Graphical Abstract

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Highlights

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- Research highlight 1
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Abstract

Optical and electrical properties of $InGaN$ alloys is being intensively studied to be combined with silicon by implementing $SiO2/Si3N4$ interlayers. Adhesion of nano-interlayer appears to reduce photonic electro-migration hurdle between InGaN and Si, in order to achieve high-efficiency solar cell. However, a relatively thick layer of $InGaN$ is difficult to grow due to the relaxation issue in material. This issue can be avoided by eboxy layer. This work, we present an $InGaN/Si$ tandem solar cell modeled using Wien2k and Solcore softwares. We have shown that 25% of indium is needed to ensure the current matching between the top cell and the bottom cell. With feasible structural parameters, we have shown that an efficiency near to 30% can be achieved with $InGaN/Si$ tandem cell.

Keywords:

1. Introduction

III-nitride (N) semiconductors, including aluminum nitride (AlN), gallium nitride (GaN), and indium nitride (InN), are highly promising building for optoelectronics and high-power electronics [1]. the III-nitrides have wurtzite crystal structure at ambient conditions, and the direct bandgap changes from 6.2 eV of AlN, 3.4 eV of GaN, to 0.7 eV of InN. III-Ns are displaying large amount of commercialized optoelectronics devices, including Photodetectors [2, 3, 4], light-emitting diodes (LEDs) ([5, 6, 7], laser diodes (LDs) [8], and solar cells [9, 10, 11],which are applied in energy harvesting.

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Compared to other semiconductors, III-Ns demonstrate a fundamental advantage of the formation of heterogeneous structures, such as quantum wells, and quantum dots. Heterogeneous structures III-N can be manufactured through key crystal growth techniques, including molecular beam epitaxy (MBE), metal-organic chemical vapor deposition (MOCVD) and hydride vapor-phase epitaxy (HVPE) [12, 13, 14].Due to the inability of a single solar cell to absorb large solar spectrum photons efficiently, multijunction solar cells have been the focus of much theoretical and experimental work in the past few decades. The most successful efforts to date have focused on the use of semiconductors such as II-VI and III-V alloys to construct such cells, achieving energy conversion efficiencies of over 30%. The $InGaN$ range band gap can be engineered from 0.7 to 3.4 eV, and this makes it suitable for a range of multijunction solar cell designs. These cells are able to use high-energy photons more efficiently than those limited to band gaps of less than 2.2 eV. These cells will also have the advantage that Si is relatively cheap and abundant as well as that the Si range gap of 1.1 eV is ideally suited to the lower connection of a high-efficiency two-link solar cell. Growth of $InGaN$-based opto-electronic device structures on Si has been extensively investigated previously with the goal of optimizing the interface layer(s) between the Si and the active layers to reduce defects in the nitride layers and to improve device performance . Hsu et al.[15] saw at an alloy composition of $In_{0.46}Ga_{0.54}N$, the conduction band of $InGaN$ has the same energy as the valence band of Si, and so a $n-In_{0.46}Ga_{0.54}N/p-Si$ interface should form a low resistance Ohmic junction. Recent studies have shown that high quality $InGaN$ nanostructures can be grown directly on Si substrate [16, 17]. In this study, we have performed a detailed investigation of the optimize and performance characterization of $InGaN/Si$ tandem solar cell.

2. Methode and modelisation

Solcore is a multi-scale, modular simulation framework for solar energy research, written in Python. Is evolved from SOL, a Fortran-based, quantum well solar cell solver developed by Nelson and Connelly [18], uses electronic and optical parameters obtained from different sources for a consistent set of electronic and optical properties. In order to calculate and model the optical response of potential solar cell and material systems, Solcore incorporates a resource of freely available optical constant data measured by Sopra S. A. and provided by Spectra Inc.[19]. To calculate the band structure of a

material Solcore includes a modified 8-band Pikus–Bir Hamiltonian under biaxial strain, considering the coupling between the conduction, heavy hole, light hole and split-off bands. The eigenfunctions ψ and eigenstates E are the solutions of the following equation, where H is the Pikus–Bir Hamiltonian:

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To evaluate the realistic optical behaviour of a solar cell, and obtain the fraction of incoming light reflected, absorbed, and transmitted as a function of the wavelength of the light and the position inside the structure. it is important to consider the interaction of incident electromagnetic (EM) radiation with a succession of both absorbing and non-absorbing planar layers using the transfer matrix method (TMM), The implementation of the TMM in Solcore uses the freely available tmm module developed by Byrnes [20]. Solcore includes four solvers to calculate the electrical properties of a single-junction device, these are: detailed balance, 2-diode equation, depletion approximation, and Poisson–drift–diffusion. To combine them into a multi-junction device, it is necessary to consider that the individual junctions are electrically connected in series and the potential coupling of light emitted by the wider bandgap junctions into those with smaller bandgap.

