INTRODUCTION OF THINNER MONOCRYSTALLINE SILICON WAFERS IN AN INDUSTRIAL CELL-MANUFACTURING FACILITY

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ABSTRACT: Cost reduction and shortage of silicon are the two driving forces for the introduction of thinner wafers in solar cell manufacturing. Nevertheless, efficiency losses and higher breakage rates may offset the benefit brought about by the lower price of the thinner wafers. In this work the balance of these factors is considered, and the necessary conditions for the cost-effectiveness of the project are quantified. Finally, preliminary results of the first large-scale experiments carried out with 270 µm and 250 µm wafers in the laser-grooved buried-grid solar cell production facility of BP Solar in Madrid are presented.

Keywords: c-Si, Cost reduction, Manufacturing and Processing

1 INTRODUCTION

The main purpose of using increasingly thinner silicon wafers for the manufacture of solar cells is to reduce production costs without introducing significant changes in the cell technology. In the present situation of the photovoltaic industry (when demands from solar cell producers are overwhelming the capacity of poly-silicon feedstock suppliers), a second reason for the movement towards thinner wafers comes into play- the need to maximize silicon utilization.

For the laser-grooved buried-grid (LGBG) solar cell technology [1], produced by BP Solar in its manufacturing plants of Madrid (Spain), the cost of the wafer represented, in 2004, about 40-45 % of the total module cost. Wafers consumed in Madrid are nominally 300 µm thick. Wafer thickness reduction can, in principle, contribute to decrease the module cost through a lower wafer price, yet it has two immediate drawbacks. Firstly, a falloff of the cell efficiency, through short circuit current losses. Secondly, a loss of production yield, due to higher breakage rates during cell processing and module assembly, and an increase in cell rejects caused by impaired cosmetic appearance brought about by the handling of thinner wafers with automated equipment.

An accurate appraisal of pros and cons is therefore mandatory before introducing thinner wafers in production. This article presents the results of the first large-scale experiments carried out with 270 µm and 250 µm wafers in the LGBG cell production facility of BP Solar in Madrid.

2 THIN WAFERS

By reducing the wafer thickness, more units can be produced out of a given volume of raw material. Figure 1 shows the number of wafers per unit of ingot length as a function of wafer thickness for three different values of the kerf loss, assuming 100 % sawing yield. A 100 µm thickness reduction (from 300 µm to 200 µm) could bring about a 25 % increase in the number of wafers (for a 200 µm kerf loss). This is certainly achievable by the multi-wire sawing technique. However, in mass production sawing yield decreases significantly when cutting thinner wafers [2], so that wafer thickness reduction does not automatically translates into silicon material gain and wafer price reduction. Currently, most solar cell wafers are cut between 250 and 350 µm.

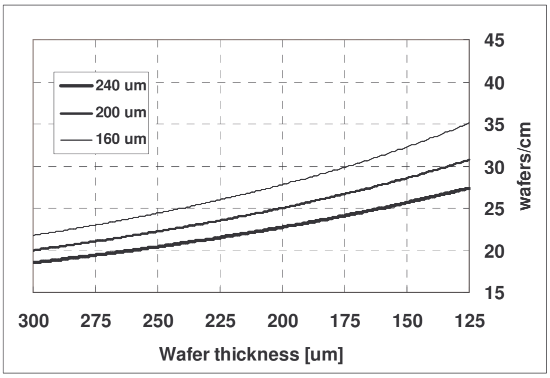

Figure 1: Maximum number of wafers per unit of ingot length as a function of wafer thickness for three different values of kerf loss (shown in the inset).

It is well known that a reduction of wafer thickness causes a decrease in cell efficiency, mainly through short circuit current losses. This is illustrated in Figure 2, where the Isc of a group of cells from the same batch, processed in Madrid, is plotted as a function of cell weight (which is proportional to wafer thickness).

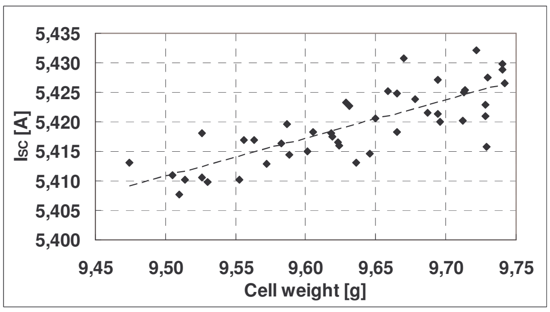

Figure 2: Short circuit current of a group of cells from the same batch as a function of cell weight.

