# HIGH EFFICIENCY BIFACIAL BACK SURFACE FIELD SOLAR CELLS

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Summary

The first high efficiency $p^+$–n–$n^+$ bifacial solar cells are presented. Efficiencies of 15.7% and 13.6% were measured under front and back air mass one illumination respectively at 28 °C. At 7 air mass one illumination and 28 °C the front efficiency increases to 16.5%.

A pilot production of 200 cells was made following a fabrication process as simple as that for conventional back surface field cells. Mean efficiencies of 13.4% and 10.7% were obtained under front and back illumination respectively. The production yield is higher than 80%.

The advantages that bifacial cells present in some applications, compared with conventional cells, have been pointed out for static [1] and quasi-static [2] concentrating systems, for luminescent concentrators [3] and also for flat panels. A transistor-like structure ($n^+$–p–$n^+$) has already been developed as a bifacial cell [4].

We have also suggested [5] and theoretically analysed [6] the use of a back surface field (BSF) structure ($n^+$–p–$p^+$ or $p^+$–n–$n^+$) as a bifacial cell. The purpose here is to demonstrate the feasibility of high efficiency bifacial BSF solar cells.

$p^+$–n–$n^+$ bifacial cells with a 5 cm$^2$ area were made on float-zone silicon wafers. The resistivity of the n-type base region was 10 $\Omega$ cm and the thickness was 260 $\mu$m. The $p^+$ and $n^+$ regions were formed by open-tube diffusions using BBr$_3$ and POCl$_3$ sources, the resulting sheet resistance being 45 - 60 $\Omega/\square$ for the $p^+$ layer and 20 - 30 $\Omega/\square$ for the $n^+$ layer. A TiO$_x$ antireflection (AR) coating was spun onto both sides of the cell; Ti–Pd–Ag grids were sputtered and lift-off defined also on both faces.

The metallization pattern was designed for the cells to operate inside static compound parabolic mirrors with a concentration factor of 5 and a non-uniform distribution of light intensity on the cell surface. The optimum grid has ten fingers per centimetre (each finger is 50 - 70 $\mu$m wide) and produces a coverage factor in the illuminated area of about 5.5%.
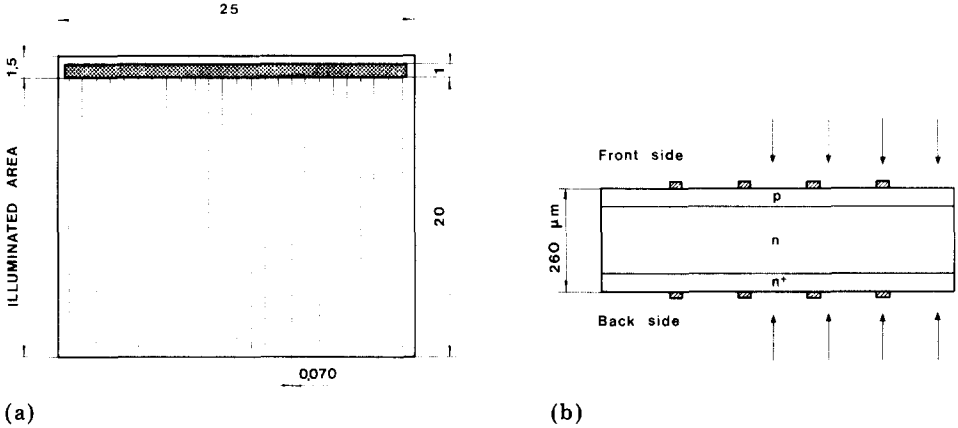
Fig. 1. (a) Metallization grid and (b) cross-sectional view of a $p^+$–n–$n^+$ bifacial cell.
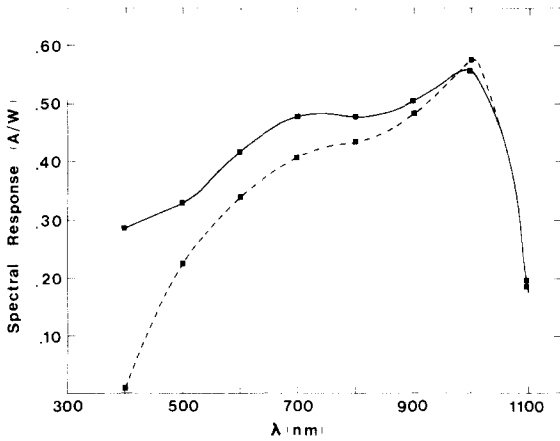


Fig. 2. Spectral response of cell JF6: ——, front illumination, $I_{scf}$ = 162 mA, $V_{ocf}$ = 600 mV, $FF_f$ = 0.76, $\eta_f$ = 14.8; – – –, back illumination, $I_{scb}$ = 130 mA, $V_{ocb}$ = 592 mV, $FF_b$ = 0.76, $\eta_b$ = 11.7.

The highest efficiencies measured on different samples are $\eta_f$ = 15.7 and $\eta_b$ = 13.0 under front and back illumination respectively. A short-circuit current density $J_{scf}$ of 33.5 mA cm$^{-2}$ and an open-circuit voltage $V_{ocf}$ of 603 mV were measured under front illumination. For back illumination the corresponding $J_{scb}$ and $V_{ocb}$ values are 28.8 mA cm$^{-2}$ and 597 mV respectively. All these values were obtained under air mass one (AM1) (100 mW cm$^{-2}$) irradiance at 28 °C and they are referred to the illuminated area. In this area the metallic fingers are included and produce a 5.5% coverage, but a 1 mm × 25 mm bus-bar is not included (Fig. 1).

