

Organic PVT - a Novel Hybrid Collector Combining Organic Photovoltaics and Polymer Absorbers

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Abstract

A novel hybrid PVT collector concept is presented which combines organic photovoltaics (OPV) with a polymer absorber plate. This combination achieves synergies in terms of temperature requirements and matching of materials. The low-cost, low-weight OPVT collector mainly employs polymeric materials with a small ecological footprint and low material costs.

This paper details the characterization of electrical and optical parameters of OPV modules, the development of an OPVT absorber with a suitable bonding process, and test results of a first unglazed OPVT collector, demonstrating the general functionality of the OPVT concept.

Challenges for the technical realization of the OPVT concepts concern degradation and ageing of OPV modules and adhesives at elevated temperatures. Moreover, high reflection losses impose a challenge for the thermal efficiency. Nonetheless, the first experimental results of the unglazed OPVT collector are promising.

Keywords: Hybrid photovoltaic/thermal PV/T collector; solar energy in buildings, solar heat; solar electricity, OPV

1. Introduction

Conventional photovoltaic-thermal (PVT) collectors typically employ crystalline silicon PV cells and a metallic absorber (Zondag 2008). However, this combination causes either the electrical or the thermal operation to underperform, due to the diverging temperature requirements.

The novel organic photovoltaic thermal (OPVT) collector combines organic photovoltaic (OPV) modules with a polymeric absorber to simultaneously convert solar energy into electricity and heat in a single component.

Sandnes and Rekstad (2002) developed a PVT collector with a polymer absorber plate but found a high difference of the thermal expansion coefficient of silicon PV cells and the polymer absorber. On the contrary, OPV modules consist of thin, active layers of light absorbing dyes, which are encapsulated in flexible polymeric films. Given their relatively high thermal expansion coefficient, OPV modules seem ideal for the combination with polymer absorbers. An adhesive between the OPV module and the polymer absorber is used for the thermal and mechanical coupling to achieve a good heat transfer and bonding forces between the OPV modules and the absorber.

Silicon PV cells operate most efficiently at low cell temperatures due to their negative temperature coefficient, while the solar thermal application requires a certain fluid temperature level (Lämmle et al. 2017). OPV modules have a constant or even positive temperature coefficient (Brabec 2004). This means that the electrical power is independent of the cell temperature, or even increases slightly with higher cell temperatures. Thus, the application of OPV modules in PVT collectors offers more synergies regarding suitable operating temperatures.

Theoretically, the OPVT collector can be carried out in an unglazed or glazed design variant, with air or water as heat transfer fluid. Fig. 3 shows a schematic cross section of a water-type, unglazed OPVT collector with an extruded polymer absorber from either PP or PPS. For instance, this low-cost, low-weight OPVT collector concept is applicable for stand-alone thermosiphon systems or façade collectors that generate both electricity and heat in a single component.

Several constructive challenges have to be met concerning the technical realization of the OPVT collector

concept, which are described in the following. Firstly, a suitable OPV module is selected and qualified regarding the electrical performance, optical parameters and degradation at elevated temperatures. Secondly, a suitable bonding technique is developed to couple the OPV module and the polymer absorber mechanically and thermally. Thirdly, an unglazed OPVT collector is designed, built, and tested to demonstrate the functionality of the OPVT concept.

2. Characterization of electrical and optical properties of the OPV module

A commercial OPV module was selected and qualified regarding its electrical performance, optical characteristics and degradation at elevated temperatures (Fig. 1).

An electrical efficiency of $\eta_{el,STC} = 5.7\%$ was measured in the flasher at the CalLab PV Modules of Fraunhofer ISE. The mentioned efficiency relates to the active OPV module area A_{OPV} , i.e. the non-active area of the cell connectors and the white module border is disregarded.

In contrast to silicone PV technologies, the module temperature has only a small effect on the electrical power. The measurement of the power temperature coefficient yielded $\gamma_{OPV} = -0.035\%/K$. Thus, the drop of electrical power due to temperature increase is smaller by a factor of 10, than for crystalline silicone PV modules, with a typical temperature coefficient of $\gamma_{c-Si} = -0.42\%/K$.

