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ScienceDirect

Energy Procedia 124 (2017) 425–434

Energy Procedia

www.elsevier.com/locate/procedia

7th International Conference on Silicon Photovoltaics, SiliconPV 2017

Selectivity issues of MoO_x based hole contacts

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Abstract

Evaporated MoO_x was investigated as hole contact for silicon solar cells. To improve understanding of the carrier selectivity of metal oxide based hole contacts the *J-V* characteristic of simple MoO_x-based solar cells was evaluated and different pre and post deposition treatments as well as the influence of the buffer layer for solar cell like precursors were investigated. Further on, the loss of selectivity with annealing was investigated with the same set of samples. While characteristic changes of the optical properties by some treatments indicated the modification of the metal oxides gap states, a clear correlation with the electrical junction properties was not observed. Since none of those treatments showed a beneficial influence on carrier selectivity, further work is needed towards an efficient engineering of the selectivity. However, evaluation of various data showed that the loss of selectivity with annealing is governed by a reduced effective work function of the TMOs.

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Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.

Keywords: Transition metal oxides; molybdenum oxide; selectivity; work function; induced bend bending; silicon heterojunction

1. Introduction

Transition metal oxides (TMOs) like MoO_x and WO_x are currently investigated as alternative selective hole contact materials for silicon solar cells [1,2]. Due to their high work function, a band bend bending and pn-junction are induced in the silicon absorber, leading to a hole selective contact. Further on, the low parasitic absorption in the blue wavelength region offers the potential of higher J_{sc} than selective hole contacts based on doped silicon layers (e.g. a-Si or poly-Si) [2]. However, one major problem of those novel contact materials is their higher sensitivity

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Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.
10.1016/j.egypro.2017.09.268

towards low-temperature annealing leading to *FF* and V_{oc} losses. While the origin of those losses is not well understood so far, it is clear that they cannot be described with the classical one diode model and the losses within this simple model (recombination, ohmic transport, ohmic shunts). These losses result from a non-ideal hole selectivity of the used TMOs due to non-ideal hole extraction from the absorber.

Fig. 1 shows the improved blue response if the a-Si:H(p) (black) at the front side of a SHJ solar cell is replaced by MoO_x (green) or WO_x (blue). This main advantage of the TMOs – the reduced band gap absorption due to their high optical band gap – comes along with two major challenges of MoO_x and WO_x: Besides the poor temperature stability, parasitic absorption for wavelengths above 600 nm is observed. The latter is caused by gap states [3,4] which define the optical and electrical properties of TMOs to a great extent [5,6]. These states are of great importance and well-studied for the gas-, electro-, and photochromic properties of TMOs [5] utilized for various application (sensing, smart windows, ...). However, their relevance for the carrier selectivity, e.g. the conductivity, effective work function and gap states which might be essential for providing an efficient transport path for the hole extraction from the absorber, is explored mainly for organic electronics [6–8]. Regarding the electrical performance of the cells from Fig. 1 it is observed that annealing has a strong influence on the selectivity and therefore *FF* and V_{oc} [2]. For example, a higher efficiency owing to improved optical and electrical properties is observed if a-Si:H(p) is replaced by MoO_x. However, annealing degrades the initial good selectivity which is reflected by a S-shaped *J-V* characteristic and a drop in *FF* and V_{oc} [2,9]. So far, it is speculated that hydrogen from the a-Si:H(i) buffer and reduced c-Si band bending [2] or the deposition of the TCO electrode [9] play a crucial role.

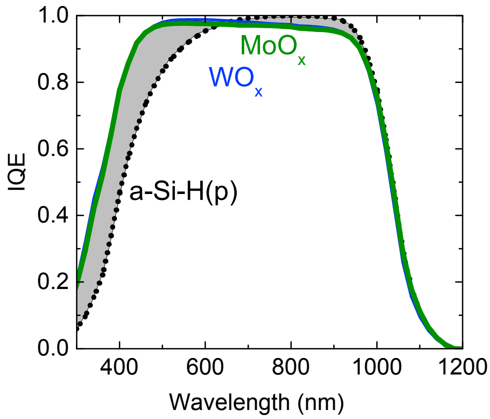

Fig. 1. IQE of SHJ cells with different thin film metal oxides at the front forming the hole contact. For a detailed discussion of those different hole contact materials see [10].

The objective of this paper is to shed some light on the selectivity related issues and the degradation of the solar cell performance. Firstly, the influence of the TMO thickness is investigated to reduce optical losses (Sec. 3.1). In the course of this optimization the influence of the a-Si:H(i) buffer on the selectivity is examined and the non-ideal carrier extraction for cells with buffer layer is described (Sec. 3.2). The second part focuses on the analysis of different treatments before and after the MoO_x deposition on solar cell like test structures for a simple and fast characterization concerning selectivity losses (Sec. 3.4 and 3.5). Here the role of hydrogen from the a-Si:H(i) buffer and the influence of different plasma treatments after the TMO deposition are investigated - with the aim to gain further knowledge about possible modifications of MoO_x and a basic understanding for engineering the TMOs towards improved selectivity.

2. Experimental details

The first part of this paper (Sec. 3.1) deals with the evaluation of simple planar front emitter solar cells with various MoO_x thicknesses as shown in Fig. 2a. In the second part the MoO_x films are investigated with solar cell like test structures as shown in Fig. 2b (QSSPC and Suns-V_{oc} samples). Their fabrication which only slightly differs from

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