Solar Energy

The Solar Energy Group (GES) performs research and development activities related with photovoltaic solar energy conversion. Main tasks are design, simulation, fabrication and characterization of crystalline silicon devices (solar cells and modules) for space and terrestrial applications. During 1997, solar cells based on monocrystalline Czochralski silicon 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 14th 1998, the Endeavour space shuttle launched the argentine satellite SAC-A at 410 km height. This satellite included the first experiment of Argentine silicon solar cells in space.

Several theoretical and experimental studies of radiation damage produced by 10 MeV protons are also being performed by means of a linear tandem accelerator and a cyclotron. Moreover, appropriate electrical and electronic characterization techniques and equipment have been developed.

In collaboration with the LAMEL Institute of the CNR (Italy), research activities related with simulation, elaboration and characterization of a-Si/c-Si and µc-Si/c-Si heterojunction (HJ) solar cells as well as homojunction c-Si devices were performed. Thin film deposition techniques have been used. The test of these devices by means of radiation damage experiments will be performed in a near future in order to evaluate its behavior in space environment.

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 2000, 13 standards for photovoltaic modules were established.

The GES begun the development of low cost solar radiation sensors (pyranometers) based on photovoltaic cells. Some prototypes were tested and calibrated by the National Meteorological Service and two of them are being used in meteorological stations in the provinces of Chaco and Corrientes.

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 LAMEL Institute. In particular, the GES has participated in the installation in Argentina of a Laser Ablation Deposition (PLD) system for thin film growing in collaboration with the Physics Department-Facultad de Ingeniería, Universidad de Buenos Aires.

Since 1998, the GES participates in the development of SnO_2 thin film micromachinated solid state gas sensors in collaboration with LAMEL Institute of the CNR (Italy) and with CITEFA (Argentina). A NO_2 selective gas sensor in the ppm range has been developed and is being tested in an electronic nose developed by the group in collaboration with INQUIMAE (Facultad de Ciencias Exactas y Naturales-Universidad de Buenos Aires) and with the School of Science and Technology (Universidad Nacional de General San Martin). Since 2000, a strategic agreement was signed with an Italian e-nose producer, Technobiochip S.R.L., for developing specific algorithms using its commercial apparatus (LibraNose) for local industry applications.

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

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

*Solid State Electronics **44/4** (2000) 719*

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.

"Determinación de parámetros característicos de celdas solares en el espacio a partir de mediciones recibidas por telemetría"

E.M.Godfrin, M.G. Martínez Bogado, M.J.L. Tamasi and J.C. Durán

*Avances en Energías Renovables y Medio Ambiente **4 (1)** (2000) 04-23*

El satélite argentino SAC-A fue puesto en órbita en diciembre de 1998 y su misión se extendió durante aproximadamente 10 meses. Este satélite llevó al espacio un conjunto de 18 celdas solares de silicio fabricadas en la CNEA. Se analizó el funcionamiento de dichas celdas mediante las mediciones eléctricas recibidas por telemetría entre enero y julio de 1999. Se estudió la variación de la tensión de circuito abierto (V_{ca}) con la temperatura (0-70ºC) y con la intensidad de la radiación solar incidente. Esta última varía debido a la presencia del albedo. Se calculó el coeficiente de temperatura para Vca. A partir de la variación de Vca con la intensidad, se realizaron estimaciones de parámetros del circuito equivalente de las celdas. La evolución temporal de los parámetros medidos no permite detectar degradación durante la misión. Los resultados obtenidos se comparan con mediciones en Tierra y con simulaciones teóricas.

