TRANSPARENT SOLAR CELLS APPLIED ON CERAMIC SUBSTRATES

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ABSTRACT

This paper describes the application of a transparent photovoltaic system on glass and ceramic substrates. The system is based on bonding two n-ZnO/p-NiO broadband semi-conductors, transparent in the visible spectrum, which absorb light within the UV range. To do so, easily scalable, low-cost chemical routes, such as spray pyrolysis or chemical plating, were used in an attempt to keep the costs of the device as low as possible. X-ray diffraction revealed the crystal structure of the FTO, ZnO and NiO layers. The devices were characterised morphologically and their microstructure was studied using scanning electron microscopy. Finally, they were characterised from the point of view of their optoelectronic performance to determine their Eff., FF., and Voc. parameters.

1. INTRODUCTION

Spain is currently immersed in implementing a whole portfolio of European guidelines and policies that attempt to encourage the use of renewable and efficient energies in urban areas[1]. In this sense, the country must meet the objectives set by the European Commission to ensure that by 2030, 32% of electricity is produced from renewable energies[2]. Therefore, developing photovoltaic technologies that can be easily integrated into buildings and urban applications is going to play a decisive role in coming years. The most important factor to accelerate growth of BIPV ("*building integrated photo-voltaics*") is developing products already available on the market towards truly integrated solutions in edifices, to replace or complement conventional items that already exist in buildings.

Despite the difficulty of the challenge, progress has recently been made in creating photovoltaics transparent or semi-transparent to the visible spectrum with light-selective technologies[3,4]. This enables devices that absorb in the UV or IR range to be developed. Devices that selectively absorb in the IR range usually comprise organic materials that degrade rapidly, despite offering significant energy conversion[5]. Therefore, efforts to design such devices have focused on developing devices comprising inorganic materials that absorb in the UV range. So far, research has been more closely linked to developing photovoltaic windows that attenuate the light coming into a building or change its hue. All such options lead to photo-voltaic devices with a degree of transparency in the visible spectrum of less than 50% and which in many cases are tinted, and that can significantly interfere with the aesthetics of the architectural design[6].

On the other hand, recent research has also looked at integrating photovoltaic devices onto ceramic surfaces and has demonstrated good results in terms of energy efficiency[7,8], but with the main drawback of being opaque and black, thus again altering the aesthetics of the building.

In view of the above, the need arises for work to develop a device that is easy to integrate onto ceramic structures and which has a transparency of over 70% and an absence of colour tinting, so as not to alter the appearance of the material on which it is fitted. To that end, it was decided to study an nZnO/p-NiO system, as these two semi-conductors have a wide band gap that makes them highly transparent in the range of the visible spectrum[9] but allows them to absorb UV radiation close to the visible spectrum, thus enabling the energy from that part of the solar spectrum to be harnessed, while also serving to protect the substrate on which it is deposited from UV radiation.

2. EXPERIMENTAL PART

Layers of aluminium-doped zinc oxide (AZO) ($Zn_{0.97}Al_{0.03}O_1$) and intrinsic zinc oxide (i-ZnO) (ZnO) were synthesised and deposited using spray pyrolysis. The following reagents were used: $ZnO(CH_3COO)_2 \cdot 2H_2O$ (99.5% pure, from PanReac Applichem), $Al(NO_3)_3$ (98% pure, Sigma Aldrich), monoethanolamine (MEA) (99.9% pure, Sigma Aldrich), ethanol (99% pure). The layers of AZO were prepared by dissolving 0.01834 moles of $ZnO(CH_3COO)_2 \cdot 2H_2O$, $5.7 \cdot 10^{-3}$ moles of $Al(NO_3)_3$, and 0.019 moles of MEA in 25ml of ethanol. For its part, the i-ZnO layer was prepared by dissolving 0.019 moles of $ZnO(CH_3COO)_2 \cdot 2H_2O$ and 0.019 moles of MEA in 25ml ethanol.

Subsequently, the NiO layer was applied by chemical plating, for which purpose, $5.47 * 10^{-3}$ moles of $NiSO_4 \cdot 6H_2O$ and $1.3 * 10^{-3}$ moles of K_2SO_4 were dissolved in 15 ml of Milli-Q water.

To complete the photovoltaic devices, the window layer of indium tin oxide (ITO) was sputtered on.

