ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Non-Crystalline Solids 354 (2008) 2430–2434

JOURNAL OF NON-CRYSTALLINE SOLIDS

www.elsevier.com/locate/jnoncrysol

Preparation of microcrystalline silicon solar cells on microcrystalline silicon carbide window layers grown with HWCVD at low temperature

Y. Huang [a,*], T. Chen [a,b], A. Gordijn [a], A. Dasgupta [a,1], F. Finger [a], R. Carius [a]

[a] *IEF-5 Photovoltaik, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany*
[b] *State Key Lab of Silicon Material, Zhejiang University, 310027 Hangzhou, PR China*

Abstract

N-type microcrystalline silicon carbide layers prepared by hot-wire chemical vapor deposition were used as window layers for microcrystalline silicon n–i–p solar cells. The microcrystalline silicon intrinsic and p-layers of the solar cells were prepared with plasma-enhanced chemical vapor deposition at a very high frequency. Amorphous silicon incubation layers were observed at the initial stages of the growth of the microcrystalline silicon intrinsic layer under conditions close to the transition from microcrystalline to amorphous silicon growth. ‘Seed layers’ were developed to improve the nucleation and growth of microcrystalline silicon on the microcrystalline silicon carbide layers. Raman scattering measurement demonstrates that an incorporation of a ‘seed layer’ can drastically increase the crystalline volume fraction of the total absorber layer. Accordingly, the solar cell performance is improved. The correlation between the cell performance and the structural property of the absorber layer is discussed. By optimizing the deposition process, a high short-circuit current density of 26.7 mA/cm^2 was achieved with an absorber layer thickness of 1 μm, which led to a cell efficiency of 9.2%.

PACS: 85.30.De; 68.55.A

Keywords: Silicon; Solar cells; Nucleation; Photovoltaics; Raman scattering

1. Introduction

Silicon carbide with wide optical bandgap has been considered as a good window layer material for solar cell applications. Recently, hot-wire chemical vapor deposition (HWCVD) process was developed for growing highly transparent and conductive hydrogenated microcrystalline silicon carbide (μc-SiC:H) films at low substrate temperatures (around 250 °C) [1–3]. Based on this development, the application of μc-SiC:H in thin film silicon solar cells on cheap glass substrates was realized. N-side illuminated, high efficiency microcrystalline silicon (μc-Si:H) n–i–p solar cells with a cell configuration of μc-SiC:H(n)/μc-Si:H(i)/μc-Si:H(p) were fabricated [4]. The n–i–p cells benefit from the high transparency of the μc-SiC:H window layers, showing high short-circuit current densities (J_{SC}). It is known that the performance of μc-Si:H solar cells depends strongly on the phase composition of the intrinsic μc-Si:H absorber layers [5], which is very sensitive to the substrate property as well as to the deposition conditions applied [6–12]. In the case of depositing μc-Si:H layer on a foreign substrate such as amorphous silicon (a-Si:H), an incubation period can occur after which nucleation of crystallites takes place [10]. The amorphous incubation layers hinder the transport of the photo-generated charge carriers in μc-Si:H solar cells and in turn deteriorate the cell performance [13]. A ‘seed layer’ technique has been reported, which is able to reduce the thickness of the incubation layer [12]. The key characteristic of the ‘seed layer’ is its (very) high crystallinity.

---

[*] Corresponding author. Tel.: +49 2461 987390; fax: +49 2461 613735. *E-mail address:* y.huang@fz-juelich.de (Y. Huang).

[1] Presnt address: Physical Metallurgy Division, India Gandhi Center for Atomic Research, Kalpakkam 603 102, TN, India.

0022-3093/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnoncrysol.2007.09.067

Such highly crystalline 'seed layers' are usually deposited at a high plasma excitation frequency or/and a high hydrogen-dilution. The 'seed layer' acts as a nucleation layer allowing a local-epitaxial growth of the μc-Si:H i-layer. It should be noted that in the n–i–p μc-Si:H solar cells, the μc-Si:H i-layers were deposited on the μc-SiC:H window layers [4]. It is known that an epitaxial growth of Si on a SiC substrate is possible only if the substrate has a 3C polytype [14]. However, the μc-SiC:H layer deposited by HWCVD consists of various polytypes [3]. It is therefore not an easy task to grow high-quality μc-Si:H i-layer directly on such μc-SiC:H layers. This work describes the preparation of 'seed layers', which enables us to grow μc-Si:H i-layers on the μc-SiC:H layers with improved quality. The effects of the 'seed layers' on the structural properties of the subsequently deposited μc-Si:H i-layers and the performance of the resultant n–i–p μc-Si:H solar cells were investigated. By optimizing the deposition conditions of the solar cells and by implementing ZnO:Al back reflectors at the p-side of the devices, cell efficiency as high as 9.2% was obtained with a 1 μm-thick absorber layer.

