Intermediate band solar cells

Solar cell materials with more than one bandgap offer the possibility to increase the efficiency of the solar cell beyond that of a single bandgap cell.

The intermediate band solar cell (IBSC) is one such possibility, where an intermediate energy band (IB) is placed in the otherwise forbidden bandgap of the solar cell material, see figure 1 [1].

Research on this device is motivated by high theoretical efficiencies [2-5]: The maximum efficiency of an IBSC, having the ideal bandgaps of ε_L=0.71 eV, ε_H=1.24 eV and ε_G=1.97 eV, is as high as 63.2 %. The single bandgap cell has an efficiency limit of 40.7%.

One attempt to realize the IBSCs relies on utilising quantum confinement of electrons in so-called quantum dots (QDs) to form the intermediate energy band, see figure 2 [1]. A QD is a nanometre sized semiconductor "particle" (made of e.g. InAs) embedded in another semiconductor with a higher bandgap (e.g. GaAs). Each QD then forms a potential well for the electrons in the conduction band, and the energy level of the confined electrons is determined by the well depth and lateral size. If the QDs are closely and evenly spaced in a three dimensional super-lattice, the confined energy levels will form an energy band; the needed intermediate band in the bandgap.

In order for such a QD-IBSC solar cell to reach its potential maximum efficiency, a high density of QDs with homogeneous sizes and shapes and a material system without defects, are some of the requirements that need to be fulfilled.

Intermediate band materials can also be realised without relying on quantum confinement effects, but instead the intermediate band is formed due to addition of (typically) metal atoms to the material. The new atoms modify the electronic energy band structure, so that an additional intermediate energy band forms in the bandgap intrinsically. Examples of such materials are Si doped with Ti, ZnS doped with Cr or the so-called highly mismatched alloys (HMAs) such as ZeMnTe:O, or GaAs:N [6].

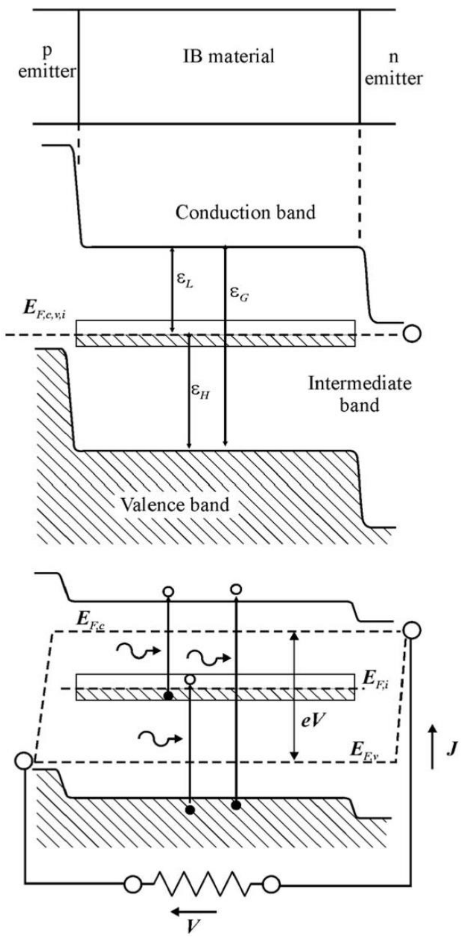

Fig. 1. From top to bottom. Basic structure of an intermediate band solar cell. Simplified bandgap diagram in equilibrium. Simplified bandgap diagram under illumination and forward bias.

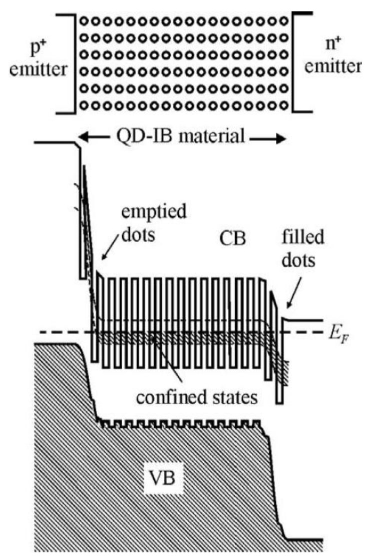

Fig. 2. Illustration of intermediate band formation by means of an array of quantum dots.

At NTNU we are currently following several routes for the realization of IB materials: We are trying to make QD materials for QD-IBSCs, by growing III-V based semiconductors (i.e. GaAs based materials) using molecular beam epitaxy (MBE) at the Department of Electronics and Telecommunication (IET). This project is collaboration between the Department of Physics (IFY) and IET, and has been going on since 2008. We also have a new project on so-called III-V dilute nitrides as HMA for IB materials, in collaboration with IET. These materials have an intrinsic IB, and might be easier to fabricate than the QD materials. Two post docs and 1 PhD student are involved in the III-V activities.

We also have an activity on bulk IB materials (doped ZnS from 2010, on doped Cu_2O from 2012, and on Cr,N co-doped TiO_2 from 2015). Here we use pulsed laser deposition (PLD), MBE and resistive evaporation to deposit the materials at IFY. For the TiO_2 and Cu_2O materials we collaborate with Sverre Selbach at IMT and Jon Andreas Støvneng at IFY, respectively, on simulations of the material's band structure using DFT calculations, and with Justin Wells at IFY on using advanced X-ray techniques to probe the states formed in the bandgap of the TiO_2 matrix. One post doc and 2 PhD students are/will be involved in these activities.

We fabricate simple devices using NTNU Nanolab, and test them using a solar simulator or a flash lamp. In addition we simulate solar cell performance, of both ideal and more realistic IBSCs.

What the student will do in the project

.. depends on the interest and qualifications of the student. It is possible to be involved in the growth; MBE, PLD, e-beam deposition or resistive evaporation, and the characterisation; atomic force microscopy (AFM), scanning or transmission electron microscopy (SEM/TEM), photoluminescence (PL), X-ray diffraction (XRD), ellipsometry etc, of the materials, as well as processing into solar cells (in NTNU Nanolab) and testing of the cells; current-voltage characteristics (IV) and spectral response (SR). Finally, it may also be possible to have a project on calculation of IBSC efficiencies.

Required from the student

Interest in experimental work and background in solid state physics or functional materials are an advantage.

Other aspects

There is a large activity at Gløshaugen on solar cell materials, and the student will get the possibility to join this activity.

Contact persons

IFY: Turid Worren Reenaas (turid.reenaas@ntnu.no, room D5-145 / Realfagbygget)
IFY: Ursula Gibson (Ursula.gibson@ntnu.no, room D5-159 /Realfagbygget)

IET: Bjørn-Ove Fimland (bjorn.fimland@iet.ntnu.no) (room A381 / Elektro A)

References

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