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The effect of the illumination intensity on the performance of Si multijunction based integrated photoelectrochemical water splitting devices

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Abstract

We present a study of the effect of illumination intensity on the performance of a photovoltaic-biased electrochemical (PV-EC) device for solar hydrogen production based on a triple junction thin film silicon solar cell. The influence of the illumination intensity was studied for the solar cell as well as for an integrated PV-EC device. We show that while the open circuit voltage decreases with a reduction in intensity, the triple junction solar cell still provides a sufficient voltage to drive spontaneous water splitting. Moreover, a slight improvement in the fill factor at lower intensities can relax the requirements to the utilized co-catalysts. As a consequence, the difference in the performance of PV-EC devices featuring very active (Pt/RuO₂) and less active (Ni/Co₃O₄) catalyst materials decreases when the illumination intensity is reduced.

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1. Introduction

Over the past years, the hydrogen production by light induced water splitting has attracted significant attention [1]. The electrolysis of water requires a minimum thermodynamic potential of 1.23 V. Practically, however, additional overpotential losses in the order of typically 0.5 V are present [2]. One possibility to supply the required

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energy for water splitting is the utilization of multijunction photovoltaic devices. Mainly two types of multijunction solar cells have been demonstrated to allow for spontaneous water splitting: III-V [3-6] and silicon based solar cells [7-13]. Thin film silicon technology provides the advantages of a low cost and scalable photovoltaic solution. Moreover, solar cells and modules can be combined in tandem, triple or quadruple junction architectures with an open circuit voltage (V_{OC}) in the range from 1.5 to 2.8 V [13-17]. The successful application of these cells in integrated photovoltaic-biased electrochemical (PV-EC) devices for light driven water splitting has been shown previously [13, 14, 15, 17].

With respect to the performance of the PV-EC device, the majority of literature concerns laboratory tests performed under standard test conditions (STC) [18], e.g. at room temperature and under 1 sun illumination intensity (AM1.5g spectrum). However, an outdoor application of PV-EC devices requires the investigation of device performances under conditions that differ from STC. In this work, we address the influence of the illumination intensity on the performance of an integrated PV-EC device for water splitting. Therefore, we studied the impact of varying the illumination intensity on the performance of a triple junction thin film silicon solar cell. Furthermore, we investigated the performance of an entire integrated device, where two different catalyst systems (Pt/RuO₂ and Ni/Co₃O₄) in combination with the multijunction cells were compared. Platinum and ruthenium oxide provide high catalytic activities towards the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER), respectively, but they are rather scarce [19]. More abundant alternatives, such as Ni (HER) and Co₃O₄ (OER), can be used only in alkaline electrolytes and usually show higher overpotentials. While under 1 sun light intensity the operation current in the PV-EC devices substantially differed between Pt/RuO₂ and Ni/Co₃O₄ systems, the difference tends to decrease with decreasing illumination intensity. The origin of this effect is addressed in the paper.

2. Experimental details

All thin film silicon layers were deposited in superstrate configuration by plasma enhanced chemical vapor deposition in a multi chamber system. For the intrinsic absorber layers a mixture of silane (SiH₄) and hydrogen (H₂) gases was used. For the n- and p-type layers, trimethylborane (TMB), methane (CH₄), phosphine (PH₃), and carbon dioxide (CO₂) gases were added to the silane-hydrogen mixture. For microcrystalline silicon (μ c-Si:H) intrinsic and p-type layer depositions an excitation frequency of 94.7 MHz was applied. For all amorphous silicon (a-Si:H) layers an excitation frequency of 13.56 MHz was applied. Triple junction (a-Si:H/a-Si:H/ μ c-Si:H) solar cells were prepared in superstrate configuration. For the intrinsic μ c-Si:H absorber layer a silane concentration (SC) of 5.0%, defined as the ratio between the SiH₄ flow and the total gas flow, and a substrate deposition temperature of 180°C was chosen. The intrinsic a-Si:H top and middle sub-cell absorber layers were deposited at 130°C with a SC of 4% and at 180°C with a SC of 10%, respectively. Low refractive index microcrystalline silicon oxide (μ c-SiO_x:H) layers [20] were implemented between sub-cells as intermediate reflecting layers to maintained appropriate current matching conditions. The solar cells were deposited on 10×10 cm² textured aluminum-doped zinc oxide (ZnO:Al) coated glass substrates (front contact) [21]. Additional details on the solar cell preparation can be found elsewhere [13]. A schematic drawing of the PV-EC device set-up is depicted in Fig. 1.

For the j - V characteristics under various light intensity conditions, a class A double source Air-Mass (AM) 1.5 solar simulator (WACOM-WXS-140S-Super) at standard test conditions (AM1.5G, 100 mW/cm², 25°C) was used. Different shading filter masks, allowing to maintain the illumination intensities of 0.64, 0.36 and 0.15 sun, were mounted in the optical path to evaluate the device performance under variable incident light intensity.

The utilized approach to calculate the photoelectrochemical performance for integrated devices in combination with different catalytic materials was previously described elsewhere [22, 23].

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