Roadmap Towards Sustainable SHJ Solar Cell Design

SUMMARY

Current industrial silicon heterojunction (SHJ) modules use scarce materials such as silver for screen-printed contacts, indium for indium-tin-oxide (ITO) transparent conductive oxide (TCO) layers and bismuth for Sn-Bi coated Cu wires for low-temperature interconnection. SHJ solar cells use double the silver (30.3 mg/W) as mainstream passivated-emitter rear cell (PERC) technology. However, the most pressing issue is indium, which reduces the sustainable manufacturing capacity (SMC) for 22.5% efficient SHJ modules to only 28 GW/year if using 20% of the current global supplies. With this, current SHJ solar panels can contribute less than 2.5% towards ITRPV's broad electrification scenario. Significant changes to cell and interconnection design are required to enable TW scale manufacturing, well beyond increasing efficiency above 25%. In this study, a potential roadmap for the sustainable manufacturing process of SHJ towards TW scale manufacturing is proposed to address such issues, along with technical challenges along the way and interdependencies on device performance and SMC. For example, there is a need to completely replace indium-tin-oxide layers with In-free (TCO such as AZO). However, if transitioning to copper plating, which is essentially required to solve silver issues to reduce silver consumption below 5 mg/W, new challenges can be introduced related to plating. In addition, the use of additional tin-bismuth coated wires/busbars to reduce silver consumption can introduce new material challenges, where bismuth has a lower global supply than silver. Reducing bismuth content could increase the SMC, but also increase melting temperature which may pose issues for surface passivation and reliability.

1. INTRODUCTION

There are many proposed scenarios to reach net-zero emissions [1],[2]. In order to reduce emissions, the rapid expansion of renewable and sustainable green energy technologies including photovoltaics (PV) is necessary. In 2020, the annual production of PV was over 130 GW/yr, representing more than 17% of the total cumulative PV capacity ($P_{PV;tot}$) of 756 GW [2]. However, the share of PV and wind energy was still <6% of the primary energy consumption in 2020 [3], which was not significant compared to that of fossil fuel technologies (>80%) [3]. Therefore, we need a more substantial expansion of renewable energies to mitigate greenhouse gas emissions such as carbon dioxide.

However, the expansion can lead to a serious issue regarding material consumption. Last year PV production required over 10% of the annual global silver supply [4], which already shows alarmingly high demand for materials. This percentage is also increasing with time. It is also noted that this was dominated by PERC with more than 80% market-share with a consumption of 15.6 tonnes/GW, based on the module efficeincy [2],[5]. New emerging cell technologies are likely to be based on n-type commercial technologies like tunnelling oxide passivated contact (TOPCon) and silicon heterojunction (SHJ) solar cells [2]. However, while they promise higher efficiencies than PERC, they require more silver than the current dominant PV cell technology of passivated emitter and rear contact cells [2], particularly for SHJ solar cells due to the use of pure low-temperature silver pastes on both the front and rear contacts (30.3 tonnes/GW) [2]. Although silver consumption for SHJ solar cells is expected to halve over the next decade to (15.6 tonnes/GW) as reported in the 2021 ITRPV, 1 TW of SHJ solar cell production with this consumption would still consume 57% of global annual silver supply, a value that is clearly not feasible. In addition, SHJ solar cells require extra scarce materials like indium for transparent conductive (TCO) layers as indium-tin-oxide (ITO) (6.5 tonnes/GW) and bismuth for low-temperature interconnection wiring (6.9 tonnes/GW). Those materials are in even shorter annual supply and global reserves than silver [6]. Therefore, material sustainability needs to be considered and corrected for more sustainable production. In this study, using known alternative approaches and materials, sustainability is assessed and a roadmap to have sustainable SHJ manufacturing is proposed.

2. METHODOLOGY

2.1. Calculation

In order to quantify the sustainable manufacturing capacity (SMC), we take the annual primary material supply (AMS) for each scarce material from the U.S. Geological Survey [6], as well as the consumption per power (CPP) of each material. We assumed that the PV industry can only use 20% of the AMS, to account for demand, which is also increasing, by other industries' for the clean energy transition. The CPP (in mg/W) is calculated as:

$$CPP = \frac{CPC}{P_{cell}} = \frac{(V \times \rho \times \%\ of\ the\ content) \times U}{(A_{cell} \times \eta \times I_{1sun})} \quad (1)$$

Where V is the volume of the composed material, ρ is the density of the material, A_{cell} is the area of a solar cell, which is based on the current industry size of 166 mm × 166 mm, η is the cell efficiency, I_{1sun} is the standard illumination intensity of 1 kW/m^2. U is the utilisation rate of each material. % of the content is determined by the weight ratio of other materials. In this study, only silver, indium and bismuth are considered, as other materials such as zinc, tin, copper, or aluminium required for manufacturing SHJ solar panels have substantially higher annual supply [6] to meet the current requirements for TW scale manufacturing, although they can still significantly impact the emissions generated through manufacturing SHJ panels.

3. ROADMAP FOR SUSTAINABLE SHJ SOLAR CELL MANUFACTURING

Here, the roadmap for SHJ solar panels towards a sustainable manufacturing future is discussed (see Fig. 1). The reference case is for 22.5% efficient SHJ modules (2021 ITPRV) [2], with silver-screen printed contacts (35.2 mg/W), indium tin oxide (ITO) for transparent conductive oxide (TCO) with 85 nm per side and 65% utilization (U) (from SHJ manufacturer data), and assumes 9 busbars multi-busbar (MBB) interconnection, 3 µm Sn-Bi coating (58%wt Bi and 42%wt Sn) on 300 µm diameter copper wires, with an SMC of ~28 GW/yr [2]. This would only allow X% contributions towards ITRPV's broad electrification scenario by 2050. Increasing module efficiency (η) to 25% will have little impact on the SMC (~10% increase in SMC) (S5). With this, significant changes to device design are required to reduce the consumption per cell (CPC) and CPP.

