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Full Length Article

Full optoelectronic simulation of all antimony chalcogenide thin film tandem solar cell: Design routes from 4-T to 2-T configuration

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ABSTRACT

Antimony chalcogenide, as a newcomer to light harvesting materials, is regarded as an auspicious contender for incorporation as a photoactive layer in thin film tandem solar cells (TFTSCs). The current study introduces the design of all-antimony chalcogenide TFTSC comprised of an Sb_2S_3 (1.7 eV) front subcell and an Sb_2Se_3 (1.2 eV) rear subcell. The challenges to migrating from four-terminal (4-T) to two-terminal (2-T) designs are highlighted and possible solutions are proposed. To commence, a calibration procedure for the two subcells is conducted in alignment with experimental investigations. The benchmarked solar cells yield a power conversion efficiency (PCE) of 8.08 % for the upper subcell and 10.58 % for the lower subcell. Subsequently, upon integration of both subcells within the initial 4-T Sb_2S_3/Sb_2Se_3 TFTSC, the resultant PV cell attains a PCE of 12.27 %. Before transitioning it to a more efficient 2T tandem configuration, we explore alternative inorganic HTL materials to the Spiro-OMeTAD HTL to overcome its practical considerations. Cu_2O is found to be the best HTL alternative to be included for both subcells. Upon stacking into the tandem structure, the combined cell exhibited an efficiency of 15.68 % and a notable J_{sc} of 16.23 mA/cm^2. To further enhance the tandem performance, the device structure is optimized by engineering the CBO of two sub-cells and employing a double ETL design for the front sub-cell. At the considered current matching criterion, the tandem device PCE and J_{sc} are boosted to 27.86 % and 17.60 mA/cm^2, respectively. Based on this full optoelectronic analysis, developed in the Silvaco TCAD environment, a 2-T all antimony chalcogenide tandem configuration can be realized and optimized, paving the way for future experimental endeavors.

1. Introduction

The widespread adoption of Si solar cells has propelled photovoltaic (PV) technology by offering efficient energy conversion [1]. To push Si solar cells further, some novel structures were proposed, including microstructures [2], and nanowires [3]. Additionally, it was shown that the insertion of multiple quantum wells made of $Si_{0.95}Ge_{0.05}$ improves the efficiency by a factor of 1.37 compared to that obtained for conventional Si nanowires [4]. Other studies related to III-V materials solar cells also show advancements, including proposed quantum dot GaAs/GaAsP structures [5]. Nonetheless, thin film solar cells have arisen as a favorable choice, boasting advantages such as flexibility, lightweight design, and cost-effectiveness, setting them apart from their Si and III-V counterparts.

Tandem solar cells, representing a remarkable advancement in PV systems, harness the cumulative power of multiple solar cell layers to capture a broader spectrum of sunlight [6–8]. This tandem approach significantly enhances the overall PCE as compared to single-junction PV cells. In the context of tandem cells, antimony selenide (Sb_2Se_3) and antimony sulfide (Sb_2S_3) materials hold immense prospects as

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