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Improvement of near-infrared diffuse reflectance of silver back reflectors through Ag_2O formation by a UV-ozone exposure process

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ABSTRACT

We report on the fabrication and analysis of highly optically reflective textured stacks consisting of silver oxide (Ag_2O) coated silver for application as scattering back reflectors in thin-film solar cells. Thin Ag_2O layers have been formed on textured silver back reflectors by using a UV-ozone (UVO) exposure technique, and during this formation, the stacks display improvement in their diffuse reflectance, particularly in the near infrared (NIR) spectral region. The silver oxide formed is composed of densely packed small grains with sizes from 20 nm to 50 nm, and their formation measurably increases the roughness of the silver reflector. The optimized silver reflector showed a ~ 6% increase in diffuse reflectance in the spectral range from 800 nm to 1100 nm while maintaining excellent total reflectance (over 95%). As a result, a high haze value (~ 98%) in the NIR region was achieved using these stacks. The stacks were tested as the back reflector in microcrystalline silicon solar cells. Due to the improved optical properties of the back reflector, a higher external quantum efficiency in the NIR region was obtained, and thus an increased short current density (from 22.3 mA/cm^2 to 23.6 mA/cm^2). It is also worth noting that the open circuit voltage was unchanged (0.529 V) while the fill factor also increased (from 66.3% to 72.3%).

1. Introduction

The incorporation of light scattering elements in microcrystalline silicon (μc-Si: H) thin film solar cells (TF-SC) is an important technique to compensate for the low absorption coefficient of this material in the near IR region. Without such elements, the combination of this low absorption coefficient (due to the indirect band gap of the material) and the short optical path necessary to ensure good carrier collection would result in only a small fraction of available light being absorbed. To implement such light scattering, one includes either a textured front transparent contact, or a textured back reflector. As the scattered light will experience an enhanced optical path of many times the layer thickness, these scattering layers must be very low loss.

When considered as a back reflector for a n-i-p μc-Si:H TF-SC, a thin silver layer deposited on chemically-textured ZnO shows the desired optical properties (high reflectivity and excellent light scattering). However, such a "bare" silver reflector must overcome two shortcomings: i) possible silver atom diffusion into the n-layer during the deposition process [1], and ii) reduced reflectivity due to the presence of surface plasmon polaritons (SPP) [2]. To overcome these challenges, the use of a ZnO-coated silver back reflector has been reported [3]. However, the use of sputtered ZnO may introduce other problems such as poor adhesion [4], as well as increasing the total cost of the process.

In this work, we explore the possibility of replacing ZnO with a new material, namely silver oxide (Ag_2O). This material has many of the properties required of the optical/barrier layer between the textured silver and the silicon, namely a high optical transmittance in the IR region [5], and a low refractive index [6,7]. The dielectric constant of ZnO [8] for visible wavelengths is around 3.6, whereas it is 1.55 for Ag_2O [9]. The resulting decreased wave vector of the surface plasmon should result in a red shift of the plasmonic absorption peak and therefore less absorption in the visible and near-infrared. In addition, this material advantageously presents a simple route to its formation through the oxidation of silver at a low oxygen partial pressure [10]. In this study, a UV-ozone (UVO) exposure technique is used to form Ag_2O. It is worth noting that this UVO technique can be conducted under ambient conditions without any requirement for vacuum, making this process more cost effective than the vacuum-based deposition process required for a ZnO layer, for example. In principle, UV radiation generated by a low pressure mercury lamp is absorbed by atmospheric oxygen, transforming it to ozone and reactive atomic oxygen, which react rapidly with Ag to form Ag_2O through the following reaction: $2Ag_{(s)} + O_{3(g)} \rightarrow Ag_2O_{(s)} + O_{2(g)}$ [11–13]. It should be noted that this is a very different process than the oxidation of silver under ambient

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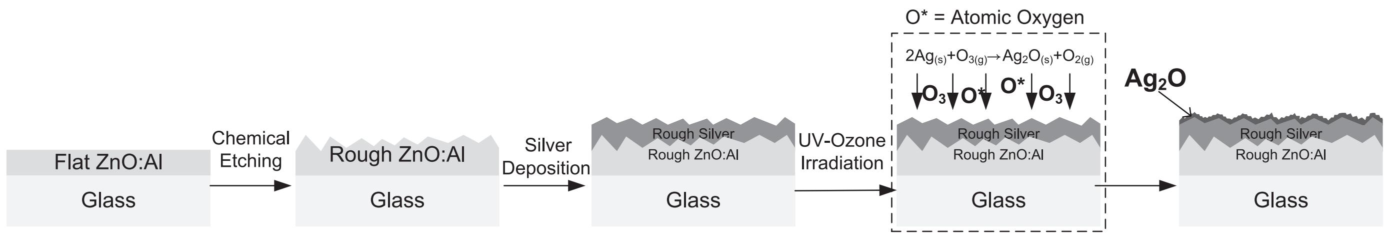

Fig. 1. Schematic fabrication process of UVO-exposed silver back reflector.

