Influence of textured interfaces in the performance of a–Si:H double–juntion solar cell

A. Garcia–Rivera, R. Valin*, E. Comesañ a, A.J. Garcia–Loureiro, and A. Martinez*
Centro Singular de Investigación en Tecnoloxías da Información, University of Santiago de Compostela, Spain
*College of Engineering, Swansea University, UK
e-mail: angela.garcia.rivera@usc.es

This paper presents a study of the impact of different textured surfaces in thin–film hidrogenated amorphous silicon double–junction tandem solar cell (a–Si:H/a–Si:H) [1]. The impact of the texture on the solar cell performance has been analysed using the drift–diffusion model. To take into account the correct behaviour of the a–Si:H/a–Si:H solar cells the contribution from all bandgap states to the recombination–generation process (Shockley–Red–Hall and Sah–Shockley mechanisms) have been implemented [2]. The light scattering effect was simulated using the Monte Carlo ray tracing model. From the optical point of view, the light trapping and the efficient use of the solar spectrum are very important to achieve high efficiency solar cells. The rough textured substrate are used in superstrate configuration solar cells to introduce rough interfaces into the device. Different roughness profiles of TCO have been simulated to calibrate the a–Si:H/a–Si:H solar cell whose structure is depicted in Fig. 1. The TCO texture was modelled using a triangular profile, as a 2D representation of the 3D pyramidal–shaped texture. The period of the triangular profiles is constant and the height is adjusted according to the simulated angle α, such as is shown in Fig. 2. The same pattern of roughness has been considered for all the layers of the a–Si:H/a–Si:H solar cell. To take into account the effect of the deposition for each layer, an attenuation factor of the height roughness has been included. The simulation parameters of the a–Si:H layers for the double–junction solar cell are shown in Table I [3]. Fig. 3 shows that the calibration of the solar cell against the experimental data is optimal for α = 26°. The value of the short circuit current density is minimum for the smooth texture (α = 0°). From this minimum, the power increases as a function of the angle up to the experimental value is reached. For values of the angle larger than 26° the power decreases. The optimal angle fits well with the characteristics of an Asahi U-type texture for the TCO used in the manufacturing process [4]. Fig. 4 shows the density of absorbed photons in a–Si:H/a–Si:H solar cell for the smooth texture and the optimal roughness. The light is absorbed by all layers when the incoming light reaches the solar cell. However, in the active regions the amount of absorbed photons is higher for the optimal roughness. The roughness improves the light trapping in the i–layers of the device, increasing the optical path length inside of the solar cell and the probability of absorbing photons [5]. Larger values of photon absorption in the active layers increase the generation of electron–hole pairs which contribute to current generation in the solar cell. Fig. 5 shows the increase of the electron generation in the active layer in the textured interfaces. The maximum value of the electron density is obtained for the optimal roughness.

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ISBN 978-2-9547858-0-6

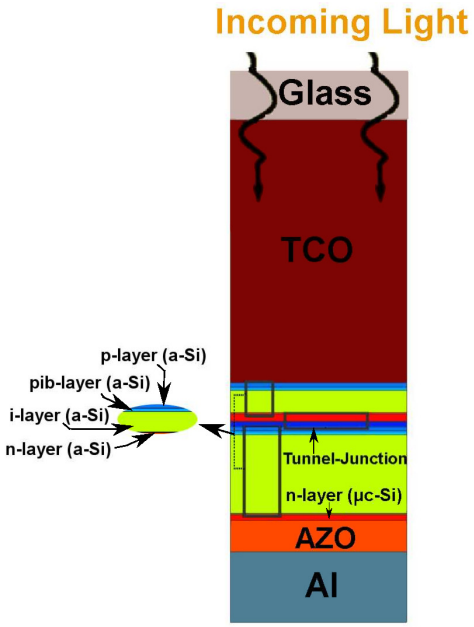

Fig. 1. Structure of the a–Si:H/a–Si:H double–junction tandem solar cell calibrated against the experimental data.

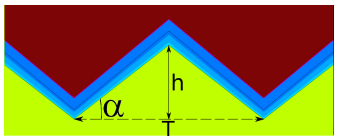

Fig. 2. Representation of the textured interface parameters. The period of the texture (T) is constant (similar to Asahi U-type texture $\sim$ 200 nm) and the height (h) is changed according to angle α.

TABLE I

THE SIMULATION PARAMETERS OF THE A–SI:H LAYERS FOR THE DOUBLE–JUNCTION SOLAR CELL.

