Influence of epoxy resin as encapsulation material of silicon photovoltaic cells on maximum current

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Abstract. This work presents an analysis about how the performance of silicon photovoltaic cells is influenced by the use of epoxy resin as encapsulation material with flat roughness. The effect of encapsulation on current at maximum power of mono-crystalline cell was tested indoor in a solar simulator bench at 1000 w/m² and AM1.5G. The results show that implementation of flat roughness layer onto cell surface reduces the maximum current inducing on average 2.7% less power with respect to a cell before any encapsulation. The losses of power and, in consequence, the less production of energy are explained by resin light absorption, reflection and partially neutralization of non-reflective coating.

1 Introduction

Even though, since mid 80's, humans are seeking solutions for climatic and energetic problems, levels of Green House Gases (GHG), such as CO and CO2 caused in big proportion by the fossil fuels used to provide global energy, have grown inordinately in the last 40 years. Unquestionably, harnessing renewable energy sources is playing an important role. In fact, for closing the gap between needing energy and actual generation and reducing GHG, solar energy has the potential to provide clean energy because of its availability and versatility that allowed decentralized and small scale generation. With this aim in view, the evolution in both materials and fabrication methods for PhotoVoltaic (PV) cells has been motivated in order to increase the rate of generated energy per kiloWatt-peak (kWp), and to reduce its cost per kiloWatt-hour (kWh), as a result of efficiency improvement. Nevertheless, worldwide PV cells production keeps mainly dominated by Silicon (Si), due to abundance of material and its relation between cost and performance [1]. Anyway, for commercial purposes of crystalline modules, Si PV cell needs to be encapsulated, bringing protection against biological agents and causing low impact in optical properties such as reflection and absorption. The most commonly materials used in the industry are Ethylene Vinyl Acetate (EVA) and silicone with non-reflective glass [2]. Some authors have performed experiments showing that the impact of these and other materials combined with different non-reflective glasses have influence onto current at Maximum Power Point response [3, 4, 5]. However, for other products design whose application and its life cycle require different characteristics in topics such as optics and manufacturing, it is necessary to use different kind of materials, and these projects involve solar energy coming with encapsulation developments with semi-transparent rigid epoxy resin. This study analyzes the behavior of current when this material is used as encapsulation. On the next section a review of the state of the art is presented, followed by a description of experimental and methodology approach. Then, the results are presented in graphical way, followed by corresponding discussion. Finally, some conclusions and further research are presented.

2 Background

Lab efficiency measured and reported in several reviews takes into consideration solar cells before they are integrated in products. In consequence, to integrate cells into products, an encapsulation process has to be accomplished. Such process consists in put a coating of transparent material on the silicon face of solar cell in order to protect it against weather, biological agents, mechanical failures, among others. Therefore, selected material must be durable (25 years at least) and it should allow light going through it. Tao & Du [4] investigated through reflection test how optical properties are influenced by presence of encapsulation, and they found that EVA mixed with different class glasses reduces up to 6% the effective light. As a result of use of encapsulation material, the positive effects generated by non-reflective coating is partially neutralized when PV cells are processed for commercial purposes. Peter et al. [5] published a detailed study about how performance is reduced through losses for reflection and absorption of encapsulation materials, where 9% of current losses are causing by absorption and reflection of EVA and glass, it

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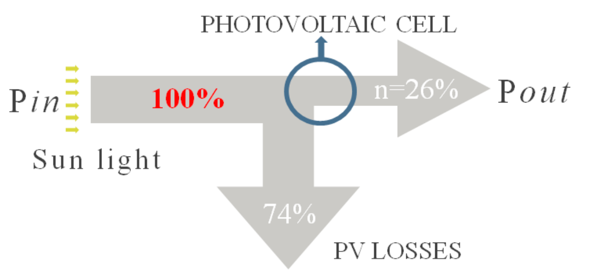
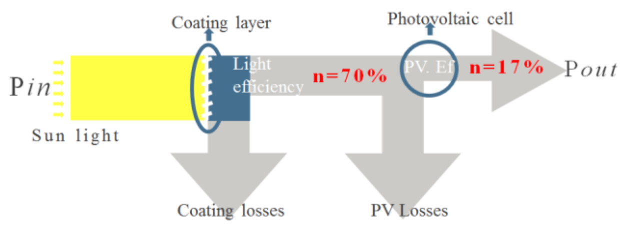
means 1.1 mA/cm². The losses are partially neutralized implementing textured glasses. Schneider et al. [3] evaluated electric performance with different textured glasses and results showed that glass can reduce influence of encapsulation by 5%. Furthermore, a manufacturing company of PV cells evaluates material in order to improve their products. The BP solar company made a comparison [2] with outdoor PV arrays during one year where performance of silicone showed advantage of 1% with respect to EVA. Moreover, Berlin University, trough simulation, noticed that 1.3% losses in Q-cells modules are given due to EVA absorption.

