# DEVELOPMENT OF LOW-COST PHOTOVOLTAIC DEVICES ON COMMERCIAL CERAMIC SUBSTRATES

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## ABSTRACT

*The present study addresses the fabrication of photovoltaic materials obtained by means of low cost technologies applied to the production of photovoltaic cells in a pre-industrial process. Specifically, electrodeposition (ED) and plasma enhanced chemical vapour deposition (PECVD) have been used. The objective of the study is to analyse the influence of the characteristics of these materials in the photovoltaic conversion of the corresponding device, and to compare those results with those obtained in commercial wafers diffused in diffusion furnaces. The ultimate objective is to propose new and cheaper processes for the processing and deposition of photovoltaic materials, which allow commercial ceramic substrates to be used.*

*The optimum materials chosen for the proposed objective meet the condition of behaving like a thin sheet photovoltaic device. That is, a thickness of less than 2 microns is required in the entire assembly for the required electric conversion. The base materials used have been mesoporous nanocrystalline semiconductors (ZnO and* $TiO_2$*) for the processing of hybrid photovoltaic cells and semiconducting amorphous silicon layers with different types of dopants, which make up the different layers of the PIN diode-type standard cell. These different materials have been characterised using various techniques to quantify the photovoltaic aptitude of the material and, at the same time, to establish a correlation between its morphology and optoelectronic properties. In particular, the optical, electrical, and structural properties have been analysed of the most suitable materials for the proposed application .*

*The developed substrate is based on commercial ceramic formulations for exterior tiling adapted to the surface requirements of fullness and absence of pollutants. It was considered important to use high-quality raw materials like clays and feldspars, and glassy surface cements, which were eco-compatible and recyclable. Specifically designed glaze layers were used in order to fit them to the photovoltaic material within the ceramic cycles, which thus go beyond the classical dimension, while at the same time assuring the various process stages through a series of strict controls*

## 1. INTRODUCTION

The integration of ceramics and the solar capture function are an important challenge facing the current ceramic industry. In effect, the development of ceramic panels for façade and roofing tiles with the capacity to generate electric energy by means of photovoltaic materials contributes an intrinsic added value to ceramics with a potential very high return on investment, taking into account the evolution of the energy sector and the low foreseeable maintenance costs. The premises of these products require a flexible and parametrisable construction, which enables the variables for the use of solar energy to be optimised, as well as their integration into façades and roofs, perfectly fitted by the installers. In the second place, though not for that reason of less importance, continuous operation needs to be assured for at least 25 years with a design aimed at the maintainability of the installation.

At the present time, the ceramic market is eagerly seeking to diversify production through the integration of new technological functionalities in order to establish a commercial barrier to products made in Asia. In the measure that a reliable and integrated product is developed, with a low production cost, the industry will be able competitively to supply the promising sustainable energy market.

The photovoltaic cells that are industrially implemented at present are stratified laminar devices, with an external surface up to several $dm^2$, made by means of the successive piling of compact films of different thickness and composition, each of which performs a different, complementary function within the device. The main features to be improved in these cells include their efficiency in regard to energy conversion, manufacturing cost, and functional integration into large surfaces, such as building construction, this being the problem that is addressed in the present paper.

The efficiency of current commercial photovoltaic cells (based on III-V semiconductors, on poly- or single-crystal Si semiconductors, or on chalcogenide semiconductors) is determined by their different manufacturing processes [1,2]. In all of these the formation of various interfaces is a common process and the type of layer growth, the type of boundary between them, the appearance of new chemical species, etc. will condition cell final efficiency and, therefore, end product quality and the degree of competitiveness of the manufacturing company [3,4]. The optimisation of those interfaces represents a challenge for the photovoltaic industry, an optimisation that needs to be based on thorough knowledge of the various joins. In this sense, the first step consists of determining the influence of the different manufacturing processes on cell efficiency.

Furthermore, the successful implementation of photovoltaic energy requires obtaining cheaper and more efficient photovoltaic cells. It is therefore necessary to lower cell costs and production time without decreasing cell efficiency; for this, it is necessary to use more effective and faster production processes. These goals are common to all photovoltaic cell manufacturers, and their attainment means greater competitiveness with all the economic and social consequences involved in achieving enhanced penetration into an emerging and highly competitive market like the solar energy market. Taking into account the foregoing scenario, a study has been undertaken of the two most promising techniques in the photovoltaic sector for making low-cost photovoltaic panels with acceptable efficiency. These basic processes have been developed based on a low-cost ceramic substrate, with promising results. The details of this study are described below.

