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Cost model for silicon wafer equivalent approach: European project ThinSi

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Abstract

Thin-film epi-Si solar cells on low-cost Si based substrates (Si wafer equivalent approach) are a promising alternative to bulk Si solar cells. ThinSi is a medium-scale focused research project founded by the European Commission, which aims to develop a solar cell processing chain for high throughput, cost-effective manufacturing of such thin film silicon based solar cells on low-cost silicon supporting substrates [1]. The substrates are made from the low-cost Si powder on the basis of innovative powder-to-substrate concepts using (i) spark plasma sintering, (ii) thermal spray and (iii) any other alternative method. Moreover, casting of a multi-Si ingot followed by sawing of wafers is used as a reference approach to prepare wafer equivalent based solar cells. To evaluate the viability of the new technology developed in ThinSi project will carry out two types of analysis: a technical assessment of the processes and the equipments used and developed in this project, and a financial evaluation of the technology based on analysis of operating costs. To realize the Strategic Research Agenda developed in frame of the PV technology platform the cost effective manufacturing of thin Si based solar cells in frame of ThinSi project will target the cost of PV modules of about 1€/Wp.

Keywords: Interdigitated back contact solar cells; silicon quantum dots; plasmonic layer; cost analysis.

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1. Project overview

ThinSi is a three-year project in which involves 11 partners from 8 member states and administers the resources in terms of personnel, knowledge and equipment that are required for success. Details can be found from the project website: http://www.sintef.no/Projectweb/ThinSi.

It is a medium size focused research project carried out in the Seventh Framework Program of the European Commission. ThinSi is an ambitious project to develop a solar cell processing chain for high throughput, cost-effective manufacturing of thin film silicon based solar cells on low-cost silicon based supporting substrates. The supporting substrates are made on the basis of an innovative powder-to-substrate concept. It will reduce the cost of solar cell modules compared to those made by the conventional wafer based approach. The ThinSi solar cell structure, being wafer and Si based is very similar to that for traditional Si wafer based cells. This will ensure a low acceptance threshold in the solar cell industry. In spite of these similarities, several essential bottlenecks and developments in low-cost process methods, and therefore in the whole process flow for the processing of poly-Si on low-quality Si substrates solar cell, must be addressed: (i) reduction of cost and simplification of processing of low-cost Si based substrates using a "powder-to-substrate" concept; (ii) methodology for cost-effective deposition of high quality active layers on low cost substrates, including Si base, emitter and TCO antireflection coatings (in case if a heterojuction approach is used for the solar cell processing) retaining a high cell efficiency; (iii) thorough understanding of the electronic properties of the deposited solar cell thin films and their interfaces as a function of deposition parameters; (iv) development of advanced methods for optical confinement; (v) implementation of "powder-to-substrate" concept based processes flow for the solar cell fabrication to existing industrial lines currently operating in frame of single Si wafer based approach.

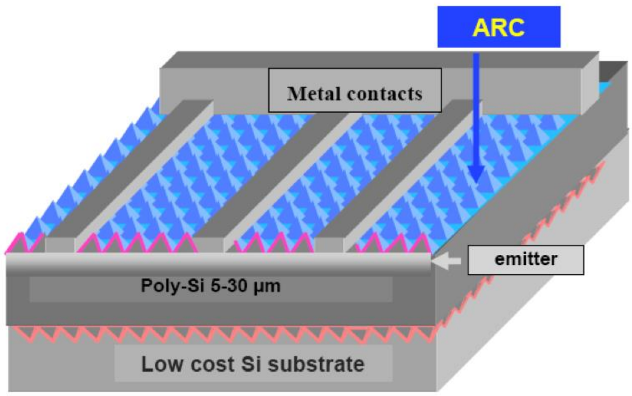


Fig. 1. General structure of poly-Si on low cost Si substrate solar cell

2. Concept of the solution

The main vision of ThinSi project is to develop a solar cell process chain for high throughput, cost effective manufacturing of thin Si based solar cells on low-cost Si substrates. A set of innovative technological processes will be developed to realize this new concept and evaluate the results at production scale.

To be able to reduce thin Si film solar cell cost, both material and material fabrication costs must be reduced. This can be achieved by growing a high quality "expensive" thin active crystalline Si layer onto a less expensive substrate. Solar cells utilizing thin-film epi-Si base on highly-doped Cz-Si substrates exhibit efficiencies above 16% [2,3].

ThinSi project is developing a new low cost substrate based on highly doped low-cost/low-purity crystalline Si. Highly doped silicon is conductive. Hence, the substrate can be used as electrode, avoiding any contacting problems. A perfect lattice match will lead to the lowest possible crystallization temperatures for the deposited high purity thin film. A porous silicon buffer layer towards the low purity substrate will serve as a gettering layer for the impurities. Lower crystallization temperatures will in addition reduce such diffusion. Silicon based low-cost supporting substrates are fully compatible with the deposition/crystallization processes of thin Si layers on top of such substrates.

