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Research Article

Cost Performance of Thin Film and Crystalline Photovoltaic Cells – A Comparative Study

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Abstract

Photovoltaic cells, also called Solar cells, are electronic devices that convert sunlight directly into electricity. The modern form of the Solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest growing renewable energy technologies and it is expected that it will play a major role in the future global electricity generation mix. This paper compares the cost performance of the two prominent PV technologies viz. Thin film Solar cells vis-a-vis Bulk film solar cells .(Sahay Amit et al 2013)

Keywords: *Thin Film and Crystalline photovoltaic cells, Cost performance, Comparison of attributes for cost comparison, Inherent properties, External factors*

1. Introduction

There are a wide range of PV cell technologies on the market today which are classified into three generations, depending on the basic material used and the level of commercial maturity.(IRENA Working paper 2012)

1.1 First-generation PV systems use the wafer-based crystalline silicon (c-Si) technology. This type of PV cell is also called the *bulk material* cell. This type of cell is mostly used for terrestrial application.

1.2 Second-generation PV systems are based on thin-film PV technologies. These are also called the *thin film* cells. These include 1) amorphous (a-Si) and micromorph silicon (a-Si/μc-Si); 2) Cadmium Telluride (CdTe); and 3) Copper-Indium- Selenide (CIS) and Copper-Indium-Gallium-DiSelenide (CIGS). Thin film PV cells are under early market deployment.

1.3 Third-generation PV systems include technologies such as Concentrating Photovoltaic (CPV) and Organic PV cells that are still under demonstration or have not yet been widely commercialised. Current *market share* of wafer-based crystalline silicon(c-Si) is 85%-90% of global PV module sale whereas the market share of PV modules based on Thin film technologies is 10%-15%. Global Thin film module production capacity has increased significantly since 2007 although the price of wafer-based crystalline silicon(c-Si) has sharply decreased. There has been discussion around the relative merits of both.

The purpose of this paper is to identify the various attributes which are important to compare the cost economy of Thin film Solar cells vis-a-vis Bulk film solar cells.

2. Modules

2.1 Thin Film Vs. Crystalline Photovoltaic Modules

Crystalline Silicon plays a major role in the PV market, with 85 - 90% of the market share, despite the development of a variety of thin-film technologies. Thin film PV technology witnessed minimal research activities since early 1980’s. Post this period it witnessed a constant advancement in terms of manufacturing technology and active material used. The pursuit of cost effective electricity generating technology led major corporations and investors towards thin film industry. The industry saw more than 100 companies entering the market between 2001 and 2009. Thin film PV technology has seen a major leap from – only being associated with the little strip of PV cells that power calculators to sophisticated BIPV (Building integrated Photovoltaic Cells) & Solar charger for mobile devices.

Most of the effort is now centred on thin film deposition rather than wafer based modules, although there is still discussion around the relative merits of both. The main arguments in favour of thin film are that it uses less photovoltaic material is much faster and simpler to produce than the complex and delicate process of

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producing wafer based bulk material cell. However the lower production and material costs are offset to some extent by lower efficiencies of thin films. The attributes which are critical to compare the cost advantages and disadvantages of Thin film Solar cells vis-a-vis Crystalline Bulk film solar cells are as follows.

2.1.1 Conversion efficiency & Fill Factor

The maximum conversion efficiency of a Solar cell is given by the ratio of the maximum useful power to the incident solar radiation (Sukhatme S P 1984)

$$\eta_{max} = \frac{\mathrm{Im\ Vm}}{\mathrm{I\ Ac}} = \frac{\mathrm{FF\ Isc\ Voc}}{\mathrm{I\ Ac}}$$

The maximum useful power corresponds to the point on the current-voltage characteristic curve which yields the rectangle with the largest area. Im and Vm are the values of current and voltage yielding the maximum power.
I = Incident Solar flux(Irradiance)
Ac = Area of the cell
The ratio ImVm/IscVoc is called the Fill Factor (FF).
Isc and Voc are the Short circuit current and Open circuit voltage respectively.
For an efficient cell, it is desirable to have high values of Fill Factor, Short circuit current and Open circuit voltage.
At present the following efficiencies and Fill Factors have been achieved.(IRENA Working paper 2012 (www. civicsolar. com)

Table 1 : Comparison of conversion efficiency

Type of cell	Efficiency	FF
C Si PV system	14%	73-82%
a Si Thin Film	8-9%	60-68%

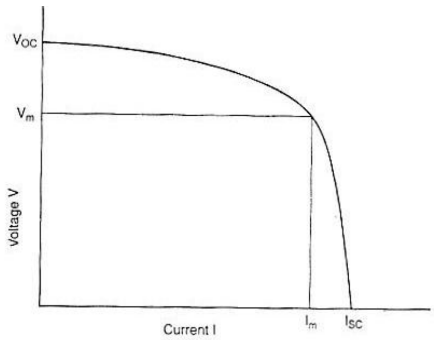

Fig 1 : Current-voltage characteristics of a Solar Cell

Table 2 : Comparison of Module cost

Type of cell	Cost (USD/Wp)
C Si PV system	1.02 – 1.24
a Si Thin Film	0.83 – 0.93

2.1.2 Module Cost

The cost of Photovoltaic modules is measured in dollars per peak watt (USD/Wp), where peak watt is defined as the power of full sunlight at sea level on a clear day. Modules are rated using standard test conditions of 1000 W/m^2, an air mass of 1.5 at 25^{o}C.

