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Towards high efficiency thin film solar cells

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ABSTRACT

As an alternative to single crystal silicon photovoltaics, thin film solar cells have been extensively explored for miniaturized cost-effective photovoltaic systems. Though the fight to gain efficiency has been severely engaged over the years, the battle is not yet over. In this review, we comb the fields to elucidate the strategies towards high efficiency thin films solar cells and provide pointers for further development. Starting from the photoelectron generation, we look into the fundamental issues in photoelectric conversion processes, including light harvesting and charge handling (separations, transportations and collections). The emerging organic-inorganic halide perovskite systems, as well as the rapidly developed polycrystalline inorganic systems, organic photovoltaics and amorphous silicon cells are discussed in details. The biggest bottleneck for the cost-effective polycrystalline inorganic cells is the composition sensitivity and deep defects; for amorphous silicon cells, it is the quantum of the dangling bonds; for organic cells, it is the low charge carrier mobility and high exciton binding energy; and for perovskite cells, it is the environmental degradation and the controversial mechanisms of generation of I-V hysteresis. Strategies of light harvesting and charge handling as well as directions to break the bottlenecks are pointed out.

Contents

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1. Introduction

Currently single crystal silicon (Si) solar cell exhibits a conversion efficiency of about 25% and has dominated the solar cell market. However, due to low light absorption and indirect bandgap features, single crystal Si layers of around 200–250 μm in thickness are usually needed to efficiently harvest the sunlight. It has been widely used in solar farms and building roofs. This, however, is not suitable for integrated photovoltaic, such as windows and facades, nor for electronic devices that require flexibility and transparency. Therefore, thin film solar cells emerged and have attracted increasing attentions. In this review, we start from the design rules and strategies for high efficient thin film solar cells, in an attempt to provide better design guidance for veterans and an effective introduction to newcomers. Thin film solar cell examples covered in this review are mainly of the following four categories: polycrystalline inorganic [$Cu(In,Ga)(S,Se)_2$ (or CIGSSe for short), and $Cu_2ZnSn(S,Se)_4$ (or CZTSSe)], amorphous silicon (a-Si), organic photovoltaics (OPV) and organic-inorganic halide perovskite (perovskite) and etc.

This review is organized into five sections. Section 1 is this introduction. Section 2 illustrates solar cell basics and the origins of thin film solar cells. Section 3 dives into how to obtain high efficiency. Section 4 focuses on the reliability and stability in perovskite cells and finally Section 5 summarizes the whole review and highlights the key bottlenecks in each of the four categories.

2. Thin film solar cells

The efficiency of conversion of light into electrical power, or simply termed conversion efficiency, is defined as the ratio of the output electricity to the input energy of sunlight. In practice, the power conversion efficiency (η) of a solar cell is defined as the ratio of the maximum power output, P_{max}, generated by the solar cell to the power input, P_{in}, based on the measurement of current density and voltage (*I-V*) curve [1]:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{mp} \cdot V_{mp}}{P_{in}} = \frac{J_{sc} \cdot V_{oc} \cdot FF}{P_{in}} \tag{1}$$

where J_{mp} and V_{mp} are the current density and voltage at the maximum power point (c.f., Fig. 1), J_{sc} is the short circuit current density, V_{oc} is the open circuit voltage, and *FF* is the fill factor. Fig. 1 is a typical *I-V* curve used in solar cell efficiency illustration.

The fill factor *FF* is introduced to simplify the calculation of the efficiency, and is defined as the ratio of the areas of the two rectangles determined by J_{mp} and V_{mp} (blue in Fig. 1) and by V_{oc} and J_{sc} (green in Fig. 1), respectively. Accordingly, the three parameters of V_{oc}, J_{sc} and *FF* combine to compute the efficiency of a device. The open circuit voltage V_{oc} is, in theory, determined by the energy difference of quasi-Fermi levels between *p*- and *n*-type semiconductors under illumination. The