3. Resultat and Discution

The simulation begins from the thickness of the nominal layer and the refractive index calculated using the DFT theory impleted in Wien 2k software, we process this optimization in two phases: a optical simulation to get approximate total thicknesses for each junction, and then a device optimization. Using TMM simulation to calculate the photogenerated current in each layer, we get an estimate of the overall thickness of each material we will need to achieve current-matching, from a purely optical point of view the thickness of the bottom Si cell should be thick to maximize absorption, which is of course not the case for a device. Once we have good values for the layer thicknesses, we use full electrical simulation to determine the n and p thicknesses to calculate an optimize possible efficiency for the 2J device. Now that the layer thicknesses have been optimized from an optical point of view, we want to design the device.

We plot the QE and IV for the best thikness

Compare the total layer thicknesses obtained from the optical and electrical simulations:

Figure 1: Structure of $InGaN/Si$ tandem solar cell.

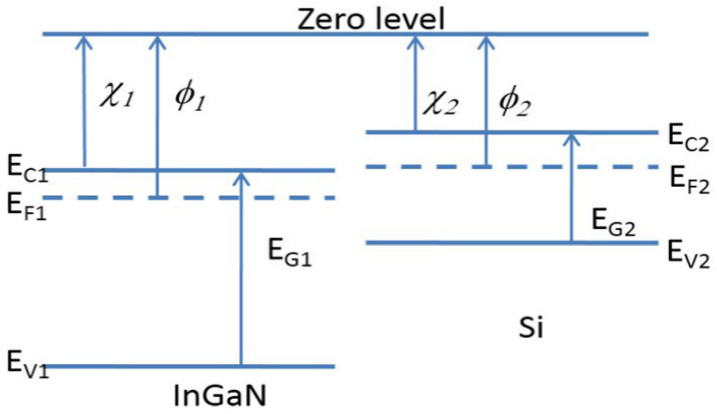

Figure 2: Band diagrams of $InGaN$ and Si before in contact

4. Conclusion

Computational models based on DFT theory and K.P method can provide significant insight into photovoltaic solar cells. Calculations can be performed behaviour, through experimentally and theoric parameters such as index coefficient, band gaps and the thickness . these combines capable of modelling the optical and electrical properties of tandem solar cells. we found the optimized band-gap and the thickness of $InGaN$ top layer were 2.2 eV and 600 nm respectively acheived optimal conversion efficiency of 30%, which is higher than that of the single junction Si solar cell.

Parametre	CdS	Si	GaN	$InGaN$

Table 1: Parameters used in simulations.

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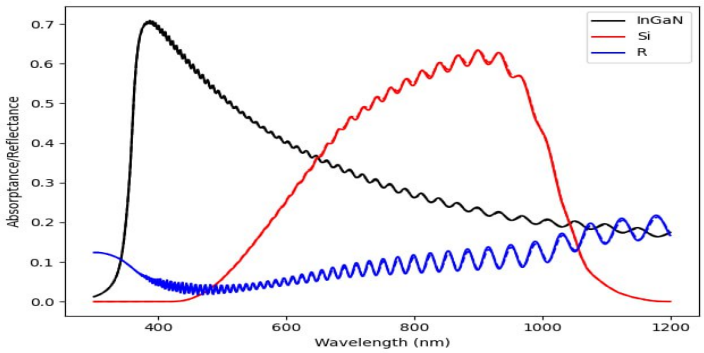

Figure 3:

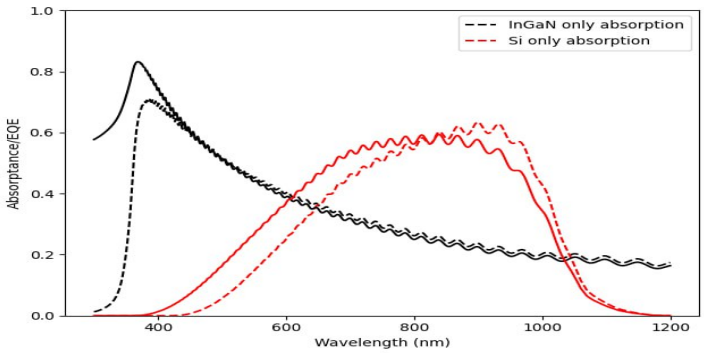

Figure 4:

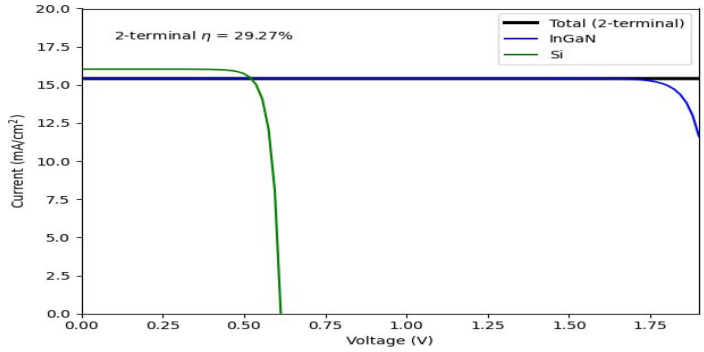

Figure 5: I-V characteristics of $In_{0.25}Ga_{0.85}N/Si$ tandem solar cell.

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