TECHNOLOGY FOR THE PRODUCTION OF 20% EFFICIENCY C-SI SOLAR CELLS FOR CONCENTRATING SYSTEMS

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ABSTRACT: In the present work we have investigated the best working-conditions applied to crystalline silicon technology developed in ENEA laboratories to transfer the concentration solar cell technology from lab-scale to pre-pilot level. We have realized different devices using FZ p-type Boron doped wafers and varying the sheet resistance of the emitters aiming at analyzing the effects of junction depth and concentration on the surface of doped elements affecting the recombination process. The very high current level of this kind of devices (Jsc: 1 up to 8 A/cm^2) imposed the use of thick fingers/busbar on the contacting structure in order to reduce the ohmic losses. Our aim is to develop a process easily transferable to industrial scale. A simplified photolitographic sequence to realize a thick layer of photoresist (>15 μm) followed by evaporation was used. We made a comparative study of the electrical behavior of different devices (current-voltage and quantum efficiency characterization) at one sun and under concentrated light, to investigate the influence of different fabrication conditions on the electrical performances of the devices. The best result achieved is η> 19% at 100 suns.
Keywords: c-Si, Concentrator Cells, High Efficiency.

1 INTRODUCTION

The PV Concentrator Technology (C-Technology) is considered an attractive and promising application to make PV technology become competitive in medium and long term. In fact by using optical concentrators to focus direct sunlight it is possible to increase the intensity of sunlight striking the cell and then to decrease solar cell area and consequently the cell cost by the concentration factor. In such way the influence of the cost of the solar cell on the whole PV system can be reduced. In the medium concentration application (<200 X) the share of the cost of the solar cells respect to the whole photovoltaic system should be negligible (<8-10%) [1,2].

A strategy to satisfy this request imposes the development of simple and cost effective technological processes able to realize high efficiency solar cells.

The solar cells for concentration differ from flat panel solar cells in their ability to work at high irradiances, and consequently at very high current density. Therefore the main differential characteristic is the contacting structure intended to reduce the ohmic losses. As an example, heavier doped substrates and deeper emitters are usually needed. These constraints, however, often give undesirable drawbacks, first of all a diminished value for the recombination lifetime in the base region.

The purpose of the Italian Phocus project (PHOCUS-PHOtovoltaic Concentrators to Utility Scale) is to develop a photovoltaic concentrators technology (C-technology) in order to demonstrate the technical feasibility of this application in Italy and to assess its greater potentials to drive a reduction of the PV System investment cost. One of the main task of this project is the optimization of a basic technology to realize high efficiency c-Si cells specific for high injection of light.

Our purpose is to find a process, easy to transfer to industrial application, able to produce solar cell efficiency of 20% under concentration regime, up to 100 suns.

In this paper we compare different cell structures in order to find a suitable compromise to optimise the cell behaviour. We have investigated the best working-conditions applied to crystalline silicon technology developed in ENEA laboratories to transfer the concentration solar cell technology from lab-scale to pre-pilot level.

2 EXPERIMENTAL

The structure of our cell is schematized in Table I and Figure 1.

crystalline base	p-type FZ 0.3 Ωcm, cSi, 250 μm thickness
Active area (~8% fingers shadowing included)	11 x 11 mm^2
Emitter	n-type 40-80 Ω/□, depth<1 μm,
Emitter passivation	SiO_x, 16-18 nm
Back contact	2 μm Al
ARC	MgF_2/ZnS, R_{eff}≈7.5 %
Finger (height/width/distance)	10 μm/12 μm/285 μm
Two busbars outside active area (height/length/width)	10 μm/11 mm/0,5 mm

Table I: Main features of the ENEA's solar cell

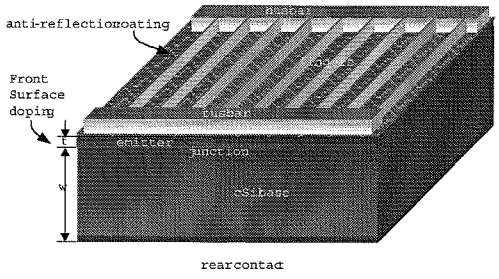

Figure 1: Structure of c-Si ENEA's solar cell

In our process we have chosen to use monocrystalline <100> oriented silicon Floating Zone 250 μm thick wafers having high p-type doping density as well as 0.3 Ωcm resistivity.

