

## Solar Energy

The Solar Energy Group (GES) performs research and development activities related with photovoltaic solar energy conversion. Main tasks are design, simulation, elaboration and characterization of crystalline silicon devices (solar cells and modules) for space and terrestrial applications. During 1997, solar cells based on monocrystalline Czochralski silicon and with 17% conversion efficiency were obtained.

The development of solar devices for space applications begun by the end of 1995, within the frame of a cooperation agreement between this National Atomic Energy Commission (CNEA) and the National Commission of Space Activities (CONAE). Activities in this field include: test of solar devices in argentine satellites, radiation damage experiments in Earth and development of characterization techniques. The main goal in the mean-range is to set up fabrication techniques for space solar modules, in order to supply in the future the power requirements (totally or partially) of missions programmed in the National Space Plan.

On December 14<sup>th</sup> 1998, the Endeavour space shuttle launched the argentine satellite SAC-A at 410 km height. This satellite performed the first experiment of argentine silicon solar cells in space including: (i) 2 panels with 7 solar cells each, to analyze the cells performance in the space environment; (ii) 4 single cells plus 1 cell in each panel, for the determination of the angular position of the satellite, being a fundamental part of the orientation subsystem of SAC-A. Telemetry showed the correct performance of all these cells during the whole mission. In parallel, several theoretical and experimental studies of radiation damage produced by 10 MeV protons were performed in Earth. Moreover, appropriate electrical and electronic characterization techniques and equipment have been developed.

For terrestrial applications, the GES promotes and participates in the establishment of national standards for solar energy systems in the frame of the Argentine Institute for Standards (IRAM). Between 1997 and 1999, 11 standards for photovoltaic modules were established.

The GES begun the development of low cost solar radiation sensors (pyranometers) based on photovoltaic cells. During 1999 two prototypes were tested and calibrated by the National Meteorological Service.

Research activities related with the deposition and characterization of thin films (InP, CdTe, YBaCuO) for solar cells, gas sensors and superconductors, are also performed in collaboration with other institutions. In particular, the GES has participated in the installation in Argentina of a Laser ablation system for thin film growing.

Since 1998, the GES participates in the development of SnO<sub>2</sub> thin film micromachined solid state gas sensors in collaboration with LAMEL Institute of the CNR (Italy) and with CITEFA (Argentina). A NO<sub>2</sub> selective gas sensor in the ppm range has been developed and is being tested in an electronic nose in collaboration with INQUIMAE (Facultad de Ciencias Exactas y Naturales-Universidad de Buenos Aires).

### **Elaboration and characterization of crystalline silicon solar cells and panels for testing in the argentine satellite SAC-A**

*C.G. Bolzi, L.M. Merino, M.J.L. Tamasi, J.C. Plá, J.C. Durán, C.J. Bruno, E.M. Godfrin, A. Lamagna, M.P. Barrera<sup>a</sup> and L.B. Quintero<sup>a</sup>*

A set of photovoltaic cells and panels has been elaborated and integrated into the argentine satellite SAC-A. Elaboration processes include fabrication of the cells, interconnection and integration of the panels. The solar cells have been electrically characterized before and after the integration of the panels. This is the first time that solar devices fabricated in Argentina are tested in space. Six cells are used as solar sensors for the determination of

the angular position of the satellite, while two panels (seven cells each) are applied for the analysis of the electrical performance of the cells during the mission. Experiments of radiation damage produced by protons and neutrons in laboratory facilities have also been performed.

*\* Avances en Energías Renovables y Medio Ambiente 1 (2), 1 (1997).*

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### **Design, elaboration and characterization of crystalline silicon solar cells with textured surface**

*J.C. Plá, E.M. Godfrin and J.C. Durán*

The development of crystalline silicon solar cells with random texture plus a SiO<sub>2</sub> layer as

antireflecting technique is presented. The antireflecting performance of the surface is analyzed in detail; the oxide thickness is optimized in order to maximize the electric response of the cell. Moreover, the appropriate parameters for growing the  $SiO_2$  are determined. A brief description of the whole process is also included:  $SiO_2$  growing, used as a mask for the definition of the active area of the device;  $n^+p$  and  $pp^+$  junctions generation with simultaneous growing of a  $SiO_2$  layer, which passivates the surface and contributes to the antireflecting characteristic; deposition of the front contact grid by means of a photolithographic technique. The current-voltage curve of the best device obtained, which has an efficiency larger than 17%, is shown.