3 Experimental proposal

In literature is evident that encapsulation material causes losses in power and current output, but analyses are reduced to commercial purposes. Nevertheless, when product life cycle is short, e.g. competition for one week, other kind of encapsulation materials become visible. As a result of new products development, Sumiglas R rigid epoxy resin was used as encapsulation material in modules for a competition solar vehicle. This research tests the hypothesis that usage of epoxy resin reduces the output power and studies the effect on current at Maximum Power Point (MPP) (IMP P) through the usage of non conventional material for solar cell encapsulation. Fig. 1 presents how the implementation of any coating onto a solar cell surface (see Fig. 1(b)) reduces the probability (also named efficiency) of converting power inlet in power outlet with respect to a non encapsulated one (see Fig. 1(a)).



(a)



(b)

Figure 1. Energy flux when solar light strikes on PV cells. (a) Flux on Non Encapsulated cell and its respective PV efficiency; (b) Flux on Encapsulated cell and its respective both PV and coating efficiency.

3.1 Sample preparation

The cell is encapsulated by molding method using vacuum bag, which is a process that consist in expel the air present between mold surface and the bag [6], employing epoxy resin and glass as mold for finishing. The module sandwich is completed by two layers of fiber glass as back-sheet. The electrical connection was performed with tin ribbon on 5 x 5 inches mono-crystalline cell. The piece stays six hours inside the bag and after that, it is post-cured for two days. There were prepared 17 samples in total: nine samples of Group NE (non encapsulated cells), eight samples of group E (encapsulated cells with 1mm thickness of rigid epoxy resin and flat roughness). General description is presented in Table 1.

3.2 Methodological approach

Measurements of Maximum Power Point (Pmpp) and their respective current-voltage (I-V) curve for each cell, were performed using a high-power LED-based solar simulator test bench [7], where the mean radiation is 1000 w/m2 . Cells were tested one by one under same conditions such as encapsulation material, thickness, radiation and time, among others. Power is proportional to voltage and current, but due to dependence of voltage with increments of temperature, which is not a controlled variable, it was decided to take current at maximum power (Imp) from I-V curve, because of relation between radiation and current is proportional to radiation and power. The data set was tested for normal distribution assumptions and a respective statistic analysis was carried out.

4 Results

Fig. 2 presents a distribution with left tail which does not present any violation to assumptions either homocedasticity or normal distribution (Levene and shapiro test p-value>0.05).

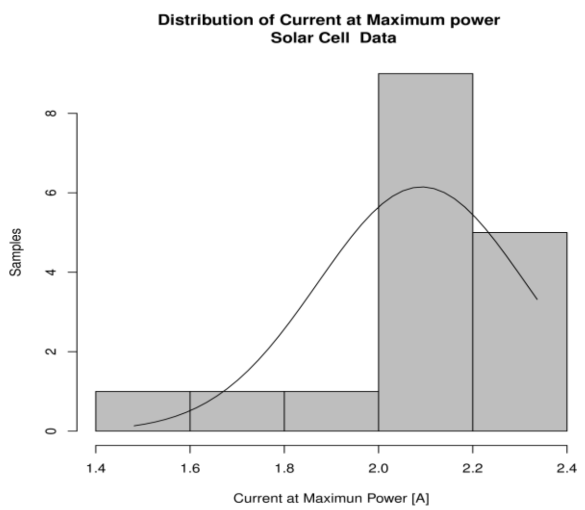


Figure 2. Data set: distribution of Current at maximum power.

