Solar Energy 143 (2017) 93–99

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

CIGS cells with metallized front contact: Longer cells and higher efficiency

Joop van Deelen *, Corné Frijters

TNO, Department of Thin Film Technology, De Rondom 1, 5612 AP Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 22 November 2016
Accepted 24 December 2016

Keywords:
Grids
Metallization
Thin-film
CIGS

ABSTRACT

We have investigated the benefit of a patterned metallization on top of a transparent conductive oxide in CIGS thin-film solar panels. It was found that cells with a grid have a higher efficiency compared to cells with only a TCO. This was observed for all cell lengths used. Furthermore, metallic grids enable increase of the cell length up to 10 mm virtually without reduction in efficiency. This result was obtained with a metallic grid of 20 μm wide and just 1.5 μm high. In addition, the following parameters were varied: TCO sheet resistance, the grid finger width and the finger height for cell lengths up to 40 mm. For cell lengths of 30 mm and 40 mm, wider and higher fingers have improved efficiency compared to fingers of 20 μm wide and 1.5 μm high, which is related to a higher fill factor.

1. Introduction

Thin-film cells are usually built up of a stack of coating materials. For record cells the surface area is small and the front contact usually consists of a doped transparent conductive oxide layer, supplemented with a metallic grid. The reported record efficiencies of thin-film cells are well over 20% (Green et al., 2015). At this high efficiency, thin-film PV technology has become a viable alternative for wafer cells. Improved efficiency is an important asset, because it reduces the cost of photovoltaic electricity production ($/kW h). Therefore, most literature concerns ways towards better cell performance.

Although the focus on higher cell efficiency gives new records every year, it should be noted that the efficiencies of thin-film solar *panels* are still substantially lower. The innovations to reduce this efficiency gap receive much less attention from academic researchers as than new materials or cell records. Thin-film solar panel are often produced by coating a large substrate and defining specific parallel areas of typically 5 mm wide by scribing. This method creates many individual solar cells on the substrate which are parallel to eachother. The front contact material, the transparent conductive oxide (TCO), is then deposited to function both as a front contact and the conductive material to form the interconnection. In contrast to wafer based cells and thin-film record cells, which have a metallic grid, for thin-film solar *panels*, this approach has not been thoroughly investigated and has not been adopted by the industry, because it was asserted that it did not give sufficient efficiency advantage. This was presumably assumed based on the state of the art inkjet technology of a decade ago with typical deposited line dimensions that were low (<1 μm) and relatively wide (>100 μm). A few reported studies concerning metallic grid on TCO have used a typical width of the grid of 100 μm and it was mainly applied for mini-modules and not for monolithically integrated panels (Wallin et al., 2012; Olaisen et al., 2005).

Fig. 1 shows three possible layer buildup configurations for solar cells: wafer based cells with a metallic grid (without TCO), thin-film monolithically integrated modules without and with a metallic grid. For a wafer cell, there is a typical pattern of narrow grid lines and wider gridlines. For the thin-film module without the grid, the grey lines indicate where the cells are interconnected. The space between the grey lines represents the cell length. For a cell with grid lines is can be seen that the finger grid is placed perpendicular to the interconnect direction.

The trade-off between transparency and conductivity of the TCO leads to higher optical and electrical losses, as compared to small cells. The effect of the front contact conductivity on the cell performance has been modeled and indicates how the cell length is limited by the front contact resistance (Denhoff and Drolet, 2009; Miyadera et al., 2012; Brecl et al., 2005; Koishiyev and Sites, 2009). Nevertheless, transparent conductive oxides are the most widely used material class for the front contact (Illiberi et al., 2012) and many studies on its deposition processes have been reported (Kartopu et al., 2014; van Deelen et al., 2014a). Recently, the improvement of the TCO front contact quality by addition of a metallic grid has been reported by our group

* Corresponding author.
E-mail address: joop.vandeelen@tno.nl (J. van Deelen).