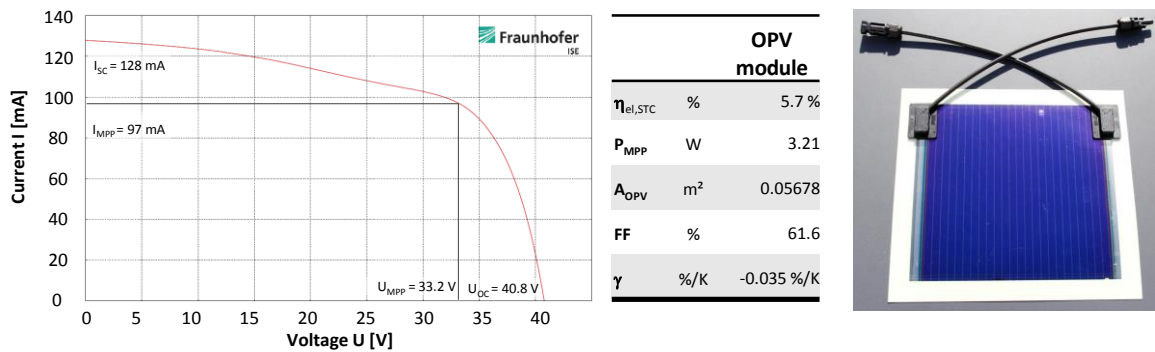


Fig. 1: Electrical characterization of an organic photovoltaic module

The relatively low electrical efficiency of organic PV modules at its current commercial stage is expected to increase in the future. Currently, the production stage of the OPV modules is still in the pilot phase. In the following years, the production lines will be scaled up with an expected drop of production costs and an increase of electrical efficiency.

A sufficiently high optical absorptance of the OPV module is important with regards to the thermal operation. The optical characteristics of the OPV module were measured in a Fourier spectrometer. A relatively low absorptance of $\alpha_{AM1.5} = 0.65$ and a high reflectance of $\rho_{AM1.5} = 0.35$ was registered in the AM1.5 spectrum (Fig. 2). The TCO front electrode and the metal back electrode are most likely responsible for the high reflection losses. The high reflectance above $\lambda = 0.8\ \mu\text{m}$ is considered a challenge for the thermal operation, resulting in a low effective transmittance-absorptance product $(\tau\alpha)_{eff}$ and a low thermal conversion factor $\eta_{th,0}$.

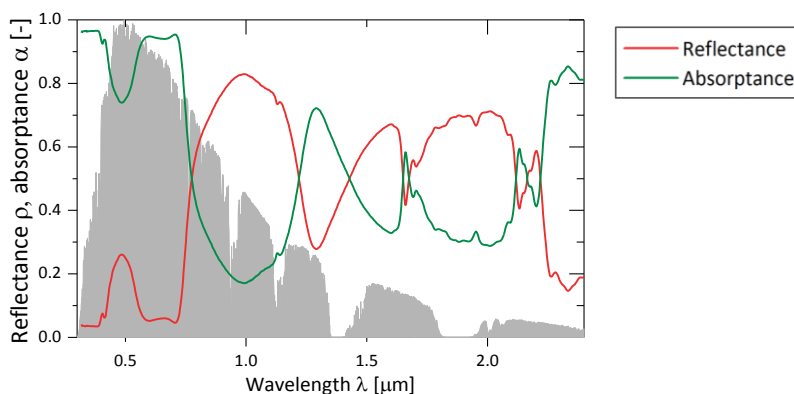


Fig. 2: Characterization of optical properties of organic photovoltaic modules for the application in OPVT collectors

3. Development of OPVT absorber and bonding process

The OPVT absorber consists of the OPV module and the polymer absorber, which are bonded by a suitable adhesive (Fig. 3). The selected OPV module uses a backsheet foil of either polyethylene terephthalate (PET) or polyvinyl fluoride (PVF). A polymer absorber in a twin-wall design from either polypropylen (PP) or high-performance polyphenylene sulfide (PPS) is employed.

