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Optimisation of p-doped μc-Si:H Emitter Layers in Crystalline-amorphous Silicon Heterojunction Solar Cells

Z.P. Ling[a,b,*], J. Ge[a,b], T. Mueller[a], J. Wong[a] and A.G. Aberle[a,b]

[a] *Solar Energy Research Institute of Singapore, National University of Singapore, 7 Engineering Drive 1, Block E3A, Singapore 117574, Singapore*

[b] *Department of Electrical and Computer Engineering, National University of Singapore, 4 Engineering Drive 3, Block E4, Singapore 117576, Singapore*

Abstract

Heterojunction silicon wafer solar cells, using a microcrystalline silicon (μc-Si:H) thin-film emitter and a very thin intrinsic amorphous silicon (a-Si:H) passivation layer between the crystalline silicon wafer and the emitter layer, have been reported to exhibit stable performance and high efficiency. Desired properties for the emitter layer include wide bandgap, low surface and interface recombination, and good doping efficiency. In this study, we report on the thin-film properties of p-doped μc-Si:H emitter layers deposited using RF (13.56 MHz) PECVD, at different SiH_4/H_2 gas flow ratios, pressures, and temperatures at the same RF power. Trends relating deposition conditions to relevant film characteristics such as thickness, crystalline fraction and conductivity are discussed. Finally, device relevant symmetrical p^+/i/c-Si/i/p^+ heterojunction lifetime test structures are investigated, using the optimised parameters for p-doped μc-Si:H layers (discussed in this paper) and for intrinsic a-Si:H layers (discussed in a companion paper [1]). These exhibit promising effective lifetimes of up to 2.4 ms at an injection level of 10^{15} cm^{-3}.

Keywords: Heterojunction solar cell; a-Si:H; amorphous silicon; microcrystalline silicon; silicon wafer solar cells; effective carrier lifetime; optical bandgap; crystallinity; p-doped microcrystalline silicon

* Corresponding author. Tel.: +65 6601 1678; fax: +65 6775 1943
E-mail address: ling.zp@nus.edu.sg.

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1. Introduction

To achieve higher photovoltaic efficiency of hetero-junction Si wafer solar cells, the optimisation of the heavily p-doped thin-film emitter layer is important [2]. Desirable properties in the emitter layer include having a wide bandgap to reduce incoming photon absorption, low surface and interface recombination, and sufficient doping efficiency. Using a thin layer of wide-bandgap emitter material can help to reduce front surface recombination, and allow most of the light to pass through to the Si wafer. Additionally, the emitter needs to be sufficiently doped to obtain a large built-in potential for efficient charge carrier separation. It has been reported previously that microcrystalline silicon (μc-Si) based solar cells have several characteristic features [3, 4] such as reduced absorption of short-wavelength photons, enhanced absorption in near IR region, and improvements over amorphous silicon solar cells in terms of improved light soaking stability and higher carrier mobility. The successful application of μc-Si:H emitter layers to heterojunction silicon wafer solar cells has been shown in Refs. [5-9].

The focus of the present study is on the material, optical and electronic properties of heavily doped thin-film p-type emitter layers, which are either amorphous (a-Si:H) or microcrystalline (μc-Si:H) emitter layers, depending on the chosen deposition conditions. A preliminary study of the optimised μc-Si:H emitter layer is also carried out by incorporating it into a device-relevant symmetrically passivated heterojunction lifetime sample (p^+/i/n-Si wafer/i/p^+) using 20 nm thick p-doped μc-Si:H emitter layers and 10 nm thick intrinsic a-Si:H layers.

2. Experimental details

The heavily doped p-type a-Si:H/μc-Si:H emitter layers studied were deposited onto planar glass, using a conventional 13.56-MHz parallel-plate PECVD reactor at different SiH_4/H_2 gas flow ratios, deposition pressures, and substrate temperatures. As summarised in Table 1, the dilution ratio ($R = H_2/(H_2+SiH_4)$), substrate temperature T, deposition pressure p were set within the ranges R ~ 0.95-0.98, T ~ 150-250 ºC, p ~ 0.5-1.9 Torr, respectively. The RF plasma power P, diborane B_2H_6 flow, and SiH_4 flow were kept at P = 0.07 W/cm^2, 2 sccm (0.5% diluted in H_2) and 6 sccm, respectively. The target thickness for the emitter layer was ~45 nm.

Table 1. Overview of process parameters

Sample ID	Pressure (mTorr)	Substrate temp (ºC)	$R = \frac{H_2}{H_2 + SiH_4}$	H_2 flow (sccm)	SiH_4 flow (sccm)	B_2H_6 (0.5%) flow (sccm)
HET060	500	150	0.95	114	6	2
HET061	500	180	0.96	144	6	2
HET062	500	210	0.97	194	6	2
HET063	500	250	0.98	294	6	2
HET064	1000	150	0.96	144	6	2
HET065	1000	180	0.95	114	6	2
HET066	1000	210	0.98	294	6	2
HET067	1000	250	0.97	194	6	2
HET068	1500	150	0.97	194	6	2
HET069	1500	180	0.98	294	6	2
HET070	1500	210	0.95	114	6	2
HET071	1500	250	0.96	144	6	2
HET072	1900	150	0.98	294	6	2
HET073	1900	180	0.97	194	6	2
HET074	1900	210	0.96	144	6	2
HET075	1900	250	0.95	114	6	2