Competitiveness of CIGS technology in the light of recent PV developments – Part 1: The state of the art in CIGS production

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Fab & Facilities

Materials

Cell Processing

Thin Film

PV Modules

Power Generation

ABSTRACT

For some years CIGS was seen as the great white hope of the PV industry, until c-Si revealed its true competitiveness in mass production. Most companies dedicated to the commercialization of CIGS, many of which were VC financed, did not survive this development. Nonetheless, the industry has recently seen new corporate entrants with impressive plans for the roll-out of CIGS. The motives for these strategic actions are of interest, so a cost-of-ownership calculation was performed for a state-of-the-art CIGS production: the result is that current production cost for a CIGS module is €0.44/Wp, with material and depreciation being the main cost drivers. Although significant progress has been made in the last few years, this is still higher than the production costs for standard c-Si modules. However, the costs for CIGS coating materials, which correspond to the wafer in a c-Si module, are significantly lower than those for a wafer. Could this be a motive for the actions that have been witnessed in the CIGS industry? The next task would be to evaluate the further cost-reduction potential of CIGS and the likelihood of its realization.

CIGS comeback?

PV has come a long, long way. In 1839 Becquerel detected the photoelectric effect, and Einstein explained it in 1904. In 1940 the photoelectric effect was observed in crystalline silicon (c-Si), and Bell Labs presented the first c-Si solar cell in 1945. The 1970s oil crises gave PV a certain momentum but not enough to create a sustainable market in the megawatt – let alone gigawatt – range. The efficiency of cells and modules improved only gradually, and the outward appearance of a PV module did not change significantly for several decades. It is no wonder that around the turn of the millennium a PV module based on crystalline silicon was considered to be a fully developed product with little potential for further enhancements in performance or reductions in production costs.

By this time it was becoming more and more obvious that the use of renewable energies would become mandatory for one reason or another – pollution, exhaustibility of fossil fuels and climate change. With the accepted deficiencies of c-Si in mind, developers turned their attention to thin-film PV; the materials involved are direct semiconductors having absorption coefficients a hundred times higher than c-Si, allowing absorber layers in the single-digit micrometre range, as shown in Fig. 1. Attention was focused particularly on those materials with high efficiency potential: cadmium telluride (CdTe) and $CuIn_{1-x}Ga_x(Se_{1-y}S_y)_2$ (CIGS). The production process – shown in Fig. 2 for CIGS – enables cell and module production to be intertwined, which was another feature that would offer the possibility of significantly lower production costs. Back then, two commercial ventures existed that used these materials, both having several decades' history: Solar Frontier (the offspring of Arco Solar) and First Solar (which started off as Solar Cells Inc.). Interestingly, it is these two companies that are today involved in true mass production – Solar Frontier has 1GWp production capacity at two sites in full swing and has reported a record-beating 14.6% (180Wp) with its module.

This particular focus of attention on CIGS has resulted in the founding of countless start-ups commercializing the numerous approaches of the technology, first in Europe, then, with a few years' delay, in the USA. PICON Solar estimates that up until 2012 roughly $5000m had been spent. Only a few of these start-ups still exist, which is due, on the one hand, to home-grown reasons: the commercialization took longer and required more resources, namely money, than initially expected. On the other hand, the product development was more challenging,

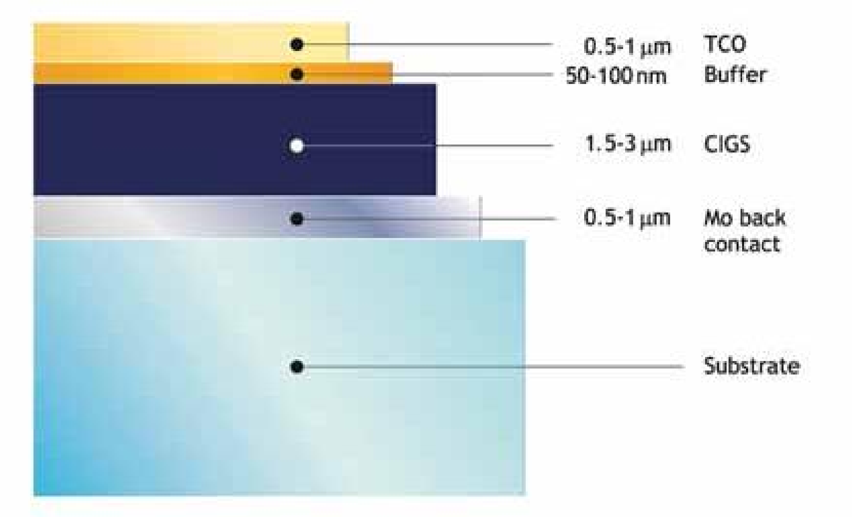

Figure 1. Schematic cross section of a CIGS thin-film device.