## 2. EXPERIMENTAL

### 2.1. CERAMIC MATERIAL

A white wall tile body composition supplied by Atomix S.A. (Onda) was used. This was fully characterised. The X-ray diffractogram is shown in Fig. 1 and the analysis results are described below.

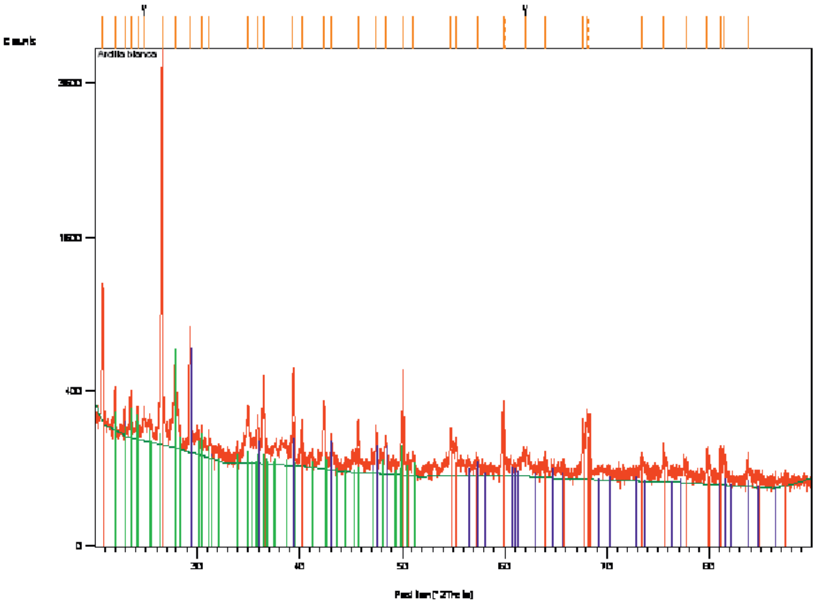

*Figure 1. X-ray diffractogram of the clay.*

Crystalline species (semi-quantitative):

Sepiolite: 3%; Calcite: 5%; Kaolinite: 18%; Quartz: 34%; Potassium feldspar: 6%; Illite (or mica): 30%; Others: 4%;

Physico-chemical processing characteristics:

Carbonates: 12-13%; Pressing moisture content: 5-7%: Fired mechanical strength: > 200 kg/cm$^2$; Firing temperature: 1070-1140 ºC; Linear shrinkage: < 0.5%; Water absorption: 8-10 %; Residue on 63 $\mu$m sieve: 1%

Properties after firing (at 1040°C):

Water absorption: 10-12 %; Breaking strength: 760 N; Bending strength: 14.6 N/mm$^2$

The spray-dried powder was pressed in a double step. The resulting piece was engobed and glazed using a bell, with a glaze matching the dilatometric characteristics of the body. To improve the crystallographic compatibility with the subsequent coating, the ZnO content in the glaze was adjusted to approximately 5%. The percentage in fluxes was conveniently selected so that the material's dilatometric behaviour in the process temperature range and service would be appropriate.

## 2.2. COATING BY ELECTRODEPOSITION

A ITO conductive layer (resistivity at ambient temperature of 10 $\Omega/cm^2$) was used on the sample. The samples with the conductive layer were cleaned by ultrasonic agitation a mixture of acetone and ethanol for 5 minutes and then rinsed in distilled water just before coating.

The samples were then electrolytically coated by the galvanostatic method, optimising the deposition conditions at 1 $mA/cm^2$ for 10 minutes, using an electrolyte with a composition 0.005 M $ZnCl_2$ and 0.1 M KCl. The temperature was fixed at 80°C with a thermostatted bath for the cell. The cell assured the working conditions and bubbling in oxygen for a platinum counter electrode and calomel reference electrode.

Different simultaneous electrolytes, $InCl_2$ and $Al_2Cl_3$, were sequentially tested in order to try to dope the ZnO structures. The samples were also subjected to annealing at 300°C for one hour in normal atmosphere. All these working conditions had been experimented in previous studies [7].

The device was not terminated with the organic layer given the low homogeneity of the deposited layer

## 2.3. COATING BY PECVD

The ceramic samples were metallised with chromium under vacuum with an average thickness of 10 nm. Four amorphous silicon layers were then deposited in successive steps with different dopants in a PECVD (plasma enhanced chemical vapour deposition) reactor at the Polytechnic University of Paris, according to the process described in [8]. The thicknesses of the different layers were adjusted in order to optimise anchoring conditions and photovoltaic efficiency. The sandwich illustrated below was finally developed.