2. Experimental

The n–i–p solar cells were deposited on textured glass/ZnO:Al substrates [15] in a multi-chamber deposition system described elsewhere [16]. The μc-SiC:H n-layers were prepared by HWCVD at a substrate temperature of 275 °C [4]. The μc-Si:H i-layers and the 'seed layers' were grown from a silane–hydrogen gas mixture using plasma-enhanced chemical vapor deposition (PECVD) at a very high frequency (VHF) (95 MHz). A shower-head type gas inlet was employed for the deposition to achieve high uniformity. To study the effect of the deposition condition on the nucleation of μc-Si:H, the silane concentration (SC) for the 'seed layer' (hereafter labeled SC_{seed}) deposition was varied from 1% to 4%. Here, SC $(=[SiH_4]/([SiH_4]+[H_2]))$ is defined by the flow ratio of the process gases. The subsequent μc-Si:H i-layers were deposited at a constant $SC = 5\%$. The deposition times were adjusted such that the thicknesses of the 'seed layers' and the subsequent μc-Si:H i-layers were about 100 and 900 nm, respectively. The active area of each cell is 1 cm^2 as defined by the geometry of the Ag back contact. For better light trapping, ZnO:Al/Ag back reflectors were implemented in some cases. The detailed cell structure is given in Fig. 1.

Raman scattering measurements were performed from the p-sides of the solar cells. The excitation wavelength of the laser source is 647 nm, which corresponds to the probing depth of about 1 μm. The Raman intensity ratio $I_C^{RS} = (I_{500} + I_{520})/(I_{480} + I_{500} + I_{520})$ based on the integrated intensities of Gaussian peaks fitted to the Raman signals originated from crystalline grains (at 500 and 520 cm^{-1}) and disordered phases (480 cm^{-1}), was used as a semi-quantitative measurement of the crystalline volume fraction [17]. The J–V characteristics of the n-side illuminated solar cells were measured under AM1.5 illumination at 25 °C.

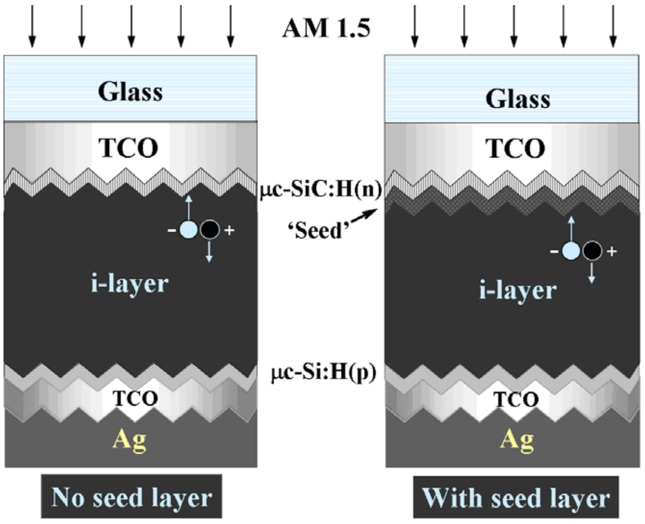

Fig. 1. Structures of the n–i–p cells with and without 'seed layer'.

3. Results

Fig. 2(a) shows the Raman spectra of μc-Si:H i-layers deposited on μc-SiC:H n-layers at $SC = 5\%$ with or without incorporating a 'seed layer'. Without a 'seed layer', the Raman spectra of the μc-Si:H film consists of a strong broad peak at $\sim$480 cm^{-1} and weak signals $\sim$500 and 520 cm^{-1}, which are ascribed to the amorphous and crystalline silicon phases, respectively. Fitting the spectrum with three Gaussian peaks, the Raman crystallinity (I_C^{RS}) is determined to be 16% (see in Fig. 2(b)). By comparison, a much higher I_C^{RS} ($\sim$60%) was obtained for the μc-Si:H

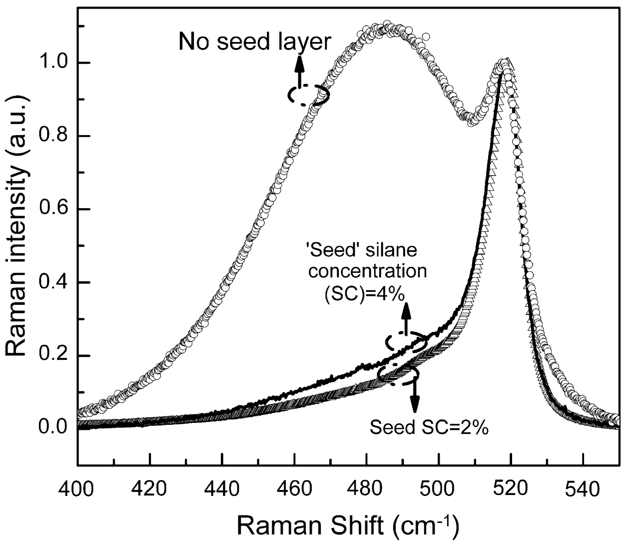

Fig. 2(a). Raman spectra of μc-Si:H i-layers grown at $SC = 5\%$ on various 'seed layers'. The measurements were done using a red laser with an excitation wavelength of 647 nm.