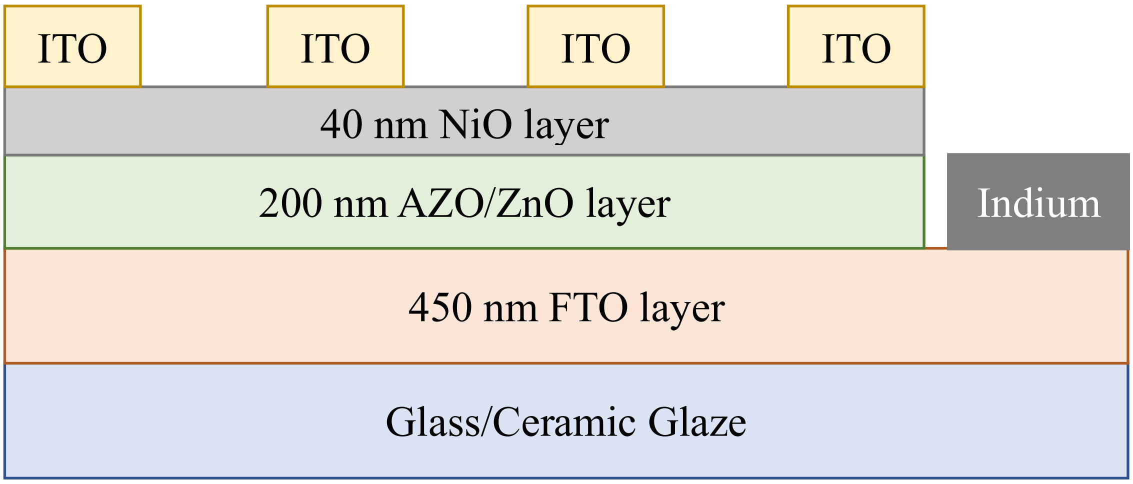

Image 2.1: *Superimposition of the various layers in a transparent solar cell*

Structural characterisation was performed using a Bruker-ASX D4 Endeavor X-ray diffractometer fitted with a copper Kα radiation source. Data was collected by scanning at different stages between 10º and 80º, with intermediate steps of 0.05º 2θ to 3 seconds. Layer morphology and width were studied using a JEOL 7001F scanning electron microscope. Electrical readings were taken by a 4-prong Ossila T2001A3, while optoelectronic parameters were obtained from I-V curves using an AAA Sun 3000 solar simulator manufactured by Abet Technology. Readings were pre-calibrated against a reference silicon cell under an illumination of 1.5 Ama 25ºC. The surface of points studied in each device was 0.07 cm^2.

3. RESULTS AND DISCUSSION

The XRD results for the ZnO layer confirm the presence of wurtzite-like crystals in the layer, oriented in the 002 plane. Diffraction peaks coincide with JCPDS pattern 01-079-225 for positions at 31.8°, 34.5°, 36.2°, 47.6°, 56.6°, 62.9°, 68.0° and 69.1°.