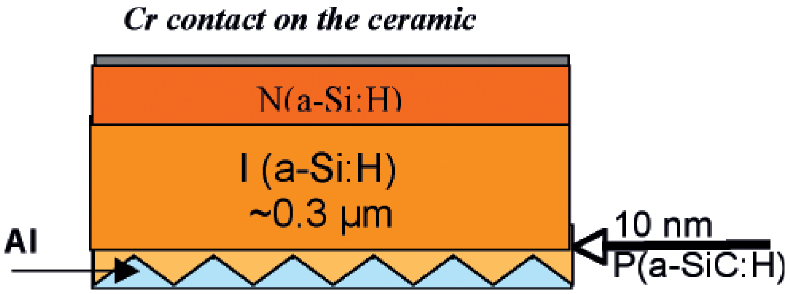

*Figure 2. Structure of the photovoltaic device in amorphous silicon*

## 3. RESULTS

### 3.1. ELECTRODEPOSITION

In the first place the presence of indium and aluminium was analysed as interstitial dopant in the ZnO crystalline lattice. The existence and evolution of the interstitial concentration of indium and aluminium were verified by X-ray diffraction (Fig. 3).

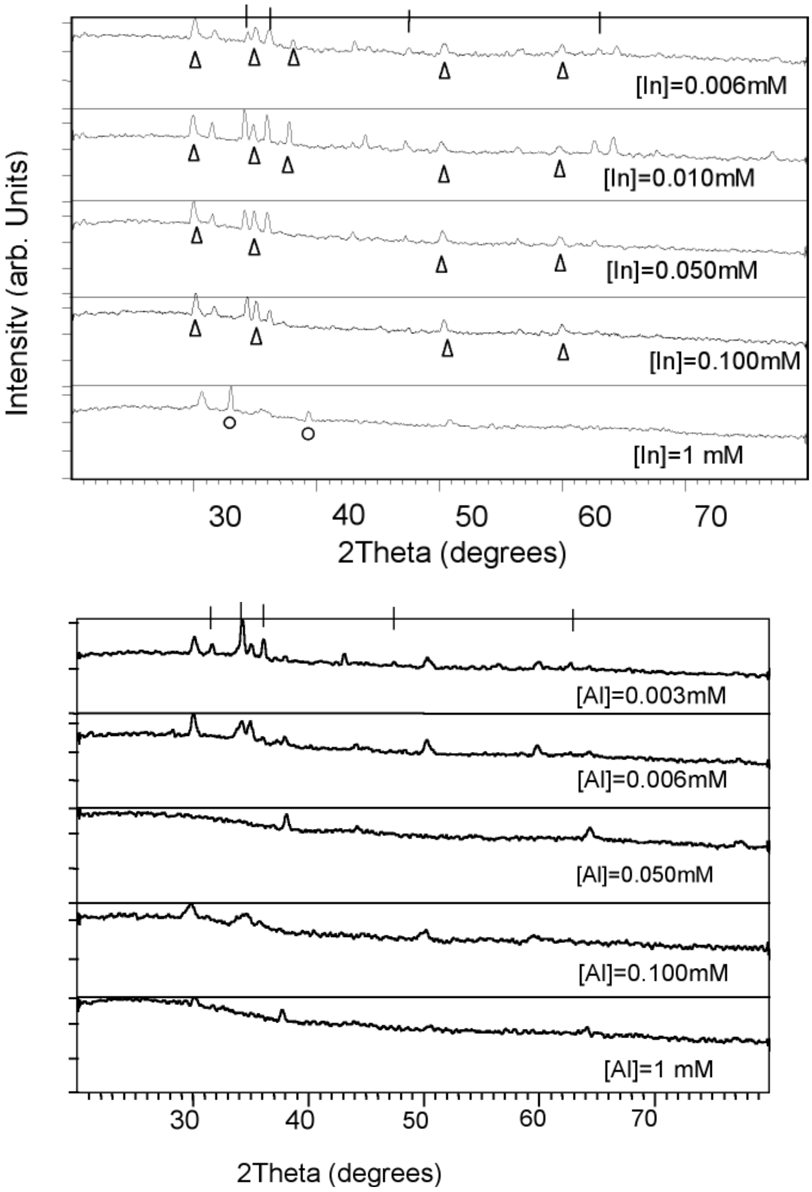

*Figure 3. X-ray diffractogram with the evolution of interstitial In and Al in the ZnO matrix.*

Column morphology was then analysed by scanning electron microscopy and EDX, and the nanocolumnar nature of the ZnO crystals, their composition, and their potential as photovoltaic device formers were verified. However, this layer was not uniform or homogeneous, so that the morphologies varied significantly (Figure 4). The crystalline nature of the nanocolumns was verified by EBSD (electron backscattered diffraction), this being defined in Wurtzite.

