

Ferroelectric-Semiconductor Solar Cells: An Alternative Configuration With High-Efficiency

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Abstract

The power generation of conventional solar cells suffers from their low open-circuit voltages that are restricted by the bandgap of employed semiconductors. We propose a novel photovoltaic cell based on the combination of ferroelectric materials and conventional semiconductors to overcome this restriction. In the proposed configuration, a semiconductor slab sandwiched between two parallel polarized ferroelectric materials attains an electric field parallel to the interfaces leading to an above-bandgap voltage across the semiconductor. Furthermore, the configuration allows the charge carriers produced in the semiconductor to be transported within the semiconductor to the contacts without having to cross the semiconductor-ferroelectric interface. The power generation is expected to be higher than those of conventional solar cells and previously studied combined designs: (i) Firstly because its open-circuit voltage can be much higher, as it is not restricted by the bandgap of the semiconductor material; (ii) secondly because certain unfavorable carrier transport processes, such as carrier tunneling through the interface and carrier transport through the low-mobility ferroelectric material, are not part of the circuit.

Keywords

Above-bandgap voltages, Induced electric field

Introduction

In conventional p-n junction solar cells, the charge carriers (electrons-holes) created by the absorption of solar photons in a semiconductor are separated from each other and forced towards the electrodes by an electric field created in a depletion region. A depletion region is formed either by asymmetric doping of a semiconductor or by interfacing semiconductors with different work functions. The power generation of such conventional cells is limited as their open-circuit voltages are restricted by the bandgap of the employed semiconductors (Würfel 2009).

On the other hand, recently certain ferroelectric materials have attracted much attention for photovoltaic cells as their natural bulk polarization can be used for carrier separation and transport (Glass et al. 1974, Basu et al. 2008, Yang et al. 2009, Choi et al. 2009). The open-circuit voltage of these polarized ferroelectric materials is independent of their bandgap and can be orders of magnitude higher than that of conventional p-n junction photovoltaics (Alexe and Hesse 2011, Yang et al. 2010). Although this natural and inexpensive charge separation mechanism in ferroelectric materials seems attractive for solar cell applications, their energy conversion efficiency is undermined by their large bandgaps, strong exciton binding energies and low carrier mobility.

In order to make efficient use of this large open-circuit voltage in ferroelectric materials, in very recent studies (Yang et al. 2012, Liu et al. 2014, Eskandari et al. 2017), ferroelectric materials were combined with small bandgap semiconductors that don't have a photovoltaic effect on their own. The role of the ferroelectric material in these combined photovoltaic cell structures was to induce an electric field in the semiconductor for carrier separation and transport. In various combined designs studied so far, the electric field induced in the semiconductor was perpendicular to the interface. Therefore, the charge carriers produced in the semiconductor were either collected by the electrodes placed at the interfaces (Liu et al. 2014) or transported through the ferroelectric material to the outer circuit (Yang et al. 2012, Eskandari et al. 2017). Nevertheless, the energy conversion efficiency of these studied configurations was not satisfactory.

Proposed design

Here, we propose an alternative solar cell design in which a semiconductor slab is sandwiched between two ferroelectric slabs that are polarized parallel to the interface as shown in Fig. 1. With this configuration, it will be feasible to induce an electric field inside the semiconductor with a component parallel to the interfaces. The potential difference across the semiconductor as a result of this component of electric field will be proportional to the potential difference across the ferroelectric slabs regardless of the bandgap of the semiconductor. Due to this potential difference, the charge carriers produced in the semiconductor will flow within the semiconductor to the contacts without having to cross the interfaces. Since certain unfavorable carrier transport processes (such as carrier tunneling through the interface and carrier transport through the low-mobility ferroelectric

material) are not part of the circuit, the efficiency of this photovoltaic cell is expected to be higher than the previously studied semiconductor-ferroelectric type cells.

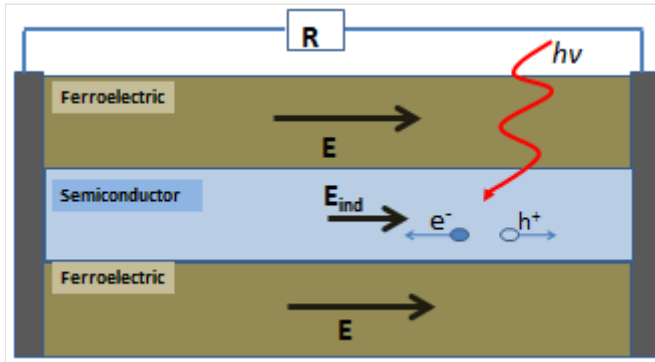


Figure 1. [doi](#)

Illustration of the proposed solar cell.

The parallel component of the induced electric field in the sandwiched semiconductor slab plays the key role in this design. The presence of this can be justified as follows: In polarized ferroelectric slabs, as the potential decreases in the direction of the electric field, the energies of the electronic states are gradually shifted upward (Yilmaz et al. 2010). Because of the covalent bonds at the interfaces between atoms of the ferroelectric slabs and those of the semiconductor slab, the energies of the electronic states in the semiconductor slab will also be pulled upward. This will result in a potential gradient, i.e. an electric field, parallel to the interface in the semiconductor slab. An undesired component of the electric field in the semiconductor slab (perpendicular to the interfaces on both sides) may still be present due to the difference between the work function of the employed semiconductor and that of the ferroelectric material. However, this can be partially avoided if the thickness of the semiconductor slab is kept small enough due to the opposing electric fields on both sides of the semiconductor slab.

Conclusion

Here, we propose a combined semiconductor-ferroelectric type solar cell to induce above-bandgap voltages in conventional semiconductors by interfacing them with polarized ferroelectric materials. In the proposed cell, the charge carriers produced by solar photons within a semiconductor are transported through the semiconductor itself to the external circuit without crossing the interface and traversing through the ferroelectric material. Consequently, we expect the large open-circuit voltages combined with the favorable charge generation and transport properties of semiconductors will lead to higher power generation in this design.

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