The lower back illumination efficiency is mainly attributed to the higher reflectivity of the back surface compared with the front surface. The reason is that the back surface is bright-etched at the beginning of the fabrication process and, consequently, when spinning the AR coating a $TiO_x$
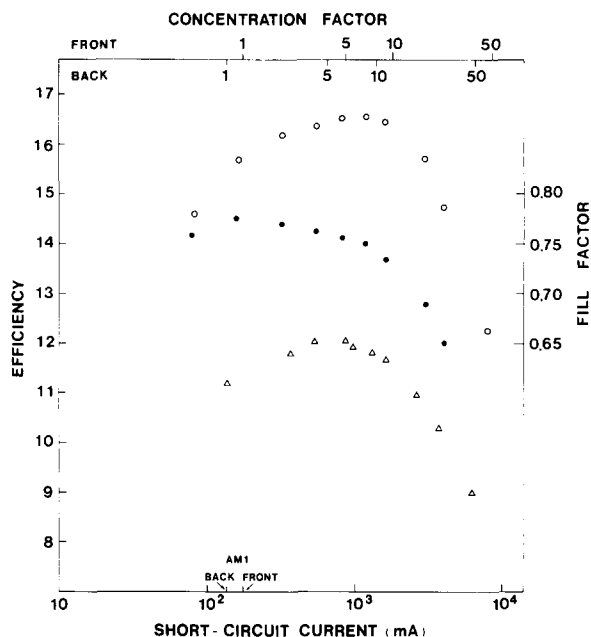
Fig. 3. Efficiency (○, front; △, back) and fill factor (●) of cell TD1 measured at 28 °C under concentrated sunlight. The concentration factor was obtained by dividing the measured short-circuit current by the AM1 short-circuit current.

layer of non-uniform thickness is obtained. The final result is that the ratio of the back short-circuit current to the front short-circuit current is typically between 0.80 and 0.85 (see the spectral response of one of these cells in Fig. 2). When the AR coating is removed from both sides the $I_{scb}/I_{scf}$ ratio increases to 0.94. Furthermore, we made $n^+$–p–$p^+$ cells with the back layer on the mirror-polished side, leading to an $I_{scb}/I_{scf}$ ratio of 1.05 for $J_{scb}$ = 30.4 mA cm$^{-2}$, $V_{ocb}$ = 599 mV, fill factor FF = 0.75 and $\eta_b$ = 13.6%. This ratio which is higher than unity confirms the above-mentioned differences in reflectivity between both faces.

High fill factors and efficiencies $\eta$ were measured under concentrated sunlight (Fig. 3), which indicates that series resistance effects are low in spite of the increased contribution of the p and $p^+$ regions due to the back metal grid. A peak efficiency of 16.5% was measured for an irradiance of 7000 mW·cm$^{-2}$ on the front face at 28 °C.

A pilot production of 200 $p^+$–n–$n^+$ bifacial cells was carried out using the afore-mentioned process. 86% of the devices show a front efficiency higher than 10%, the mean value being 13.4%. 81% of the cells have a back efficiency higher than 8%, with a mean value of 10.7% (as indicated in the histograms in Fig. 4).

Although float-zone material was used for the pilot production, some cells were made on Czochralski-grown silicon obtained from a different supplier to check the influence of the quality of the starting material on the
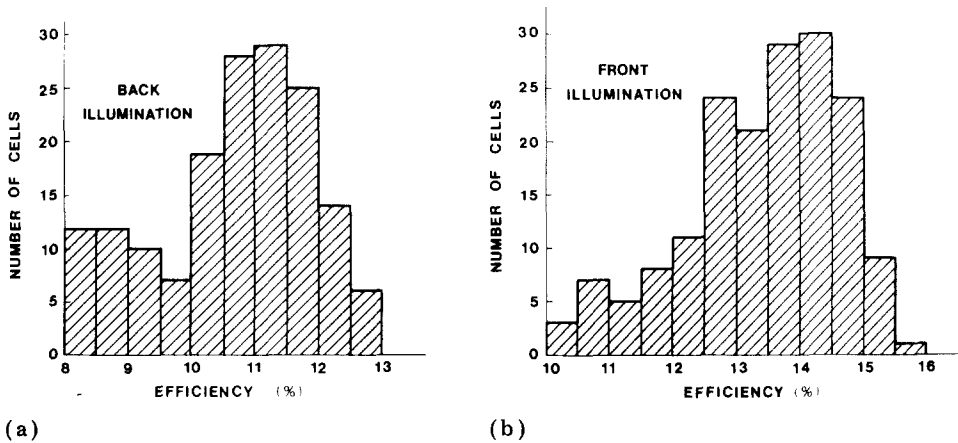
Fig. 4. Efficiencies of a pilot production of 200 $p^+-n-n^+$ bifacial cells: (a) back illumination; (b) front illumination.

efficiency (especially on the back efficiency). The polarity of the base region was also changed and some $n^+-p-p^+$ cells were made on 10 $\Omega$ cm p-type wafers. In both cases the results obtained were similar and efficiencies as high as those reported for $p^+-n-n^+$ cells made from float-zone silicon were measured.

It is important to emphasize that the process for making these bifacial cells is essentially as simple as the fabrication process of conventional BSF cells. Since their efficiency is similar, the use of bifacial BSF cells can be very advantageous in many applications such as those mentioned above.

# References

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