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Transparent conducting oxide layers for thin film silicon solar cells

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ABSTRACT

Texture etching of ZnO:1%Al layers using diluted HCl solution provides excellent TCOs with crater type surface features for the front contact of superstrate type of thin film silicon solar cells. The texture etched ZnO:Al definitely gives superior performance than Asahi SnO_2:F TCO in case of nanocrystalline silicon (nc-Si) type of solar cells. The stress of the ZnO:Al film changes from tensile to compressive with the increase in substrate temperature of sputter deposition and the *rms* roughness and the haze of the film seem to have a correlation with the stress of the film prior to etching; the sample made at 150 °C is most tensile and the etching rate and the evolved roughness is least at this condition whereas the sample made at 350 °C with a compressive stress character gives a high roughness. At present the ZnO:Al made at room temperature provides the best combination of the electrical property and the scattering property of the texture etched layer. A current density of ~24 mA/cm^2 has been obtained for a nc-Si cell of 2200 nm thick. To apply such a texturing technique to make rough ZnO:Al TCO layers on PET and PEN substrates for solar cells on plastics, an additional step of embossing the plastics prior to the sputter deposition of the ZnO:Al layers was employed to release the undue stress. The texture etching of such layers on plastics showed excellent scattering properties in addition to the good electrical properties. As far as ZnO:Al as back reflector is concerned, use of a thick, low doped ZnO:Al in combination with white reflectors, instead of metals, will be a possible solution to avoid surface plasmon absorption loss. We have successfully applied this concept using 0.5% Al doped ZnO to a superstrate type a-Si solar cell using upconversion material at the back of the solar cell. In case of substrate type solar cells on plastics, the ZnO:Al layers that are used as the Ag/ZnO:Al back reflector as well as barrier layers, have to be thin and made at a low stress condition. Such a process resulted in ~6% efficiency of n-i-p a-Si solar cells on PET and PEN substrates.

1. Introduction

Optical confinement plays an important role in case of thin film solar cells due to its role in facilitating a near complete absorption of above band gap light in photoactive layers which are not thick enough to sufficiently absorb light in a single pass. Recent advances in either varying the band gap of the materials or using multi-junction structures have extended the absorption strength of the solar cells to longer wavelengths [1]. Moreover, use of nano-dots to adapt the absorption characteristics [2] and upconversion or downconversion of light are the techniques that are also being followed to address this absorption issue from multiple directions. However, the deterioration of electronic quality of the new materials, has so far limited such techniques to succeed and light trapping process is still a sought after method to enhance current in solar cells. We will discuss here transparent conducting oxide (TCO) layers, mainly Al doped zinc oxide (ZnO:Al) in thin film silicon solar cells in which they are used at front and back contact regions.

For amorphous silicon (a-Si) solar cells, SnO_2:F has been the most favored TCO for the high temperature resistant substrates such as glass [3] or metal foils [4]. SnO_2:F TCOs with naturally grown pyramidal surface textures by atmospheric pressure chemical vapour deposition (APCVD) are commercially available and U-type TCO from Asahi Co. has delivered state of the art efficiencies for a-Si type of cells. Doped (Al, Ga, B) ZnO layers [5–7] have recently received much attention due their high stability against atomic hydrogen and broad range of processing temperatures, that allow to fabricate solar cells even on plastics. Three concepts have recently come into picture, which define the required surface texture and optical/electrical properties of the TCOs for light scattering and optical confinement. (1) The feature size of the textured surface has to be designed appropriately for the type of i-layer in the cell for optimal scattering. A high roughness TCO is used for nc-Si cell whereas the a-Si cell performance is best for small roughness (such as Asahi U-type TCO). A combination of these types of surfaces is now considered to be appropriate for tandem cells that use a-Si and nc-Si as component cells. W-textured SnO:F (HU type) developed by Asahi Co [3] is one such example. (2) Rough surfaces cause defective regions in the silicon i-layers that lead to shunting paths [8]. Adapting/modifying a high scattering rough surface to achieve high open circuit voltages is an effective way to obtain high efficiencies [7]. (3)

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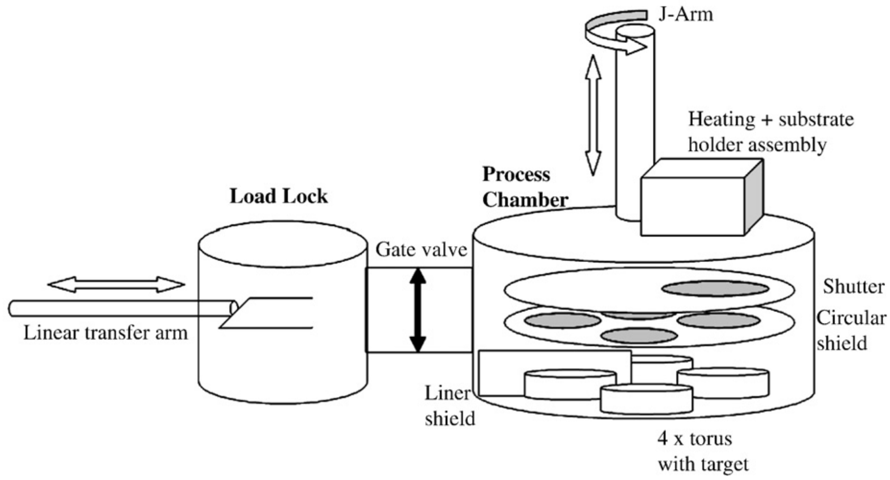

Fig. 1. Schematic diagram of the RF magnetron set up SALSA.

