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Continued Development of All-Back-Contact Silicon Wafer Solar Cells at ANU

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Abstract

The collaboration between the Solar Energy Research Institute of Singapore (SERIS), Trina Solar and ANU is progressing well, and ANU has already developed all-back-contacted (ABC) silicon wafer cells with best one-sun efficiencies of 21.2% and 22.1% on FZ material, when measured with the aperture areas of 16 cm^2 (includes busbars) and 13 cm^2 (excludes busbars) respectively. This paper presents the continuing development of ABC cells targeting the efficiency of 23.5% on 16-cm^2 cell area. Further developments such as optimising front surface field (FSF), rear diffusion, anti-reflection coating (ARC), and incorporation of lithographically aligned metal contacts were undertaken on the ABC cells. Phosphorus diffusion of the FSF was made lighter from the sheet resistance of 190 Ω/□ to 240 Ω/□, resulting in the reduction of the saturation current density (J_{oe}) of the FSF by 22 fA/cm^2. The optimised thickness of anti-reflection coating (ARC) PECVD SiN_x further reduces the average reflectance across the wavelength range of 300 to 1200 nm by about 4%. Incorporation of aligned metal contacts and heavier rear phosphorus diffusion has contributed to the reduction in the total series resistance by 0.08 Ωcm^2. The above optimised improvements have increased the efficiency of the champion ABC cell by 0.5% absolute. In addition, we present further refinements in areas of texturing; FSF passivation; electrical shading loss in terms of cell pitch, busbar and base doping; and metallisation to aim for the 16-cm^2 ABC cells with the conversion efficiency > 22% in the near term.

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Keywords: back-contact; FSF; electrical shading loss; photoconductance; OPAL 2; PC2D

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1. Introduction

In 2010, the leading PV manufacturer Trina Solar and the Solar Energy Research Institute of Singapore (SERIS) signed a research agreement to develop high-efficiency ABC silicon wafer solar cells. The research agreement targets to realise up to 21.5% production efficiency, and up to 23.5% laboratory test efficiency [1]. The involvement of the Australian National University (ANU) in the project is to develop laboratory-sized (16-cm^2) ABC silicon solar cells on n-type wafer substrates, targeting to an efficiency of 23.5% within two years of project commencement.

The quest of the research collaboration between Trina Solar, SERIS, and ANU to develop high-efficiency ABC silicon wafer solar cells is driven by the fact that the cost of the silicon wafer material is still significant in a photovoltaic module, and the photovoltaic industry is always in search of thinner wafer and different solar cell manufacturing technique, with the aim of further driving down the cost of photovoltaic module. Rear contact solar cells offer the opportunity to increase cell efficiency. Key advantages associated with the ABC solar cell design involve no optical shading loss with front metal grid, independent optimisation of surface passivation and optics at the front, large metal coverage on the rear that minimises series resistance, improved rear optics, simpler cell interconnecting system, and ease of adopting n-type Si, which is resilient to metal and oxygen impurities.

Schwartz and Lammert of Purdue University first proposed the ABC cell structure for concentrator applications [2, 3]. Research on ABC cells was further carried out by Sandia [4, 5] and Stanford University [6, 7]. SunPower was then established in 1985 to commercialise the Stanford developed technology. In 2010 SunPower reported remarkable efficiencies of large-area solar cells (155.1 cm^2) of up to 24.2% in a commercial production environment [8, 9].

At ANU, since the project commenced in March 2011, ABC silicon solar cells made from FZ wafers with encouraging conversion efficiencies of 19% (16-cm^2), 21.2% (16-cm^2) and 22.1% (13-cm^2) have been developed, and the results of which have been published elsewhere [10-12]. Table 1 shows the one-sun electrical parameters of 16-cm^2 (which includes busbars) ABC cell [12]. In this publication, we analysed the improvement items – optimisation of FSF, ARC, rear diffusion and aligned metal contacts – that were incorporated in the current process. In the analysis, the results of current process on further optimisations will be compared against that of the old process, described elsewhere [12]. Besides, we present the results of further refinements to incorporate in the next cell processes. Refinements include improved texturing; advanced passivation; minimising electrical shading loss in terms of substrate resistivity, busbar geometry and device pitch (i.e. n- to p-diffusion); and improved metallisation scheme.
We use photoconductance (PC) technique to analyse the performance of passivation and extraction of saturation current density (J_{oe}); spectral response analysis to determine the front surface reflectance; OPAL 2 to analyse the performance of anti-reflection layer and texture condition [13], and PC2D to model the performance of ABC cells based on different pitches and substrate resistivity [14].

Table 1. One-sun electrical parameters of ABC cells measured using 16-cm^2 aperture mask, published elsewhere [12].

Cell	Voltage	Jsc (mA/cm2)	FF	Efficiency
14.5B	0.684	39.0	0.794	21.2
14.5A	0.682	38.3	0.794	20.8
14.1A	0.684	38.7	0.799	21.2

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