion barrier layer and back contact deposition.

4.1 Pilot TCO Glass Coating Line with PVD Method

PVD method is a process whereby atoms are ejected from a solid target material due to bombardment of the target by energetic ions. This method is commonly used for thin-film deposition, etching analytical techniques. The coating method involves purely physical processes such as high temperature vacuum evaporation or plasma sputter bombardment. Consumable materials are SiO_2 and Indium doped Tin Oxide (ITO) metallic targets and gases i.e. O_2, Ar, N_2 and compressed-dry-air ITO with a diffusion barrier between glass and TCO where the diffusion barrier is SiO_2. This pilot TCO glass coating line has 2 low vacuum chambers, 2 high vacuum chambers, 3 buffer transfer chambers and 3 process chambers and can produce 150,000 pieces of TCO glass size 630 x 1,250 mm annually. The system utilizes an electrically powered, multi-zone heating system to preheat the substrates up to a maximum temperature of 300°C prior to film deposition. After the glass substrate is heated to proper temperature, SiO_2 layer will first be deposited to form the diffusion barrier between glass surface and ITO layer which will later be deposited on top of SiO_2 layer. The depositions of these layers as shown in Figure 5 take place in the vacuum chambers. The properties of in-house produced TCO glass will render the same optical requirements as the commercial TCO glass manufactured with APCVD method (see Table 2).

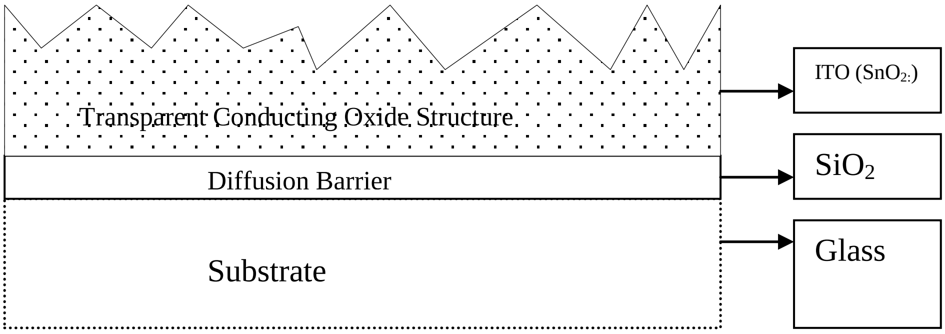

Figure 5: Schematic of ITO and diffusion barrier bi-layers structure

Table 2: The properties of in-house produced TCO glass by NanoPV Technologies Inc., USA

Properties	
Sheet resistance:	<15 ohm.square
Transmission:	> 80%
Thickness variation:	< +/-10%
- SiO_2:	~25 nm
- ITO(SnO_2):	~170 nm
Haze:	> 10%

4.2 Location of the TCO Coating Line

The TCO glass coating line was installed in the process between wash 1 and P_1 layer patterning equipment. The soda lime glass (which is now used as raw material instead of commercial TCO glass) will be polished and cleaned before proceeding to TCO glass coating line. The TCO glass leaving the coating line can be patterned with the laser scribing equipment without additional washing.

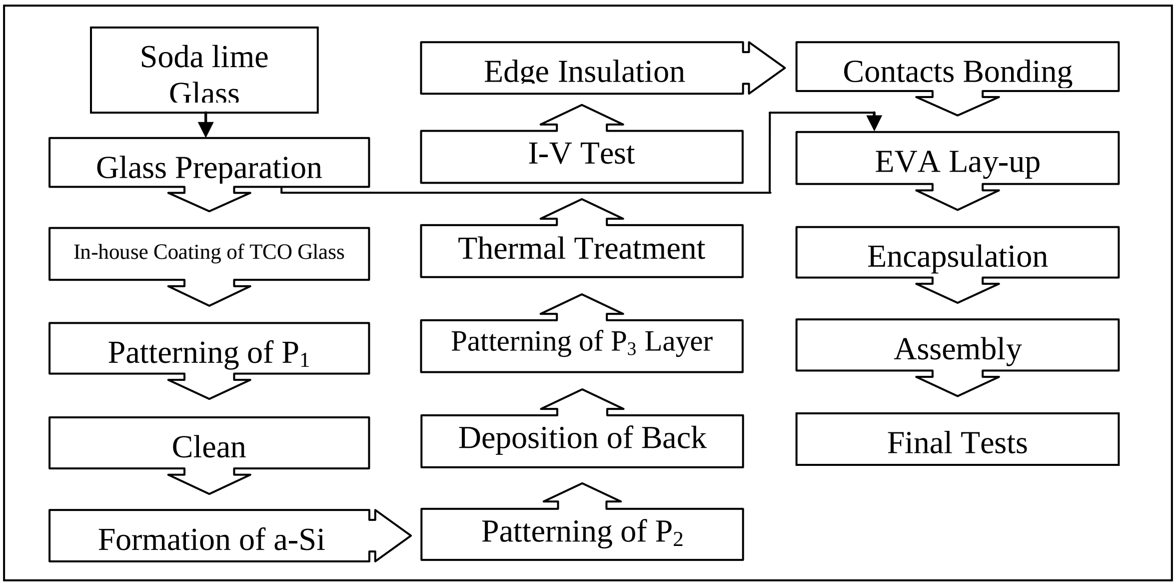

Figure 6: Production of thin-film a-Si PV modules with in-house coating of TCO glass

4.3 Criterion and Cost Estimation

The total investment cost of this TCO glass coating line and related facilities is approximately THB 87,500,000. Lifetime of the equipment is more than 10 years, but in the calculations, 7 years depreciation period was used.

Table 3: The criterion used for production cost estimation:

Criteria	Parameter
• Annual capacity (pcs)	150,000
• SnO_2 layer thickness	170 nm
• SiO_2 thickness	25 nm
• Number of shifts/hours per day	3/24
• Number of working days per year	295
• Number of direct labor	2
• Direct labour cost per hour	THB 40
• Electricity cost (per kWh)	THB 3.50
• Production yield target	95%

From the Table 3 criterion and data provided by the equipment supplier, production unitary cost of TCO glasses can therefore be calculated. For simplicity, the cost of building and relevant existing utility and facility are not taken into account in the calculations.

Cost	THB per pce.
• Cost of soda lime glass of 0.8 square meter	84.20
• Cost of depreciation	83.33
• Cost of consumable materials	61.33
• Cost of electricity	10.02
• Direct labor and overhead (inclusive of overtime)	47.60
• Maintenance and quality control	4.80
• Cost for waste treatment	1.00
Total cost per piece	**292.48**

From cost calculation, it is found that in-house produced TCO glass can be approx. 40% cheaper than the imported commercial TCO glass. The direct material cost of TCO glass using in-house with PVD method will be substantially reduced from THB 480 per 0.8 square meter (THB 600 per square meter) to THB 300 per piece making the direct production of the PV module 20 percent lower[8].

5. Conclusion

The cost of in-house produced TCO glass is 40 percent cheaper than commercial TCO glass. Such cost reduction will help lowering the total cost of this type of PV module by around 20 percent. Simpler PVD method can be used to produce TCO glass and can replace complicated conventional APCVD method. Fully or partly produced TCO glass in-house can help the thin-film silicon PV module manufacturer reducing the supply uncertainty and market price fluctuation risk.

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