Spectrally Engineered and Scalable SiO_2/ZnO Antireflective Coatings for High-Efficiency and Durable Silicon Solar Cells

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The application of multifunctional antireflection coatings (ARCs) on solar cover glasses is essential for minimizing optical losses, providing ultraviolet (UV) protection, lowering operating temperature through infrared (IR) reflection, and thereby improving photovoltaic efficiency and long-term durability. In this context, we designed and fabricated two optimized double layer coatings composed of SiO_2 and ZnO onto glass substrates. These coatings were specifically designed to provide broadband antireflective and omnidirectional performance across two spectral ranges: (a) 380–800 nm and (b) 380–1000 nm. Silica (SiO_2) layer was deposited using a low-temperature linear hollow-cathode plasma-enhanced chemical vapor deposition (HC-PECVD) process with a silane (SiH_4) precursor. On the other hand, zinc oxide (ZnO) layer was deposited via magnetron sputtering from two distinct targets: (AZO) aluminium-doped zinc oxide (2 wt.% Al) and zinc tin (ZnSn) (10 wt.% Sn) to study their effect on performance and durability.

The optical, chemical, and structural properties of the coated glass substrates were systematically characterized using UV–VIS–NIR spectroscopy, X-ray photoelectron spectroscopy (XPS), and X-ray diffraction (XRD). The deposited films reduced reflectance from approximately ~8% (uncoated) to ~3–5% within the targeted spectral regions, exhibiting a pronounced increase in IR reflectance (up to 25% beyond 1100 nm), and effectively filtered out harmful UVB radiation. Consequently, electrical characterization showed an increase in short-circuit current density owing to enhanced light transmission, leading to improvement in conversion efficiency from 10.61% to 11.04%, a relative gain of approximately 4%. Additionally, coatings were subjected to rigorous environmental and mechanical durability tests simulating accelerated outdoor conditions, demonstrating outstanding performance and robustness. These results highlight the potential of our coatings not only in enhancing solar cell efficiency but also in providing reliable, long-term durability.

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