On the other hand, the use of thinner wafers in the cell production line gives rise to a higher breakage rate, due to their lower mechanical stability. Figure 3 shows the average breaking force of as-cut wafers of three different thicknesses, used in this work, measured with a stability testing tool, in the twist configuration [3].

Thinner wafers are indeed more flexible, but the force needed to fracture them is smaller, due to the larger part played by surface defects and the lower resistance the material offers to crack growth.

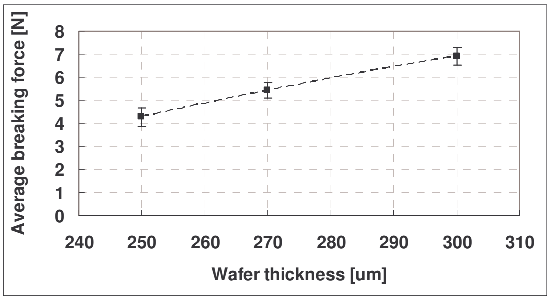

Figure 3: Average fracture forces for varying wafer thicknesses. Error bars are the standard deviations for each group of measured wafers. The line is a guide to the eye.

Given these two factors (efficiency losses and breakage rate increase), movement towards thinner wafers will have a cost-reducing effect only if the wafer price decrease ultimately offsets those losses. Figure 4 illustrates this point with a theoretical case. Assuming a price of 3,00 €/wafer, a cell efficiency of 17 % (for a pseudo-square wafer of 154,29 cm^2 area), and a production yield of 95 %, the part of the cost per Wp associated to the wafer price would be 1,20 €. If thickness reduction allows the wafer supplier to charge 2,5 % less for every unit, the transition to a thinner wafer will be profitable for the cell manufacturer only if mechanical yield does not fall below 92,6 %, assuming there is no efficiency loss. If the efficiency loss is not null, the balance point moves to higher values of the production yield. Figure 4 plots the cost per Wp reduction as a function of production yield for different efficiency losses.

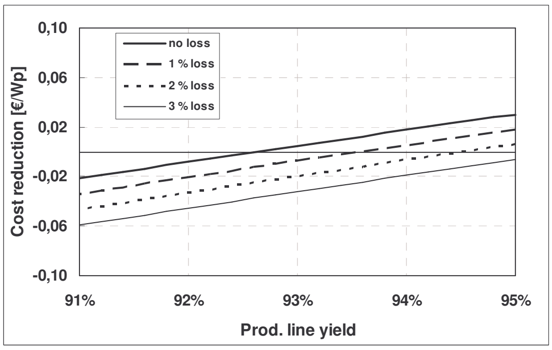

Figure 4: Cost reduction brough about by a 2,5 % decrease in wafer price, as a function of production yield for four different values of efficiency loss (shown in the inset).

The 2,5 % discount rate has been chosen as a fairly realistic figure. It must be noted (see Figure 1) that a thickness reduction of 30 µm (*e. g.*, from 300 µm to 270 µm, with a kerf loss of 200 µm) allows the wafer supplier a maximum output increase of 6,4 %: from 20,00 to 21,28 wafers/cm. Unfortunately, this must be compounded with a possible decrease of sawing yield or throughput, and depreciation of whatever expenses the supplier incurs for this technological improvement. Taking this into account, a final price reduction of a mere 2,5 % is quite on the mark.

3 RESULTS

A group of 5.000 wafers supplied by M-Setek, with 270 µm nominal thickness, was processed through BP Solar's LGBG solar cell manufacturing line in Madrid. Standard processes and practices were followed at every step of the process route. The purpose of the trial was to get an indication of the effect of a thinner wafer on the mechanical yield of the line (adapted to the process of 300 µm wafers), and on the electrical performance and cosmetic appearance of the finished cell. Breakages at every process or transfer step were readily recorded, so as to identify the more troublesome areas where action was demanded to keep mechanical yield at the current level.

The same exercise was repeated with another group of 5.000 wafers from the same supplier, with 250 µm nominal thickness.

The results are shown in Figures 5 and 6.