After standard RCA cleaning procedure the n-type emitter is realized on the top of the wafer by a diffusion

process at 850°C starting from a $POCl_3$ source. The remaining SiO_2-P_2O_5 is removed by a wet chemical etching in 5% HF bath. The emitter formation ends with a subsequent drive-in process at 940°C. SIMS and SRP profile have been carried out on the n-p junction to optimize the doping distribution and the n^+ depth to 1μm from the surface of the wafer. To reduce surface recombination velocity we perform a thermal oxidation of the wafer at 850°C. On this emitter a 16-18 nm thick thermal oxide is grown in order to passivate the silicon surface.

The emitter realization has been monitored measuring the minority carrier lifetime after the realization of each high temperature step, using the transient photoconductive decay revealed by a WCT 100 lifetime tester [3, 4].

The back contact of the cell is realized by e-beam evaporation of 2 μm Al layer annealed at 550 °C. Several solutions to obtain an effective back surface field are under investigation. Such a task is still a challenge for this kind of heavily doped substrates. The front contact is ensured by an e-beam evaporation of a trilayer of Ti, Pd, Ag on which a grid for the impinging light is obtained by lift-off process. A thickness of 10 μm is needed to collect the photogenerated carriers and to reduce series resistance losses under 100 sun radiation intensity. A 15 μm deep trench is formed by a wet chemical etch around the perimeter of the cell. A double antireflection layer of ZnS and MgF_2 evaporated on the top of the device has been optimized to reduce the total reflectance down to 8%.

These solar cells have been characterized by Quantum Efficiency and current voltage measurements performed in dark and light range from 1 sun up to 100 sun at room temperature condition.

The apparatus WCT 100 has been also used to measure the pseudo-IV curve of the cells under concentrated light. The curves measured in this way have to be considered as an upper limit for the performances of the cells. The comparison with a real IV measurement permits to obtain parasitic components and to relate them to the cell structure [5].

3 DISCUSSION

We made a comparative study of the electrical behavior of different devices (current-voltage and quantum efficiency characterization) at one sun and under concentrated light, to investigate the influence of different fabrication conditions on the electrical performances of the devices, for each technological step of the process. The investigation includes the analysis of the SIMS and SRP profiles of the emitter doping (Figure 2) and measurements of the minority carrier lifetime after the realization of each high temperature step (Table II).

The feasibility of the devices is proven by the fabrication of several cells with similar performances.

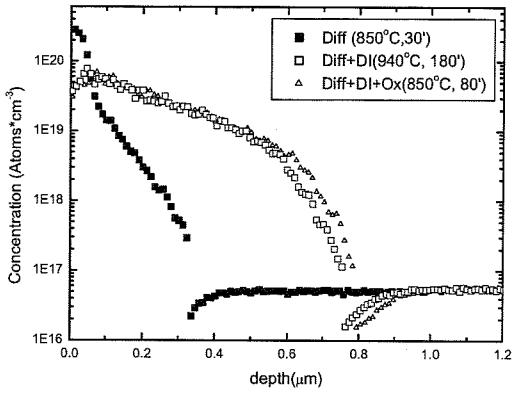

Figure 2: SRP profile of the emitter layer after diffusion and diffusion + drive-in processes.

Sample	Process features	τ (μs)
FZ, N, 500 Ω cm (τ check)	Phosphorus diffusion (850 °C, 30')	175
FZ, N, 500 Ω cm (τ check)	Phosphorus diffusion (850 °C, 30') + drive in (940 °C,180')	220
FZ, N, 500 Ω cm (τ check)	Phosphorus diffusion (850 °C, 30') + drive in (940 °C,180') + oxidation (850 °C, 80')	229
FZ, P, 0.3 Ω cm	Phosphorus diffusion (850 °C, 30')	5.2
FZ, P, 0.3 Ω cm	Phosphorus diffusion (850 °C, 30') + drive in (940 °C,180') + oxidation (850 °C, 80')	11
FZ, P, 0.3 Ω cm	Phosphorus diffusion (850 °C, 30') + drive in (940 °C,180') + oxidation (850 °C, 80') + oxide removal	4.6

Table II: Measure of the effective lifetime after different steps of the Phosphorous diffusion processes (WCT-100 lifetime tester).

