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Tailoring the surface morphology of zinc oxide films for high-performance micromorph solar cells

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ABSTRACT

Self-textured zinc oxide polycrystalline films prepared by metalorganic low-pressure chemical vapor deposition combine excellent transparency, conductivity and light-scattering ability when used as electrodes for high-efficiency thin-film silicon solar cells. However, the growth of silicon layers with low defect density, which are necessary for high-performance solar cells, often requires the rough surface morphology of as-deposited zinc oxide films to be smoothened. This is usually achieved by a post-deposition argon plasma-etching treatment. We investigate here an alternative method to modify the surface morphology by changing the zinc oxide growth conditions over only the last hundreds of nanometers of the total film thickness. We discuss two types of zinc oxide cap layers, one grown with the addition of ethanol and the other with an enhanced diethylzinc (DEZ) precursor flow. We show that the presence of either type of cap layer does not alter the layer's electrical properties, but does slightly diminish the layer's light-scattering ability. The cap layer grown with ethanol leads to a more pronounced leveling of the film texture, while the high-DEZ-grown layer better preserves the sharp features of the underlying ZnO. Finally, zinc oxide films with cap layer are used as front electrodes for tandem amorphous/microcrystalline silicon solar cells, and are compared to rough films treated with an argon plasma. With rising thickness of the capping layers, the efficiency of tandem cells increases reaching values over 12%, and approaches that of cells on Ar plasma treated ZnO films.

1. Introduction

Transparent conductive oxide (TCO) electrodes of thin-film solar cells have the challenging tasks of simultaneously providing sufficient conductivity to collect carriers without losses, transparency to minimize parasitic light absorption, and light scattering to enhance photocurrent generation in the absorber layers [1–9]. In addition, the electrode itself is often the substrate for device active layers. This requires its topography to be suitable for the subsequent materials' growth, and that its material has to be stable toward these preparation processes [10,11]. Finally, if the device is produced on an industrial scale, the availability, production cost and environmental impact of the TCO electrode material also have to be taken into account [12–14].

Zinc oxide (ZnO) polycrystalline films grown by metalorganic low-pressure chemical vapor deposition (LPCVD) largely meet all of these criteria for thin-film Si solar cells. The electrical properties of LPCVD ZnO films can be adapted to maximize transparency. Moreover, the randomly distributed pyramidal surface features of LPCVD ZnO provide strong light scattering into Si absorber layers, resulting in light trapping of near-bandgap wavelengths [15–18]. In addition, the surface morphology can be optimized in a single- or multi-scale architecture, leading to outstanding micromorph (tandem hydrogenated amorphous Si/hydrogenated microcrystalline Si (a-Si:H/μc-Si:H) solar cell performance [19–21]. Besides, zinc and oxygen are non-toxic and abundant [13], although DEZ itself is a dangerous toxic substance, and ZnO is chemically more stable than tin- or indium-based oxides toward reduction in hydrogen-rich plasmas like those used to grow Si films [22,23].

Unfortunately, while the light-scattering faculty of self-textured LPCVD ZnO films is excellent [24], the actual topography characterized by narrow and sharp valleys in between (sharp) pyramidal features causes the growth of a nanoporous defective phase (commonly

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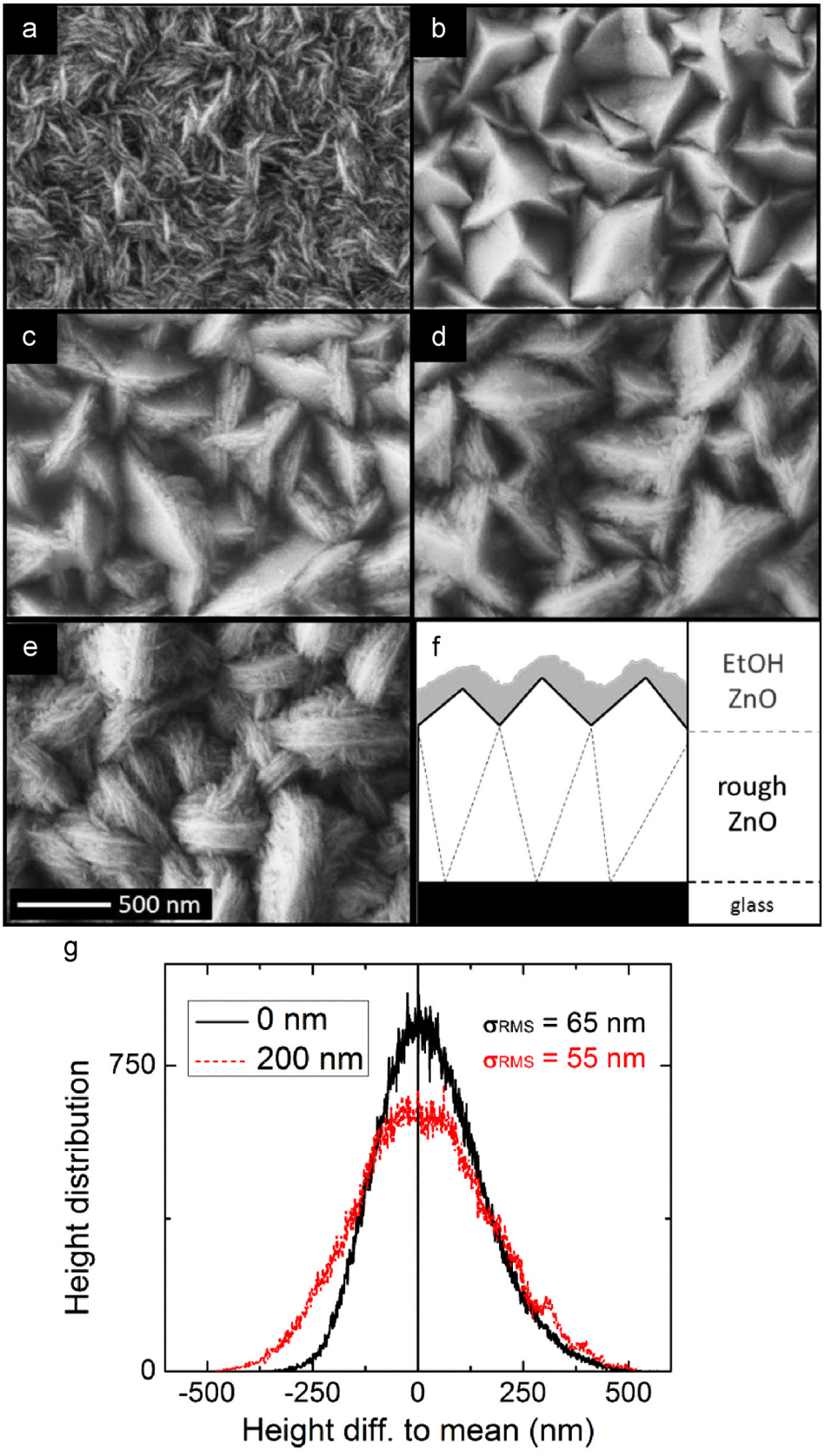

Fig. 1. SEM images: a) a 1.3-μm-thick EtOH ZnO film (cracks not shown), b) a 2-μm-thick rough single-layer ZnO film, c–e) 2-μm-thick ZnO films with 30-, 100- and 200-nm-thick EtOH cap layers. f) A schematic of a ZnO bilayer with an EtOH ZnO cap. g) Height histogram and RMS roughness (extracted from AFM images) of 2-μm-thick ZnO films with 0- and 200-nm-thick EtOH ZnO cap layer thicknesses.