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Effect of thickness on bifacial silicon solar cells

A. C. Pan, C. del Cañizo and A. Luque
Universidad Politécnica de Madrid – Instituto de Energía Solar
ETSI Telecomunicación, Ciudad Universitaria, 28040 Madrid – Spain
Tlf. 34 91 549 57 00 (ext.4322) Fax 34 91 544 63 41 e-mail: aline@ies-def.upm.es

Abstract—**The influence of the thickness reduction of bifacial solar cells has been investigated using Czochralski (Cz) substrates with thicknesses of 140 and 240 μm. Thickness reduction has increased cell performance for both illumination modes, and unlike the conventional structure, the thin one presents higher efficiency when illuminated by the n^+n junction. The good light trapping properties and low rear recombination have revealed efficient once the influence of bulk recombination is reduced thanks to thinning.**

Index Terms—**bifacial; Cz silicon; thin solar cells; monocrystalline;**

I. INTRODUCTION

RECENTLY the demand for silicon solar cells has increased significantly. While the production capacity of PV wafers, cells and modules has expanded to meet this demand, the one of solar silicon feedstock has not grown at the same pace [1]. On the other hand, it is also known that for monocrystalline silicon solar cells the wafer cost is the larger contribution (50-60%) to the total cost per Wp [2]. Using thinner substrates can help in addressing those issues, provided cell performance is not reduced with respect to that achieved with typical thicknesses

The PV industry has been steadily reducing the thickness of the silicon wafers used to manufacture solar cells from a typical thickness of around 450 μm in the mid-1980's to a thickness of 200-250 μm today [3]. A reduction of thickness of the silicon wafer to the 150 μm level would produce a reduction of the cost between 12 and 21% of the total, provided cell efficiency is maintained, which highlights technology interest on the mechanisms of light trapping (texturing, back reflectors and antireflection coatings) and rear side recombination [4].

Bifacial cell structures present advantages when thinning, as compared to standard ones, even if they are used in a "monofacial mode" (illumination on just one side). As an example, Fig. 1 shows efficiency vs. thickness of both a Phosphorus/Boron (P/B) bifacial structure and a Phosphorus/Aluminium (P/Al) monofacial one, whose main parameters are fitted from experimental data. While P/Al cell performance is degraded when thinning, the P/B structure does not degrade, and it can even improve a bit. Main reasons are the better light trapping properties and the reduced rear recombination of the bifacial structure.

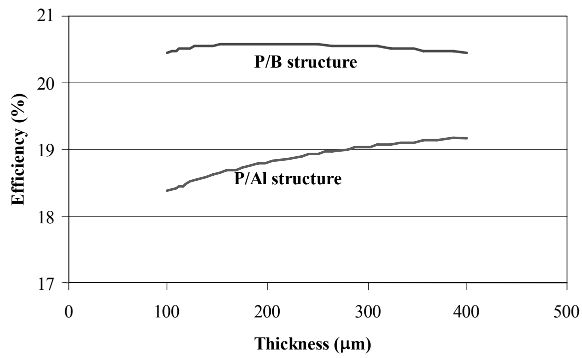


Fig. 1. Effect of the wafer thickness on the cell performance. This curve is obtained by PC1D simulation of a P/Al monofacial structure and P/B bifacial structure with optimal parameters (i.e. Si FZ, large lifetime).

In this paper we report on the fabrication of P/B bifacial solar cells on thick and thin Cz substrates, and present an analysis of the results.

II. EXPERIMENTAL

With the objective of verifying the effect of the thickness reduction on the bifacial solar cell performance, 4 cm^2 bifacial solar silicon cells have been manufactured on n-type and p-type substrates of 140 μm and 240 μm thicknesses. Wafer resistivity is 1-10 Ωcm for n-type substrates, and 1-20 Ωcm for p-type ones, and initial lifetimes is in the range of 10 μs.

The use of n- and p- type substrates allows to obtain p^+nn^+ and n^+pp^+ structures, where emitters have been implemented by P and B diffusion from liquid sources ($POCl_3$ and BBr_3, respectively). A total of 30 bifacial solar cells have been processed where its characteristics can be observed in Table I.

The process sequence previously developed at our institute for this material has been implemented [5], and is sketched in Fig. 2.

TABLE I:
CHARACTERISTICS OF USED SUBSTRATES

Substrates	Wafer thickness (μm)	Resistivity (Ωcm)	Number of wafers
n	140-160	5	12
n	240-300	7	4
p	140-160	4	10
p	240-300	7-15	4