τ-check wafers are high resistivity wafers used to "check" the diffusion processes. Drive-in and oxidation clearly result in a lifetime improvement.

The reproducibility of the process and the performances of the devices were checked during samples realization in each batch of samples as well as batch-to-batch.

We focused our attention on two different types of emitter: one with a thickness of 0.35 μm and another with a thickness of 0.80 μm.

The best cell realized in our laboratory using a specific grid for concentration application, achieved the efficiency of 18.54% at 1 sun illumination condition (Voc=634 mV; Jsc=35.45 mA/cm^2; FF=82.40%) (Figure 3 and 4).

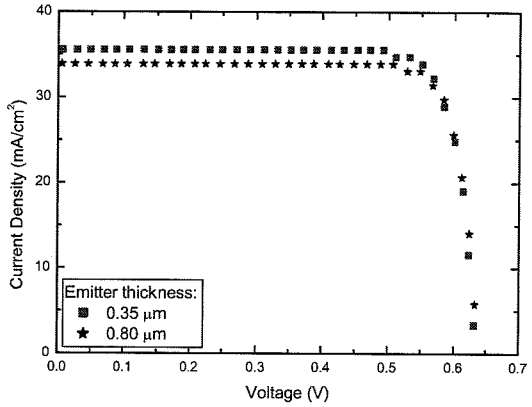

Figure 3: I-V curves at 1 sun for devices with different emitter thickness.

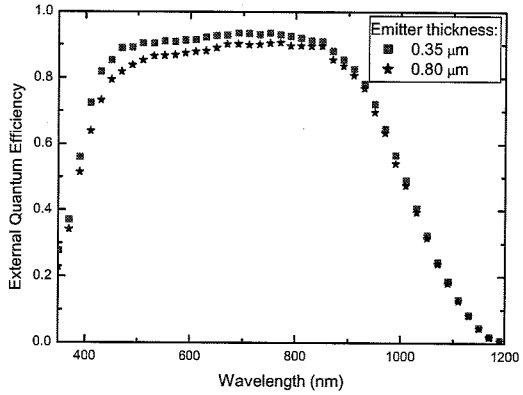

Figure 4: External Quantum Efficiency of devices with different emitter thickness.

The cells have been characterized under concentrating light using a flashed simulator (Pasan Sun Simulator III) with a pulsed xenon lamp (AM 1.5 spectral distribution and 1000 W/m^2 irradiance). Light has been concentrated using a Fresnel lens.

The cells have been assembled to easily make all the measurements and to guarantee an extended contact that can reduce considerably the series resistance during the characterization.

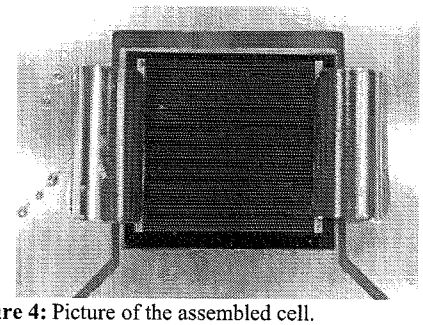

Figure 4: Picture of the assembled cell.

The best results are reported in Figure 5. All the measurements were carried out at 25°C.

