

## LOW CONCENTRATION PV WITH POLYCARBONATE

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**ABSTRACT:** Today's modules use commonly glass as encapsulation material. Plastics offer a unique solution with a set of advantages versus glass. This paper outlines the material properties especially in view of usage for low concentrator PV.

**Keywords:** Photovoltaic, Plastics, Concentration

### 1 INTRODUCTION

Transparent plastics, especially polycarbonate (PC), are suited in various respects for use in photovoltaic modules. Firstly, they considerably reduce the total weight in comparison to conventional glass modules. In addition, the plastic has a high breaking strength and toughness. Also, the flexible production technique, plastic extrusion, offers a wide range of material modification and surface design options. However, the overall "module" concept is tailored to the material glass. It should be checked, therefore, whether the materials used in the combination to date are also suitable for plastic glazing. The manufacturing process, e.g. the lamination of films, also needs to be checked/adapted. In the framework of the existing research, it should primarily be established which encapsulation materials can be used for a PC-glazed photovoltaic module and which advantages and disadvantages they have compared with a conventional module. The basic design of a conventional PV module is illustrated in Figure 1.

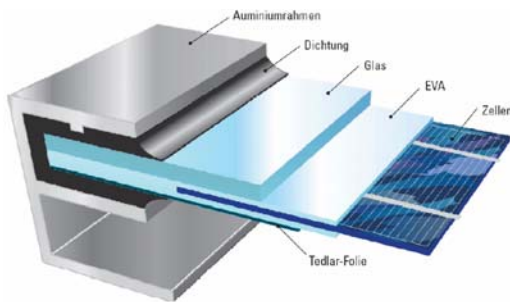


Figure 1: Basic design of a PV module [DGS - Berlin]

### 2 POLYCARBONATE AS A MATERIAL

Plastics in general are being used more and more in all areas of technology, as they can - for the most part - be manufactured economically, using little energy, and with short cycle times. They offer a high degree of design freedom with regard to construction as well as numerous function integration options - for example, mounting devices, seals, etc. can be inserted into the plastic directly in the production process.

Property	Value	Standard
Luminous transmittance	88-90%	ASTM D1003
Turbidity	< 0.8%	ASTM D1003
Tensile elasticity module	2350 N/mm <sup>2</sup>	ISO 527
Tensile stress at yield	63 N/mm <sup>2</sup>	ISO 527
Tensile strain at break	100%	ISO 527
Izod notched impact strength, 23°C	12 kJ/mm <sup>2</sup>	ISO 180/1A
Izod notched impact strength, -30°C	10 kJ/mm <sup>2</sup>	ISO 180/1A
Vicat B50 heat distortion temperature	140°C	ISO 306

Table 1: Material values of polycarbonate for external applications [Lexan 123 R]

The material polycarbonate (PC) is an amorphous, technical thermoplastic, which is distinguished by its high level of transparency as well as its strength and rigidity. By virtue of its outstanding toughness, PC is one of the few polymeric transparent construction materials that tolerates high impact stresses. Polycarbonate is therefore used as a glass substitute in applications where high resistance to breakage is critical, e.g. motorcycle helmet visors, sports goggles, and in medical engineering.



Figure 2: Roof of the Amsterdam Arena, made of Lexan solar control IR@ [Sabic Innovative Plastic]

In the building and construction industry, polycarbonate in the form of solid and multi-skin sheets has proven its worth for decades, e.g. in the construction of transparent roofs (stadiums, train stations, etc.). Concepts for the long-term durability of PC components, even when subject to natural weathering, have been purposefully enhanced. Today, life cycles of more than 20 years are now possible particularly as a result of the innovative UV coatings. This thereby meets the requirements for PV modules and building elements. These properties offer a great range of application possibilities especially for building-integrated photovoltaics. Table 1 lists some of the main values of polycarbonate. In Figure 2, a typical external application of UV-stabilized PC is shown.

### 3. SOLAR CELL ENCAPSULATION - FUNDAMENTAL CONSIDERATIONS

Conventional photovoltaic modules consist of an upper glass layer, beneath which solar cells encapsulated on both sides are located. The rear side can also consist of glass (glass-glass modules) or else of sealing film (glass-film modules, see Figure 1). The material used for

encapsulating the solar cells is predominantly ethylene vinyl acetate (EVA). Although the latter has proved itself in practice, there is still potential for optimization. Therefore, encapsulation materials based on other synthetics, such as rubbers, were developed.