"Influencia de la difusión de aluminio y fósforo sobre la vida media de portadores minoritarios en obleas de silicio cristalino"

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

*Avances en Energías Renovables y Medio Ambiente **4 (1)** (2000) 04-17*

Los procesos de difusión de dopantes utilizados en la elaboración de dispositivos fotovoltaicos de Si cristalino pueden promover mecanismos de atrapamiento de impurezas. Entre las técnicas habituales se destacan la difusión de P, como dopante tipo n, a partir de fuente líquida de $POCl_3$, y de Al como dopante tipo p. A fin de estudiar la captura de impurezas asociada a estas técnicas, se realizaron difusiones simultáneas de P y Al, y de P solamente, para obtener estructuras n^+pp^+ y n^+p, respectivamente. Empleando una variante del método de decaimiento de la tensión a circuito abierto (OCVD), se midió la vida media efectiva de los portadores minoritarios en diferentes etapas del proceso para evaluar el mecanismo de atrapamiento y sus consecuencias sobre las características eléctricas de las celdas solares. Se presentan asimismo simulaciones teóricas relacionadas con la influencia de la recombinación superficial en la cara posterior sobre la vida media efectiva.

"SAC-A satellite: first experiment of Argentine solar cells in space"

C.G. Bolzi, C.J. Bruno, J.C. Durán, E.M. Godfrin, M.G. Martínez Bogado, L.M. Merino, J.C. Plá, M.J.L. Tamasi and M. Barrera

Proc. 28th IEEE PVSC, Alaska, USA (2000) 1344

On December 1998, the Endeavour space shuttle launched the Argentine satellite SAC-A. Among several technological experiments, this satellite included a set of crystalline silicon solar cells fabricated in Argentina to test them in the space environment. In this paper, we describe the experiments associated with these solar cells and analyze the corresponding telemetry data received from January to July 1999. Simultaneously, several radiation damage experiments using 10 MeV protons supplied by a cyclotron accelerator were performed. The variation of the electrical characteristics of the irradiated cells are also presented.

"Low Temperature Fabrication Process for µc-Si / c-Si Heterojunction Solar Cells"

J. Plá, E. Centurioni, R. Pinghini, C. Summonte, R. Rizzoli, F. Zignani, A. Desalvo

Proceedings of the 16th European Photovoltaic Solar Energy Conference(Glasgow, Scottland) (2000) 597

The optimisation of the fabrication process of µc-Si/c-Si heterojunction solar cells is discussed, in order to obtain high efficiency / low cost devices. The deposition of the various layers of the device, having p^+-i-n-n^+ structure, is carried out by Plasma Enhanced Chemical Vapour Deposition (PECVD) at Very High Frequency (VHF), with a process temperature as low as 170ºC. An hydrogen plasma treatment is also used as alternative to the intrinsic layer for interface passivation. The front contact is obtained by a transparent conducting Indium Tin Oxide (ITO) layer, deposited by RF sputtering at 250ºC, with an Al grid on top of it. This grid and the Al back contact are thermally evaporated. Particular attention was put in determining and minimising the contribution of each interface to series resistance. As an example, low temperature processing prevents from applying the standard metal alloying procedures used in silicon based microelectronics for contact fabrication. An alternative low temperature process for the rear contact formation is used, which gives a contact resistance lower than 0.03 ohm.cm^2. We studied each single interface, including the junction, by electrical characterisation. In this way, the interfaces affecting the series resistance can be identified and improved, and the technology needed for the production of µc-Si/c-Si heterojunction solar cells can be accurately designed. Details of each process step and results obtained are discussed. An efficiency in excess of 13% was measured on test cells.

"Plasma Deposition of Amorphous Free Microcrystalline Silicon Films Thinner than 20 nm"

R. Rizzoli, C. Summonte, J. Plá, E. Centurioni, R. Pinghini, A. Desalvo and F. Zignani

Proceedings of the 16th European Photovoltaic Solar Energy Conference (Glasgow, Scottland) (2000) 593

Highly crystallised, thin p-type silicon films are deposited by very high frequency plasma-enhanced CVD. Under high H_2 dilution conditions, the effect of chamber contamination is shown to have consequences on the microcrystalline (µc) fraction and electrical characteristics of the deposited films. In view of applications on heterojunction solar cells, p/i double layers a re deposited on silicon and on glass. Optical characterisation shows that the µc fraction is much larger on silicon substrate. A 15 nm amorphous buffer layer deposited on silicon is observed to completely recrystallise upon p-type µc-Si deposition, which is attributed to the effect of undetectable crystalline seeds in the amorphous phase.

