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Influence of emitter bandgap on interdigitated point contact back heterojunction (a-Si:H/c-Si) solar cell performance

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ABSTRACT

We report on the theoretical investigation of a silicon-based interdigitated back contact back heterojunction (BHJ) solar cell that combines the advantages of heterojunction with intrinsic thin layer (HIT) solar cell and point contact back junction c-Si solar cell. Our results show an optimum bandgap for emitter (p-type a-Si:H) layer for this cell to be approximately 1.72 eV. As we increase the bandgap from 1.3 eV to 2.2 eV, the open circuit voltage (V_{oc}) increases from 0.45 V to 0.75 V and then saturates, while the short circuit current density (J_{sc}) remains constant at 35 mA/cm^2 up to about 2.0 eV, and then decreases to zero. Fill factor (FF) increases from 57% to a maximum of 75% as the bandgap increases from 1.3 eV to ~1.72 eV, respectively, and then decrease to 5% when the bandgap reaches 2.1 eV. Efficiency increases from 7% and reaches a maximum of about 19% at around 1.7 eV and then decreases to zero at 2.1 eV. These results can be correlated to changes in valance band spike (barrier) when emitter bandgap increases from 1.3 eV to 2.2 eV, and are explained in terms of band alignment between p-a-Si:H/i-a-Si:H/n-type-c-Si.

1. Introduction

Silicon-based solar cell technology has grown in leaps and bounds over the years, particularly as the demand for solar power has grown. Recently reported efficiency for silicon based HIT solar cell (i.e., a-Si:H/c-Si), which is the most common heterojunction structure, has been as high as 23.7% [1].

However, in the front heterojunction structure, a limiting performance factor is the inevitable shading loss due to current collecting grid structure on the illuminated front side. This has recently been reported to be as high as 4% [2]. Shading loss can be reduced by making smaller grid structures. However, this results in an increase in series resistance, and consequently, reduction in the collection efficiency.

In this paper, we address the above mentioned issues by investigating the performance of a new solar cell structure—the point contact BHJ structure. In this structure the emitter (in our case p-type a-Si:H) as well as both collection grids (for p-type and n-type contacts) are placed on the non-illuminating rear side of the Si wafer, with the collection grids forming an interdigitated pattern. Therefore in the BHJ cell structure, the photovoltaic junction lies on the rear side of the wafer. This design consequently eliminates reflective and shadowing losses, and also the trade-off between reflection and series resistance, thus allowing for sufficient contact metal, and thus reducing resistive losses. Fig. 1 depicts the cross-sectional schematics of such a solar cell. BHJ cell can therefore be divided into three broad regions, viz., (1) p-type collection region, (2) n-type collection region, and (3) diffusion region [3]. The dimensions mentioned in the schematics were utilized in our performance study, which we discuss below shortly.

From Fig. 1 it is clear that the BHJ has several advantages over a front heterojunction structure. The grid less front surface enhances light incident area and hence enhances J_{sc} as well as FF. Also, as compared to front heterojunction structure, a transparent conductive oxide (TCO) layer and a-Si:H emitter layer on the front side are not required in the BHJ structure. Therefore, TCO absorption loss and emitter absorption loss in the short wavelength can be avoided [4], which in turn leads to an improvement in internal quantum efficiency of the cell in the short wavelength region.

Concomitantly, the point contact structure in this solar cell provides additional advantages over a line-contact structure [5]. This includes increased cell output voltage because of a reduced emitter component of the dark current. Also since undoped, uncontacted regions act as reflectors [6] than the contact region, doped a-Si:H regions are shrunk to points to accommodate more

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intrinsic a-Si:H region, which results in increased light absorption in the cell [6]. Furthermore, when contacts are reduced to points, built-in electric field at the backside can trap charge carriers and yield high (near unity) collection efficiency when lightly doped or undoped Si wafers are used for fabrication [6]. Therefore, low doped or even intrinsic Si wafers with high diffusion length of 1500 μm (2–3 times the wafer thickness) and very high life-time of 2–3 ms, resulting in low charge carrier transport losses, are desirable for the fabrication of this solar cell. The cell operates in a high level injection mode, where the number of photogenerated charge carriers are very large compared to the background doping density of the Si wafer. Hence in principle the operation of the cell is similar to that mentioned in [3,7]. Due to concentration gradient, photocarriers generated near the front diffuse to the back until they reach the built-in electric field. These carriers are then separated laterally by the built-in electric field across the depletion region and reach their respective electrodes. This results in a lateral flow of current from the n-type contacts (also called base fingers) to the p-type contacts (also called emitter fingers). Therefore front surface recombination and diffusion length of minority carriers are the significant parameters that control the efficiency of this solar cell.

In this paper we focus on band alignment studies between p-a-Si:H/i-a-Si:H/n-type-c-Si to determine the cell performance. Simulation studies on band alignment between p-a-Si:H/n-type-c-Si heterojunction solar cell has previously been reported [8].