http://dx.doi.org/10.1016/j.solener.2016.12.050

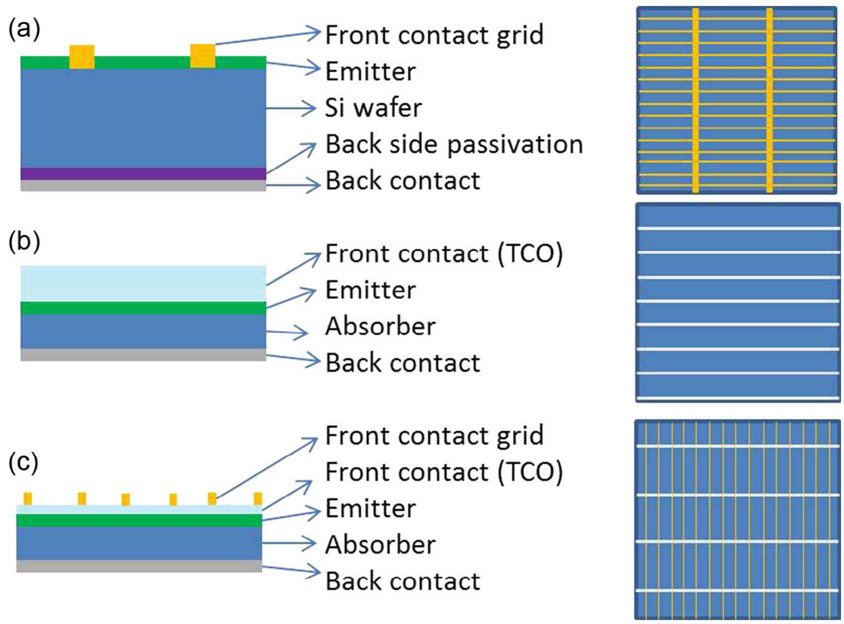

Fig. 1. Schematic representation of layer buildup of different solar cells (left column) and a top view (right column) of: (a) a wafer based cell with a metallic grid, (b) a thin film stack with TCO as a front contact (typical in thin film panels) and monolithic integration, as depicted by the grey lines that indicate the interconnection areas, (c) a thin film stack with both a grid and a TCO as front contact. This front contact allows for longer cells, i.e. less interconnect zones.

(van Deelen et al., 2010, 2014b) and set against various materials solutions reported in the literature (van Deelen et al., 2011). For thin-film cells, a metallic finger grid has been proposed for small cells (Malm and Edoff, 2008) and mini-modules (Kessler et al., 2003; Brecl and Topic, 2008). There is a renewed interest in the application of metallic grids for thin-film solar modules (Li et al., 2011) and the potential of this approach has been modeled for thin-film cells and suggested that more than 15% relative increase in module efficiency can be achieved compared to TCO (van Deelen et al., 2014c; van Deelen et al., 2015a). One of the important conclusions of this study was that fingers as narrow as 20 μm are optimal, but fingers as wide as 60 μm or even 100 μm can also have a major boost in efficiency if the finger thickness is increased to levels above 1 μm.

The present work shows the impact of the improved front contact configuration and cell length on the efficiency of CIGS cells. It provides experimental support that the application of grids allow an upscaling of small cells to monolithically integrated panels while maintaining a high efficiency. For various TCO sheet resistances, grid heights and grid widths, cells were made and measured for cell lengths between 5 and 40 mm. Even though the height of the metallic grid in these experiments (1.5–7 μm) was lower than the optimal height according to the outcome of previous modeling studies (10–50 μm), a clear benefit of grids over TCO only was measured for the same sheet resistance of the TCO of 32 Ohm/sq.

2. Experimental

2.1. CIGS cell stack deposition

CIGS layers with a thickness of 2 μm were deposited on Mo coated SLG substrates using a three-stage co-evaporation process at 550 °C. Immediately after the CIGS deposition a 50 nm CdS layer was deposited using chemical bath deposition. On top of the CdS, a 40 nm i-ZnO layer was sputtered using 500 W RF power and 15 sccm Ar at base pressure of 10^{-6} mbar on all three substrates. The TCO was a sputtered ZnO:Al layer, using 800 W RF power and 15 sccm Ar. The thickness of the ZnO:Al layer can be varied by the amount of passes the substrate underwent in front of the sputter target. Finally, a copper grid was evaporated through a shadow mask onto the solar cells at a pressure of 10^{-6} mbar at a rate of 17 nm/min.

2.2. Front contact configurations

Fig. 2 shows the layout of the cell configurations used in the experiments. The whole sample is a glass plate of 100 × 100 mm with a complete CIGS cell stack. The metallization forms cells of different sizes. Around these patterns, the cell is scribed as to separated it from the rest of the surface. Large cells are 15 mm wide and the front contact includes a 1 mm wide busbar (which is not taken into account in the efficiency calculation), unless indicated otherwise. The large cells with metallic grid vary in length between

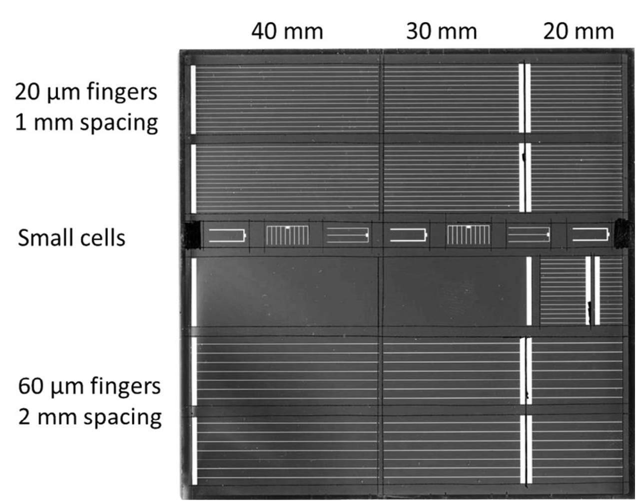

Fig. 2. Image of the solar cell design with grids that was used in this work. 20, 30 and 40 mm cell lengths were in duplicate, while 5 and 10 mm only one sample could be taken. The areas without thin grid line function as TCO only samples.