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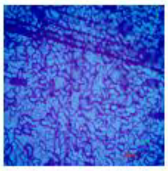
Besides, residuals analysis in linear model are fitted to curve in the Q-Q Plot (see fig. 3). In consequence, current at maximum power is selected as data set for ANOVA. Fig. 4 presents data for finished surfaces and it is possible to infer that the usage of epoxy resin works as a shield which leads to reduce the mean power and current that can be converted. Table 2 proves initial hypothesis with p-value<0.05 and it is accepted that encapsulation with resin, in the same way that EVA and silicone, reduces the probability to convert light in energy.

Table 1. Description of PV cell samples.

	Category	PV cell Surface [20μm]	Description	Mean Maximum Power Measured [mW]
NE	Non-Encapsulated (Control)		Non encapsulated mono-crystalline cell and non backsheet. Image at 20μm	670
FR	Flat Roughness		Semi-transparent rigid epoxy resin flat roughness encapsulated mono-crystalline cell with fiber glass backsheet. Image at 20μm	645

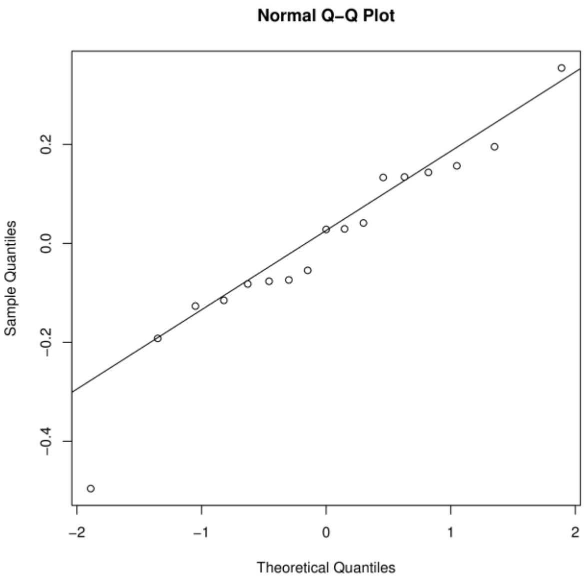


Figure 3: Data set: distribution of Current data residuals and fit curve.

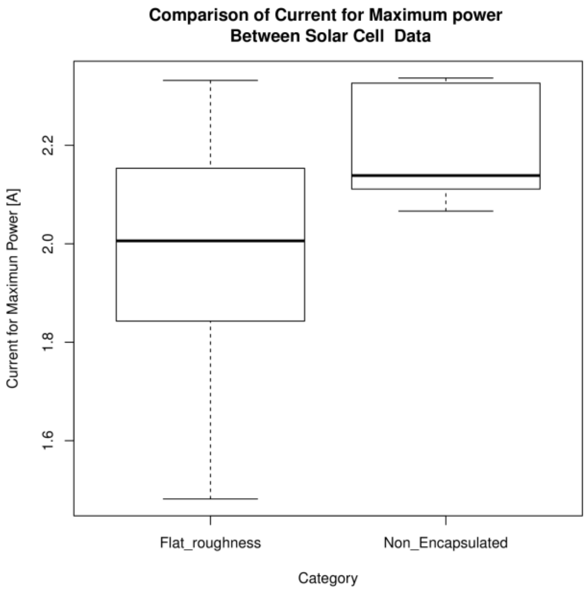


Figure 4: Data set: observed data by category

Table 2. Analysis of Variances.

	Degree freedom	Sum Square	Mean Squarere	F Value	Pr(> F)
Treatment	1	0.1974	0.19738	5.095	0.0393*
Residuals	15	0.5811	0.03874		

5 Conclusions

The usage of resin epoxy as encapsulation impacts the power output of solar cells, generating a decrement of 2.7% in Encapsulated cell with respect to a Non Encapsulated one. The phenomenon is explained since encapsulation works as a shield which interferes the light way until the PV cell surface. Further research should include an approach to implement Textured encapsulation in order to increment the power output, as glasses according to literature. In addition, resin epoxy losses more energy than EVA and silicone but it works better in short life cycle. For further work, we will implement other methods to collect information about solar cells and perform experiments with natural light sources in order to validate the data set. Besides, we keep researching about materials which allow short life cycle, good efficiency and low cost, and texture for surface finishes. It would be interesting to test bigger modules in order to know losses in wire and other components.

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