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# Optical and electronic simulation of gallium arsenide/silicon tandem four terminal solar cells

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**Abstract**

A tandem solar cell in a mechanical (stack like) arrangement of gallium arsenide and silicon solar cells is evaluated as a pathway towards higher efficiency terrestrial solar cells. In this work the technical feasibility of the tandem solar cell is investigated. Here we report on detailed electrical and optical simulations of this structure quantifying various theoretical and practical loss mechanisms in the interface and in the device and indicate that an efficiency improvement of 5.13% would be attainable with the present generation of gallium arsenide and silicon solar cells in this configuration. The optical and electrical parameters for gallium arsenide and silicon simulation models were extracted from experimental devices and material vendors. The developed simulation models were validated by comparing the performance of standalone gallium arsenide and silicon solar cells with experimental devices reported in the literature.


*Keywords:* Tandem solar cell; Electronic modeling; Optical modeling; Silicon solar cell

## 1. Introduction

Worldwide electricity consumption in 2008 was estimated to be 19.1 trillion KW h and it is projected to increase by 85% to reach 35.2 trillion KW h in 2035 according to the US Energy Information Administration (2011). Though abundant fossil fuel reserves exist on the planet to support this growth in electricity consumption, concerns of global warming may limit its utilization. On the other hand, there is abundant solar energy irradiation on the planet to meet the world's electricity demand and the cost of solar energy generation has also been falling rapidly bringing it closer to grid parity (Woodhouse et al., 2011). But the challenge is the intermittency of solar energy sources and large land area required to generate the energy using present technologies. If 20% of the projected global electricity demand in 2035 is met by photovoltaic devices, contributing 7 trillion KW h, that would entail a global installation of 3.85 terawatts (TW) (considering average solar irradiation of 5000 Wh/sq.m per day). In 2011 about 70 GW of solar module manufacturing infrastructure was online (Mehta, 2012), so a couple of TW scale installation is possible in less than 20 years because of the decreasing solar costs and growing manufacturing capacity. However the corresponding land area required for 3.85 TW will be approximately 47,000 sq km with present generation of silicon solar cells having 16–18% efficiency. Such a high land area requirement would pose significant challenges for Asia, Western Europe and parts of Africa and South America, which are some of the most densely populated regions in the world.

Therefore, a pathway to higher module efficiency at a reasonable cost is essential if solar energy is destined to play a significant part of the global electricity generation mix. Present generation of silicon solar cells have reached a laboratory efficiency of 24.7% (Zhao et al., 1999) and it has a theoretical efficiency of 33% as shown in Fig. 1a. Higher power conversion efficiencies would be possible by more efficient broadband absorption of the solar

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spectrum (Henry, 1980). Various device architectures have been demonstrated for this purpose namely multi-junction (series-connected 2 terminal) solar cells (King et al., 2007; Bertness et al., 1990 and Karam et al., 1999) and mechanical tandem (stack like) solar cells (Burgess et al., 1988; Gee and Virshup, 1988; Gale et al., 1990; Liska et al., 2006; Flamand et al., 2009 and Ito et al., 2011). The mechanical tandem solar cell architecture is attractive because two separate devices could be developed independently targeting a specific part of the incident spectrum and subsequently put together to form a tandem module avoiding tunnel junctions. It is especially attractive if it can utilize the existing multi-GW manufacturing capacity of silicon solar cells. Fig. 1b shows the theoretical power conversion efficiencies for two junction (mechanical stack) solar cells based on Shockley–Queisser's (Shockley and Queisser, 1961) calculations using sunlight with AM 1.5 spectrum.