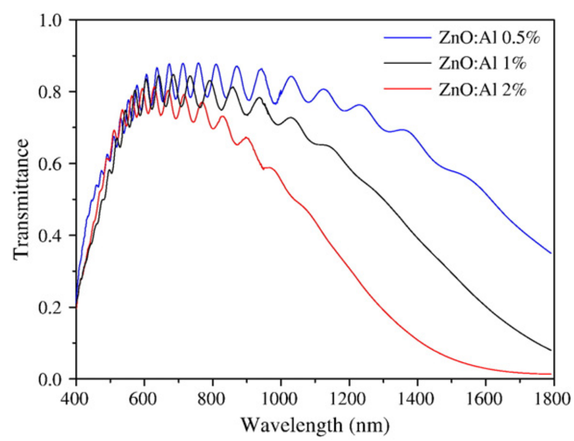

Fig. 2. Transmittance of ZnO:Al layers with various doping concentrations.

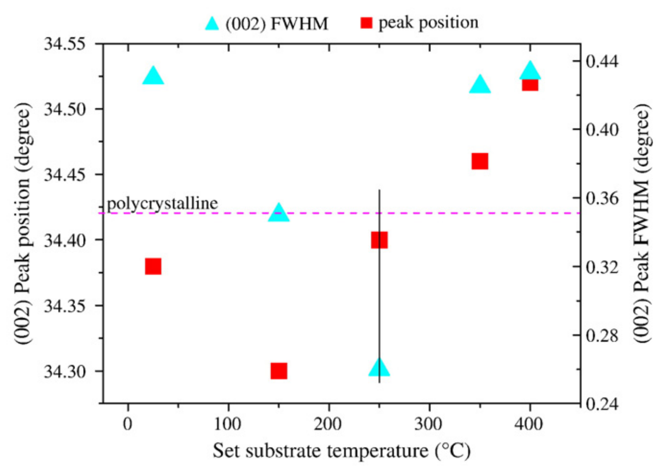

Fig. 4. Peak position and FWHM of (002) peak in the XRD spectrum of ZnO:1%Al layers at various substrate temperatures.

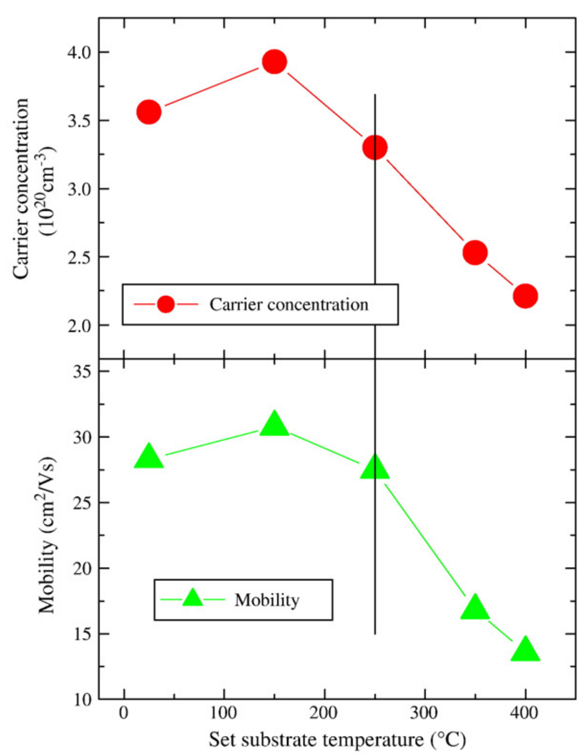

Fig. 3. Dependence of carrier concentration and mobility of ZnO:1%Al layers on set substrate temperature.

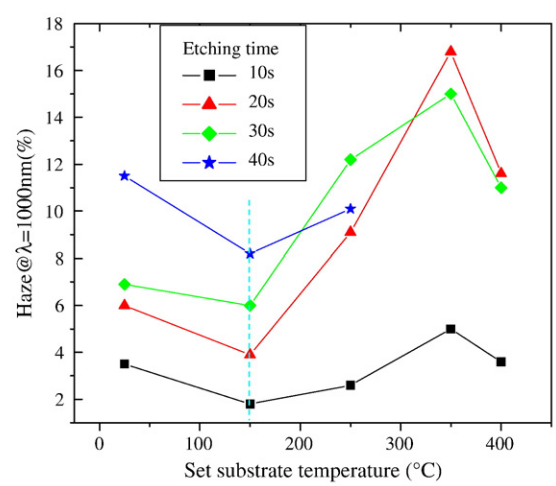

Fig. 5. Dependence of the haze on etching times of ZnO:1%Al films made at various substrate temperatures.