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Solar Energy Technologies Program

National Solar Technology Roadmap:

Intermediate-Band PV

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National Solar Technology Roadmap: Intermediate-Band PV

Scope

This roadmap addresses intermediate-band (IB) solar cells.

Technology development stage: Concept.

Target applications: All.

Background

The addition of an intermediate band has been proposed as a method for creating a single-junction cell with a theoretical efficiency similar to that of a three-junction solar cell. The basic idea is to introduce an IB of energy levels within the normally forbidden energy gap of the host semiconductor to enable the absorption of sub-bandgap photons. The challenge is to design a material system that possesses an IB and the correct absorption properties, but which avoids detrimental processes such as enhanced recombination via the IB. Such IB cells, if realized, are expected to have advantages over series-connected, three-junction cells: only a single semiconductor material may be required; interconnection between sub-cells is not an issue; and spectral sensitivity is reduced. Multiple research papers have been published, but the concept that the IB can be used to increase the efficiency has not yet been demonstrated.

Roadmap Overview

The concept of this technology is illustrated in Fig. 1. By introducing an IB of levels within the normally forbidden energy gap of the host semiconductor, it was proposed (Luque and Marti 1997, Wolf 1960) that an electron could be excited from the valence band (VB) to the conduction band (CB) via the IB by a two-step absorption process (transitions 1 and 2) of sub-bandgap photons. This generates a net electron-hole pair that adds to the current generated in the cell by the normal VB-to-CB absorption process (transition 3). Successful operation of an IB cell also requires that the output voltage of the cell is limited by the bandgap (E_g) of the host semiconductor and not by either of the lower energy transitions 1 and 2 (Fig. 1). The optimal energies E_g, E_L, and E_H and limiting efficiencies for an IB cell under different incident spectral conditions have been calculated. This concept has generated much excitement because of the high efficiencies that are predicted for relatively simple structures. However, the theoretical predictions neglect fundamental loss mechanisms that may prevent the concept from being useful. Specifically, to efficiently use the light energy, each photon must be absorbed by the transition that is closest to it in energy (photon absorption selectivity). Also, the theoretical efficiency calculations

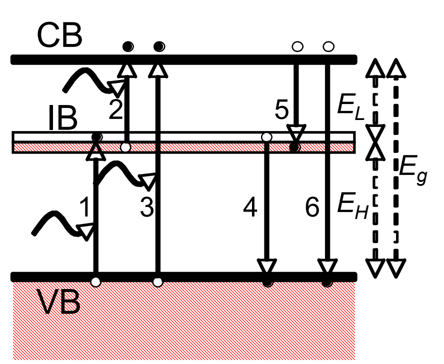

Figure 1. Simplified band diagram of an IB material showing conduction band (CB), valance band (VB), intermediate band (IB), and absorption (1–3) and recombination (4–5) processes between bands.

assume that there is no nonradiative recombination. So far, an increase in cell efficiency due to the presence of an IB has not been experimentally demonstrated because a suitable materials system with the required properties has yet to be discovered.

By 2015, it is hoped that IB cells will be fabricated with efficiencies that exceed the current record efficiency for a single-junction solar cell (~25%). The key areas of advancement that will lead to meeting this goal are the following: (1) Identify the materials system requirements to generate an IB and the properties of the IB needed for efficient IB cell operation; (2) Determine the materials system or device properties needed for photon absorption selectivity; (3) Ascertain the materials system/device requirements for minimizing harmful nonradiative recombination; (4) Discover the materials systems (e.g., novel alloys, compounds, quantum dot arrays) and device structures expected to possess the required properties; (5) Grow/synthesize the most-promising identified candidate IB materials systems; (6) Investigate experimentally the existence of the required properties in the grown IB materials systems (e.g., existence of IB, photon absorption selectivity, dominance of radiative over nonradiative recombination); (7) Fabricate and measure test IB cells; and (8) Optimize properties of IB cell materials and device design to maximize efficiency.

Metrics

Parameter	Present Status (2007)	Future Goal (2015)
Understand the material design needed to implement the IB concept.	The importance of choosing a materials system with the IB at optimal energy is understood, but a method to avoid harmful nonradiative recombination is lacking.	By **2010,** identify the material requirements needed to demonstrate added efficiency from excitation through the IB.
Identify a materials system: new compound (e.g., GaPTi); new alloy (e.g., ZnMnOTe); quantum dot array, with the required properties to demonstrate an IB cell with an efficiency greater than the present record efficiency for a single-junction solar cell.	Not accomplished (NA)	Demonstrate an IB cell with an efficiency that exceeds the present record efficiency for a single-junction solar cell (~25%).
Champion device efficiency (1 sun)	NA	>25%
Champion device efficiency (under concentration)	NA	>30%
Cost target (assuming a single-junction single-crystal IB cell with an efficiency of 40% under concentration can be fabricated	NA	5–7 ¢/kWh

with a similar cost to a single-junction crystalline Si cell.)		
Cost target (assuming a single-junction IB cell with an efficiency of >20% can be fabricated by a low-cost route similar to CIGS thin films.)	NA	7–10 ¢/kWh

Identified Needs

Need	Significance	University	Nat'l Lab: NREL	Nat'l Lab: Sandia	Nat'l Lab: Other	Industry: TPP	Industry: Incubator	Industry: Other
Identify the materials system requirements to generate an IB and the properties of the IB (e.g., partial filling, width) needed for an efficient IB solar cell.	Necessary condition for successful operation of an IB cell	x	x					
Determine the materials system or device properties needed to optimally use the incident spectrum by photon absorption selectivity.	Prerequisite to identifying candidate materials systems that could achieve the ideal performance	x	x					
Ascertain the materials system/device requirements for avoiding harmful nonradiative transitions.	An IB that catalyzes nonradiative recombination will decrease, rather than increase, the cell efficiency.	x	x					
Examine how realistic it is that a materials system/device structure can be found that satisfies the above requirements.	If it seems impossible to find such a materials system/device structure, then halt research.	x	x					
Discover the materials systems (e.g., novel alloys, compounds, quantum dot arrays) and device structures expected to possess the above-required properties.	Vital to avoid wasted experimental effort	x	x					
Grow/synthesize the most-promising identified candidate IB material systems.	Essential for further progress toward devices	x	x					
Investigate experimentally the existence of the required properties in the grown IB	Required to eliminate unsuitable IB materials before progressing to	x	x					

materials systems (e.g., existence of partially filled IB, photon absorption selectivity, dominance of radiative over nonradiative recombination).	device fabrication							
Fabricate and measure test IB cells.	Essential to prove that the concept works	x	x					
Optimize properties of IB cell materials and device design to maximize efficiency.	Needed to take full advantage of expected increase in cell efficiencies	x	x					
Assess if technology is able to meet efficiency, cost, environmental goals for residential, commercial, utility, or other specialized applications.	Necessary to make a decision as to whether to proceed further	x	x					
If IB cells meet required performance goals, contact industry.	Establish route to commercialization of this new technology.	x	x			x	x	x