The three terminal heterojunction bipolar transistor solar cell: a novel structure for multi-junction solar cells

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Diodes (pn junctions) are the conventional building blocks of multi-junction solar cells. We propose here the use of npn or pnp (transistor structures) as new building blocks. A npn semiconductor structure can substitute a more complex np/p+n+/np structure (being the p+n+ junction a tunnel diode) while performing equivalently to a multi-junction solar cell consisting of two solar cells independently connected. In the npn solar cell structure the first two top np layers are made of a high bandgap semiconductor and lead to the top solar cell. The middle p layer (high bandgap) and the bottom (low bandgap) n layer constitute the bottom cell. Hence, the middle p layer is common to the top and bottom cell.

1. Introduction

Pn junctions are the building blocks of solar cells. Their model was first described by Shockley [1] and is supposed to be sufficiently well known to the reader as for not revising it here. In this respect, we wonder why the next building block in semiconductor devices, the bipolar transistor (npn or pnp semiconductor structures) has not been considered in photovoltaics to implement solar cells. What the limitations or advantages would be? We discuss this topic in the next sections.

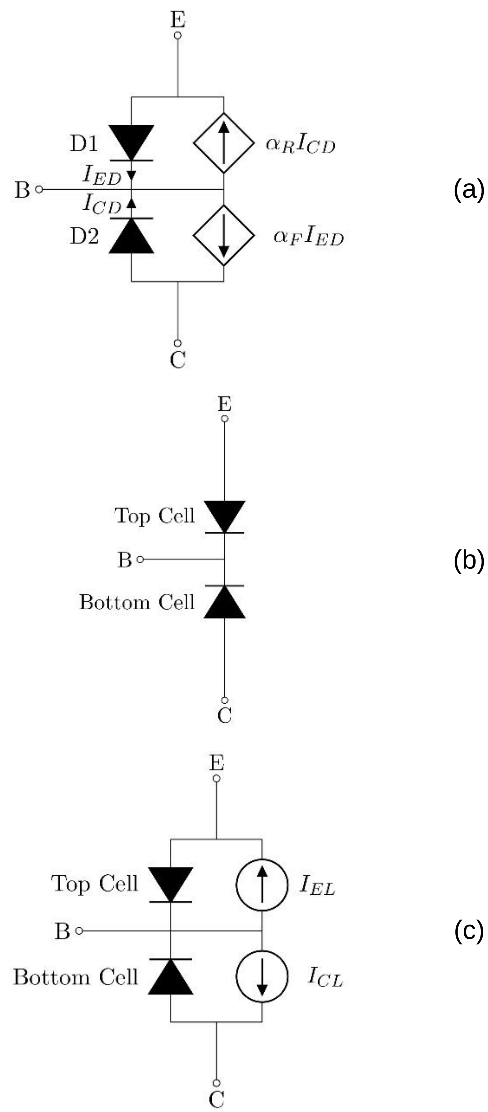
2. The bipolar transistor circuit model

Fig. 1,a shows the circuit model of a bipolar transistor according to Ebers-Moll [2]. Two diodes, D1 and D2 model the base-emitter and base collector junctions respectively. The controlled current generators take into account the coupling between the two diodes or, in other words, the transistor effect. When the two diodes are well apart (because the base, for example, is very long and/or the minority carrier diffusion length in the base is very short) the controlled current generators disappear and the electric model becomes the one represented in Fig. 1,b. This circuit suggests a multi-junction solar cell, in a three terminal configuration, consisting of two solar cells that share a common region (the base of the transistor). The equivalent circuit model of this cell would be the one represented in Fig. 1,c where the independent current generators account for the photogenerated current in the cell. The structure of the corresponding solar cell would be that in which the emitter and the base are made of a high bandgap semiconductor (assuming the emitter is the semiconductor layer facing the sun) and the collector is made of a low bandgap semiconductor. The top cell would then be formed by the emitter-base semiconductors and the bottom cell would consist of the heterostructure formed by the base and the collector semiconductors (Fig. 2). We call this cell "three terminal heterojunction bipolar transistor solar cell (3T-HBTSC) [3]. The question that arises is: would be the performance of the cell benefited if we recover the transistor effect, that is, if we include the controlled current generators?

