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Selective emitter technology global implantation through the use of low ultraviolet cut-off EVA

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A B S T R A C T

Selective emitter diffusion technology has demonstrated a direct PV cell efficiency increase, due to a good ohmic contact and high blue response. These PV devices will be assembled to fabricate the final and commercial PV modules where the power enhancement is the most valuable one. The traditional encapsulant material is ethylene-vinyl-acetate (EVA) which ultraviolet wavelength cut off is placed in the region where selective emitter technology improvement is performed. Photovoltaic industry has developed innovate materials to overcome these issues. Among them, a low ultraviolet cut off EVA can be easily acquired. Our study demonstrates that with the correct PV module encapsulant configuration, part of the developed PV cell efficiency improvement related to selective emitter technology can be successfully translated at the end of the value chain; that is, the final PV module.

1. Introduction

Photovoltaic energy is a renewable energy source that has successfully grown over the last decades. In fact, the total global capacity overcame 150 GW in early 2014 [1]. Part of this success can be related to photovoltaic solar cell and photovoltaic module (hereafter PV solar cell and PV module respectively) producer efforts to reduce production costs and increase energy conversion efficiency. These two items are directly connected because cost reduction depends largely on the cell efficiency improvement and technology fabrication choice. In addition, one of the most usual methods to improve PV products cost per watt peak (W_p) is the PV device efficiency enhancement by the productive process optimization, while the costs remain as low as possible. In the specific case of PV monocrystalline silicon solar cells with the typical screen-printed technology, the course of actions places a focus on each of the mean production stages: (1) to increase light trapping effect by improvements on the texturization stage, (2) to optimize diffusion profile on the front surface, (3) to design thinner front metallization contacts, (4) to reduce the recombination losses by the deposition of a suitable passivation layer on both surfaces and (5) an appropriate electrical contact design together with a correct calibration procedure at classification stage [2]. Regarding phosphorous diffusion process (2), it is one of the most sensitive steps during the PV solar cell fabrication process since emitter type and quality have a large influence on the final cell efficiency. At industrial level, there are two well established current diffusion patterns. The traditional one develops a homogeneous distribution of the phosphorous dopant level over the whole silicon surface. The second one is named selective emitter technology (hereafter named as SE technology) and it is based on a non-homogeneous emitter front surface distribution. These PV cells present heavy doped areas under front contacts, while the doping level of the area between fingers keeps low. Good ohmic contact and high blue response are both provided by this front diffusion architecture [3]. Nowadays, different SE technologies have been developed for the purpose of its implementation in industrial mass production, namely: doped Si inks, oxide mask process, ion implantation process, etch-back process, laser doping via P-glass, laser doping via laser chemical processing and laser doping and plating [4]. After these technologies, PV cell efficiency increases 0.5–0.6%, which leads to efficiencies around 19% due to an improvement in the short circuit current (I_{sc}) and better open circuit voltage (V_{oc}) [4].

However, the final commercialized and installed PV device is the PV module and not the PV individual units. It has been a rather widespread concept in the PV industry, that the unique function of the PV module materials are the PV cell protection (glass, encapsulants, backsheets and frame) [5] and electrical contact establishment (tab

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ribbons and junction box). Nowadays, and with the aim to make profitable the whole involved materials in the PV device [6], PV module materials are being considered as an active device part which can positively contribute to solve relevant problems like potential induced degradation [7] or to improve PV module efficiency by a suitable PV cell to PV module technology transfer [8].

Regarding SE technology, its incorporation at PV cell mass production leads to a revision of the PV module encapsulant materials, since the principal modifications in the PV cell spectrum induced by SE are located at the ultraviolet and blue region. This implies that the key issue to accomplish this incorporation is the optical coupling between the SE PV cells and the material used as encapsulant. The traditional PV module encapsulant material is ethylene vinyl-acetate (hereafter named as EVA). It blocks the solar radiation below the wavelength of 360 nm [9–11], just in the region where the SE technology cell efficiency improvement is achieved. This implies that a large part of the PV cell power increase provided by SE technology will not be reflected in the final PV device. This EVA negative effect concerning transmittance can be overcome by the use of alternative materials like silicones, due to their higher transparency over the range between 250 and 400 nm [12–15]. The industrial shift towards silicone is not a trivial issue, because it implies important machine changes in the PV module assemble line [16]. A more direct SE technology adaptation is available by a special EVA design (hereafter named as SE EVA) with a lower ultraviolet cut off [17]. SE EVA as encapsulant material presents two fundamental advantages: first of all, its physical (thickness, density and colour) electrical (volume resistivity, surface resistivity and dielectrical strength) and mechanical properties (glass and backsheet adhesion, Young module, moisture ingress) are rather similar to standard EVA (hereafter STD EVA) and secondly, it can be processed in the same line and with the same lamination conditions. The unique relevant change that this material presents is related to its optical properties: transmittance in the visible region and ultraviolet (hereafter named as UV) wavelength cut off.