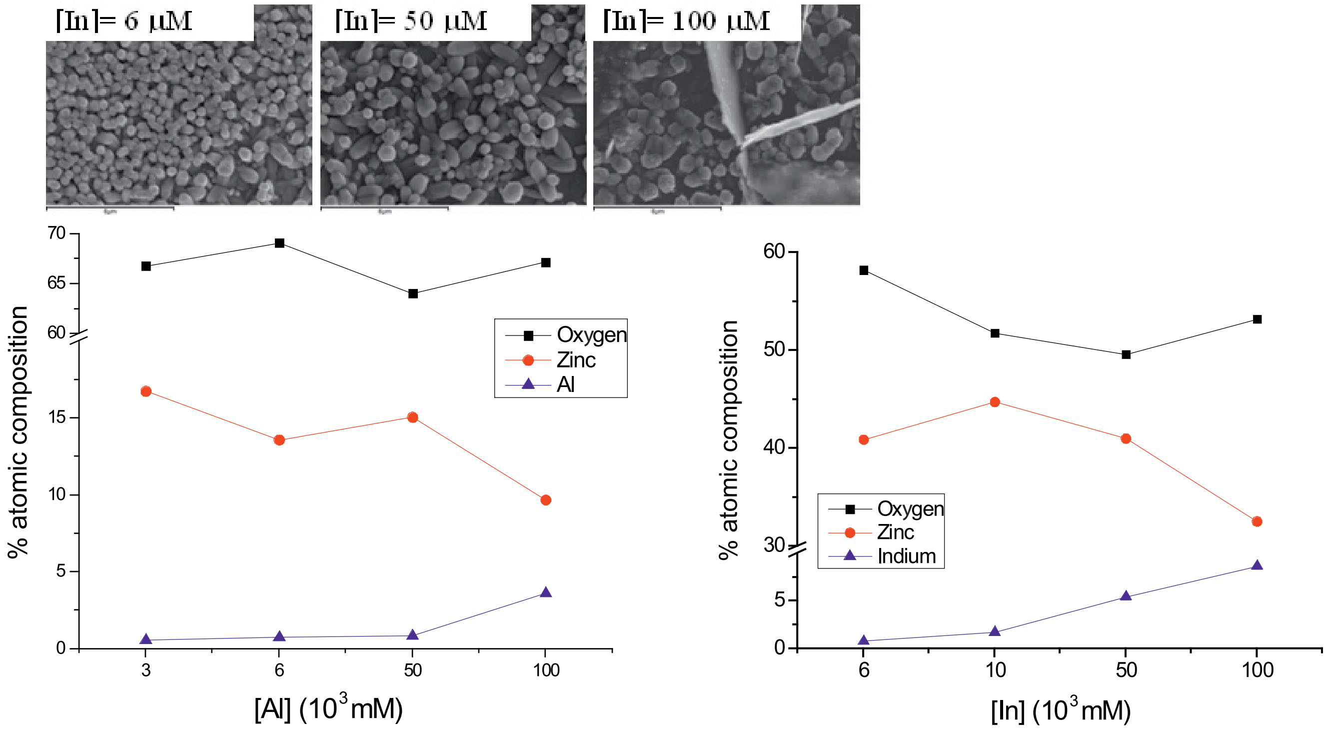

*Figure 4. SEM and composition of nanocolumns of ZnO.*

Finally, the mobility of the major carriers was determined by the Hall effect measurement system. The results obtained are presented in Figure 5, and show a carrier mobility, in the case of the Indium doping, of 21 cm²/Vs, which was appropriate for the development of these devices..

