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High efficiency microcrystalline silicon solar cells with Hot-Wire CVD buffer layer

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Abstract

Microcrystalline silicon (μc-Si:H) solar cells with *i*-layers deposited by hot wire chemical vapor deposition (HWCVD) exhibit higher open circuit voltage and fill factor than the cells with *i*-layers deposited by plasma enhanced (PE)-CVD. Inserting an intrinsic μc-Si:H *p*/*i* buffer layer prepared by HWCVD into PECVD cells nearly eliminates these differences. The influence of buffer layer properties on the performance of μc-Si:H solar cells was investigated. Using such buffer layers allows to apply high deposition rate processes for the μc-Si:H *i*-layer material yielding a high efficiency of 10.3% for a single junction μc-Si:H solar cell.

Keywords: Microcrystalline silicon; Solar cells; Hot-Wire CVD; Deposition rates; PECVD; Interface treatment

1. Introduction

Microcrystalline silicon (μc-Si:H) thin film solar cells prepared by both plasma enhanced chemical vapor deposition (PECVD) at high deposition rates or by hot wire (HW)CVD exhibit high solar cell efficiencies above 9% [1,2]. Generally, solar cells with *i*-layers prepared by HWCVD show higher open circuit voltages (V_{OC}) and fill factors (FF) than solar cells prepared entirely by PECVD for a given crystalline volume fraction [1–3]. Using PECVD for the *i*-layer deposition yields V_{OC} up to 550 mV for optimum solar cells. Using HW deposited *i*-layer material on the other hand, yields V_{OC} up to 600 mV in solar cells with high fill factors and efficiencies. We found that for solar cells deposited by PECVD and HWCVD, the differences between them can be attributed to effective carrier extraction from the *p*/*i* interface in the HWCVD solar cells [3]. We show that incorporating an intrinsic μc-Si:H buffer layer at the *p*/*i* interface deposited by HWCVD into PECVD solar cells nearly eliminates the differences between them by improving V_{OC} and FF. Such buffer layers could be of advantage for high deposition rate processes [4]. We also investigated the influence of the buffer layer properties, like thickness, crystallinity or quality of the buffer material, on the solar cells performance. It is concluded that for preparation of μc-Si:H solar cells a combination of the two deposition methods HWCVD and PECVD with their respective advantages should be further explored in the future.

2. Experimental details

Solar cells were prepared on similar substrates, with identical doped layers and with (i) HWCVD *i*-layers, (ii) PECVD *i*-layers, and (iii) PECVD *i*-layers with an undoped μc-Si:H HWCVD *p*/*i* buffer layers. If not otherwise stated, all solar cells have a total *i*-layer thickness of about 1 μm, including the thickness of the buffer layer. Use of a cluster tool deposition system with both HW- and PE-CVD process chambers connected by a transfer lock chamber allows application of layer sequences from the two preparation methods without air break. The silane concentration $SC=[SiH_4]/([SiH_4]+[H_2])$, defined by the gas flow ratio of silane and hydrogen, was adjusted to obtain *i*-layer material with optimized crystalline volume fraction [1,2]. Solar

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cells were deposited in *p-i-n* sequence on 10×10 cm^2 texture-etched ZnO-coated glass substrates. The 1×1 cm^2 back contacts (Ag or highly reflective ZnO/Ag for selected samples) define the individual solar cell area. The microcrystalline *p*-layer and amorphous *n*-layer were prepared by PECVD. The *i*-layers of HWCVD solar cells and the high quality HW buffer layers were

