# IMPROVED LIGHT MANAGEMENT ON STANDARD SILICON SOLAR CELLS & MODULES USING HOT EMBOSSING PROCESS

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**ABSTRACT:** The key criterion for the development of solar photovoltaics is the cost of the watt-peak (for full solar illumination) at the module level. The improvement of light harvesting at the module level also has the potential to reduce very significantly the cost of solar energy, specially if low cost technologies are implemented.

The main objective concerns the development of the improved light management schemes for a new generation of silicon solar cells and modules. The structuring aims at collecting lost photons in order to redirect them in the direction of the Si-PV. Thus the main motivation of this research program is to develop new concepts of solar cells and modules based on a new low cost hot embossing technology for surface structuring. Particularly, it will develop:

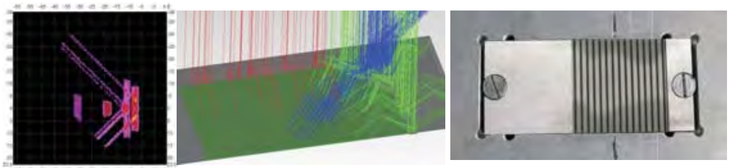
- structuring of the front layer deposited over PV cells (on cell level) and
- structuring of the back plate of a module to allow redirention of light in regions between solar cells (module level).

## INTRODUCTION

The structuring by hot embossing is an emerging topic as it provides very low cost structuring if compared with conventional methods (e.g. µ-machining, EDM). Nevertheless, this technology is today under development and is limited today by the cost of the tools. It makes this technology only interesting for large-scale market applications. Today there are no real applications on medium-scale low cost applications. It is the focus of this research to address both a low cost tool achievement and high flexibility in order to make adaptable embossing profile.

## TOOL DESIGN

Based on results of optical simulations of the ideal profiles of the surface structuring on solar cells and modules, the embossing tools were developed. The efficiency of a solar cell can be enhanced by patterning of an additional layer over the solar cell. This layer serves to redirect the lost light (over metalization grid lines) into cell active region.



*Left: Light intensity redirected into Si solar cell, middle: ray-tracing of the reflected light from the embossed optical profile, right: fabricated embossing tool and implemented in the embossing machine.*

## POLYMER DEPOSITION

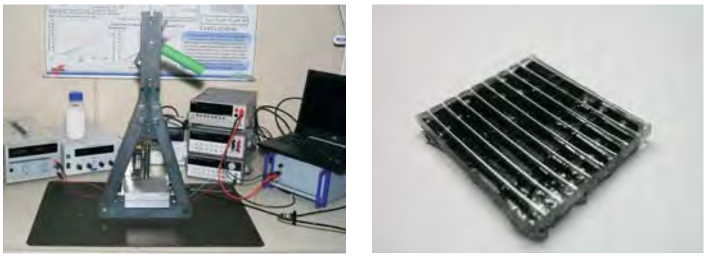
Polycarbonate (PC) was chosen as the material which best fulfills all required properties, has n=1.59 and a high optical transmission (> 98% for films of some mm thicknesses). Simulations showed that the problems are not expected due to thermal mismatch between PC ($\alpha$=0.65e-4 1/K) and Si ($\alpha$=200e-4 1/K) as long as the PC film stays in the proposed thickness range. It is well known, that the embossing technology on PC can be done successfully. There is a wide range of commercially available PC materials that compensate the degeneration processes (temp., UV) to achieve long lifetime.

As base material for the tests commercial PC Foils (thickness 30µm-100µm) and PC pellets where used. The PC layer deposition under embossing conditions ( T=138°-145°C, P= 0.1-5kg/cm²) showed a uniform thickness but a poor adhesion to all substrates. For this reason we have first deposited thin layer of PC using spin coating. In this case, a solution of PC with Dichloromethane (DCM) with concentrations ranging from 0.5-15 weight % served as starting material. Achieved film thicknesse were in range of 0,16µm to 6µm.

## HOT EMBOSSING

The embossing chamber can be evacuated by an external pump. The embossing force (possible up to 4000N) is applied by a piezo stack actuator. Both mold and sample can be heated independently by two integrated heating elements. Operating temperatures up to 250°C were tested until now. Temperature changes with 1°/s for heating as well as 0.15°/s for cooling can be applied to the samples. The temperature is monitored by two Pt100 resistance thermometers. Positioning control is monitored using a laser system with accuracy of 1µm ± 0,1µm. This set up allows position as well as speed controlled embossing. The maximum sample / mold size is limited to 5cm x 3,5cm.

The processign was made on a solar cell from the company BCE, with a surface of 2 x 2cm. Over solar cell an adhesive PC layer (200nm) was spin coated and then 1mm PC foil by heat treatment attached to the cell. With the embossing tool presented here, the PC layer was structured (embossing parameters temperat.=160°C, time=5min., pressure 50N/cm², demoulding T=100°C).



*Left: Hot embossing set-up developed on TUW, right: one embissed sample (polycarbonate layer over the solar cell)*

## CONCLUSION

Promising and satisfying results were achieved using numerical simulations for the design of optical elements in order to enhance the light managemnet on the cell and module level. To perform the structuring in PC layer, an experimental set up was build for the first embossing experiments. The results showed to be promising.

Using this approach, it is possible to design optimised embossing tools at very low cost for solar PV requirements but the developments carried out within the project can find applications in various domains, e.g. antireflective layers, anti counterfeit marking etc.

## ACKNOWLEDGEMENTS

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