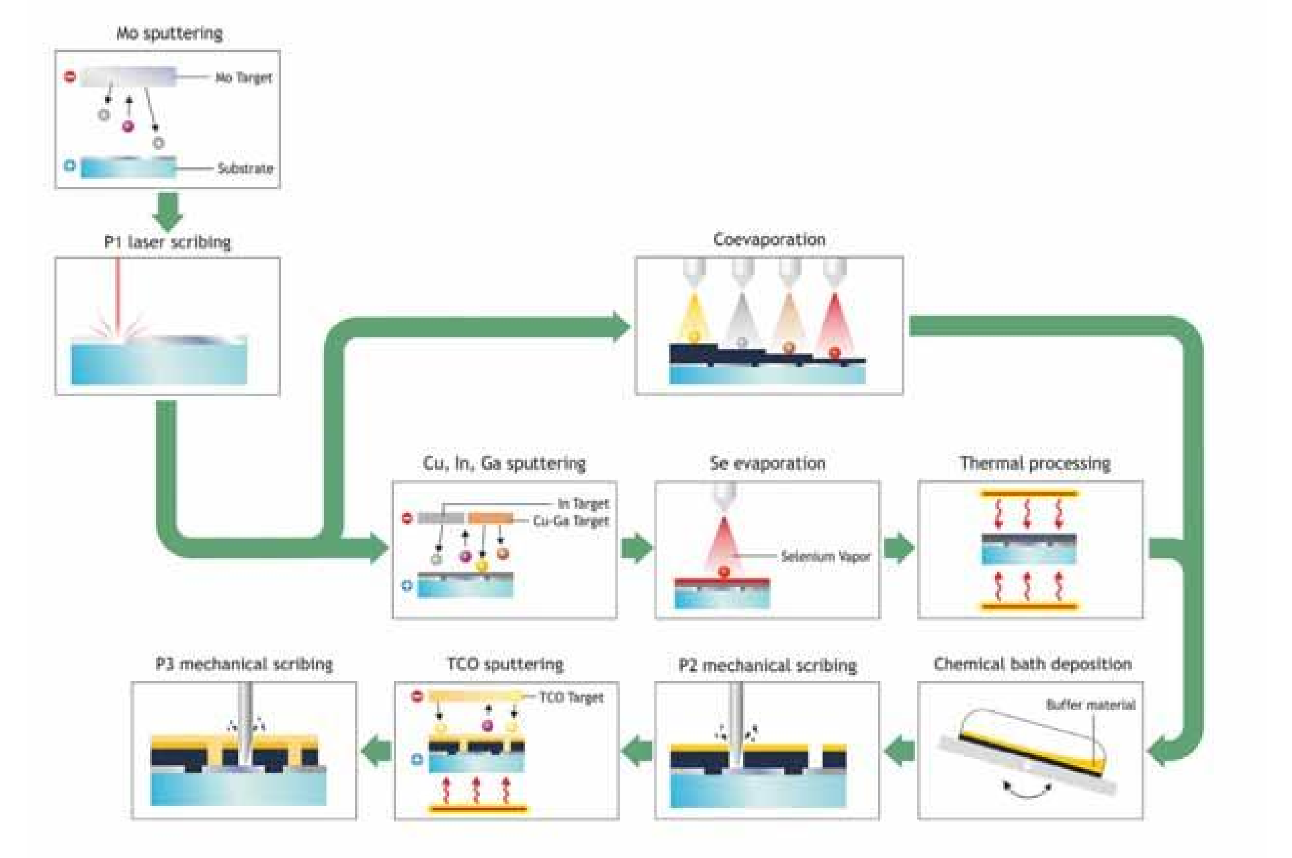

Figure 2. Production scheme for CIGS thin-film modules.

as thin-film modules turned out to be more delicate than their c-Si counterparts in terms of long-term stability. But this is what you expect from VC-financed start-ups. More crucial was the fact that they were (and still are) chasing a moving target.

