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Focused ion beam based sputtering yield measurements on ZnO and Mo thin films

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Abstract

In order to facilitate the lateral structuring of solar cell multilayer structures, the ion beam sputtering behaviour of Mo and ZnO thin films deposited onto soda-lime glass and single crystalline Si substrates was studied. Prior to ion beam processing the layers were analyzed by Energy Dispersive X-Ray Spectrometry (EDS), X-Ray Diffractometry (XRD) and Rutherford Backscattering (RBS). In order to characterize the ion beam sputtering of the investigated layers, $2 \times 2\ \mu\text{m}^2$ fractions of the thin films were removed by a scanned 30 keV focused Ga^+ ion beam (FIB) in a dual beam system. SEM images taken during the milling process allowed continuous monitoring of the process without breaking the vacuum. The depth of the groove after removal of the layers was measured by Atomic Force Microscopy (AFM) and was plotted as a function of the ion dose. The sputtering depth has a dependence on the ion dose that is close to linear. The deviation from linearity is produced by heating effects at high beam currents. Sputtering yield values calculated from the experiments and simulations showed good agreement in the case of Mo but deviation was found in the case of ZnO.

Keywords: FIB milling; Sputtering yield

1. Introduction

Solar cells are one of the most likely candidates for environmentally friendly power production. Different materials have been used for solar cell manufacturing, like crystalline Si

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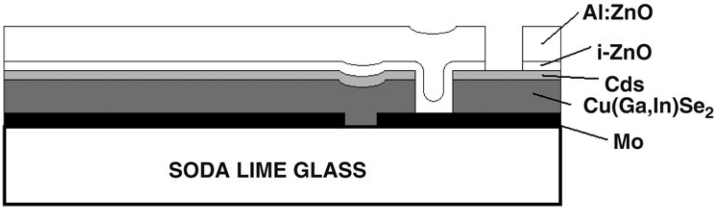

Fig. 1. Schematic cross section of the typical layer structure of a CIGS solar cell.

[1,2], poly Si [3], amorphous Si [2,4], CdTe [5], and CIGS [6], with typical energy conversion efficiencies between 6.0 and 19.2% [7,8]. For practical applications low technological costs [6, 9] are of paramount importance.

Recently, the chalcopyrite semiconductors CuInSe2 (CIS) and Cu(In, Ga)Se2 (CIGS) have also been used as active layers in thin film solar cells.

The layer structure of such a solar cell consists of soda-lime glass/Mo/Cu(In,Ga)Se2/CdS/ZnO/Al:ZnO layers [10], where the soda-lime glass is used as the substrate, Mo as the back contact, CIGS as the photon absorber layer, ZnO as the buffer layer, and Al doped ZnO as the transparent front contact layer (Fig. 1).

The individual solar cells can be cut out from the multilayer CIGS panel either mechanically or by a laser process, each of them bearing some risks. Mechanical scribing can scratch the substrate glass, while laser scribing might generate rough edges. An alternative way to prepare the necessary cuts in the layer is ion-beam scribing, or using FIB processing (sputtering). With ion beams, sub-micrometre precision in positioning and roughness can be achieved, as currently used in integrated circuit manufacturing. To get more insight in the basic processes occurring during ion beam sputtering of the typical materials constituting the CIGS solar cells, a FIB study was carried out. In this paper we investigate the morphology and the beam current dependence of ion beam milling of Mo and ZnO layers, prepared by sputtering and electron beam evaporation on glass and crystalline Si substrates. In order to make use of ion beam scribing, the sputtering characteristics, such as the volume of sputtered material and possible effects arising from beam heating vs. beam current, must be accurately known. The major advantage of a cross beam FIB system is that the ion beam processing can be simultaneously monitored during the process by using a high resolution SEM without breaking the vacuum.

2. Experimental

The Mo and ZnO thin films were sputtered onto 5.5×5.5 cm^2 glass substrates. The substrates were moved under the target with a speed of 5 cm/s in forward and backward cycles. Mo was sputtered from a metallic Mo target in Ar plasma (at a flow rate of 50 sccm) at 381 V bias and in constant power (1500 W) control mode for 20 cycles. ZnO layers were obtained by reactive sputtering from a metallic Zn target in an Ar plasma (30 sccm) with O_2 (30 sccm) at 403 V bias and in constant power (1500 W) control mode for 20 cycles. The thickness of the thin films (210 nm for Mo, and 200 nm for ZnO) was measured with a Talystep profiler.

To compare the milling characteristics of Mo layers prepared by different evaporation methods, an e-beam evaporated layer was deposited, too. The deposition rate of 1 monolayer/s in a 0.13 mPa vacuum yielded a typical thickness of 29 nm, as confirmed by Talystep measurement.

Areas of the films of 2×2 μm^2 were sputtered away by the scanned 30 keV focused Ga^+ ion beam in a LEO 1540 XB cross beam system. In the experiment four different ion beam currents