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Design and analysis of Sb_2S_3/Si thin film tandem solar cell

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ABSTRACT

Antimony sulfide (Sb_2S_3) and thin crystalline silicon (c-Si) are considered suitable top- and bottom-cell candidates for tandem solar cells (TSCs), owing to their natural abundance, non-toxicity, cost-competitiveness, and complementary bandgaps. The current work proposes and investigates a two-terminal (2T) monolithic Sb_2S_3/Si thin film TSC via TCAD simulation. The Sb_2S_3 cell, with a bandgap of 1.7 eV, is utilized as a top sub-cell, and the bottom sub-cell is utilized by a thin c-Si cell having a bandgap of 1.12 eV. The calibrated standalone top and bottom cells provide a power conversion efficiency (η) of 4.31% and 14.26%, respectively. Upon incorporating the two cells into a 2T Sb_2S_3/Si monolithic TSC, the resultant tandem cell achieves an η of 10.10% implying that the top cell should be optimized in order to get a tandem efficiency higher than the bottom cell. Thus, the Sb_2S_3 cell is optimized by designing the cell without the organic hole transport layer (HTL) (resulting in an np heterojunction) and engineering the conduction band offset (CBO) between the electron transport layer (ETL) and the Sb_2S_3 absorber. Then, the tandem structure is optimized starting from the ETL thickness and doping concentration. Also, the impact of changing the absorber defect density and the series resistance of the top cell on the TSC performance is investigated to demonstrate the maximum available η. At reduced defect density and series resistance, the overall efficiency of the tandem cell is improved to 19.51%. Furthermore, we explored the impact of top and bottom absorber thicknesses on TSC working metrics. At the designed matching point, the tandem efficiency is enhanced to 23.25%, and J_{sc} also boosts to 17.24 mA/cm^2. The simulation study is intended to provide a tandem configuration that is based on an all-thin-film design which may be suitable for applications like wearable electronics due to its flexibility. All TCAD simulations are performed using the Silvaco Atlas simulator under standard one Sun (AM1.5G, 1000 W/m^2) illumination.

1. Introduction

One of the technical solutions for reducing the cost of photovoltaic (PV) power generation is to increase solar cell efficiency by designing tandem solar cells with several absorption layers and complementary bandgaps [1–4]. Schematically, tandem devices can be designed in either 2T, 4T, or 3T configurations. The 2T tandem configuration combines wide and narrow bandgap p-n junctions which serve as the top and bottom cells, respectively. The two sub-cells are electrically connected via an interlayer known as the recombination layer or tunneling junction. However, although the two cells of the 4T tandem device are internally separated, they are coupled to combine their full output power [5]. E. Warren et al. [6] recently presented a hybrid tandem photovoltaics configuration known as a 3T tandem configuration. Despite its simplicity of fabrication, external wiring on the front and rear of the solar cell stack is required. For cost-effective applications, the 2T arrangement is preferred due to its reduced fabrication steps. Yet, the top cell of the 2T device is manufactured atop the bottom, making the synthesis process more challenging [7]. Moreover, selecting the top and bottom sub-cells concerning their bandgaps is critical to the performance of both 2T and 4T architectures. The theoretical analyses that have been published offer a guided direction for the choice of optimal bandgap sub-cells. In this context, a 2T monolithic tandem configuration with 1.7 eV top and 1.12 eV bottom cells can accomplish a high conversion efficiency of up to 40% [8].

In addition, tandem cells have been utilized commercially for a wide range of absorbers, from relatively inexpensive hydrogenated amorphous silicon (a-Si:H) to high-performance III-V group materials [9,10].

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