Re-Use of c-Si Solar Cells from Failed PV Modules

Heng-Yu Li[1], Yun Luo[2], Christophe Ballif[1], Laure-Emmanuelle Perret-Aebi[1]

[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Photovoltaics and thin film electronics laboratory, Breguet 2, CH-2000 Neuchâtel, Switzerland.
[2] 3S MODULTEC, Meyer Burger Group, Schachenweg 24, Lyss, Switzerland
Email: hengyu.li@epfl.ch Tel: +41 32 718 3245 Fax: +41 32 718 3201

ABSTRACT: The recycling or re-use of failed c-Si PV modules could be a significant concern in the near future. The existing approaches for cell recovery can be improved both environmentally and economically friendly. Here we propose a novel double encapsulation module with an optical coupler (DEMOC) module design for convenient c-Si cell recovery. In this paper, the concept of DEMOC is illustrated. We successfully determine the materials and lamination recipes for single-cell re-usable mini-modules. The optical reflection and IV performance of DEMOC are measured and prove to surpass those of an earlier-proposed design without optical coupler. The cell recovery procedure of the DEMOC design is discussed at last.
Keywords: PV Module, Recycling, Encapsulation, Environmental Effect, Silicon Solar Cell

1 INTRODUCTION

Photovoltaic (PV) has experienced unprecedented growth in recent years. It is forecasted that the new PV capacity added worldwide in 2011 will be of 22 gigawatts (GW) [1]. This number is expected to show continuous growth in the coming years. PV modules typically possess a lifetime guarantee of 20-30 years, which means the world will face ever-rising pressure of PV modules recycling. In the near future, millions of end-of-life PV modules will have to be discarded or recycled annually. The failure of c-Si PV modules mainly results from the degradation of the packaging materials and not from the solar cell itself which has a much longer life time. The cost of Si cell (including Si material, wafering and cell fabrication) represents over 70% of the module cost [2]. In terms of the energy-based recovery rate, the cell represent 65.4% of the total energy consumed during PV module manufacturing according to the Life Cycle Analysis [3]. Therefore reusing the Si cells from the PV modules have significant economic and environmental meanings.

Current approaches for c-Si cell recovery are divided into two categories: heat treatment or chemical treatment [10]. In heat treatment, the cells are recovered by incineration in either atmosphere or nitrogen [4]. This method requires high energy and cost inputs. The cell recovery rate should be improved. Moreover, the recovered cells generally show considerable efficiency degradation. The chemical treatment can be subcategorized into either inorganic etching [5] or organic dissolution [6]. The inorganic etching offers high cell recovery rate but is not environmental friendly. The organic dissolution only gives about 10% cell recovery rate. Furthermore, both methods are time consuming. Therefore, till now none of the proposed recovery methods are both environmentally and economically friendly. There is a need to seek a better solution which allows the re-use of c-Si solar cells.

A re-usable PV module requires novelty on the module design. Previously, a ‘Double Encapsulation Module (DEM)’ design was proposed [7, 8]. The DEM offers good cell recovery rate and damp heat reliability. However the power output of a DEM encapsulated module is degraded due to the air gap existing between the non-adhesive sheet and the cell front, which causes worsened optical incoupling. In this paper we demonstrate a new concept of encapsulation based on DEM. It allows re-using c-Si solar cells from the end-of-life PV modules, while minimizing the electrical performance loss due to additional optical reflection compared to the standard encapsulation scheme.

2 NOVEL MODULE DESIGN

2.1 DEM with optical coupler (DEMOC)

The name of the new design is abbreviated to be DEMOC. The structure of DEMOC is illustrated in Fig.1, in a cross-sectional view. The front superstrate is a 3mm Optiwhite glass. The rear substrate is a polymeric composite back sheet. The encapsulant used is commercial grade EVA film at the front and the back. Two layers of non-adhesive film are inserted next to both sides of the cell for easy release during the cell recovery. To reduce the optical reflection occurring at the air gap, an additional layer of optical coupler between the front non-adhesive film and the cell front is used.