After the removal of all bottlenecks in the supply chain, the prices of c-Si PV modules fell dramatically as production capacity significantly outpaced installation. Rock bottom was reached in 2012/13, when very few of the production players throughout the value chain were still profitable, which forced the various players into the systems business. As of today, average sales prices of c-Si PV modules are of the order of €ct50/Wp in Europe and slightly above $ct60/Wp in the USA. Direct production costs for PV in the range $ct50–60 for a PV module using standard solar cells (p-type silicon, anti-reflective coating, back-surface field, Al rear-side metallization, Ag front-side metallization) can be considered feasible, at least in China. Jinko published production costs of $ct50/Wp and Yingli reported $ct55/Wp last year. In 2011 the costs were still in neighbourhood of $1, which means they have decreased 50% in two years. However, it is not within the scope of this article to analyse what has led to this development. Technology road maps and PICON Solar's investigation [1] moreover reveal that there is still cost-reduction potential for standard technology.

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In the wake of all the c-Si turmoil, new and potentially large players began to appear on the CIGS scene. TSMC licensed the technology from Stion to further develop it on its own, recently reporting a module efficiency of 15.7% (corresponding module power 171Wp) in 2013 and a production capacity increase from 40MWp to 120MWp in 2014. Hanergy went on a shopping trip and ended up with Solibro, MiaSolé and Global Solar Energy in its trolley. The record module efficiency (at the time) of 14.7% (138Wp) had already been achieved in 2011. Hanergy announced plans to ramp up the production capacity to a cumulated 3GWp for both the Solibro technology (currently 135MWp) and the MiaSolé technology (currently 150MWp). Equipment for an annual production 600MWp was ordered at beginning of 2014.

This new configuration – with at least three CIGS players having the potential financial resources to go all the way – calls for the previous cost of ownership calculation (CoO) of Schuler, Luck & Berghold [2] to be revisited in order to check whether the current status of the technology and its future potential would justify these moves. No such activities can be identified for c-Si: large players would rather back out than boost new technology steps, as the example of Bosch and GE shows. In the remainder of this paper the CIGS CoO result will be analysed for its main cost drivers and a brief comparison made with its fellow competitor c-Si.

Basic assumptions and CoO result

For the direct cost of ownership calculation, the costs are broken down into blocks, specifically material, equipment depreciation, facility depreciation, energy, labour, maintenance and consumables. The basic assumptions for the calculation are:

- A fictitious 143Wp CIGS glass/glass module with a total area of 1.1m^2 and 13% efficiency. These values are derived from the data sheets for the CIGS modules from Solar Frontier, Solibro and TSMC. This represents today's feasibility in mass production.

- The absorber layer (1.6µm) preparation used is the coevaporation of the elements method. An average metal evaporation coefficient of 40% is assumed.
- Today's metal prices are taken from internet sources (e.g. www.metalprices.com).
- The molybdenum back contact (0.3µm), the sodium diffusion barrier and the zinc oxide front contact (1µm) are deposited by sputtering without material recycling. An average rotatable target utilization rate of 75% and an average sputter material transfer coefficient of 55% are assumed.
- The CdS buffer layer (50nm) is applied using a wet chemical deposition step.
- EVA is used for encapsulation. A tape is used for edge sealing.
- The series interconnection of the cells is realized by monolithic integration.
- The nameplate capacity is 1000MWp, which allows economy-of-scale savings in raw material procurement comparable with that of c-Si fellow competitors. From a production point of view, a reasonable production capacity might be lower; in this case, however, several such production lines should be in operation.
- The production line operates 24/7/360 with an overall yield of 95%. No production drops occur due to seasonal markets.
- The production line operates in Europe, with corresponding costs for labour, building and technical infrastructure. Overheads are not considered.
- Equipment investment and the corresponding depreciation are taken from the latest press release of Solar Frontier, in which the company states that it spends $125m on 150MWp production capacity. This is even below the equipment expenditure reported for their previous 900MWp nameplate capacity. A currency exchange rate of €/$1.35 is assumed. Depreciation period is six years. The technical infrastructure is written off entirely in this time period, while the building is written off to 50% of its initial value.
- Yearly maintenance and consumables are kept at 5% of the initial equipment invest.
- The impact of any subsidies and capital costs is not taken into account.

