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Mesoporous silica nanocomposite antireflective coating for Cu(In,Ga) Se_2 thin film solar cells

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ABSTRACT

A single layer anti-reflective (AR) mesoporous silica nanoparticles coating on Cu(In,Ga)Se_2 (CIGS) thin film solar cells has been fabricated. Unlike traditional vacuum deposited AR coatings, this nanoparticle coating is applied using simple wet deposition techniques. In this study we investigate the structural properties and anti-reflection effects of the nanoparticle coating on the CIGS solar cell. The reduction in reflection and increase in the short circuit current shows the potential of this nanoparticle coating to compete with current technology.

1. Introduction

Photovoltaic (PV) cells have been the topic of intense research over the past few years as they offer a low carbon alternative to fossil fuels. Traditionally silicon wafers have been used as the active component in PV cells [1], however thin film solar cells possess the advantage of low weight and a potentially lower cost of production, driving the $/W electricity cost down once mass production is achieved. Chalcopyrite Cu(In,Ga)Se_2 (CIGS) thin films solar cells are one of the most promising thin film solar cell technologies due to their bandgap, high absorption coefficient and also due to the fact that they can be produced on flexible substrates, thus increasing the scope of possible applications [2,3]. Recently efficiencies of over 20% have been reported for small area CIGS cells [4–6]. Over the past decades significant research has been devoted to improving the efficiencies of CIGS cells. Most of this research has concentrated on absorber fabrication and various deposition techniques for the absorber layer [7–9]. All deposition methods other than co-evaporation need a post selenization and often an additional sulfurization process, which is an issue for high throughput manufacturing [10]. However, due to the good scalability of the deposition methods involved (mostly sputtering), the presently largest industrial fabrication facility relies on this technology and has recently demonstrated its high potential to reach world record efficiencies [11]. Direct sputtering of a CIGS thin film from a composite target without further selenization has also shown to be a viable option for a possible future one-step sputtering fabrication routine, further reducing production cost [12].

For the demonstration of world record efficiencies optical losses within the complete device have to be reduced. A standard approach to achieve this is to reduce the Fresnel reflection of the cell at the air/device interface. Commonly this is attained by application of an anti-reflection coating (ARC) [13–15]. Conventional ARC's for photovoltaic cells may consist of either multi or single layer structures [16]. Current ARC technology relies primarily upon vacuum deposition techniques such as sputtering or physical and chemical vapor deposition. However, although vacuum deposited coatings do suppress Fresnel reflection there are disadvantages associated with these coatings such as thermal expansion mismatch. Vacuum deposited coatings are expensive and may also suffer from material limitations, that is, they could be sensitive to humidity [17,18].

In terms of cost and from a processing perspective it is desirable to move away from vacuum deposited ARC's and have a single layer ARC. A number of examples have been discussed in the scientific literature [19–22]. One such approach is nanoscale architectures that completely suppress Fresnel refection due to their graded refractive index [23], however this requires multiple process steps and is not cost efficient. Sol-gel coatings are also common but their properties are not equivalent to multi-layer

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coatings, the literature quotes a minimum reflection ~0.8% [24] and there is a high temperature sintering (200–500 °C) step involved, which – due to the reduced thermal stability of thin film solar cells – makes direct application of this technology difficult. Nanoparticle systems such as SiO_2 and TiO_2 can be used to create single layer anti reflection coatings [25,26]. We have previously demonstrated the deposition of a robust single layer ARC consisting of mesoporous silica nanoparticles in a silica binder material on glass and polymeric substrates [27–29], which can suppress Fresnel reflections down to as low as 0.1%. The binder system is used with the mesoporous particles to fine tune the refractive index to match the substrate material to achieve optimum antireflection properties on any given material [27,28]. These coatings are applied using simple wet deposition techniques at ambient temperature. Even though the coating is a single layer, the reduction in Fresnel reflections is still significant at high angles of incidence, which is important for solar applications [27,28]. To our knowledge there are few studies that have directly deposited a single layer nanoparticle ARC using wet deposition techniques onto a CIGS photovoltaic cell.

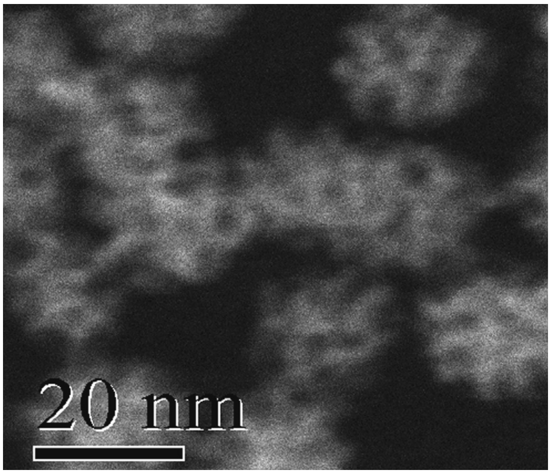

Fig. 1. High resolution TEM images of mesoporous silica nanoparticles. The particles were deposited on a holey carbon grid.