"Primera Experiencia de Celdas Solares Argentinas en el Espacio: Elaboración, Caracterización y Análisis de Datos de Telemetría del Satélite SAC-A"

C.G. Bolzi, C.J. Bruno, E.M. Godfrin, M.G.Martínez Bogado, L.M. Merino, J.C. Plá, M.J.L. Tamasi, J.C. Durán

*Energías Renovables y Medio Ambiente **8** (2000) 1*

El 14 de diciembre de 1998 el Transbordador Espacial "Endeavour" puso en órbita el satélite argentino SAC-A desarrollado por la Comisión Nacional de Actividades Espaciales (CONAE). Entre otras experiencias, la carga del SAC-A incluyó un conjunto de celdas solares de silicio monocristalino fabricadas en la CNEA. Este primer experimento de celdas solares argentinas en el espacio se encuadra dentro de un acuerdo de colaboración entre ambas instituciones cuyo objetivo principal es la puesta a punto en el país de la tecnología de fabricación de paneles solares para usos espaciales. Se describen los procesos utilizados en la elaboración de los dispositivos, su caracterización y los ensayos realizados en Tierra. Asimismo, se analiza el funcionamiento de las celdas solares en el ambiente espacial a partir de las mediciones eléctricas recibidas por telemetría entre enero y julio de 1999. Los resultados obtenidos se comparan con mediciones en Tierra.

"Identification of Pollutant Gases and its Concentrations with a Multisensorial Arrangement"

S. Reich, R.M. Negri, A. Lamagna and L. Dori

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Multisensor arrays constituted by non-specific sensors, like in the case of electronic noses, is an appropriated approach to identify the presence of a particular gas in a mixture. While the dependence of the sensors signal output by the concentration of each single gas can be determined through a sensor calibration procedures., it is much more difficult (and of non- practical use in most of the cases) to know the response of the individual sensors when exposed to mixtures containing several components. In a previous work, Bartlett and Gardner have used a phenomenological linear model to simulate the response of semiconductor sensors to such a mixture. The concentration dependence of a sensor signal in a gas mixture of N components of concentrations {C1,...., CN} was calculated as a linear combination of the sensors response to every individual gas in an artificial and well controlled atmosphere.

The aim of this work is to analyze the capability of an electronic nose model to identify gases, mainly CO and NO_2 , normally present in polluted atmospheres. It is relevant also to identify organic reducing gases like isobutane (ISBU) which is emitted in a variety of different industrial processes. To reach the objective it is not a simple task because the output of each individual sensor is non-specific, but conditioned by the presence of the different gases. For example it is well known that tin dioxide (SnO_2) sensors are particularly sensitive to alcohol's, mainly ethanol (EtOH). Other gases, although not pollutants, such as methane (CH_4), are present in the atmosphere and its concentration can drastically increase due to emissions from gas lines or natural fermentation processes.

For these reasons we have implemented a theoretical electronic nose model, composed by a few number of commercial tin dioxide sensors (Taguchi), addressed to identify the presence of CO, ISBU, CH_4 and EtOH and to determine their concentration. In this case the gas concentration ranges between few hundred to thousand parts per millions, which is the characteristic for Taguchi sensors. The concentration dependence of the sensors signal output to the single gas was taken from available Figaros Inc. sensor data sheets. Efforts have been made not only to identify the individual gas in humidified synthetic air, but to obtain the gas concentration of each individual compound, Ci, when the gases are contemporary present in a mixture of a given total analytical concentration. The linear response dependence assumed by Bartett and Gardner was generalized using non-lineal interpolation functions.

In a second part of the work, the electronic nose model was simulated using the experimental output of 100 nm thick SnO_2 sensors deposited upon a substrate heater element realized upon micromachined silicon substrate having 200 nm Si_3N_4 membrane as physical support of the entire sensor stack and developed by the LAMEL Institute, Bologna. The sensitivity towards several reducing and oxidizing gases is in the range of small fraction of ppm. This sensitivity level makes them suitable for environmental monitoring of pollutant gases such as CO, NO_2, benzene, and a mixture of toluene and xylene (TX).