The CoO assumptions result in €0.44/Wp production costs for a CIGS-based thin-film PV module (Table 1). An aluminium frame would add €0.04–0.05/Wp to the calculation. The cost structure is dominated by materials, with an overwhelming 44%, and depreciation holds a significant 25% share (Fig. 3). Other large cost drivers are energy at 11% and labour, which contributes 9%.

"Compared with previous CoO calculations, CIGS production costs have fallen by €0.14/Wp."

Compared with previous CoO calculations [2], CIGS production costs have fallen by €0.14/W_p – a reduction

Cost structure	[€/Wp]	
Total material cost	0.193	44%
Equipment depreciation	0.109	25%
Facility depreciation	0.018	4%
Energy cost	0.049	11%
Maintenance cost	0.016	4%
Consumables cost	0.016	4%
Labour cost	0.039	9%
Total cost	0.440	

Table1. Absolute and relative cost contributions of various segments to CoO.

Thin Film

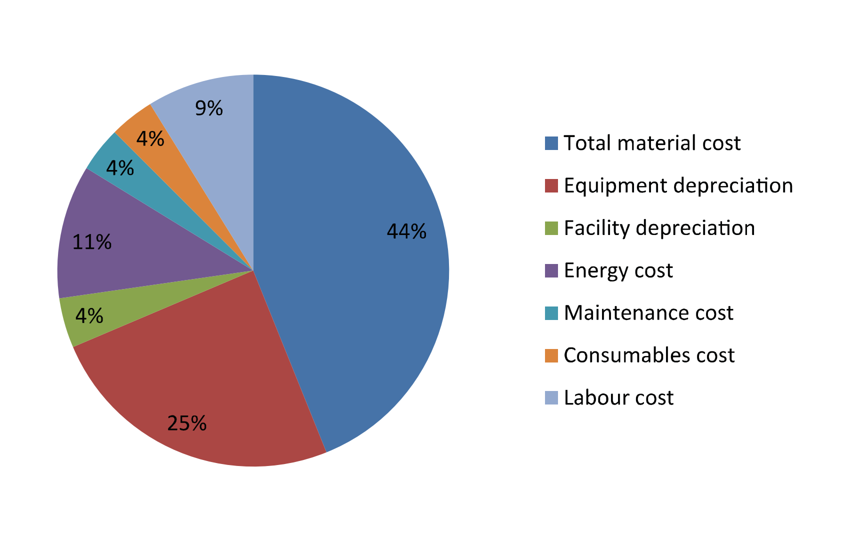

Figure 3. Relative cost contributions of various segments to CoO.

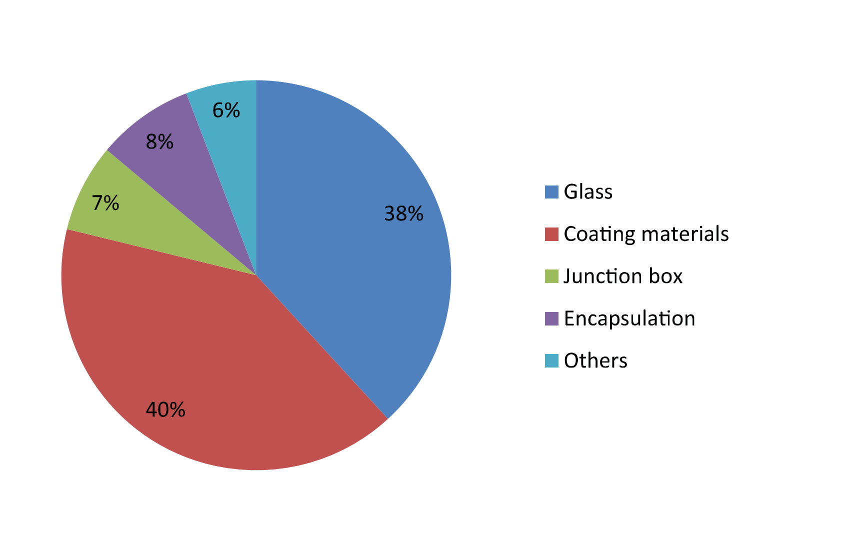

Figure 4. Relative contributions of the different material sections.