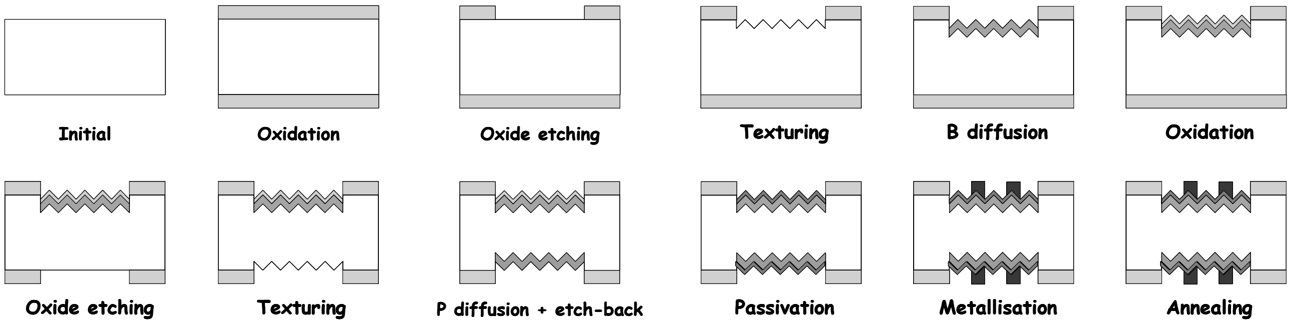


Fig. 2. Bifacial solar cells fabrication process.

Illuminated I-V characteristics of all cells have been measured, and also reflectance, carrier lifetime and spectral response of selected cells, which will be presented in next paragraphs.

III. Results

A. Cell Performance

Table II gives the electrical characteristics of selected bifacial solar cells, measured at standard conditions.

TABLE II:
BIFACIAL SOLAR CELL FOR THICK AND THIN CZ SUBSTRATES

Thickness (μm)	Substrates/ Illumination	J_{sc} (mA/cm²)	V_{oc} (mV)	Fill Factor	Efficiency (%)
140	n/n^+	36.3	0.612	0.764	17.0
	n/p^+	31.6	0.610	0.772	14.9
240	n/n^+	33.2	0.591	0.724	14.2
	n/p^+	32.6	0.590	0.775	14.9
140	p/n^+	35.0	0.587	0.779	16.0
	p/p^+	30.0	0.571	0.762	13.0
240	p/n^+	32.6	0.588	0.723	13.8
	p/p^+	33.0	0.589	0.704	13.7

It can be noticed that the values of efficiency in the thin solar cells are always superior to the thick ones. The best result is obtained for a thin n-type cell with 17% of efficiency when illuminated by the n^+ side and 14.9% by p^+ side.

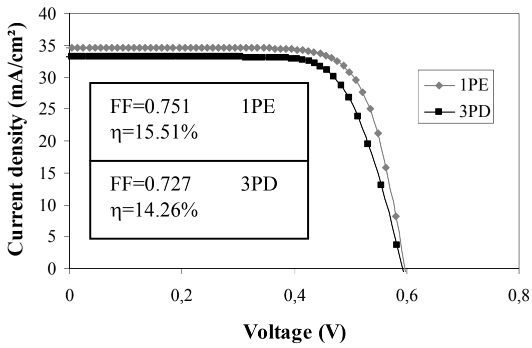
The "symmetry factor", defined as the ratio of short circuit currents for front and rear illumination modes has been reached satisfactory values, since in all the cells they are superior to 75%.

The results of the experiments validate the assumption that the thinning reduces the impact of bulk recombination, and benefits from reduced rear recombination and better light trapping as compared to current monofacial cells.

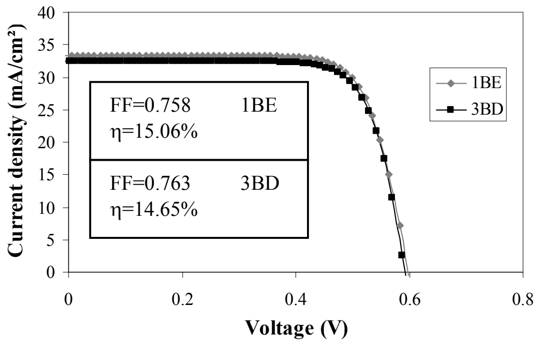
Other significant parameter observed is that better solar cells manufactured (thick and thin) are n-type substrates.

B. Cell Characterization

Fig. 3 (a) and (b) present illuminated I-V characteristics under monofacial illumination by the region n^+ and p^+ respectively, of one of the fabricated thin cells (1E) and one thick cell (3D). They are both on n-type Cz substrates. Thickness reduction has increased cell performance for both illumination modes, and unlike the conventional structure, the thin one presents higher efficiency when illuminated by the n^+n junction (high-low junction).



(a)



(b)

Fig. 3. Current-voltage characteristics of a thin bifacial solar cell (1E, 160 μm) and a bifacial solar cell of typical thickness (3D, 240 μm) illuminated by the n^+ side (a) and the p^+ side (b). They are both on n-type Cz substrates.

Our analysis shows that the main factor explaining the results has been the reduction of bulk recombination. This is consistent with our simulations [6], and is also confirmed by the experimental measurements of bulk lifetime after different process steps for thin solar cells (see Fig. 4). The improvement thanks to the P gettering step can be clearly realised, but lifetime is further degraded due to the passivation step by thermal oxidation. Because of a lower bulk recombination, and therefore a higher ratio of the diffusion length compared to the cell thickness, thin solar cells show lower photodegradation.