\* *Energías Renovables y Medio Ambiente* 4, 1 (1998).

### Comparison of different simple fabrication processes for high efficiency silicon solar cells

*M.J.L. Tamasi, J.C. Plá, C.G. Bolzi, M.G. Martínez Bogado, G.L. Venier and J.C. Durán*

Two simple fabrication processes for high efficiency crystalline silicon solar cells, proposed in the literature during the last years, are analyzed and compared, essentially in what concerns to the diffusion and drive-in steps. Both use  $POCl_3$  liquid source for  $n^+$  doping. Alternative processes are also proposed. The influence of the concentration of  $POCl_3$  during the predeposition step on the repeatability of the wafers sheet resistance is evaluated. The thickness of the passivating  $SiO_2$  layers grown during the diffusion process for different techniques are also presented. Techniques to produce devices with a thin  $SiO_2$  film, appropriate as a passivation interface but not interfering with a more sophisticated antireflecting coating, are proposed and analyzed. Several  $n^+pp^+$  silicon solar cells were fabricated on Czochralski  $p$ -type wafers using the processes previously analyzed. Characterisation of the final devices is given.

\* *Proc. Second World Conference on Photovoltaic Energy Conversion, Vienna, Austria, p. 1874 (1998).*

### Ray tracing vs. electromagnetic methods in the analysis of antireflective textured surfaces: a first approach

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We investigate the validity of the ray optics approach for the analysis of antireflecting structures used in photovoltaic solar cells. The antireflecting

structure is simulated by a periodic grating with triangular profile and the reflected fields are calculated using two methods: one based on the ray optics approach and the other based on rigorous electromagnetic theory. As a first approach to the real problem, we consider a perfect conductive media. The parameter used for the characterisation of the problem is the wavelength to period ratio  $\lambda/d$ . The theoretical analysis presented here shows important discrepancies between the results obtained using the ray tracing approximation and those obtained using a rigorous electromagnetic method, even for small values of  $\lambda/d$  (of the order of 0.1) for which the geometrical optics approach is usually expected to hold.

\* *Optik* 107, 141 (1998).

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### Determination of minority carrier lifetime in solar cells: a novel biased OCVD technique

*C.J. Bruno, M.G. Martínez Bogado, J.C. Plá and J.C. Durán*

A new simple method for the determination of the minority carrier lifetime ( $\tau$ ), based on a biased open circuit voltage decay (OCVD) technique, is analyzed. In this case the excitation is given by a pulsed light source (time dependent contribution) added to a continuous background illumination (continuous forward bias). Under appropriate conditions this configuration produces an exponential voltage decay with a time constant which depends on the bias. This constant tends to an effective lifetime for the base region for large values of the bias voltage (typically, 400-500 mV).

An inexpensive equipment has been developed. Measurements have been made on several crystalline silicon solar cells and on one high efficiency float zone silicon solar cell. Experimental results show good agreement with the theoretical model presented and with numerical PC-1D simulations.

\* *Physica Status Solidi (a)* 174, 231 (1999).

### Short circuit current vs. cell thickness in solar cells under rear illumination: a direct evaluation of diffusion length

*J.C.Plá, M.J.L. Tamasi, C.G.Bolzi, G.L.Venier and J.C.Durán*

The dependence of the short circuit current of a solar cell with its thickness is analysed for rear illumination. Under certain conditions, a simple

linear regression in a semilogarithm scale is found. Using these results, an almost direct evaluation of the minority carrier diffusion length in the base region of crystalline silicon solar cells is achieved. For the other hand, from the experimental point of view, monochromatic light is not required and the equipment requirements are minimised. The model presented in this paper is theoretically evaluated using a 1-dimensional simulation code. Some preliminary experimental results are also shown.

\* *Solid State Electronics*, in press (1999).

