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High and low work function materials for passivated contacts

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Abstract

The tunnel oxide passivated contact (TOPCon) is a promising technology improving the efficiency of Si solar cells by cutting recombination losses and simplifying the solar cell design (1D junction design). The objective of this paper is to investigate possible contact materials having a high/low work function for passivated contacts thereby enabling the realization of a double-sided contact Si solar cell featuring n-type TOPCon on the front and p-type TOPCon at the rear side. The main part of this paper deals with the eligibility of thin atomic layer deposited (ALD) AZO (aluminum doped zinc oxide) interlayers sandwiched between n-TOPCon and ITO (tin doped indium oxide) in order to avoid sputter damage. It will be demonstrated that the insertion of ALD AZO improved the efficiency by 0.8% abs. and lead to a maximum efficiency of 20.2%. Finally, WO_x and MoO_x which have a high work function are identified as promising contact layers for p-TOPCon.

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Keywords: surface passivation; carrier-selective contacts; passivated contacts; work function, TCO

1. Introduction

Double-sided contacted heterojunction solar cells with intrinsic thin-film (HIT) achieve record efficiencies of 24.7 % [1]. The outstanding V_{oc} of 750 mV can be ascribed to the excellent surface passivation provided by the amorphous silicon layers. However, these layers though only about 10 nm thick account for a large part of parasitic absorption in the transparent conductive oxide (TCO)/a-Si:H front junction which significantly harms the blue response of the solar cell [2]. Alloying of the a-Si:H enables higher J_{sc} but comes at the cost of a further lowered doping efficiency. This particularly adversely affects the TCO/a-Si:H Schottky contact and, thereby, the *FF* can be significantly reduced. Yet another drawback is the temperature restriction of the a-Si:H layers requiring a dedicated back-end processing (low-temperature TCO and metallization).

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Today research is directed towards the poly-Si contacts [3, 4], which are thought to have some benefits over HIT, e.g. lower parasitic absorption, higher conductivity, and improved tolerance to high-temperature back-end processes (TCO deposition, metallization, module integration). The latter is an important advantage over HIT cells as back-end processes which are rather close to the well-established standard metallization procedure of homojunction cells (e.g. standard pastes with a lower Ag content than polymer pastes) can be used. In addition, TCOs deposited at a higher temperature of about 300 °C typically have superior material properties than those TCOs deposited at lower temperatures [5]. For poly-Si contacts extremely low J_0 values have been reported [6] but still information on device performance is missing. On the other hand, the carrier-selectivity of the closely related TOPCon approach (tunnel oxide and Si compound layer) was already demonstrated using a double-sided contacted solar cell structure. Since this concept makes use of very thin (10-20 nm) Si films which can have a large fraction of crystalline Si phases, it can possibly reduce the parasitic absorption of light in the short wavelength range compared to the a-Si:H films of HIT cells. Since the sheet resistance of TOPCon is still high a TCO on the front side is required in order to enable an efficient lateral charge carrier transport to the metal electrodes and to minimize the reflection losses. When using a textured rear side a TCO layer on the rear contact is needed as well in order to buffer the evanescent light waves from the rear metal contact [7]. While the development of a TCO layer for the front side is typically more challenging, both TCO layers should make a low resistive contact to the underlying carrier-selective contact and ensure that the surface passivation quality is preserved. For TOPCon it was found that sputter deposition of ITO invoked a severe loss in surface passivation which could not be completely recovered. Thus, the V_{oc} and *pFF* of a double-sided contacted TOPCon solar cell was limited to 694 mV and 83%, respectively [8].

It is well known that sputter deposition has a negative impact on the properties of a-Si:H [9] and, thus, adversely affects the surface passivation of HIT cells [10]. In order to preserve the surface passivation the insertion of a thin interlayer, which is deposited by a soft deposition method such as ALD, was proposed [11]. In the best case such an interlayer should have a low (high) work function (WF) thereby making good contact to the electron (hole) contact. This would eventually lead to lower requirements on the work function of the bulk TCO and this layer could be optimized for transparency and resistivity. On the other hand, a large WF mismatch between a-Si:H and TCO leads to a significant Schottky barrier, which can limit the *FF* of the solar cell [12]. For instance, Demaurex et al investigated the contact properties of ZnO:Al (low WF material) to doped a-Si:H. They reported that a 20 nm thick interlayer of ZnO:Al protected the a-Si:H/c-Si junction from sputter damage and, thus, allowed for higher *pFF*. However, a markedly lower *FF* was observed for all cells with ZnO:Al interlayer and was partly ascribed to the formation of a thin SiO_x layer at the a-Si:H/ZnO:Al interface.

The objective of this paper is to screen TCOs having distinctive work functions for an application as a thin interlayer between TOPCon and ITO thereby mitigating sputter damage and improving the contact properties. Special attention is paid to the WF of the contact material to avoid large WF mismatches between TOPCon and TCO. Please note, TOPCon might be less prone to a WF mismatch due to the much higher doping efficiency of the semi-crystalline Si layer. The main part of this paper is concerned with the application of ALD deposited (Al-doped) zinc oxides to n-TOPCon. Firstly, the effect of TCO deposition on the surface passivation provided by n-TOPCon and the ability of these thin TCO interlayers to screen the radiation damage invoked by sputtering of the bulk TCO will be investigated. Secondly, solar cells featuring a ZnO/ITO or an AZO/ITO stack or ITO single layer as the front TCO which is in contact with n-TOPCon will be analyzed with focus on the electrical properties. Thirdly, metal oxides with a high WF, which are a novel class of materials for Si solar cells, will be applied to p-TOPCon.

2. Experimental details

The impact of the surface passivation provided by TOPCon and the contact properties of the different TCOs were studied on test structures having either an $n^+/P/p^+$ (used to probe the contact to n-TOPCon) or $p^+/N/n^+$ structure (used to probe the contact to p-TOPCon). Their fabrication which only slightly differs from the fabrication of the solar cells is outlined in the following and an overview of the samples under investigation can be found in Table I.