The aim of this work is to carry out a suitable SE diffusion technology transfer from the PV cell to PV module, without a significant new PV module production machinery invests. It is important to point out that this study does not try to determine which SE PV cell technology fabrication is the most suitable for its industrial application, due to this, just one of them has been selected for this study because of its accessibility. An exhaustive analysis of PV solar cell response for every diffusion technology has been performed in order to determine in which spectrum region the solar cell response has been substantially modified. Due to this, the PV cell unit analysis has been focused on a detailed comparison between the solar response of PV cells after homogeneous and SE diffusion profile process. Their photo-response to different wavelength (external quantum efficiency) and their I-V curves have been analyzed. In addition, a PV cell batch with SE technology has been fabricated in industrial lines and the power distribution has been compared with the power distribution after a homogeneous diffusion profile process. At PV module level, the main task is to determine the advantage that SE EVA presents versus STD EVA when both materials are used to encapsulate SE PV cells. The study has been developed at two different levels: laboratory sample analysis and large size crystalline PV modules. Optical properties and UV aging test have been selected to perform the sample analysis. The encapsulant transmittance measurements will provide information about the UV wavelength cut off and the average solar radiation that reaches the PV cell. UV aging test has been performed over one-cell frameless mini-modules and their I-V curves have been measured prior and after the light degradation. The former test is relevant for this report because the UV photon range that can reach the encapsulant material will be longer for SE EVA than for the STD EVA. This implies that the acetic acid generation can be promoted in the case of using SE EVA leading to a SE PV module useful lifetime reduction. As PV modules involve the application of two encapsulant foils, it is necessary to carry out the optical analysis with single and double films: STD-STD EVA, SE-SE EVA and SE-STD EVA. Finally, 60 large-size monocrystalline silicon solar cells PV modules have been fabricated in automatic industrial lines. All the processed PV cells were processed using SE technology and they have been encapsulated with two different encapsulant configurations: STD-STD EVA and SE-STD EVA. In the last case, PV modules with SE-SE EVA encapsulant configuration have not been processed because the large UV degradation possibility would not be suitable for its commercialization because of the large amount of UV radiation that would lead to the backsheet delamination.

2. Experimental methods

The experimental section has been developed at PV cell and PV module level. The first one is focused on the study of PV cell and it concerns the two different diffusion profiles: homogeneous and SE. The second part is devoted to SE integration at the final PV device, this means, encapsulant analysis and the own PV module solar response.

Regarding PV cell study, the cell current-voltage curves (I-V curves), power-voltage curves (P-V curves) and their external quantum efficiency (EQE) have been profusely compared for the two diffusion profiles. The PV cell based technology is the same for both diffusion profiles. They are p-type Cz-Si wafers of 238.95 cm^2 area, 180 µm thickness, base resistivity between 1.0–3.0 Ω×cm, and minority carrier

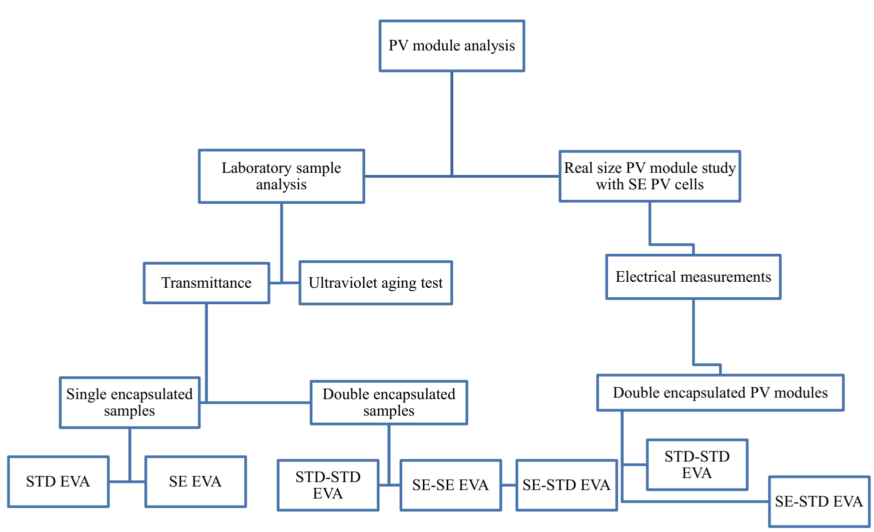

Fig. 1. Experimental sequence for the PV module analysis.