The cell design can be optimised to have a trade-off among the scarce materials. For example, reducing the finger spacing on the rear leads to higher tolerance with higher lateral resistance of TCO such that a thinner ITO layer could potentially used (noting potential changes in optics), while silver consumption (+5%) is expected to be increased (S1) but it can still be optimised with reduced finger width. Using a different structure like interdigitated back contact (IBC) structure [7] or a single side TCO structure (S3) can almost double the indium-limited SMC. However, these could unfavourably introduce manufacturing challenges for the case of IBC or reliability issues with the absence of a layer between the a-Si layers and metal, particularly for copper plating. Dual layer TCO layers could also be used such as on the rear with 44nm aluminium zinc-oxide (AZO) and 44nm ITO (S2) demonstrated at 3 mg/W (SMC = 66 GW/year), or more desirably 20nm AZO/80nm ITO on both surfaces (S4). Essentially, SHJ solar cells can only tolerate 0. 58 nm/cell even for a 26.7% efficient device with 100% indium utilisation. Therefore, ITO must be completely replaced to eliminate indium-based constraints and enable TW scale manufacturing, with indium-free layers such as AZO (S6) [8] already demonstrated over 24% efficiency, and a non-disclosed TCO structure by LONGi over 25%.

Once SHJ solar cells are indium-free, the next pressing issue is silver. Efforts to reduce silver consumption in screen-printed SHJ cells with the same number of busbars (even assuming silver-free busbars or busbar-less) will undoubtedly decrease efficiency. Reducing from current consumption down to a target of 5 mg/W finger consumption [9] (silver-free busbar) will drop efficiencies by ~2% relative, although manufacturing cost my also reduce by ~5-10%, leading to a lower $/W. In addition, with Meyer Burger now operating as a solar panel manufacturer, it is unclear whether this option would be made available to competitors. Copper pastes can also be used, but care must be taken to account for oxidation of the copper and interactions with encapsulants. To address this, silver-coated copper pastes have demonstrated promising silver reductions ~50% (S9). Silver can be replaced with copper to have a silver-free design. Sundrive has recently demonstrated a great potential of copper metallisation SHJ cells with over 25.5% [10]. However, plating has proven challenging when combined with an In-free TCO such as AZO, and must be addressed [11].

Once silver-free, the remaining concern for SHJ modules is bismuth. Reducing the bismuth content in Sn-Bi coatings can reduce CPP of Bi for interconnection wiring (eg. 37%$_{wt}$). (S12), although increase the melting temperature, which could create challenges for interconnection and damaging a-Si passivation. Electrically conductive adhesive (ECA) paste can eliminate the usage of bismuth, but this must avoid the use of silver-based ECAs (S14). Another option is shingle module interconnection technology, which can be done using FoilMet®[12]. However, if reliant on silver screen-printed fingers, relative power losses could be prohibitively high for 5 mg/W finger silver consumption. **Full details, cost estimates and additional scenarios will be shown in the final paper.**

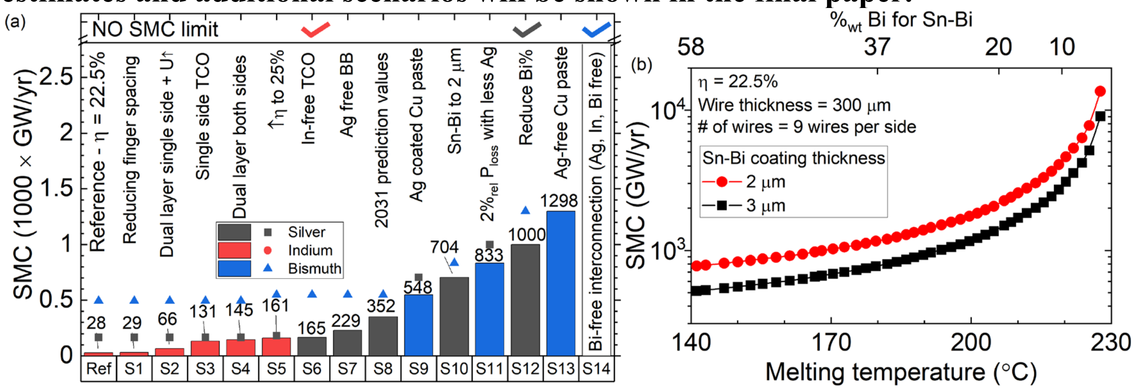

FIG. 1. (A) A proposed roadmap towards TW scale manufacturing for SHJ solar cells/modules. (b) SMC as a function of melting temperature for different Sn-Bi coating thickness on Cu wires.

[1] International Energy Agency (IEA), Net Zero by 2050: A Roadmap for the Global Energy Sector, 2021.
[2] ITRPV, International Technology Roadmap for Photovoltaic, 2021.
[3] BP, Statistical Review of World Energy, 2021.
[4] The Silver Institute, World Silver Survey 2021, 2021.
[5] Y. Zhang et al., Energy Environ. Sci. (2021).
[6] U.S. Geological Survey, Mineral Commodity Summaries 2021, 2021.
[7] A. Louwen et al., Sol. Energy Mater. Sol. Cells **147** (2016) 295–314.
[8] L. Lou Senaud et al., IEEE J. Photovoltaics **9** (2019) 1217–1224.
[9] P.J. Verlinden, J. Renew. Sustain. Energy **12** (2020).
[10] PV-magazine, (2021).
[11] E. Photovoltaic et al., (2016) 487–494.
[12] J. Paschen et al., Prog. Photovoltaics Res. Appl. (2021) 1–10.