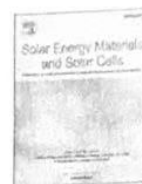




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Preparation of UV cutoff anti-reflective coatings by sol-gel method in view of silicon heterojunction solar cells

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ABSTRACT

Silicon heterojunction (SHJ) solar cells employ a hydrogenated amorphous silicon (a-Si:H) layer to achieve highly efficient passivation of the crystalline silicon (c-Si) surface, thereby enabling high open-circuit voltage (V_{oc}). However, during long-term operation, the intrinsic amorphous silicon (i-a-Si) passivation layer is susceptible to degradation under ultraviolet (UV) irradiation, resulting in performance decline. To mitigate this issue, the present study develops a ZnO-based anti-reflective (AR) UV cutoff multilayer film. A zinc oxide (ZnO) precursor is prepared via a simple sol-gel method, and subsequently subjected to high-temperature curing to form a uniform coating on the glass surface. An additional AR layer is then deposited using the same process to further enhance transmittance and weather resistance. Experimental results demonstrate that the fabricated ZnO-AR film exhibits significantly reduced transmittance in the 250 nm - 380 nm UV band while maintaining an average transmittance of 94.52% in the 380 nm - 1100 nm visible-to-near-infrared range. The film also shows excellent environmental stability, with performance retained after high-temperature, high-humidity, and UV aging tests. SHJ cells coated with this film achieve a short-circuit current density of 37.27 mA cm^{-2} , representing a 5.16% improvement compared to cells with uncoated glass. Given its straightforward fabrication process and robust weather resistance, this approach offers effective technical support for the practical outdoor deployment of SHJ solar cells.

1. Introduction

Amidst the backdrop of continuously rising global energy consumption, the fossil fuel dominated energy structure faces significant environmental challenges [1]. As a way to convert the solar energy, which is a kind of clean energy, to electricity, photovoltaics (PV) has experienced rapid development in recent decades [2,3]. Among these, SHJ solar cells have emerged as a prominent research focus for high-efficiency silicon-based photovoltaics due to their high open-circuit voltage, favorable temperature coefficient, and exceptional bifacial power generation performance, which collectively contribute to superior energy output [4–6]. However, compared to Passivated Emitter and Rear Cell (PERC) and Tunnel Oxide Passivated Contact (TOPCon) cells, SHJ solar cells exhibit higher performance degradation rates during operation [7,8], which stems from the impact of UV radiation. Fundamentally, UV energy triggers microstructural changes and defect

evolution within the intrinsic amorphous silicon (i-a-Si) passivation layer. On one hand, UV radiation causes the breaking of Si-H and Si-H₂ bonds within the a-Si:H layer, accelerating carrier recombination. On the other hand, UV radiation induces Fermi level shifts at the a-Si:H/c-Si interface, reducing the enthalpy for hydrogen-related defect formation, leading to a surge of state density at the interface, disrupting the passivation and carrier transport at the interface [9–12]. Furthermore, the mainstream encapsulation material ethylene vinyl acetate copolymer (EVA) undergoes yellowing and delamination under UV exposure, which would be accelerated in high temperature environments, reducing light transmittance and thereby impairing cell efficiency [13–15]. These factors collectively cause sustained performance degradation in SHJ cells, ultimately shortening their operational lifespan.

To mitigate the aging of the modules caused by UV radiation, spectral conversion technology and UV cutoff technology have emerged as

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