The glued OPVT compound couples different materials with different thermal expansion coefficients. This requires a balanced choice of components and materials to reduce thermo-mechanic stress and enhance heat transfer.

A multitude of samples with varying type of adhesive, layer thickness, surface pretreatment and method of application were designed. Prior and after ageing, their mechanical properties were characterized. Accelerated ageing tests based on IEC VDI 61215 (2016) included high temperature exposure, thermal cycling, humidity freeze, damp heat, and combined thermal and mechanical loads.

A butyl rubber-based adhesive was selected for the application in the OPVT absorber. The selected adhesive combines good mechanical properties, temperature stability, processability and good heat transfer characteristics.

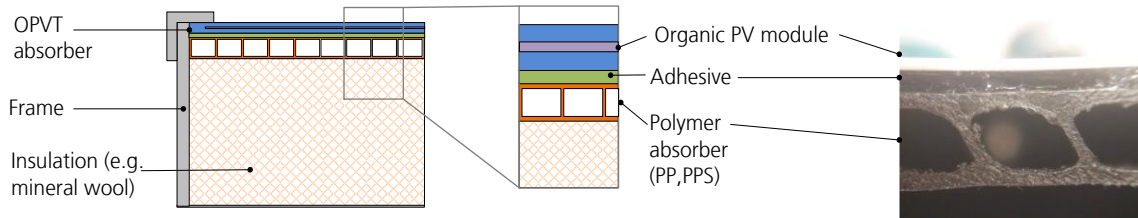
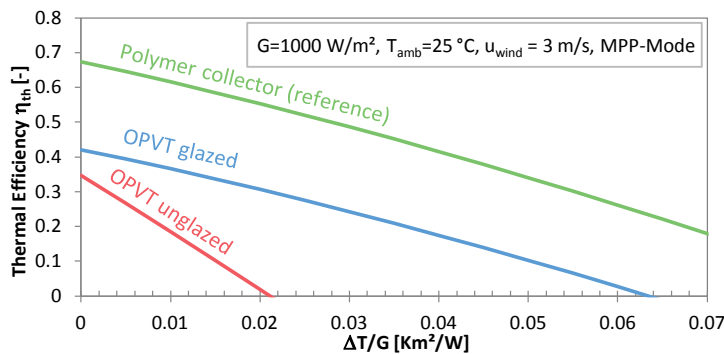


Fig. 3: OPVT collector concept: schematic cross section of an unglazed collector and a glued OPVT absorber compound

4. Test results of OPVT demonstrators

Different collector concepts were assessed numerically with a validated numerical PVT collector model (Lämmle et al. 2016). Fig. 4 shows the resulting simulation results of an unglazed and glazed OPVT collector at wind speeds of $u_{wind} = 3$ m/s.



	OPVT glazed	OPVT unglazed
$\eta_{th,0}$	0.421	0.347
c_1 W/m ² K	5.316	15.971
c_2 W/m ² K ²	0.021	0.021
T_{stag} °C	113.5	71.1

Fig. 4: Simulation results of thermal efficiency of an unglazed and glazed OPVT collector

Due to the high reflection losses, the conversion factor $\eta_{th,0}$ is significantly below that of the Aventa reference polymer collector. The thermal losses of the unglazed PVT collector are high due to the absence of a front cover. At the same time, the stagnation temperatures are uncritical and remain below $T_{stag} = 72$ °C.

An optimized collector design for the OPVT collectors was derived from the numerical simulations (Fig. 5). By adjusting the level of thermal insulation, these designs take into account the maximum stagnation temperatures, which the materials (OPV module, adhesive) should not exceed.