The question for the present research was:

*Which encapsulation material is suitable for use in a photovoltaic module with polycarbonate glazing?*

The research involves several materials, about which information was collected under the following areas:

- Basic suitability of the material for solar cell encapsulation
- Compatibility with polycarbonate
- Processing technique

Two basic types of encapsulations can be distinguished, i.e. laminating films and cast resins, whereby the former are established in volume applications. The following material descriptions are divided according to Figure 3 into cast resins (polyurethane cast resin and silicone cast resin, possibly also fluorosilicone and epoxy) and laminating films (EVA, TPU, PVB, ionomer).

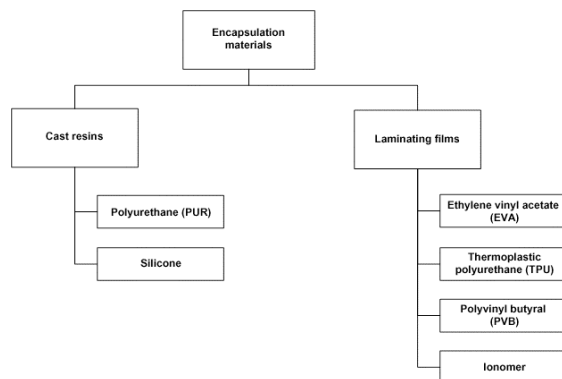


Figure 3: Classification of various potential encapsulation materials for PV modules

Modern material developments attempt to meet the complex life cycle, tightness, and design freedom requirements of PV modules with the aid of so-called multi-layer encapsulations.

## 4. Encapsulation materials

### 4.1 Cast resins

In the literature researched, references were found to two cast resin materials for the encapsulation of solar cells: polyurethane and silicone. Due to their gel-like character, cast resins can presumably guarantee a better balance of thermomechanical tensions, e.g. in the combination of substrates with strong differences in expansion behavior (PC/solar cells). However, these are crosslinking systems, i.e. in the course of encapsulation, a reaction between two or more reactants takes place, from which the cast resin is formed. This can lead to comparatively long cycle times. Also, the processing methods may be more time-consuming than for film lamination.

#### 4.1.1 Polyurethane cast resin (PUR)

There are already PC thin-layer modules on the market in which the solar cells are embedded by means of PUR cast resin. These modules have covers made of PC (and PMMA) and are installed e.g. on boats or bus shelters. By virtue of the soft, gel-like PUR mass, the different expansion behaviors of PC and silicon cells are compensated. With cast resin, it is a matter of a reactive polyurethane system on the basis of a modified isocyanate.

Polyurethanes are formed from the reaction of isocyanates with polyols. Catalysts are also added to accelerate the relatively slow hardening reaction.

In principle, it is to be accepted that suitable PUR cast resins are highly compatible with PC. It should be noted, however, that the group of PUR elastomers have a broad chemical spectrum, and thus compatibility should be checked individually for each one. Through the chemical reaction in the production process, the PC also comes in contact with the low-molecular initial components isocyanate and polyol, possibly even for longer periods, if hardening is not complete. Further reservations about PUR include e.g. its sensitivity to moisture. On the whole, it is right to assume, according to the current state of knowledge and development, that no commercially-available polyurethanes are capable of supplying the long-term stability required by the relevant standards in a module construction with polycarbonate glazing.

#### 4.1.2 Silicone cast resin

Silicone is a classic material for the encapsulation of electronic components. Similar to polyurethane, it can also be set to be soft and gel-like.

With the material Sylgard 184, the Dow company offers a casting material specifically for conventional photovoltaic modules (glass). This two-component molding compound has been proven in the field for over 20 years; good UV-stability can be expected. As applications in the field of encapsulation, there are solar lights, albeit with glass covering. But Sylgard 184 is also used as an embedding material in the PMMA-glazing of "solar concentrators".

#### PC-silicone cast resin combination:

A palette of primers exists for the adhesion of Sylgard to various substrates (including plastic). Initial tests on the

adhesion of silicone adhesives to plastics (including PC) were carried out. The tests revealed that they can balance the different thermal expansions between polycarbonate and the solar cell extremely well. By virtue of their elasticity, they protect the solar cell by dampening vibrations and knocks, such as those that can arise from hailstones or transport and mounting, for example. When handling them, it should be ensured that no air pockets can form between the solar cell and the polycarbonate sheet. This can be achieved by using silicones with lower viscosity.