The concept of crystalline silicon thin-film solar cells on low-purity substrates allows substantially reduce the consumption of high-purity silicon material and has at the same time potential to reach high efficiencies comparable to wafer silicon solar cells.

ThinSi will is applying a "powder-to-wafer" approach, which simplifies the wafer based processing of Si solar cells, and thereby reduces the cost. Moreover ThinSi applies a low grade starting material thereby reducing the costs even further. When the powder is shaped and sintered into an appropriate substrate, it will be a suitable poly-Si seeding material, which will provide good crystallisation conditions for any Si based layers deposited and annealed at appropriate conditions.

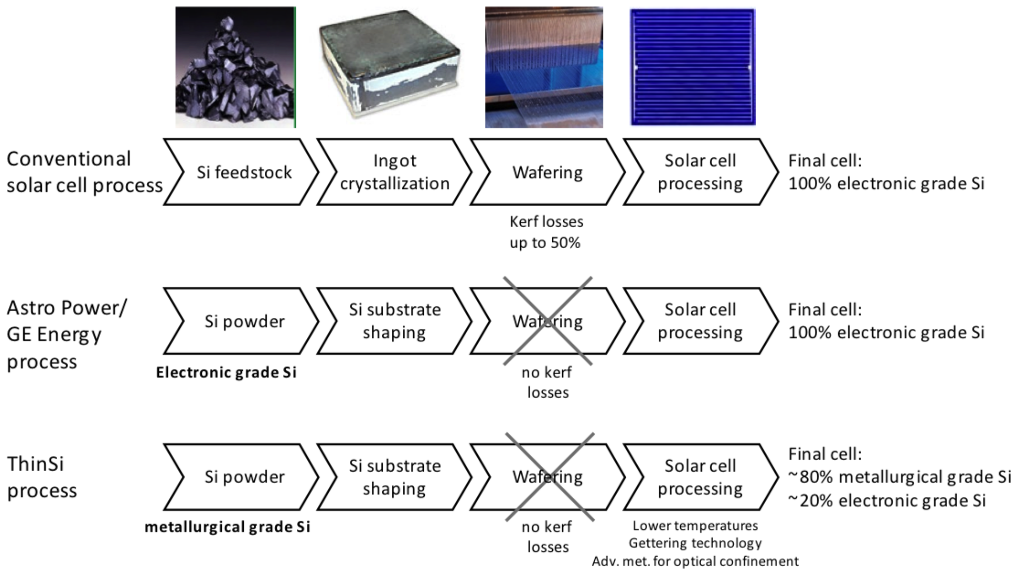


Fig. 2. ThinSi process compared to other technologies

3. Cost model for ThinSi technology

A cost model for a standard technology of crystalline silicon cells has been developed to use as reference for the ThinSi process chain. The breakdown of the model consists of wafer, solar cell and module steps. The wafer step implies polysilicon, ingot growing and wafering; the standard solar cell process consist of saw damage etching, alkaline texturing, phosphorous diffusion in quartz tube by liquid source ($POCl_3$), PSG removal, SiN deposition by PECVD as antireflection layer, three-step screen-printing metallization, laser isolation and electrical measurement and quality control; the module fabrication process include the glass washing, stringing, lamination, junction box mounting, electrical measurement, framing, cleaning and packing. To build up the cost model have been considered the complete list of equipments and its features (power energy consumption, depreciation cost, maintenance needs), materials and consumables for production, direct labour and fixed costs (that include indirect labour, services, rents, air cooling, taxes, etc.)

The cost of standard technology based on p-type monocrystalline silicon solar cells and BSF-Al device have been estimated as reference. The general assumptions of cost model have been the following:

- 50MW production line size that working with three shifts
- Ten years for depreciation time of equipments
- Electricity cost average is 0.110€/kWh [4]
- 156mm x 156mm Cz-Si wafer price is assumed as 1.22 €/piece [5].
- An average efficiency of 17.5% at mass production level is assumed for BSF-Al technology.

The output result of the model is 0.84€/Wp as average cost per watt peak for standard photovoltaic module based on BSF-Al solar cell. In table 2 and figure 3 is shown the cost breakdown of the standard technology.