In this work, using a simple one step wet deposition technique, we have applied a single layer of mesoporous silica nanoparticles to the surface of a CIGS thin film photovoltaic cell and investigated its performance as an anti-refection coating.

2. Experimental details

Mesoporous silica nanoparticles were synthesized by the standard method reported by Bein et al. [30]. The coating was achieved by dispersing mesoporous silica nanoparticles in anhydrous isopropanol (3.4 wt%). The binder solution is made up of 100 μL of tetraethyl orthosilicate (TEOS), 2 mL of isopropanol and 50 μL of 0.1 M hydrochloric acid (HCL). The silica nanoparticles and the binder are mixed together in an appropriate ratio (for this study the ratio of particle to binder was 55:45). The change in refractive index is a function of how much binder is inserted into the gaps between the silica particles. The solution was then spin coated down onto a CIGS photovoltaic cell. By varying spin speed and dwell time (3000 rpm@20 s), the thickness of the film was altered to give a minimum reflection (maximum transmission) at a wavelength of approximately 750–800 nm.

The type of CIGS thin film device used in this study consists of a Mo/CIGS/CdS/i ZnO/ZnO:Al layer stack on a glass substrate, with a Ni/Al front contact grid [31]. The CIGS thin film with a thickness of ~2 μm and a surface roughness of <200 nm is co-evaporated onto a Molybdenum back contact covered flat glass substrate.

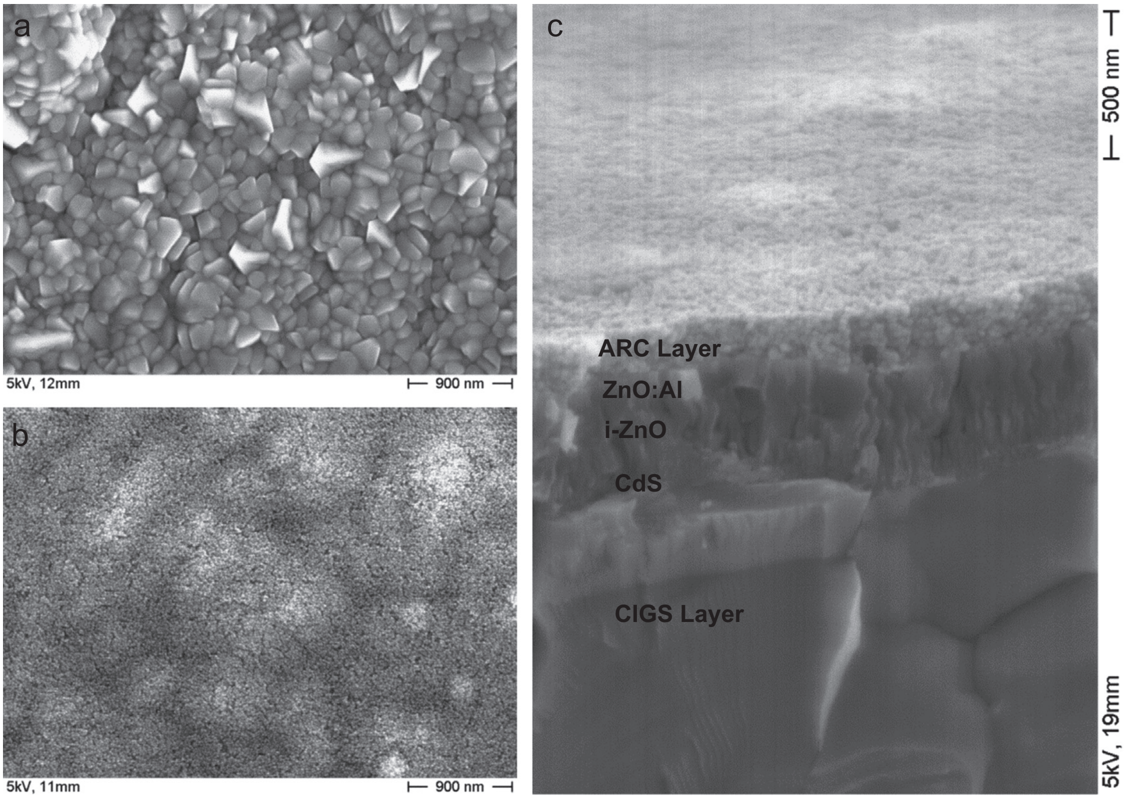

Fig. 2. (a) Plane view SEM of CIGS solar cell surface. (b) Plane view SEM image of nanoparticle ARC on top of CIGS cell. (c) Cross-section view SEM of CIGS solar cell with nanoparticle ARC.