#### 4.2 Laminating films

By the end of the research, it had emerged that the combination of plastic glazings and the thin laminating films is perhaps less than ideal. It seems that the large difference in the thermal expansion coefficients of solar cells and plastic cannot—in contrast to cast resin encapsulation—be absorbed by a laminating film. On the other hand, there has clearly also been positive approaches in development already. The following information, which was acquired previously, should be considered in this aspect.

##### 4.2.1 Ethylene vinyl acetate (EVA)

EVA is the classic encapsulation material for PV modules with glass covering. Due to large-scale application, it is inexpensive, but has the following drawbacks: a comparatively poor storage stability of the initial components, long cycle times as a result of the necessary crosslinking, and a less than optimal UV resistance.

Therefore, to date, this material has been excluded in the development of a new module concept.

##### 4.2.2 Thermoplastic polyurethane (TPU)

Thermoplastic polyurethane is available as a film, amongst other things. Aliphatic, weatherproof TPUs are used for photovoltaic applications.

Suppliers include PP GmbH with Etimex Vistasolar TPU and Bayer MaterialScience with Desmopan. The corresponding processing technique, vacuum-free continuous laminating, was patented. Advantages of TPU in comparison to EVA:

- Thermo-plastically processable, i.e. short lamination times,
- recyclable/repairable
- Processing in the roll laminator (no vacuum)
- Fewer problems with the storage stability of the initial components.

##### PC-TPU combination:

In principle, this material combination is regarded as compatible, as shown by the corresponding compatibility tables and applications, e.g. in 2-component injection molding. Also, sensitivity to moisture is to be noted in the case of TPU. Modules must be very well encapsulated to avoid water penetration. With glass-film modules, for example, a rear film with a TPT-aluminum combination is recommended. The silane contained in the TPU acts as a bonding agent between the PC and the film.

##### 4.2.3 Polyvinyl butyral (PVB)

PVB film is known from glazing. It is used as a layer in laminated safety glass e.g. for car windshields, in bulletproof glass, etc. In the past few years, there have been efforts to use PVB as an EVA substitute in photovoltaics. The advantages over EVA include better UV-stability and better adhesion to glass. The UV-transparency is almost as good as that of EVA. A disadvantage, however, is the moisture sensitivity of PVB, although improvements could be made in this regard. Lamination times can be reduced by about half; an autoclave is not needed.

##### PC-PVB combination:

There are occasional references in the literature to combinations of PC and PVB. However, the plasticizer portion in the PVB appears to be critical for the long-term stability of the PC. This presumably makes an application inadvisable.

##### 4.2.4 Ionomer

Surlyn® is a thermo-plastically processable, transparent ethylene methacrylic acid copolymer (E/MAA), an "ionomer," which is marketed as a film and for injection molding parts. There have been long-standing film applications, for example in the packaging industry, but there is also a photovoltaic version of Surlyn. Advantages of ionomer in comparison to EVA are:

- Thermo-plastically processable, i.e. short lamination times,
- recyclable/repairable
- Fewer problems with the storage stability of the original components
- Less intense yellowing even without UV-stabilizers
- Longer and better adhesion to the surrounding components
- High volume resistance, high degree of toughness, non-corrosive

To date, there are no documented positive findings regarding a combination of ionomer and PC for photovoltaics.

#### 5. Summary

This research undertook to seek out materials that are suitable for an encapsulation of solar cells in a polycarbonate-PV module and to compare them in terms of their application suitability.

Essentially, there are two module encapsulation possibilities: cast resins are assumed to be better for plastic glazing because they are capable of compensating the different thermal expansion behaviors prevailing in the combination. Although laminating films enable better automatability and lead to a very compact module combination, they are still possibly only second choice due to their limited expansibility. The following table provides an overview of the advantages and disadvantages of the respective encapsulation materials.

	PUR	Silicone	EVA	TPU	PVB	Ionomer
Moisture influence	bad	average	average	bad	average	good
Processing	average	average	bad	good	good	good
Long-term stability	average	good	average	good	average	good
PC-compatibility	average	good	unknown	good	bad	unknown
Expansion behavior of the combination	good	good	bad	bad	bad	bad