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Organic-silicon solar cells exceeding 20% efficiency

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Abstract

After a brief review of the recent evolvement of organic-silicon heterojunction solar cells, we present here our latest measurements of the saturation current densities (J_0) and contact resistances (R_C) of crystalline silicon (c-Si)/poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) junctions. We determine the J_0 values by means of contactless carrier lifetime measurements and the R_C values by comparing sheet resistance measurements with numerical device simulations of the corresponding test structure. Application of an adopted PEDOT:PSS blend and an optimized silicon surface treatment results in a minimal J_0 value of 46 fA/cm², limiting the solar cell open-circuit voltage to V_{oc_limit}=708 mV, and a minimal R_C value of 100 mΩcm². Our optimized silicon surface pre-treatment in combination with the adapted PEDOT:PSS blend are successfully implemented into a cell process with the PEDOT:PSS layer located at the rear surface (the so-called 'BackPEDOT concept'). Record-high efficiencies of 18.3% and of 20.6% are achieved on *n*-type silicon and on *p*-type silicon wafers, respectively. Finally, we compare the internal quantum efficiency of our champion BackPEDOT solar cell with that of a state-of-the-art Al_2O_3/SiN_x-passivated PERC solar cell.

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Keywords: Organic-silicon; solar cell; PEDOT:PSS; surface passivation

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1. Introduction

The interest in combining organic and inorganic materials for photovoltaic applications has skyrocketed in recent years. Tremendous attention was paid to perovskite materials, where methylammonium is incorporated into an inorganic matrix of lead and iodide. Within few years an impressive efficiency of 20.1% [1] was achieved. However, those remarkable results were obtained on extremely small areas of 0.1 cm^2. An alternative very attractive organic-inorganic approach is the combination of a hole-conducting polymer (such as poly(3,4-ethylenedioxythiophene) : poly(styrenesulfonate) [PEDOT:PSS]) with crystalline silicon to form a new type of heterojunction [2-5]. This organic-silicon heterojunction has already shown to lead to astonishingly low saturation current densities J_0 of 80 fA/cm^2 [6]. PEDOT:PSS on the rear surface of a silicon wafer serves as an emitter for *n*-type silicon and as a 'back-surface-field' for *p*-type silicon. The solar cells made by this so-called 'BackPEDOT concept' [7] were so far strongly limited by a relatively high series resistance (>2 Ωcm²), leading to low fill factors FF < 70%, while open-circuit voltages V_{oc} > 660 mV were obtained. Since the commercially available PEDOT:PSS dispersion (Heraeus Clevios™ F HC Solar) was not optimized so far for the application to an organic-silicon heterojunction, we have developed a new PEDOT:PSS blend and an optimized silicon surface treatment. We have transferred our adopted PEDOT:PSS material into an organic-silicon solar cell resulting in a record-high efficiency of 20.6% [8]. In this contribution, we give a brief review of the recent evolvement of organic-silicon heterojunction solar cells. We then analyze our adopted PEDOT:PSS/silicon heterojunction in terms of saturation current density and contact resistance. The new PEDOT:PSS dispersion and our optimized silicon surface pre-treatment are then implemented into organic-silicon heterojunction solar cells.

2. Organic-silicon heterojunction solar cell evolvement

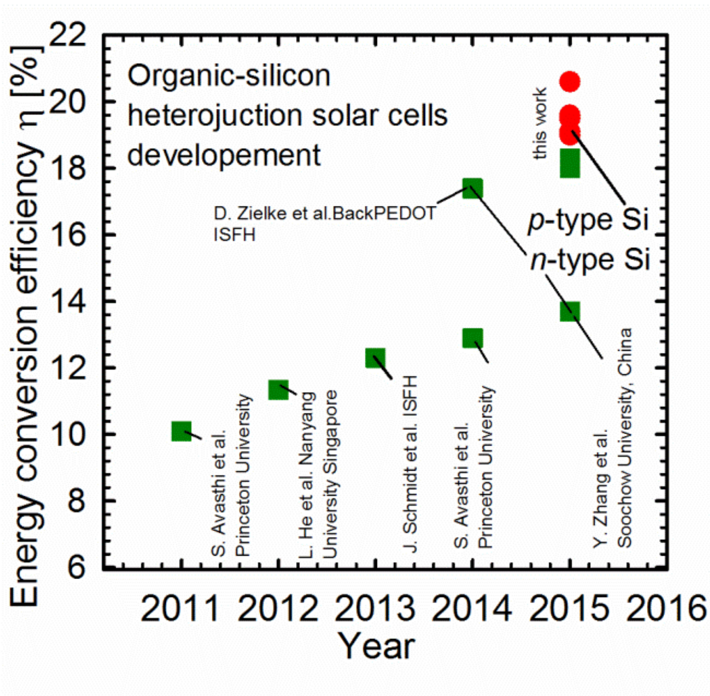

Fig. 1 Organic-silicon heterojunction solar cell efficiency evolvement over time. The organic material used is the hole-conducting PEDOT:PSS for all cells. Solar cells fabricated on *n*-type silicon are shown as green squares, whereas cells made on *p*-type silicon are shown as red circles.