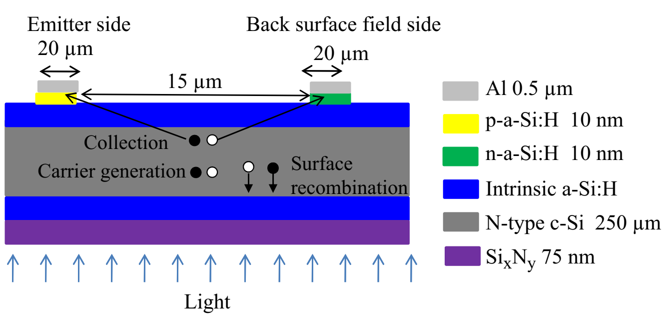

Fig. 1. Schematic cross-sectional view of point contact BHJ solar cell structure used in our simulation. Emitter and both grids (for p-type and n-type) are formed at the rear side of the base (n-type c-Si). Solid circle represents electrons and empty circle represents holes (picture not to scale).

However, the effect of an intrinsic a-Si:H layer between p and n interfaces has not been determined. In particular, the relation between emitter bandgap on cell performance has received little attention in reported literature [4,7,9–12]. In this work, we have investigated band alignment in the emitter junction region and device performance by varying emitter bandgap. Emitter bandgap impact on V_{oc}, J_{sc}, FF, and η are also investigated. Section 2 of the paper describes our device models and parameters, while Section 3 discusses the results from our studies. Conclusions are drawn in Section 4.

2. Device models and parameters

In our investigation, we considered a 250 μm thick c-Si as the starting substrate with n-type doping concentration of $1.0\times10^{15}\ \mathrm{cm^{-3}}$. A 2 nm intrinsic a-Si:H buffer layer was added to both sides of the substrate for surface passivation. The buffer layer reduces the defect density on both front and rear surfaces of c-Si, as well as surface recombination. Since intrinsic a-Si:H layer at the rear side restricts the flow of minority carriers (holes) in reaching the emitter and affects fill factor, we used very thin intrinsic layer in order to achieve low resistance for carrier flow at the interface. The grid less front side, where light enters the cell, was covered by a 75 nm thick silicon nitride (Si_xN_y) layer as an antireflection coating. On the rear side, for junction formation and carrier collection, heavily doped ($1.0\times10^{19}\ \mathrm{cm^{-3}}$) alternating p- and n-a-Si:H, each with a thickness of 10 nm and a circular area of 20 μm, and touching the metal layer were used. While an increase in emitter size increases hole collection and FF, the larger size also results in higher recombination at the metal-semiconductor (i.e., emitter) contact. Therefore we selected 20 μm circle as the emitter size for our simulations. After device fabrication, the back side substrate will appear as depicted in Fig. 2. Also as shown in Fig. 2, the space between the metal lines was kept constant at 15 μm. An up to 50 μm space between the doped layers has previously been reported [7].

In undertaking our stated investigation, we used Silvaco ATLAS tools [13] to study carrier generation-recombination, mid-gap traps, and ray tracing effect in BHJ solar cell structures. We did not consider light-trapping in our simulation studies. We used all material layers to accurately investigate electrical transport in

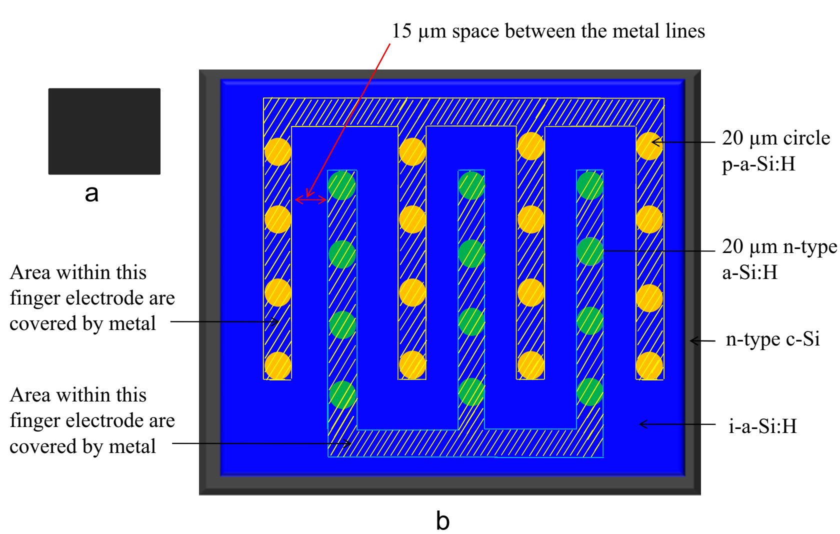

Fig. 2. Schematic diagram of (a) gridless front side and (b) back side substrate view of BHJ solar cell. Lines within the grids represent Al for contact electrodes for both p-a-Si:H and n-a-Si:H. Al metallization pattern forms an interdigitated pattern.