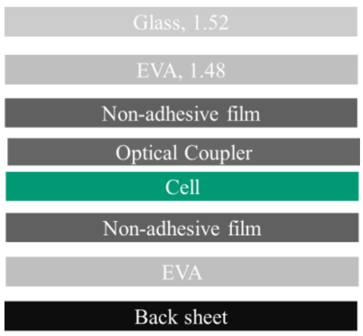

Figure 1: The structure of the DEMOC module design: a cross-sectional view.

The main criteria the film selection include optical transparency, refractive index matching, working temperature, stability and the compatibility with other module components. A commercial grade of ETFE is selected for this study.

For the optical coupler selection, optical transparency, refractive index matching, heat/optical stability are considered. Furthermore, the material compatibility to lamination process is critical. After several trials, a commercial grade of 2-components liquid silicone is selected.

2.2 Lamination process

All module components are laid up during the sample preparation. The two sides of ETFE film are different with only one side plasma-treated. This side has good adhesion to EVA and is used to adhere to the EVA layer. The 2-component liquid silicone is mixed and not applied on the cell front until it becomes void-free. The lamination and thus the curing of EVA are performed in a controlled manner in a flat-bed laminator (3S S1815). The plate temperature is set at 140 ℃. After a preheating step on pins, the pins are removed and a 1-bar pressure was immediately applied on the laminates. The curing process undergoes in the vacuum of about 1mbar. After a set curing time (typically 600s to 900s), the pressure is removed and the module is taken out [9]. The T/P –time curve during the lamination process is seen in Fig. 2.

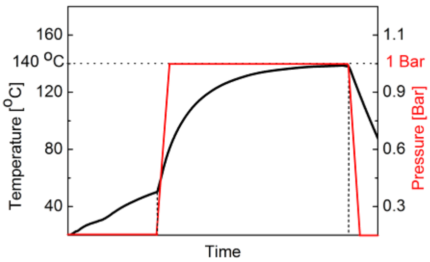

Figure 2: The temperature and pressure profile during a standard EVA lamination process of PV modules.

To avoid further complications on the standard EVA lamination process, the A/B ratio of the 2-component liquid silicone is tuned to be 1:15 to get accommodated. This ratio affects the curing rate of the l-silicone. If it cures too fast, it will get stiff before the press is applied onto the module layup and therefore greatly increases the probability of cell breakage during lamination. If it cures too slowly, the viscosity will stay too low when applying pressure leading to a significant bleeding of silicone .

3 OPTICAL CHARACTERIZATION

By controlling the experiment condition, a void-free and breakage-free single-cell DEMOC module can be obtained. One example is shown in Fig.3a. For comparison, Fig.3b shows a DEM module laminated with the same process but without the optical coupler. The DEM module exhibits brighter outlook than the DEMOC module under identical illumination condition.

Ultraviolet/Visible/Near infrared (UV/Vis/NIR) spectroscopy (Perkin Elmer, Lambda 900) is used to study the reflection from the two module designs. The measured wavelength range was set to 320–1400 nm. Total reflection is obtained using an integrating sphere.

Fig.4 shows the results of the optical characterization. Fig.4a shows the total reflection from the front sides of three different c-Si module designs: standard (Glass/EVA/Cell), DEM (Glass/EVA/ETFE/Cell) and DEMOC (Glass/EVA/ETFE/l-Silicone/Cell). The ETFE layer in the DEM design increases the total reflection in the whole wavelength range measured. In the DEMOC design, due to the additional OC layer, the total reflection is greatly reduced compared to DEM.

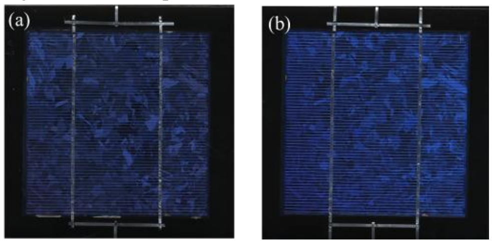

Figure 3: Photos of successfully laminated PV modules. **a**: DEMOC module; **b**: DEM module without optical coupler layer.