2.1.3 Levelised Cost of Electricity

The cost of electricity produced by different sources can be compared with a Levelised Cost of Electricity (LCOE) calculation. One approach of calculating LCOE is based on discounted cash flow analysis.(IRENA Working paper 2012)

LCOE = All costs discounted to first year of operation ÷ Lifetime Electricity production discounted to first year of operation

Table 3 : Comparison of LCOE

Type of cell	LCOE (USD/KWh)
C Si PV system	0.25 – 0.65
a Si Thin Film	0.26 – 0.59

LCOE can be thought of as the price at which electricity must be sold to break even over the lifetime of the electricity producing installation.

2.1.4 Manufacturing technology

Manufacturing of Crystalline silicon PV cell involves process viz purification of silicon, growing of crystal, slicing into wafers, surface preparation, dopants diffusion, grid formation, anti-reflective coating (Garg H P et al 1997) Thin film PV cells are made by using a chemical vapour deposition technique. Lrge vacuum chambers are filled with mixture of silane gas and small quantities of doping agents like boron. The gas is ionized and ionized atoms of silicon are deposited on glass substrate. The main advantages of manufacturing process for a-silicon Thin film solar cell. (Sukhatme S P 1984)

- The technique is suitable for high automation
- Large size cells can be fabricated
- Potential for reducing manufacturing costs is high
- Low capital investment
- Faster deployment

2.1.5 Consumption of active material, Silicon

Crystalline silicon (c-Si) is a relatively poor absorber of light and hence requires a considerable thickness of ~ 300-400 µm of material. In Thin film Solar cells the selected materials are strong light absorbers and only need to be about 6-10 µm thick.

2.1.6 Temperature coefficients

The I-V curve of a PV device under illumination is a strong function of temperature. Isc has the smallest temperature dependence, caused by the semiconductor bandgap shifting to longer wavelengths with higher temperatures. Voc and Pmax, degrade rapidly with increasing temperature due to rapid increase in reverse saturation current. Thin film Solar cells have lower Temperature coefficients which is favourable at high temperatures.(Osterwald Carl R 2005) (Yong Sin 2011)

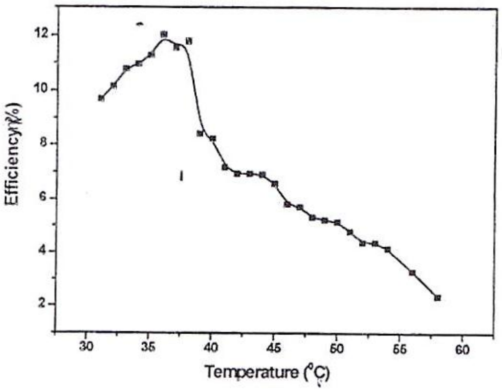

Fig 2 : Variation of efficiency vs. Temperature

2.1.7 Structural flexibility

In crystalline Solar cells, the semiconductor layer usually consists of one or more crystals. Since crystals have specific cleavage planes they are brittle. a-Si Thin film Solar cells do not have cleavage planes and hence it can be made flexible and suit to different shapes. Cost of land is a major component of any Solar PV project. In order to significantly reduce the cost of PV system the thin-film PV structure can be integrated into building materials such as roofs or windows. These Building-integrated PV (BIPV) applications reduce the cost of PV systems since the product has dual use.

2.1.8 Staebler-Wronski effect

Large changes in photoconductivity and dark conductivity is observed in a-Si Thin film Solar cells due to prolonged exposure to sunlight. The efficiency of a-Si Thin film Solar cells typically drops during the first six months of operation. The stabilised efficiency may be 10-30% less. This is called as Staebler-Wronski Effect (SWE). This is perfectly reversible upon annealing at or above 150 ^{o}C. Carlson David E 2005) Crystalline Solar cells does not exhibit this effect.

2.1.9 Productivity during diffused / indirect sunlight

Thin film Solar cells have broader spectrum absorption range that includes more infrared and even some ultra violet light. They have better weak light performance, allowing them to generate power in the early morning, or late afternoon and on cloudy and rainy days. (www.solartown. com)The efficiency of crystalline Solar cells drops substantially at diffused / indirect sunlight.

Conclusions

We have made one-to-one comparison of the various *attributes* of Thin-film as well as Crystalline Solar panels. We find that these attributes have bearing on the capital cost as well as operating cost of the Solar panels. Table 4 gives the comparison of attributes in tabular form. It indicates which attribute suits the particular *photovoltaic technology* for cost effective operation. The attributes discussed are actually the *inherent properties* of the particular photovoltaic technology. These attributes are very useful for proper selection of the correct photovoltaic cell required for any *application.* The application refers to the *external factors* viz. type of usage, geographical location, cost of land, availability of sunlight etc. Decision making tools can easily be used to select the right technology. Therefore the choice of a particular type of Solar cell will depend on the attributes discussed in this paper, the application and applying suitable decision making technique.

Table 4 : Comparison of attributes

S. NO	Attributes for Cost Performace	Thin Film Solar cells	Crystalline Bulk Film Solar Cells
2.1.1	Conversion Efficiency & Fill Factor		✓
2.1.2	Module Cost	✓	
2.1.3	LCOE	✓	
2.1.4	Manufacturing Technology	✓	
2.1.5	Consumption of Active material	✓	
2.1.6	Temperature coefficient	✓	
2.1.7	Structural Flexibility	✓	
2.1.8	Staebler Wronski effect		✓
2.1.9	Productivity during diffused / indirect sunlight	✓	

Note : ✓ Indicates the attribute which is favourable for the particular Photovoltaic technology

The attributes are very useful for proper selection of the correct photovoltaic cell required for any application. Decision making tools can easily be used to select the right technology. Therefore the choice of a particular type of Solar cell will depend on the attributes discussed in this paper and applying suitable decision making technique.
The understanding of attributes will encourage experimental study to establish the relative cost advantages and disadvantages. It will also facilitate the investors to make choice on which technology to invest.

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