POLYCRYSTALLINE SOLAR CELLS FROM UP-GRADED METALLURGICAL SILICON

P. V. Santos*, I. Chambouleyron*,
V. Bolzan ** and P. Mei**

*Institute of Physics and **Faculty of Engineering, UNICAMP
P.O. Box 6165, 13.100 Campinas, S.P., Brazil

ABSTRACT

A process to obtain solar grade polycrystalline silicon from metallurgical silicon is presented. The raw material (99% purity) is purified by chemical leaching, melted in a graphite crucible and unidirectionally solidified. We present results on impurity content at each step of the process and on final structure. p-n solar cells were fabricated on selected wafers. Conversion efficiencies greater than 5% were obtained in small area cells. We analize their behavior and discuss future improvements.

INTRODUCTION AND WAFER PREPARATION

We describe a process to obtain polycrystalline Si for solar energy purposes using metallurgical grade Si as starting material. After grinding to particle size of some tenths of a millimeter, the raw material (99% purity MG Si) is purified by chemical leaching. The material is then melted in a graphite crucible and an ingot, 10 cm length, 5cm diameter, is grown by unidirectional solidification with a 0.0125 mm/s solidification rate. The ingot possesses columnar structure, the grains having a diameter of ~ 1mm and several millimeters length in the growth direction. Impurity contents of the starting silicon, the leached material and the ingot are presented in Table I for a selected number of elements. Chemical leaching and unidirectional solidifications are very efficient methods to reduce metallic impurities. Phosphorus and boron removal appears to be much less efficient by these processes. This can be seen when measuring the resistivity and the conduction carrier type along the ingot. The botton region is p-type having an average resistivity of 1.1 Ω-cm. The central and top regions are n-type having resistivities of 1.6 and 0.4 Ω-cm, respectively. Resistivity variations were also measured along the cross section of the ingot.

CELL PROCESSING

n-p solar cells were fabricated onto p type, 1-5 Ω-cm wafers selected from the original ingot. After surface damage removal with an acid etchant, the wafers were phosphorus diffused from a liquid source at 875ºC. Sheet resistances of nearly 50 $\Omega_\square$ were obtained for the n^+ layer. Metallic contacts were made as follows. At the back side, after elimination of the diffused layer, aluminum was deposited and annealed. Front grid and back contacts were made by Ti (Pd)Ag metallization. No antireflective coatings were deposited onto the cells.

RESULTS

Large area cells (~10 cm^2) showed low parallel resistance and poor photovoltaic performance. Small area cells (0.1 to 0.2cm^2) were then formed by selective etching of the n^+ layer of the original cells. All these small cells exhibited much better photovoltaic response (figure 1). AM1 J_{SC} higher than 14mA/cm^2 and V_{oc} = 490 mV were obtained for the best cells, together with effective area efficiencies higher than 5% (no antireflective coating was applied).

Figure 2 shows a quantum efficiency plot of one of the small cells. The quantum efficiency of a Wacker-Silso polycrystalline cell processed in an identical way is plotted on the same figure. The response of our cells is lower in the long wavelength range due to a smaller substrate minority carrier (electrons) diffusion length. Although the diffusion length in a polycrystalline material varies from grain to grain, we estimated an effective diffusion length L_{eff} by fitting the experimental data (600nm to 1050nm range) to an analytical

CH2019-8/84/0000-1395 $1.00 © 1984 IEEE

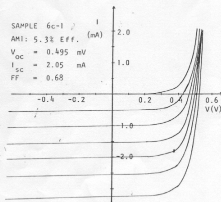

Figure 1: IxV characteristics with different light intensities of a small area cell.

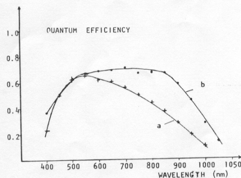

Figure 2: Quantum efficiency x wavelength for a) metallurgical up-graded silicon cell and b) Wacker-Silso polycrystalline cell.

expression for the quantum efficiency(1,2).

We obtained L_{eff}'s in the range 15 to 20μm in the up-graded metallurgical material, as compared to L_{eff} ~ 70μm in the Wacker-Silso cell.

EBIC and laser scanning short-circuit current profiles were measured for the small cells. Good cells have flat profiles, with current leaks in the grain boudaries. In lower performance cells (figure 3) dark areas of low EBIC response are seen not only in the grain boundaries but also in whole grains. From EBIC profiles along grain boundaries we estimated the intra-grain diffusion length to be in the range 15 to 25μm (3).

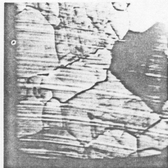

Figure 3: EBIC micrograph (x27) for a metallurgical up-graded silicon cell. The horizontal stripes are due to sawing surface damage.

Preliminary hydrogen passivation experiments were performed. The cells were annealed for an hour on a grounded heater at 300°C in a hydrogen RF plasma (0.2Torr). We observed (figure 4) an improvement in V_{oc}, J_{sc} and cell efficiency after annealing. More systematic studies on the influence of hydrogen passivation are under way.

CONCLUSIONS

Polycrystalline solar cells with AM1 efficiencies higher than 5% (without AR coating) were obtained in selected areas (0.1 to 0.2 cm^2) of silicon wafers obtained from unidirectional solidification of up-graded metallurgical silicon. Material inhomogeneities and localized defects degrade the efficiency of large area cells. Modifications in the leaching and solidification processes will improve the material quality. These preliminary results show the potential of this material for low cost photovoltaic applications.

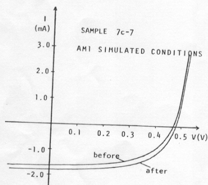

Figure 4: IxV characteristics before and after hydrogen passivation.

ACKNOWLEDGEMENTS

We thank A.C. Ramos, R. Assumpção (UNICAMP) and I. Pereyra (EPUSP) for the EBIC and laser scanning measurements. We also acknowledge the finantial support from FINEP, Brazil.

REFERENCES

1. O. Bell, G.M. Freedman, Proc. 13th IEEE Phot. Spec. Conf., IEEE Press, (1978), 89.

2. H. J. Hovel, "Solar Cells" in R. K. Willardson and A.C. Beer, "Semiconductor and Semimetals", vol. 11, Academic Press, New York, 1975.

3. J. Marek, Proc. IEEE Phot. Spec. Conf. IEEE Press (1982), 627.

TABLE I

Impurity concentration in Si material obtained from emission spectroscopy (ppma).

IMPURITY		B	P	Fe	Mg	Mn	Ni	Al	Ti	Ca	Cu
SOURCE		16	100	1420	68	214	36	583	93	573	43
LEACHED		16	61	188	<17	35	<4.5	68	13	35	7
INGOT	TOP	13	100	< 36	< 13	<4.5	<4.5	<29	<19	< 9	<5.5
	CENTER	8.8	38	< 36	< 13	<4.5	<4.5	<29	<19	< 9	<5.5
	BOTTON	8.3	< 36	< 45	< 13	<4.5	<4.5	<29	<19	< 9	<5.5