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Mechanically Stacked Solar Cells for Concentrator Photovoltaics

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Abstract

The power output of dual-junction mechanically stacked solar cells comprising different sub-cell materials in a terrestrial concentrating photovoltaic module has been evaluated. The ideal bandgap combination of both cells in a stack was found using EtaOpt. A combination of 1.4 eV and 0.7 eV has been found to produce the highest photovoltaic conversion efficiency under the AM1.5 Direct Solar Spectrum with x500 concentration. As EtaOpt does not consider the absorption profile of solar cell materials; the practical power output per unit area of a dual junction mechanically stacked solar cell has been modelled considering the optical absorption co-efficients and thicknesses of the individual solar cells. The model considered a GaAs top cell and a Ge, GaSb, $Ga_{0.47}In_{0.53}As$ or Si bottom cell. It was found that GaSb gives the highest power contribution as a bottom cell in a dual junction configuration followed by Ge and GaInAs. While the additional power provided by a Si bottom cell is less than these it remains a suitable candidate for a bottom cell owing to its lower cost.

Keywords
Mechanical Stack, GaAs, Photovoltaic, Concentration, Modelling

1. Introduction

Photovoltaic (Solar) energy is playing an increasingly significant role in meeting European and Worldwide targets for renewable power generation [1]. Monolithically-grown triple-junction III-V/Ge PV solar cells currently represent the state-of-the-art in terms of the highest sunlight to electricity conversion efficiencies achieved to date. Nevertheless, drawbacks associated with current matching, crystal lattice mismatch between optimum cell materials and cell interconnect (tunnel junction) reliability, particularly in the case of solar concentrator systems, are of some concern [2]. Mechanically stacked solar cells (MSSC) can overcome these issues [3], however, they present alternative challenges primarily due to the complexity of integration of the various sub-cells with minimal optical loss and at minimal cost. Currently the state of the art MSSC, using a spectral splitting approach, has reached a photovoltaic conversion efficiency of 38.5% under x20 concentration [4].

In this study the theoretical power performance of dual-junction mechanically stacked solar cells using the solar cell simulation program EtaOpt [5] is presented. The optimum multi-cell configuration was determined for use in a terrestrial concentrating (500 suns) photovoltaic system. An additional modelling approach was also developed to investigate the effect of the optical absorption properties and cell thickness on MSSC performance. This modelling approach was adapted from those already used to investigate the effect of cell thickness on power output from monolithic multi-junction solar cells [6, 7]. These two modelling approaches were used to evaluate the power output of MSSCs incorporating GaAs single junction top-cells with Ge, GaSb or $Ga_{0.47}In_{0.53}As$ (GaInAs) bottom cells.

2. Theoretical Modelling

a) Bandgap Selection (EtaOpt)

The choice of bandgap for both solar cells in a dual junction mechanical stack will determine the likely power output from the device. The detailed balance limit of efficiency [8] is commonly used to evaluate the potential power output of solar cells. This method assumes a solar cell behaves according to the one-diode model and considers radiative recombination as the only loss mechanism i.e. an ideal solar cell with no resistive, thermal or optical losses which are highly dependent on cell structure and design. EtaOpt is a free software program available from the Fraunhofer Institute [5] which uses the detail balance limit of efficiency to compare the performance of various bandgap arrangements in single or multi-junction solar cells. EtaOpt also makes a number of additional assumptions about the solar cells:

- All photons with $E>E_g$ are absorbed
- Each absorbed photon creates an electron-hole pair

The first model considered was a dual junction mechanical stack. Figure 1 is a plot of the expected photovoltaic conversion efficiency of this stack as a function of top and bottom cell bandgaps. The bandgap arrangement is illuminated by the AM1.5d (direct) spectrum under a concentration of 500 suns. The p-n junction temperatures were held constant at 300 K. The plot shows GaAs (1.41 eV) to be the ideal top cell in a dual junction mechanically stacked solar cell with a bandgap of 0.7 eV being ideal for the bottom solar cell. This corresponds closely to a number of candidate materials namely Ge, GaSb and GaInAs which have corresponding bandgaps of 0.67 eV, 0.72 eV and 0.75 eV respectively.