The effect of the optical coupler (OC) is further illustrated in Fig.4b. It shows the change of the total reflection in DEM and DEMOC module design, as compared to that of standard module. The improvement due to the additional OC layer is obvious. At 650nm, DEM increases the total reflection by over 20%, while DEMOC controls the increase within 1%. This result proves the effectiveness of the l-silicone optical coupler layer for the total reflection reduction.

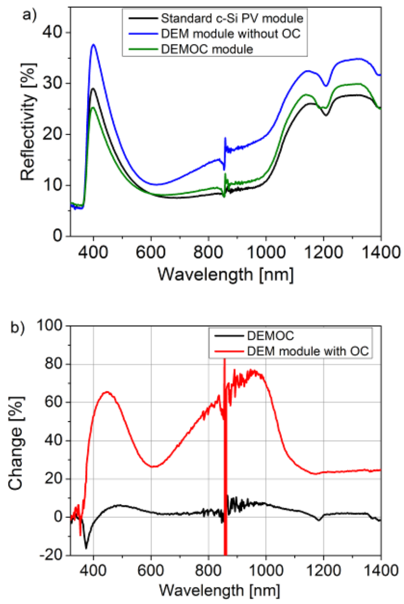

Figure 4. a: The total reflection from the front of the different c-Si PV modules, namely standard, DEM and DEMOC, respectively. **b**: The change of the total reflection as compared to a standard module. The improvement due to the additional OC layer is obvious. Note: the sharp valley at about 850nm is due to the detector change.

4 IV CHARACTERIZATION

The IV characterizations are performed on a DC Pasan table equipped with halogen lamps. The IV curves of all the cells used in this study are measured after soldering, before and after lamination under the same test conditions. . The changes of the Isc before and after lamination for different module designs are listed in Table I. Each number is based on the average of at least 3 samples per conditions. Given the IV measurement error and the limited amount of modules laminated, it is difficult to compare quantitatively the ΔIsc of the different module designs. However, the magnitude of the difference between DEM and DEMOC modules are large enough to show the improvement on the Isc due to the additional OC layer.

Table I: Change of Isc in [%] for different module designs compared to Isc before encapsulation

	Standard	DEM	DEMOC
ΔIsc [%]	-1.0	-10.1	-2.5

5 CELL RECOVERY TEST

After the series of characterizations, all modules are attempted to be disassembled. For the standard modules, due to the strong adhesion between EVA and cell, it is impossible to recover the complete cell from the modules. For the DEM modules, the disassembly starts with cutting the back sheet along the cell perimeter, keeping a short distance from the cell edges. After this step, the complete cells are ready to be removed from the rest of the DEM modules. The DEM design with ETFE as non-adhesive film offers more than 90% cell recovery rate.

The disassembly process of the DEMOC modules is more complex than the DEM design. The first cutting step remains the same. After that, the cut area of the back sheet can be removed from the rest. As the chosen l-the silicone has a weak adhesion with the cell front surface, it is not straightforward to directly remove the cell. Our strategy is to gently remove the assembly of cell+OC from the ETFE by using a thin wire to facilitate the interface separation. After getting acquainted, one can successfully recover the complete cell+OC assembly from the rest of the module. The last step is to remove the cured l-Silicone OC from the cell front, which tends to be easy. The cell recovery rate of the DEMOC design is about 50% and therefore unsatisfactory. Further improvement could be achieved by tuning the l-silicone formulation and final curing state for adjusting its surface property.

5 CONCLUSION AND OUTLOOK

We propose a novel double encapsulation module with optical coupler (DEMOC) design. This module design allows relatively easy cell recovery while reducing the electrical performance loss compared to DEM design. We believe it is a promising candidate for future re-usable c-Si PV modules. In the work presented, the major achievements include:

(1) The non-adhesive film and optical coupler has been chosen and accommodated to the standard EVA lamination process. The successful lamination recipe has been settled.
(2) The cell recovery procedure has been found.
(3) Optical and IV studies have proved the effectiveness of OC layer to reduce the optical total reflection.

Future work should be focused on increasing the cell recovery rate and evaluating the reliability of the DEMOC modules in the damp heat, thermal cycling, etc. Application on the multi-cell modules will also be considered.

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