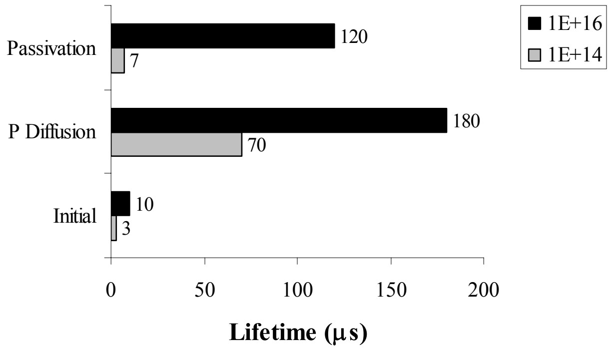


Fig. 4. Carrier lifetime for the bifacial solar cells after different steps of the process as measured by Photoconductive Decay on test samples. Values for two different injection levels (10^{14} and 10^{16} cm^{-3}) are presented.

As it is possible to verify graphically from Fig. 5, the data of reflection of the solar cells shows that they have good light trapping properties (by the texture and the antireflection coating). That is relevant in the manufacture of thin solar cells since otherwise the reduction of the thickness produces a decrease in the number of photons that can be absorbed, and so a fall in the current [7].

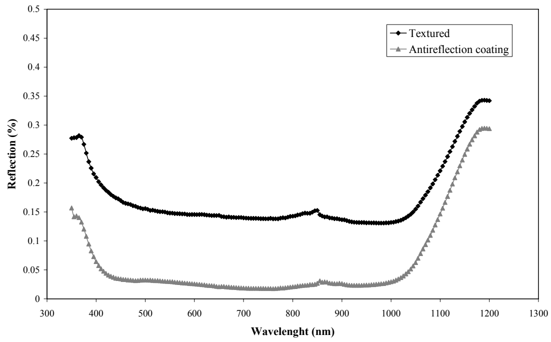


Fig. 5. Percentage of normally incident light reflected from a textured thin solar cell and one with antireflection coating, as a function of wavelength.

IV. DISCUSSION

The thin cells present greater efficiency when illuminated by the high-low junction (n^+n). This is because we obtain a good passivation of the surfaces, an important factor in thin cells. Fitting experimental I-V curve and Quantum Efficiency (see Fig. 6) of some of the cells, final bulk lifetime in the range of 20 µs is obtained (corresponding to a diffusion length of 155 µm). So in the 240 µm cells the bulk recombination limits cell performance, and precludes a good performance when illuminating by the high-low junction n^+n; while in the 140 µm samples, carriers generated all through the substrate are efficiently collected, and recombination at surfaces becomes predominant.

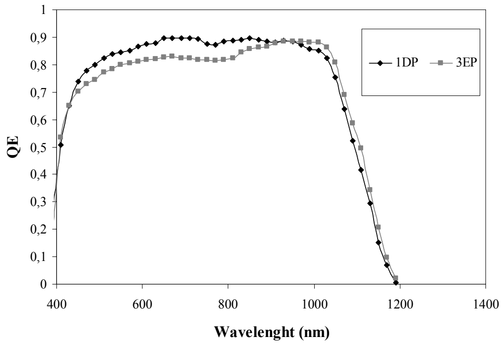


Fig. 6. Quantum Efficiency (QE) of a thin bifacial solar cell (1DP, 160 µm) and a bifacial solar cell of typical thickness (3EP, 250 µm) illuminated by the n^+ side. They are both on n-type Cz substrates.

Fig. 7 presents quantum efficiency of a thick cell for both illumination modes. It can be observed that recombination at the boron emitter is higher than at the phosphorus one. Therefore, when we compare the thin and thick cells with the same lifetime this factor is determinant. Since the bulk recombination is not important for the thin cells, the performance is better when illuminated for by the phosphorus emitter (although being the high-low junction). On the other hand, for the thick cells the higher efficiency is reached when illuminated by the pn junction, as bulk recombination is the limiting factor.

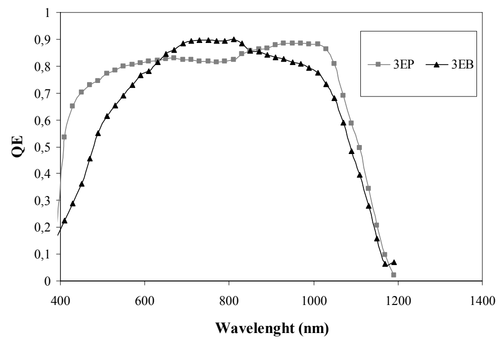


Fig. 6. Quantum Efficiency (QE) of the thick bifacial solar cells (240 µm) on n-type Cz substrate. Illuminating by the n^+ side (3EP) and p^+ side (3EB).

V. CONCLUSIONS

A highly effective approach for a cost reduction of crystalline silicon solar cells is the better utilization of the material by cutting thinner, and therefore more wafers, per crystal length. Solar cell performance should not be degraded because of that to really take advantage of wafer thinning.

We have shown that bifacial cell structures are good candidates when thinning, even if used in “monofacial mode”, by comparing cell performance of two different thicknesses. Further experiments are needed to confirm that thinning is also not detrimental for substrates with high final bulk lifetime.

ACKNOWLEDGMENT

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