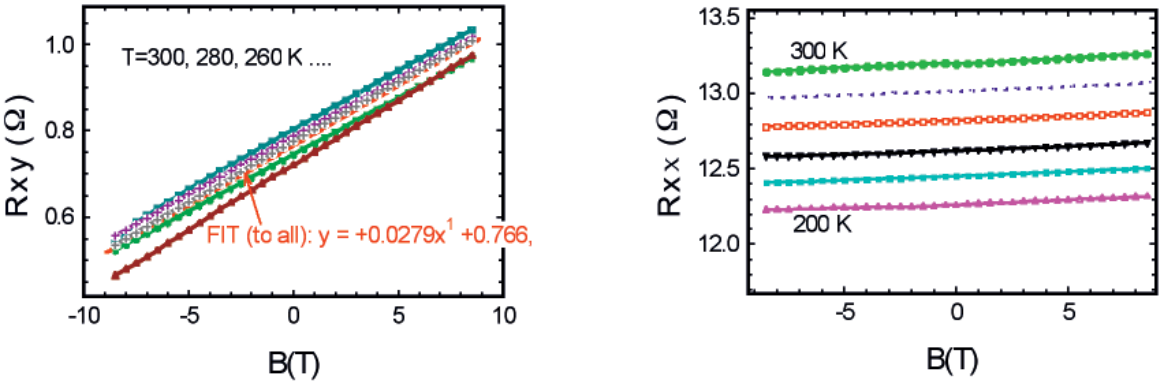

*Figure 5. Carrier concentrations*

## 3.2. PECVD

A SEM morphological analysis of the photovoltaic device made was performed first. The amorphous nature of the silicon layer can be observed in Figure 6. Since the metallised chromium replicates in a few nanometres the underlying topography, the presence of surface irregularities is due to the glaze layer on the ceramic substrate. In addition, small black dots were observed on the surface, which, after detailed study, were found to correspond to short circuits that harmed the integrity of the photovoltaic device.

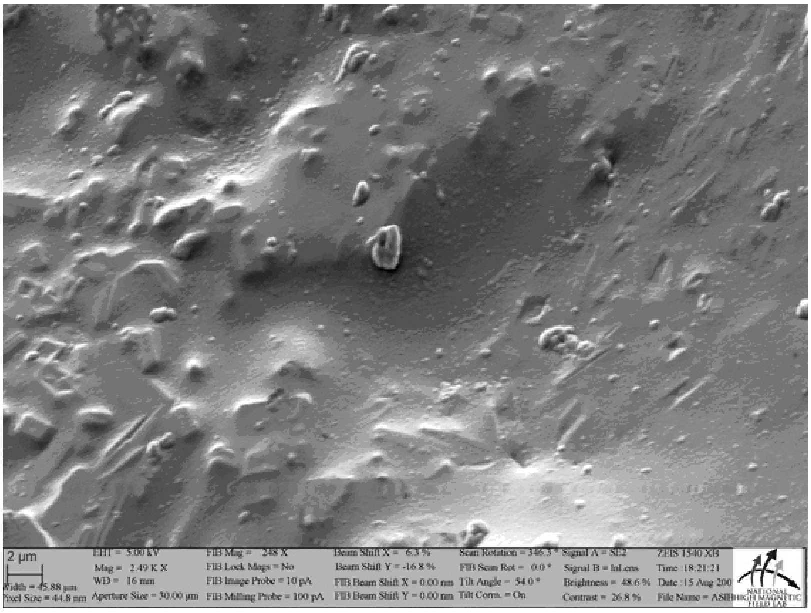

*Figure 6. SEM of the amorphous silicon sample*

The I-V curve of the entire device was then obtained in order to verify the actual photovoltaic nature, as shown in Figure 7. This curve had to be made in point form because the existence of short circuits in certain areas prevented analysis of the surface as a whole.

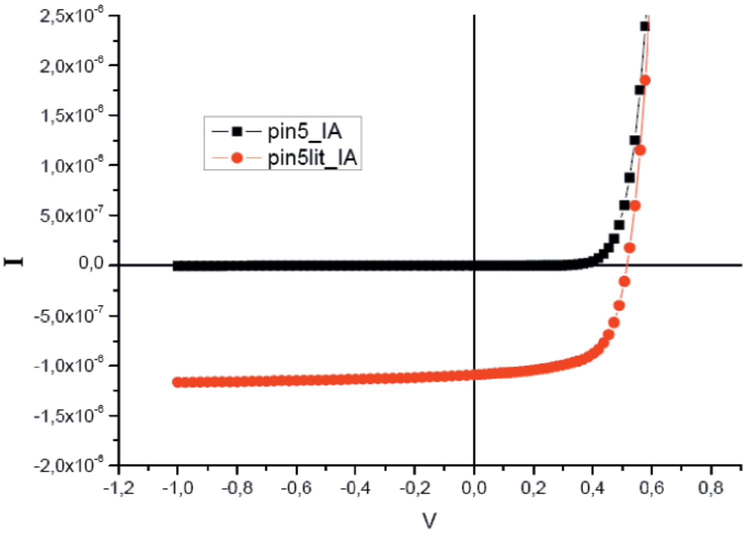

*Figure 7. I-V curve of the device made with amorphous silicon*

## 4. CONCLUSIONS

The results obtained in the study demonstrate the real possibility of directly obtaining industrial photovoltaic devices on ceramic substrates. The techniques used have the potential to provide a reasonable cost for industrial production on ceramic substrates, with direct integration into the construction, thus reducing the operating costs involved in solar use in buildings.

## 5. ACKNOWLEDGEMENTS

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