of more than 20% over the last two years. Materials have held their ground as the dominating segment in the cost structure, and equipment depreciation is still by far the second-largest position. Everything else (facility depreciation, energy, maintenance, consumables and labour) can be regarded as more or less stable. The overall decrease in production costs is attributable to two main factors:

1. An increase in module efficiency (total area) of 1%, from 12% to 13%.
2. A significant fall in equipment investment of almost 40%.

An analysis of the materials segment of the CoO reveals that the €0.19/Wp contribution is mainly made up of the glass and the coating material costs. Together these constitute almost 80% of total material cost (Fig. 4). Other noticeable shares come from the junction box and the encapsulation material.

CIGS compared with c-Si

Before continuing with sensitivity analyses of the CoO calculation, it is useful to take a quick look at the production costs of the fellow competitor c-Si. As mentioned in the introduction, these costs are around $ct50–55/Wp, which correspond to €0.37–0.41/Wp. This means that the fictitious CIGS factory would produce CIGS thin-film PV modules at either significantly or slightly higher costs. While costs have come down by 50% in c-Si module manufacturing in two years, only a 20% cost reduction has been achieved for CIGS within the same time frame. When comparing these two developments, one should keep in mind that the collapsing silicon prices have helped a lot in the case of c-Si. However, the question immediately arises as to where the difference in production costs comes from.

The impact of investment/depreciation is obvious: while €620,000 must be paid per MWp production capacity for CIGS, a c-Si cell/module fab can be constructed for anything between €90,000 and €110,000 per MWp. The impact on the cost structure is radical, to such an extent that depreciation becomes an insignificant portion of the cost structure. The high investment also imposes a very effective market-entry barrier, thus preventing CIGS module production reaching critical mass.

The lower module efficiency of 13% for CIGS, compared with at least 16% for c-Si, influences the cost structure in a similar fashion. The efficiency aspect can simply be translated into throughput: the higher the efficiency, the lower the investment for a certain production capacity. The other way to look at it is that you get more production capacity for your money. In either case, the depreciation per Wp decreases. The lower efficiency of CIGS is also a disadvantage when per item cost factors are considered; items such as junction boxes and sealing are required per module, not per Wp. The lower the module power, the higher the impact of these items on the cost structure. The third area where the low efficiency is undoubtedly disadvantageous is the balance-of-system (BOS) costs in PV systems engineering: this evaluation, however, is beyond the scope of this paper.

Depending on the particular estimates being considered, the raw material c-Si wafer, which corresponds to the coating material in the CIGS module, makes up anything between 32% [3] and 41.2% [4]. However, the coating materials in CIGS make up 40% of the materials costs, which equates to only 20% of the total costs. In absolute numbers, that translates to around €0.07/Wp, which is significantly lower than what must be paid for a wafer. With respect to the cost of the absorber (coating) material at least, CIGS technology has clearly met expectations.

"With respect to the cost of €0.07/Wp for coating material, CIGS is highly competitive and beats c-Si impressively."

Summary and outlook

The CoO calculation has demonstrated that the production of CIGS thin-film PV modules is currently more costly than the production of c-Si modules – even under best-case assumptions, such as a very high overall production yield. Production costs for CIGS are at €0.44/Wp, with materials and equipment depreciation being the main cost drivers (70% of the total costs). However, with respect to the cost of €0.07/Wp for coating material, CIGS is highly competitive and beats c-Si impressively.

To evaluate what needs to be done in order to bring the costs down further, sensitivity analyses with a careful interpretation of the results need to be carried out. These will be the topic of discussion in a follow-up paper, which will look into the impact of varying efficiency, investment costs, material pricing, production yield, energy and labour. The likelihood of certain variations occurring or being achieved will also be commented on.

Acknowledgement

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