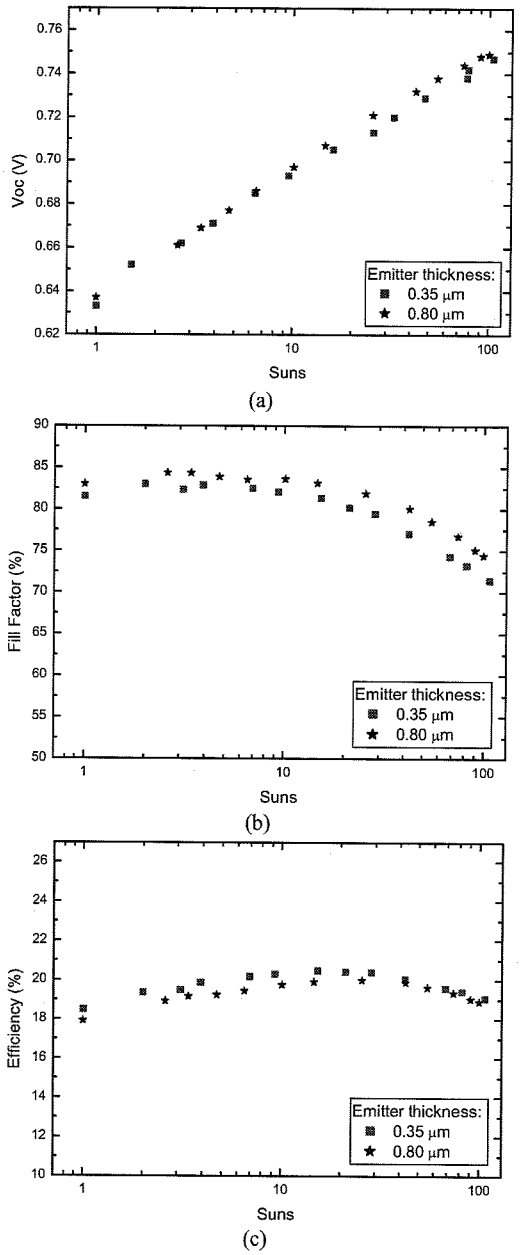

Figure 5: Comparison of measured parameters for cells with different emitter thickness until 100 suns concentration: (a) Open circuit voltage; (b) Fill Factor; (c) Efficiency.

As expected, while the cell with thin emitter shows better performance at 1 sun illumination conditions and under low concentration (<30 suns), the cell with thicker emitter shows better results under concentrated light (>30 sun). The best result obtained is η> 19% at 100 suns.

Pseudo IV curves, acquired with WCT-100 QSS Photoconductance tool (Suns-Voc setup) provide a semi ideal characterization: the voltage drop on the cell is always measured with zero current (the value of the corresponding current comes from a reference cell). The resulting pseudo-Fill Factor and pseudo-Efficiency values do not take into account the limits imposed by

shunt and series resistance and can be considered an upper limit to the real values, providing information about the device potentiality. The difference observed in Figure 6 in between real and pseudo-Fill Factor could be reduced by improving the current collection at higher concentrations.

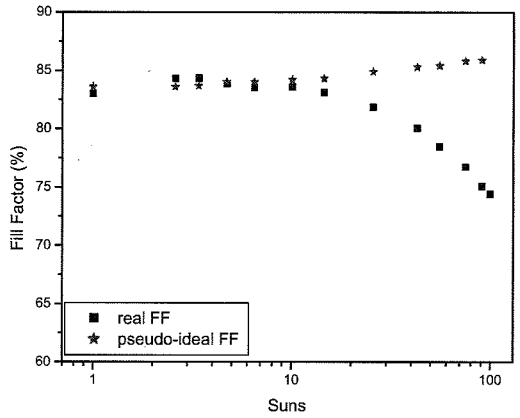

Figure 6: Comparison of measured Fill Factor values with pseudo-ideal ones for the cell with the thicker emitter.

4 CONCLUSIONS

In this work we show the realization of a c-Si Solar cell with an efficiency > 19% at 100 Suns. The technology used to obtain the devices is based on simple fabrication steps making the whole process easily transferable from lab to industrial scale. The feasibility of the devices is proven by the fabrication of several cells with similar performances.

The electrical features of devices with two different emitters have been compared.

Different grid geometry and the possible realization of a BSF will be taken into account, paying attention to maintain the simplicity of the whole process.

Further work will be also dedicated to investigate possible technological improvements and the best emitter features aiming at operating at higher sun concentration.

5 REFERENCES

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