Table 2. Breakdown of cost for photovoltaic module based on BSF-Al solar cells

Breakdown of cost for photovoltaic module based on BSF-Al solar cells	€/Wp	%
Wafer (polysilicon + ingot growing + wafering)	0.30	36%
Solar cell	0.21	24%
Module encapsulation	0.33	40%
Total	0.84	

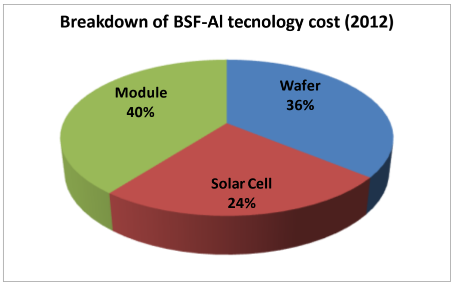


Fig. 3. Breakdown of cost for photovoltaic module based on BSF-Al solar cell technology

In ThinSi project several structures will be analyzed and studied, so we have developed a cost model useful for most of them. In this paper we have focused on following approach: low-cost substrate and epi-Si layer process by CVD.

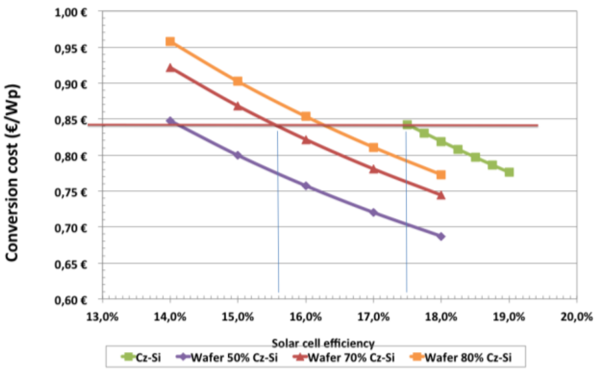
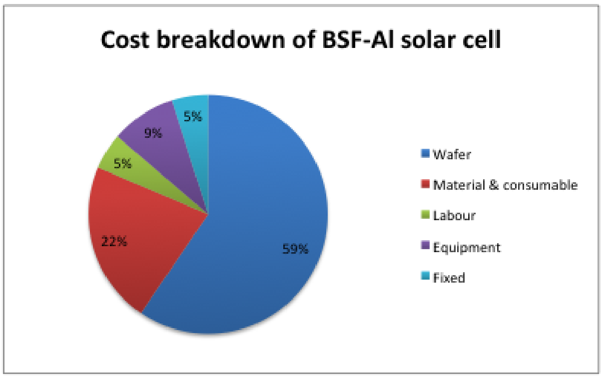


Fig. 4. Estimated manufacturing cost for ThinSi device

The solar cell process that has been taken into account in this model consist of: low-cost wafering, high-temperature CVD process for epi-Si layer deposition, diffusion emitter by quartz tube, SiNx deposition by PECVD, screen-printing metallization, laser isolation and electrical measurement and quality control. In figure 4 is shown the output results of cost model for ThinSi device and standard BSF-Al technology. The reference module cost is 0.84€/Wp (as it shown in figure 4 it is matched with 17.5% solar cell efficiency at mass production level). The cost estimated for Cz-Si substrate from Upgraded metallurgical-grade silicon (UMG-Si) is about 70% of standard Cz-Si (red curve of figure 4). The reference price for UMG-Si considered has been 5€/kg. In this approach, the threshold solar cell efficiency to assure the industrial viability of ThinSi device is 15.6% at mass production level. It is shown in figure 4 the sensibility of substrate cost and the effect in threshold efficiency.

In figure 5 is shown the cost breakdown at solar cell level for standard and ThinSi approach. The wafer weight in the manufacturing cost has been clearly reduced.



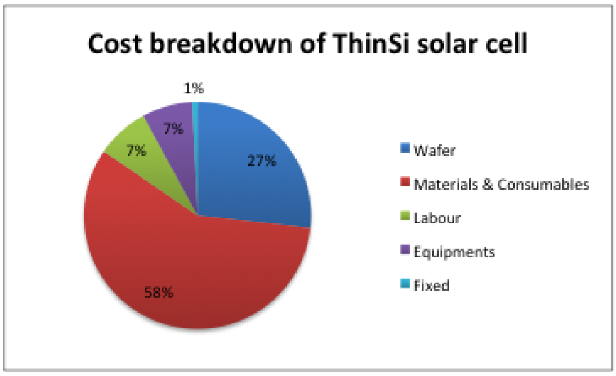


Fig. 5. (a) Cost breakdown of standard BSF-Al solar cell; (b) cost breakdown of ThinSi solar cell based on Cz-Si from UMG-Si and epi-Si layer deposition by CVD

4. Conclusions

The ThinSi approach to reduce the photovoltaic energy cost and advance to the grid parity goal has been presented. In this project is being explored the route of low-cost Si substrate and high-purity thin layer deposition.

The industrial viability of this photovoltaic device has been analyzed, the process flow has been presented and a cost model for standard BSF-Al technology and ThinSi device based on low-cost Si substrate and epi-Si layer deposition by CVD has been developed.

The threshold efficiency at mass production level to assure the industrial viability of the technology has been estimated. The sensibility of substrate cost in this threshold efficiency has been shown.

Acknowledgements

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