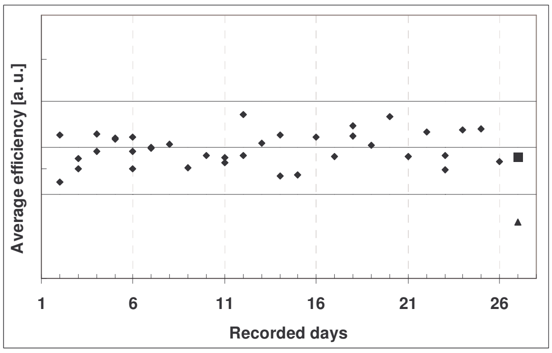

Figure 5: X-bar quality control chart for average batch efficiency of standard 300 µm production. Point ■ at day 27 corresponds to 270 µm wafers. Point ▲ corresponds to 250 µm wafers.

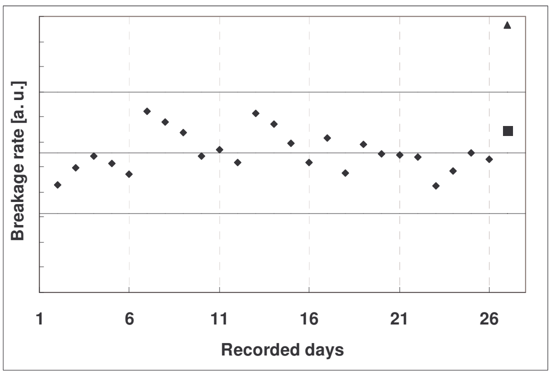

Figure 6: X-bar quality control chart for average breakage rate of standard production. Points ■ and ▲ correspond to 270 µm and 250 µm wafers.

Figure 5 is the X-bar quality control chart for average batch efficiency of standard production, recorded on a daily basis for a period of approximately one month in advance of the test. Average, upper and lower 3-σ control limits are represented therein. The square at day 27 represents the average efficiency of the 270 µm batch of

5.000 wafers. The average value of efficiency for the batch of 250 µm wafers has been represented by a triangle. While the thinner 250 µm wafers outstand as an out-of-control point, the performance of 270 µm wafers is well within the range of standard production.

Similarly, the average breakage rate X-bar control chart is represented in Figure 6. Once again, while the thinner wafers breakage rate is significantly higher than the upper control limit, the result of the 270 µm wafers batch is comparable to that obtained with standard material.

Figure 7 shows the breakdown of breakage events by process/transfer step.

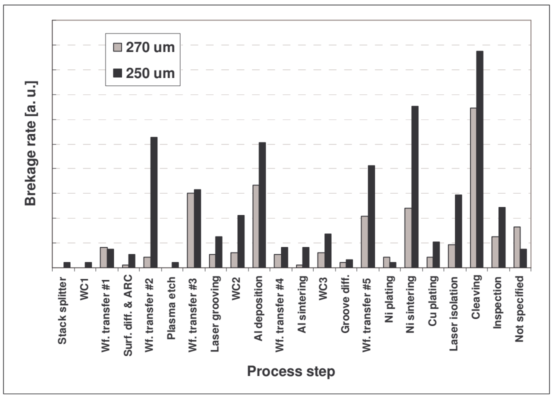

Figure 7: Distribution of wafer breakages across the manufacturing line for the two groups of tested wafers.

The troublesome points coincide for both groups of wafers (and, in fact, also for 300 µm wafers), yet their incidence is approximately double for 250 µm than for 270 µm wafers. Besides, most breakages are associated to automated transfer tools or manual handling of the cells. Only a negligible fraction of the events occur during wet chemical or high temperature processes.

4 CONCLUSIONS

Given that the material was processed without altering the standard procedures, the results for 270 µm wafers are most encouraging and suggest that introduction of this substrate may be realized, if not outright, at least with only minor adjustments in the manufacturing line.

On the other hand, reduction of cutting thickness from 300 µm to 270 µm is probably a step most wafering companies are in a position to take without significantly affecting their yields or the quality of their products, thus effectively offering to the cell producer a reliable route to cost reduction.

For 250 µm wafers, the main problems to tackle have been identified. Improvement of wafer handling practices and adjustment of automation tools, must be accompanied by on-going projects to improve the effectiveness of the back surface field within the LGBG technology.

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