### **Construction and testing of low cost photovoltaic pyranometers developed in the Argentine National Atomic Energy Commission (CNEA)**

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Pyranometers based on crystalline silicon photovoltaic cells were constructed using two kinds of cover-glasses (transparent and burnished glass). The angular response, from normal incidence till 90° incidence angle, was measured and compared to the cosine law. The performance of the pyranometers have been studied under actual operating conditions in the open air. They were calibrated towards a precision thermoelectric pyranometer. Both daily and hourly integrals were analyzed. The linear regression used for the determination of the daily mean calibration constant gave rise to a determination coefficient of 0.99, similar to values obtained for commercial photovoltaic pyranometers.

\* *Avances en Energías Renovables y Medio Ambiente 3 (1)*, 04.29 (1999).

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### **First experiment of argentine solar cells in space: preliminary analysis of the performance**

*E.M. Godfrin, M.G. Martínez Bogado<sup>a</sup>, M.J.L. Tamasi and J.C. Durán*

A preliminary evaluation of the electrical performance of the argentine solar devices mounted on the scientific applications satellite SAC-A has been accomplished. SAC-A was launched on December 1998 and has been in orbit till October 1999. Telemetry data include electrical measurements (e.g., open circuit voltage and short circuit current) and operation temperature of solar devices. Electrical characteristics of solar cells as a function of time for few orbits are presented and its dependence on the operation temperature is

analyzed. Open circuit voltage data show good linear correlation with temperature, in good agreement with theoretical simulations. On the other hand, the short circuit current has a more complicated characteristic as a function of temperature, due to the influence of the solar radiation reflected on the Earth. The evolution of the electrical performance of the cells during the mission is evaluated in order to estimate degradation associated with radiation damage.

\* *Avances en Energías Renovables y Medio Ambiente 3 (1)*, 04.25 (1999).

<sup>a</sup> Fellowship of the Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT).

### **Pulsed laser deposition of Al<sub>2</sub>O<sub>3</sub> thin film on Si**

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Al<sub>2</sub>O<sub>3</sub> thin films were fabricated by pulsed laser deposition (PLD) on Si<sub>3</sub>N<sub>4</sub>/Si, to improve the thermal and electrical isolation of gas sensing devices. The microstructure of the films is analyzed as a function of the deposition conditions (laser fluence, oxygen pressure, target-substrate distance and substrate temperature). X-ray analysis shows that only a sharp peak that coincides with the corundum (116) reflection can be observed in all the films. But, when they are annealed at temperatures above 1200°C, a change in the crystalline structure of some films occurs. The stoichiometry and morphology of the films with and without thermal treatment are compared using environmental scanning electron microscopy (ESEM) and EDAX analysis.

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### **Identification of pollutant gases with a multisensorial arrange**

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The measurement of low concentrations of NO<sub>2</sub> and CO in air atmosphere with solid state gas sensors cannot be carried out with a unique sensor, due to the concurrent reactions of the oxidizing NO<sub>2</sub> and the reducing CO, resulting in a near zero output signal. It is well known that the semiconductor metal oxide films as SnO<sub>2</sub> are basically used for the detection of reducing gases, otherwise the phthalocyanines are organic semiconductors with high thermal and chemical stability that have been used as active element for the detection of oxidizing gases.

In this work we show preliminary results of the variation in the performance of 100 nm thick SnO<sub>2</sub> sensors doped with 30 nm of tetra t-Butyl Zinc Phthalocyanine (t-Bu-ZnPc), in order to enhance or at least change the selectivity to NO<sub>2</sub>.

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### **Thin film CdS/CdTe solar cells prepared by electrodeposition using low cost materials**

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This article describes the elaboration process of thin films for CdS/CdTe solar cells using low cost materials and a very simple process. The device

structure (SnO<sub>2</sub>:F/ /CdS/CdTe/Cu/Au) is deposited on coverglass substrates.

The crystal structure of the films were determined by X-ray diffraction analysis. The surface morphology and microstructure of both films were subsequently characterized using a conventional scanning electron microscopy (SEM) and an atomic force microscopy (AFM). An enlargement of the grain size structure is observed after the thermal annealing.

Finally, the solar cells prepared using this process exhibited a short circuit current density of  $J_{sc} = 18 \text{ mA/cm}^2$ , open circuit voltage of  $V_{oc} = 600 \text{ mV}$  and efficiencies above 5% under AM 1 simulated solar illumination.