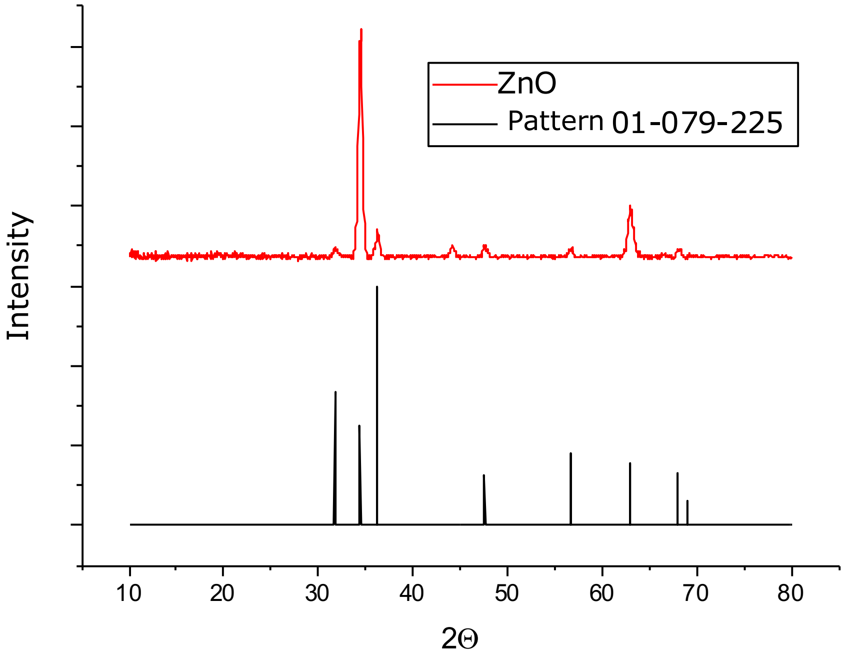

Figure3.1: *Comparison of X-ray diffraction between a ZnO pattern and the sample*

The diffraction graph shown in Figure 3.2 compares the layer obtained from NiO with a pattern of the same compound, and the presence of three main peaks of the compound is confirmed at 37.1º, 43.2º and 62.49º. Less crystallinity is observed than in the previous case and there is no sign of a secondary phase.

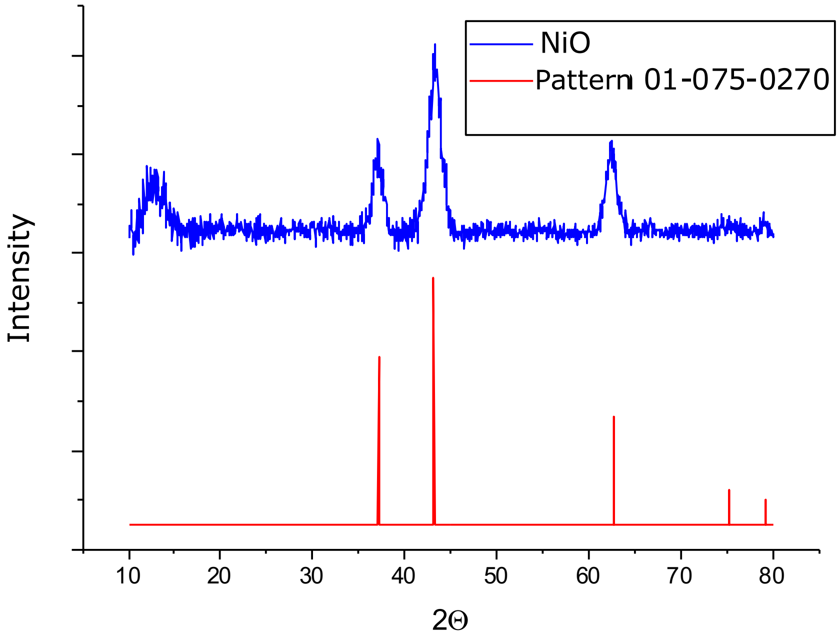

Figure 3.2: *Comparison of X-ray diffraction between a NiO pattern and the sample.*

SEM images of samples prior to the ITO layer show the size and the morphology of each of the layers. The FTO layer reveals a size of around 450nm with a well-sintered layer, where geometric structures are visible that indicate the layer's significant crystallinity. The AZO and ZnO layers are located in the centre with a size of about 210nm, as can be seen in image 3.3b. As both layers are zinc oxide, it is impossible to discern the size of each with this technique. In the enlarged photo (3.3b), a thinner third layer can also be seen that belongs to the NiO - the size of this layer varies between 20 and 50nm.