3. Top and bottom cell voltage decoupling

To answer this question we draw in Fig. 2 the electron and hole quasi-Fermi level split of the cell in operation. We know that, in order to minimize the series resistance of the cell, carrier mobility should tend to infinity. This also makes the base electrically "short", irrespective of its thickness. In addition, as mobility tends to infinity, quasi-Fermi levels become flat and, as illustrated in Fig. 2a, we reach a situation in which the voltage of the bottom cell (determined by the quasi-Fermi level split at the base-collector junction limits the output voltage of the top cell (which is given by the quasi-Fermi level split at the top base-emitter junction).
In order the top cell can preserve its output voltage from the bottom cell, the hole quasi-Fermi level (for a pnp structure) should be allowed to bend, as illustrated in Figure 2b. However, allowing the hole quasi-Fermi level to bend implies we admit finite mobility for holes in the

base and therefore ohmic losses. In spite of this, ohmic losses contributed by holes can be minimize if we minimize the hole current in the base that is, if the transistor emitter and collector injection efficiency tends to zero. This leads to α_F α_R equal to zero in the circuit of Fig. 1.a and, therefore, to cancel the transistor effect.



(c)

Fig. 1 *(a) Ebers-Moll bipolar large signal bipolar transistor model (b) Equivalent circuit when the transistor effect disappears (c) Solar cell circuit model.*

4. Conclusions

The key physical aspect to be taken into account is that, although the pnp (npn) structure reminds that of a transistor, the transistor effect (that is, the achievement of a high collector/base current gain) has to be prevented or, otherwise, the performance of the solar cell would be jeopardized. The use of independently connected multi-junction solar cells is of interest in order to maximize the production of annual solar energy avoiding the limitation of series-connected solar cells that become blocked, as the number of solar cells in the stack increases, if a spectral component is missed.

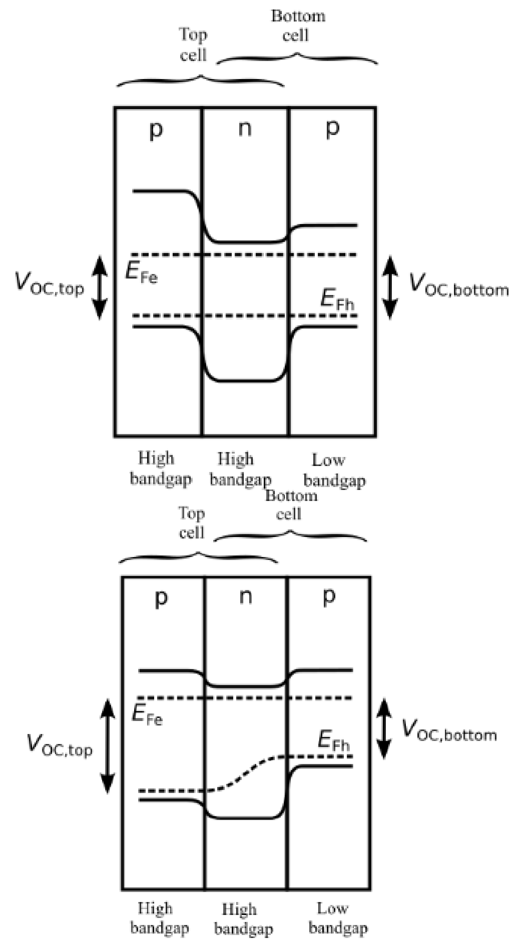


Fig. 2. *Structure of a 3T-HBTSC and quasi-Fermi level split (a) for infinite mobility and (b) for finite mobility.*

5. Acknowledgments

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6. References

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