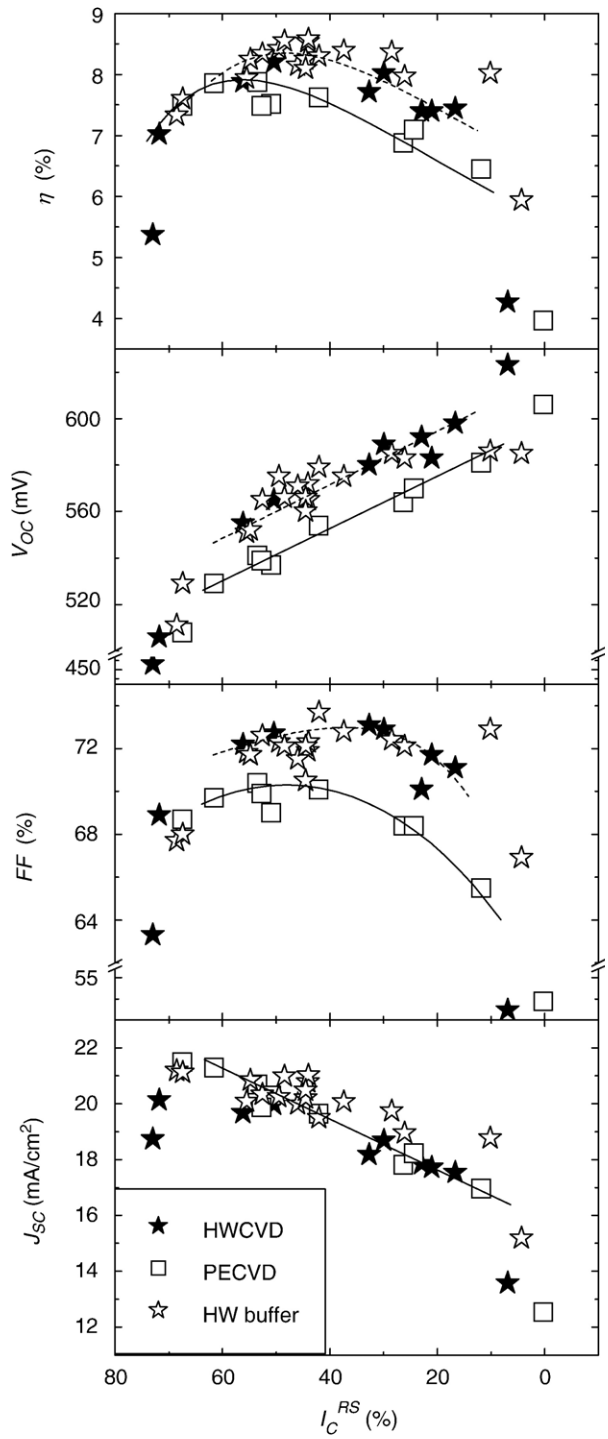

Fig. 1. *J-V* parameters, η, V_{OC}, FF and J_{SC}, of μc-Si:H solar cells with *i*-layers deposited by PECVD, HWCVD, and PECVD with HW *p*/*i* buffer vs. I_C^{RS}. All PECVD *i*-layers are prepared in the lplP deposition regime. Lines are guide for the eye only.

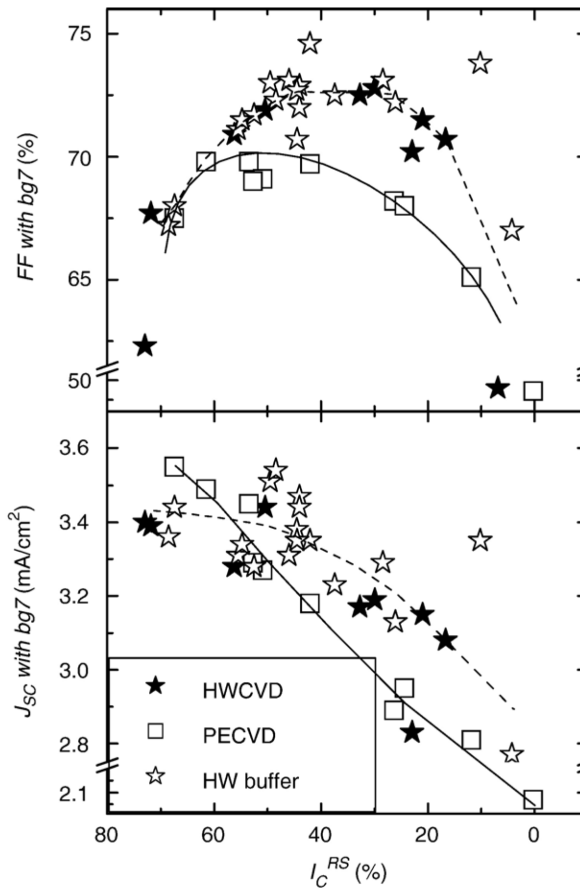

Fig. 2. *FF* and J_{SC} of solar cells (same as in Fig. 1) under the illumination of AM1.5 through a short wavelength band-pass filter (bg7). Lines are guide for the eye only.

deposited at a gas pressure of 3.5 Pa with Ta filaments at 1650 °C, measured during the deposition process, which results in a substrate temperature of 185 °C. For deliberately low quality HW buffer material with high defect density the gas pressure was increased [2]. PECVD *i*-layers were prepared with very high frequency of 95 MHz. In the low pressure low power regime "lplP", used for the majority of PECVD samples, the discharge pressure,

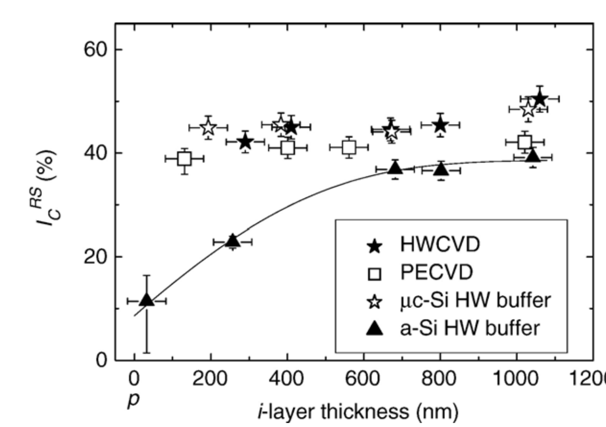

Fig. 3. I_C^{RS} of solar cells at different stages of *i*-layer thickness. Position $x=0$ corresponds to the position of the *p*-layers.