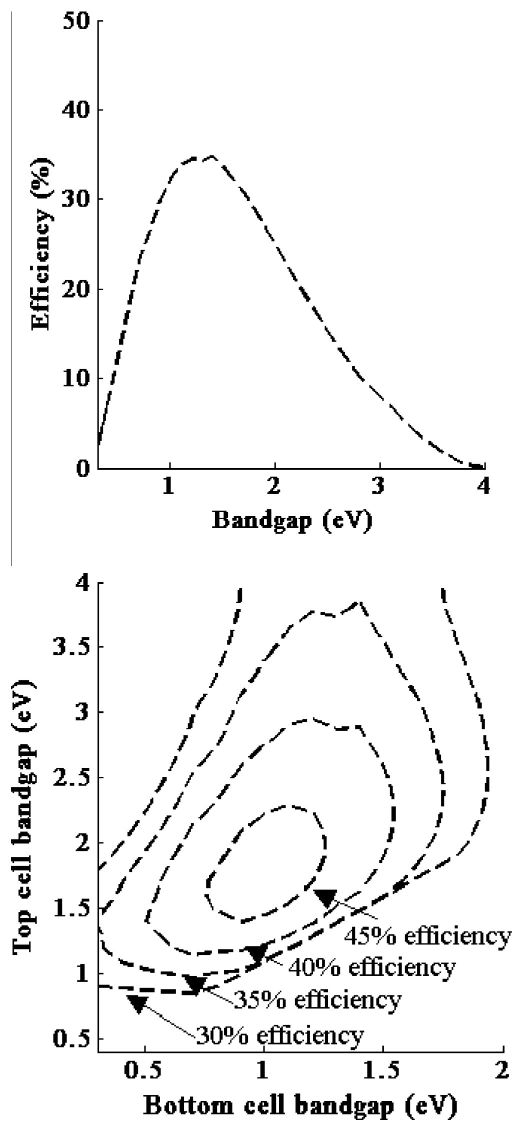


Fig. 1. (a) Theoretical conversion efficiencies based on Shockley and Queisser limit and (b) two junction (mechanical stack) solar cells under AM 1.5 solar spectrum.

In this work we examine a mechanical tandem structure with gallium arsenide as the high band gap top cell, which has a band gap of 1.43 eV, and silicon at 1.11 eV as the low band gap cell. The theoretical efficiency of a gallium arsenide/silicon tandem device is calculated to be as high as 44% as shown in Fig. 1b. The increase in ideal theoretical efficiency compared to a single junction silicon device is 11%, so low cost, mass manufactured and efficient solar cells targeting high band gap spectrum in tandem with the silicon solar cell would be an attractive alternative for densely populated regions where land-area may limit installations. The illustration of the device architecture is shown in Fig. 2. We report here on the electrical and optical simulations of this tandem structure, quantifying the various theoretical and practical loss mechanisms in the encapsulation, interfaces and in the device. Based on these studies we find that a practical efficiency improvement of over 5% may be attainable in this configuration with present technology.

## 2. Experimental – device modeling

The gallium arsenide solar cell was modeled as a thin film device with gallium indium phosphide window layer as shown in Fig. 3. Thin film gallium arsenide solar cells reduce the cost of the device by limiting the expensive gallium arsenide substrates. Such devices have been demonstrated before (Bozler et al., 1981 and Bauhuis et al., 2009) and now Alta Devices Inc. (Mattos et al., 2012) is working to commercialize these devices. The device was modeled here with a heavily doped n-type and p-type region at the front and back surface to form good ohmic contacts with the external metal contact (Belghachi and Helmaoui, 2008). A 0.025 μm thick gallium indium phosphide window layer is modeled to reduce the front surface recombination achieving a low rate of 200 cm/s (Plá et al., 2007). Individual doping concentrations and thickness of the various gallium arsenide solar cell layers were based on the device fabricated and characterized by Lee et al. (2012) with the emitter, base and back surface field being 0.15 μm, 3.5 μm and 0.075 μm thick, respectively, and the corresponding dopant concentrations being $1 \times 10^{18}$,

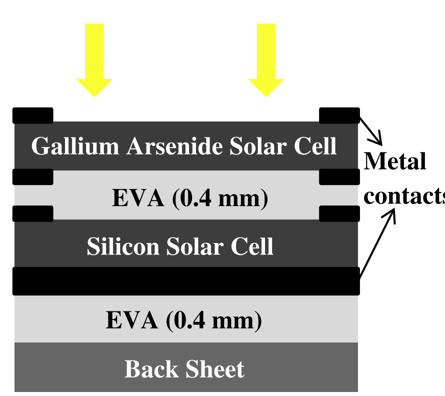


Fig. 2. Illustration of the proposed GaAs/Si tandem solar cell.