Layer	p–layer	i–layers	n–layer
MATERIAL PARAMETERS			
Thickness (nm)	10 – 30	40 – 70 / 200 – 300	1 – 5
Doping (cm^{-3})	3×10^{18}	10^{15}	8×10^{18}
ϵ_r	7.2	11.9	11.9
χ (eV)	3.90	4.00	3.99
E_g (eV)	1.95	1.78	1.80
μ_n (cm^2/(Vs))	20	20	20
μ_p (cm^2/(Vs))	5	5	5
N_c (cm^{-3})	1×10^{20}	1×10^{20}	1×10^{20}
N_v (cm^{-3})	1×10^{20}	1×10^{20}	1×10^{20}
TAIL STATES PARAMETERS			
${N_c}^{tail}$ (cm^{-3}/eV)	2×10^{21}	8×10^{21}	1×10^{21}
${N_v}^{tail}$ (cm^{-3}/eV)	1×10^{21}	4×10^{21}	2×10^{21}
${E_{c0}}^{tail}$ (eV)	0.180	0.032	0.070
${E_{v0}}^{tail}$ (eV)	0.090	0.047	0.160
C_p^-, C_n^+ (cm^3/s)	10^{-8}	10^{-8}	10^{-8}
C_p^0, C_n^0 (cm^3/s)	10^{-10}	10^{-10}	10^{-10}
DANGLING BOND STATES PARAMETERS			
σ (eV)	0.144	0.144	0.144
N_{DB}^{tot} (cm^{-3})	8×10^{18}	5×10^{16}	2×10^{19}
$E_{DB}^{+/0}$ (eV) (from CB)	-0.70	-0.89	-1.40
U (eV)	0.20	0.20	0.20
$C_{p,n}^0$ (cm^3/s)	4×10^{-9}	8×10^{-10}	4×10^{-9}
$C_{p,n}^{+,-}$ (cm^3/s)	4×10^{-8}	8×10^{-9}	4×10^{-8}

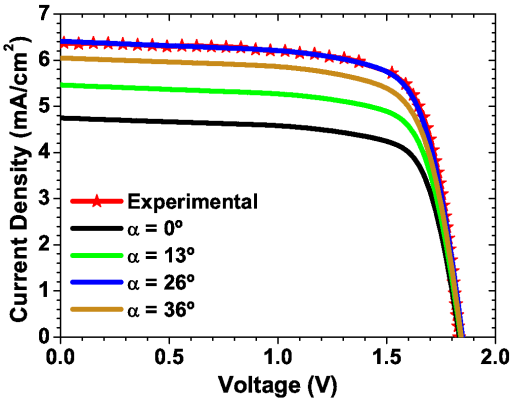

Fig. 3. J–V characteristics for the experimental data and simulated textured interfaces with different values of α.

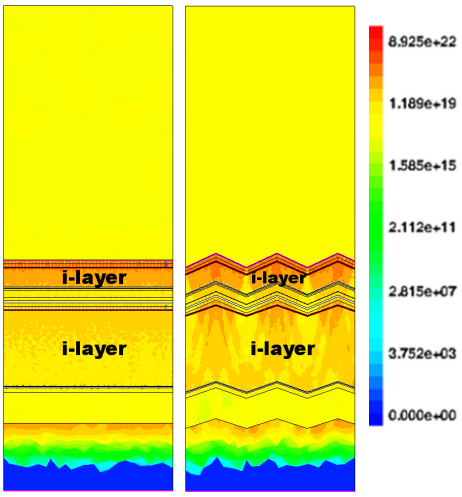

Fig. 4. Density of absorbed photons (cm^{-3} s^{-1}) in a–Si:H/a–Si:H structure solar cell for α = 0° and α = 26°.

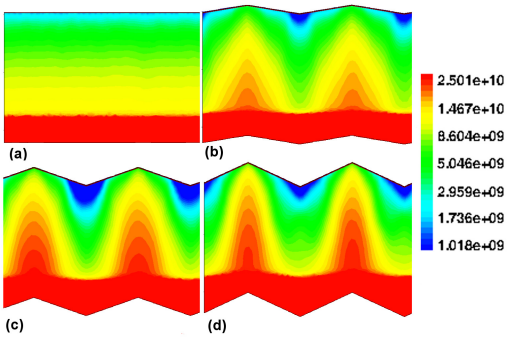

Fig. 5. Density of electrons (cm^{-3}) in the i–layer of the bottom cell for each one of the analysed textured interfaces. a) α = 0° b) α = 13° c) α = 26° and d) α = 36°.