SOLAR CELLS FROM UNIDIRECTIONAL SOLIDIFIED METALLURGICAL SILICON.

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ABSTRACT

Polycrystalline silicon was grown from Metallurgical Grade source material using the unidirectional solidification method. In this method the material is initially purified by chemical leaching and melted in a graphite crucible. Solar cells were fabricated onto n and p-type wafers selected from the obtained ingot. Three structures were fabricated: n^+-n; SnO_2-Si(n) and n^+-p. Efficiency between 2 and 4% was obtained in large area solar cells.

1. INTRODUCTION

Solar cells are so far fabricated from silicon single crystals grown by the Czochralski method with the use of high purity silicon. Even the polycrystalline solar cells use silicon of high purity produced from 98 - 99% pure metallurgical grade silicon (MG-Si) through complicated and expensive processes. The impurity content in the base material used to fabricate solar cells may be higher than in the material used for microelectronics. The silicon solar cell efficiency does not greatly depend, within a limited impurity range, on such concentrations.[1] The unidirectional solidification is a simple and inexpensive method to produce a suficiently pure polycrystalline silicon to be used in solar cells fabrication. In this work we report on the photovoltaic performance of different solar cell structures manufactured with solar grade polycrystalline silicon (SG-Si) produced by the unidirectional solidification method.

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2. EXPERIMENTAL PROCEDURES AND RESULTS

a) The solar grade silicon:

In order to improve the purity of the MG-Si the following steps were accomplished[2]:

1. The MG-Si was crushed until a particle size in the order of tenths of a millimeter was obtained.
2. The powder resulting from process 1 was leached with acid solutions (HCℓ, H_2SO_4, HNO_3 and HF). In this process metallic impurities are dissolved. The remaining silicon is extracted by filtration[3]. The relevant parameter are: the temperature, the time spent by the chemical reaction and the concentration of the different reagents.
3. The leached silicon powder was them induction melted into graphite crucibles, in an argon atmosphere. By slowly removing the crucible from the heating zone a unidirectional solidification process is established. A purifying effect occur due to solute segregation from the bottom to the top of the ingot and as a result of the slowness of the solidifying process (typically 1.5 cm/hour).

From the standpoint of photovoltaics the resulting cylindrical polycrystalline ingot (5 cm diameter and ~7 cm lenght) reveals two desirable crystallographic aspects: a large mean grain size and an almost fully longitudinal disposition of the crystalline grain boundary.

The botton region of the ingot is p-type while the central and top regions are n-type. Table 1 shows the results of an emission spectroscopy analysis of MG-Si and SG-Si. We can observe that the final ingot has a lesser impurities concentration.

TABLE 1: Impurity concentration (in ppma) in MG-Si and SG-Si obtained by emission spectroscopy.

	Aℓ	Fe	Cn	Mn	Ni	B	P	Ti	Mg	Ag
MG-Si	>500	>1000	>250	>250	250	40	180	380	100	8
SG-Si	500	150	>250	9	<9	9	100	9	<25	-4,5

b) Solar cells:

We selected n and p-type wafers from the ingot and fabricated three different structures: n^+-n, n^+-p and SnO_2-Si(n). The surface damage of the wafers was removed with an acid etchant. n^+-n and n^+-p cells were made as follows. The wafers were phosphorus diffused from a liquid source at 900°C to obtain a n^+ layer, having sheet resistance of nearly 50 $\Omega_\square$. The diffused layer of the back side was eliminated with acid etchant. Metallic contacts were made as follows. At the back side aluminum was deposited and annealed. Front grid and back contacts were made by Ti-Pd-Ag metallization. A SnO_2 antireflective coating was deposited by chemical spray. The SnO_2/Si(n) structure was fabricated onto n-type SG-Si wafers. A n^+ layer was grown

at the back side to provide an ohmic contact. At the top of the wafer a ~750 Å SnO_2 layer was deposited in order to have a SnO_2/Si(n) heterojunction. Front grid and back contacts were made in the some way as in the other cells.

All cells were measured at dark and under AM1 conditions (100 mW/cm^2). Current vs. voltage plots were obtained and the photovoltaic parameters were determined (Fig. 1). This figure shows the open circuit voltage; short circuit current, fill factor, efficiency, area and a schematic diagram of the fabricated structures. Efficiency of 4.0%, 2.0% and 3,7% were obtained with the n^+-n, n^+-p and SnO_2/Si(n) structures respectively.

3. CONCLUSIONS

Polycrystalline solar grade silicon was grown by the unidirectional solidification method. Brazilian (98% pure) Metalurgical Grade Silicon was used as a source material. The resulting ingot presents a large mean grain size and a columnar structure. The botton of the ingot is p-type while the middle and the top are n-type. n^+-n and SnO_2/Si(n) solar cells were fabricated onto n-type material and n^+-p structure was made onto p-type wafers. Efficiency between 2 - 4% was obtained in large area cells (0.9-6,7 cm^2). More work is under way in order to improve material quality and solar cell manufacturing processes.

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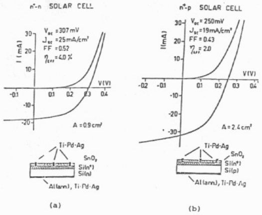

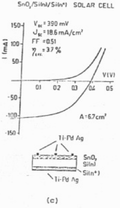

FIG. 1

n^+-n (a), n^+-p (b) and SnO_2/Si(n) (c) dark and illuminated current vs. voltage characteristics.

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