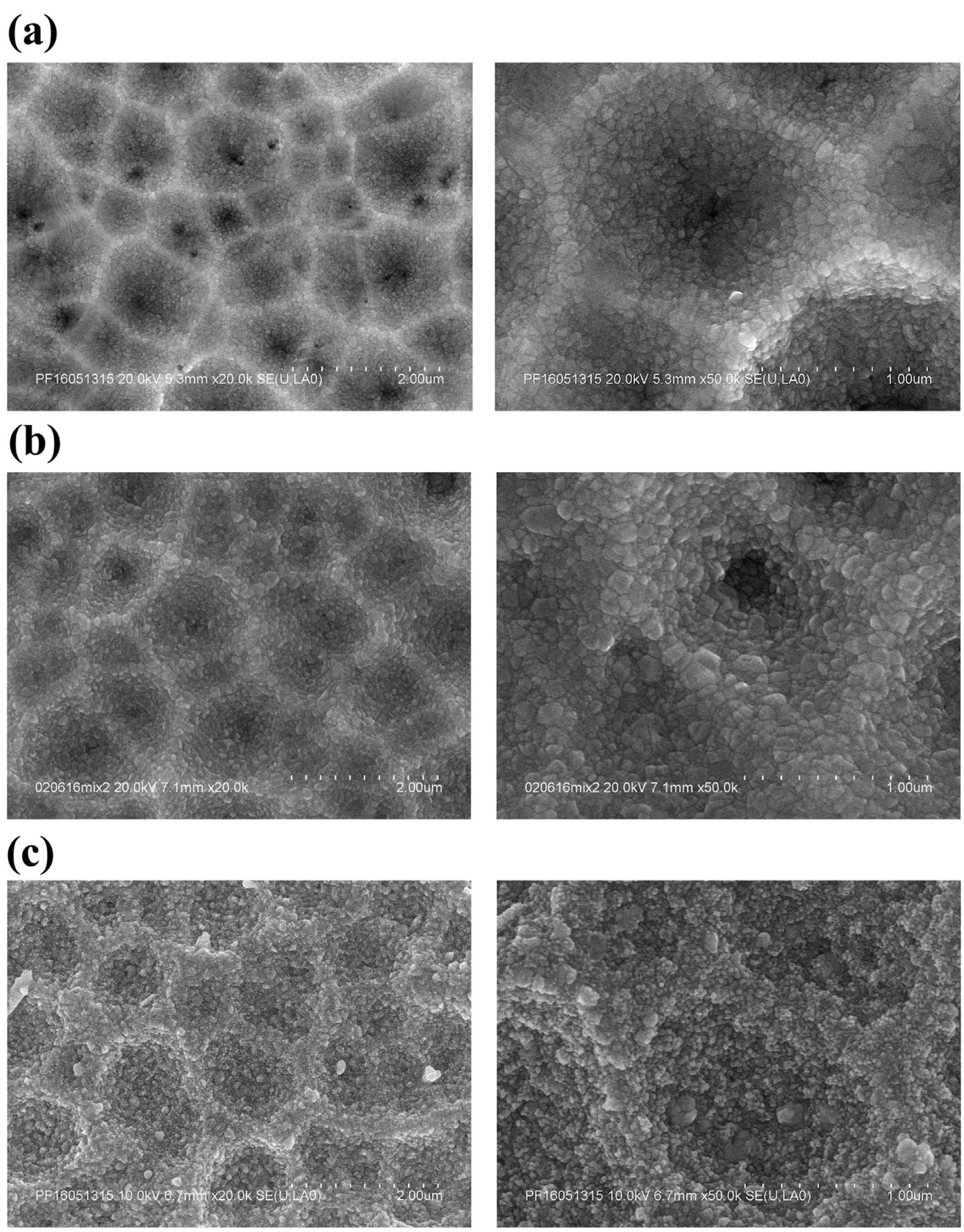

Fig. 2. SEM pictures of SBR (a) without UVO treatment (b) with UVO treatment (60 s) (c) with UVO treatment (120 s). [Scale bar is inside].

conditions [11].

Previous results from the literature have demonstrated an improvement in the performance of top-emitting organic light-emitting diodes and top-illuminated organic solar cells by forming Ag_2O on a ***flat*** Ag reflector through the use of UVO exposure [5,12]. However, the surface modification of ***textured*** Ag by a UVO treatment has not yet been studied, and such structures would be interesting for their application as a light scattering/trapping element in thin film silicon solar cells. Herein, we perform such a UVO exposure on textured silver reflectors to form a surface layer of Ag_2O, and then investigate its impact, focusing on optical properties and morphology.

2. Experimental

2.1. Fabrication of UVO-treated silver back reflector

A set of ZnO: Al (AZO) thin films (1 µm thickness) have been sputtered using an RF (13.56 MHz) magnetron system and setting the following process conditions: argon flow rate (30 sccm), RF power (100 W), temperature (325 °C), and process pressure (4.3 ×