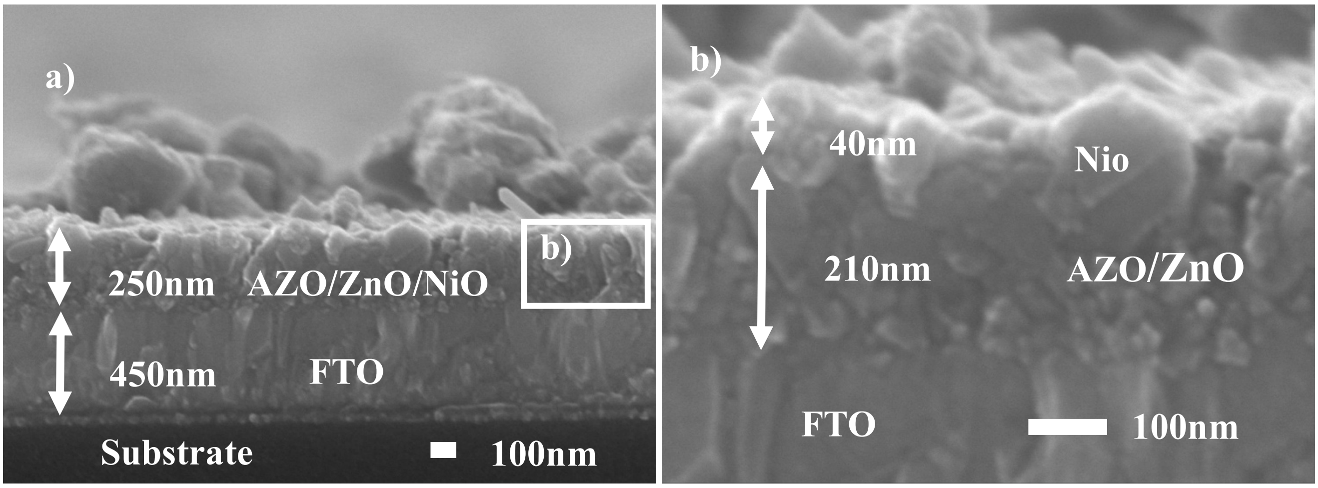

Figure 3.3: *SEM images a) cross-sectional image of the solar cell at 50,000x magnification b) enlargement of image a) at 150,000x magnification, where the size of the NiO layer is noticeable.*

As can be seen in image 3.4, photovoltaic devices are highly transparent in the visible spectrum and without any discolouring that affects the tone of the substrate on which they are deposited.

Figure 3.4: *Image of 2 devices superimposed on the logo of Jaume I University evidencing the transparency of the layers.*

Measurements of solar cell performance confirm the device's response to light exposure, as seen in Figure 3. The device's optoelectronic properties were characterised under an intensity of 1.5AM. Table 3.1 provides data concerning the cells' behaviour towards irradiated light.

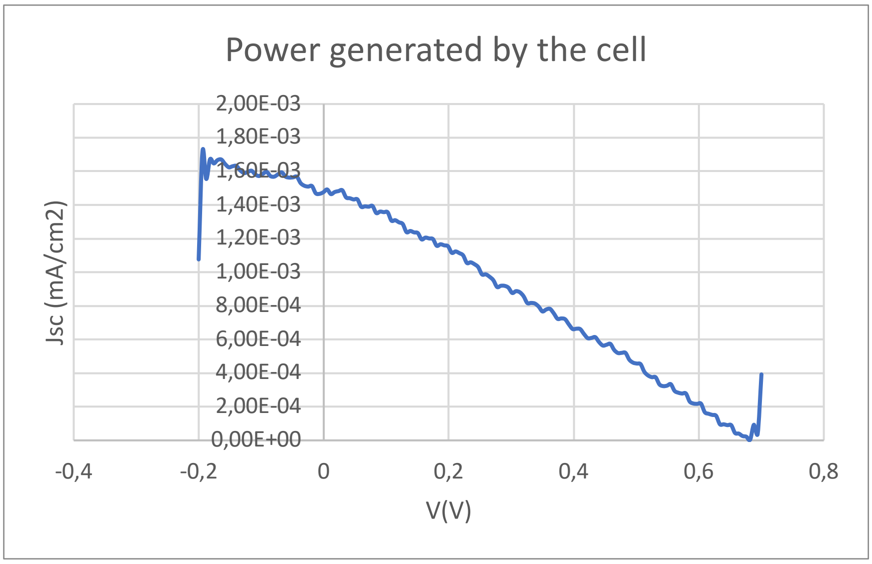

Image 3.5: *Power generated by the photovoltaic solar cell under the influence of light*

Sample	Jsc (mA/cm^2)	Voc (mV)	FF(%)	UV Eff. (%)
1	0.00145	667	28.52	0.01
2	0.00148	692	27.62	0.01

Table 3.1: *Cell optoelectronic parameters*

4. CONCLUSION

An application made from ceramic materials (metal oxides) with good transparency and functionality has been devised using low-cost chemical deposition methods that make it a viable option for integrating photovoltaic systems onto ceramic substrates easily and cheaply. As the SEM and the XRD proved, the material comprises homogeneous, well-defined layers of a crystalline nature and the system gives an electrical response when exposed to light.

5. REFERENCES

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