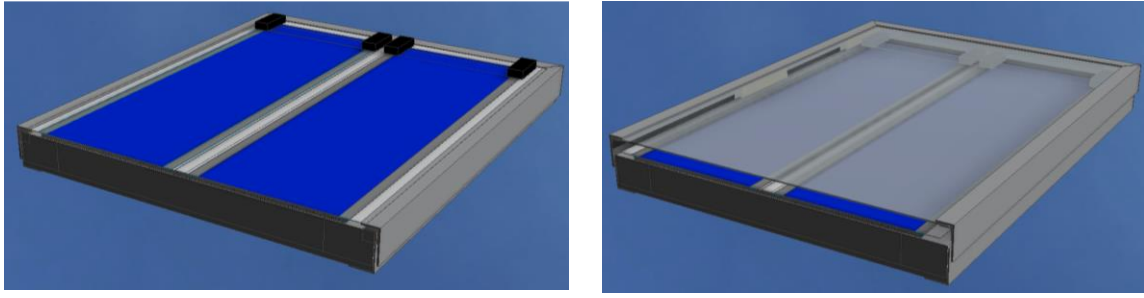


Fig. 5: CAD drawings of the unglazed and glazed OPVT collector designs

As first demonstrator, the unglazed OPVT collector was built. The unglazed OPVT collector features two strips of OPV film glued to a twin-wall PP absorber with the mentioned butyl rubber adhesive. The aperture dimensions amount to 2.0 m x 0.6 m, or 1.21 m², while the active OPV area amounts to 0.92 m². Thus, the collector achieves an electrical packing factor of PF = 0.76.

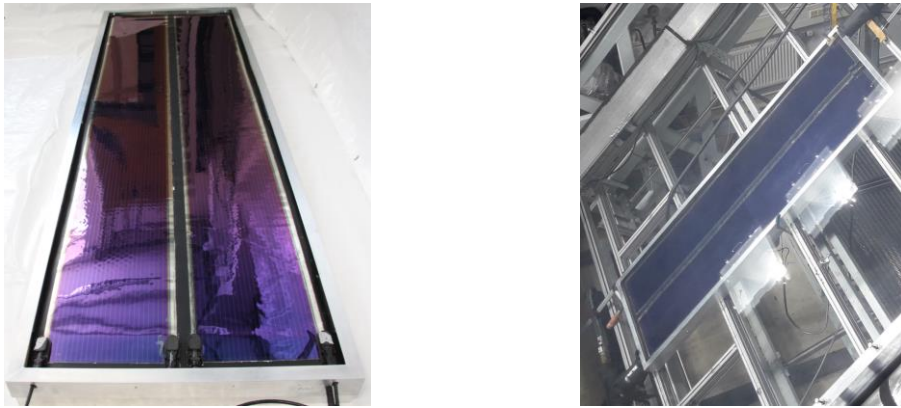


Fig. 6: Unglazed OPVT collector in the solar simulator

The performance of the unglazed OPVT collector was characterized with the steady-state approach in the solar simulator of the TestLab Solar Thermal Systems of Fraunhofer ISE (Fig. 6). The tests of the wind and infrared sensitive collector (WISC) take into account three levels of wind speed in the collector plane ($u_{wind} = 0$ m/s, 1.5 m/s, 2.6 m/s).

Fig. 7 shows the electrical and thermal performance curves for the different wind speeds. The infrared sensitivity, denoted by the collector parameter c_5 , was excluded from the analysis. Hence, the collector parameters $\eta_{th,0}$, c_1 , c_3 and c_6 are evaluated to describe the thermal power output, based on ISO 9806 (2017):

$$\eta_{th} = \frac{\dot{Q}}{A_{ap}G} = \eta_{th,0} - c_1 \frac{(T_m - T_{amb})}{G} - c_3 \frac{u_{wind}(T_m - T_{amb})}{G} - c_6 u_{wind} \quad (\text{eq. 1})$$

The performance parameters indicated in Fig. 7 are obtained by the application of multiple linear regression. In contrast to ISO 9806 (2017), the efficiency relates to the aperture area ($A_{ap} = 1.21$ m²) instead of the gross collector area ($A_g = 1.38$ m²).

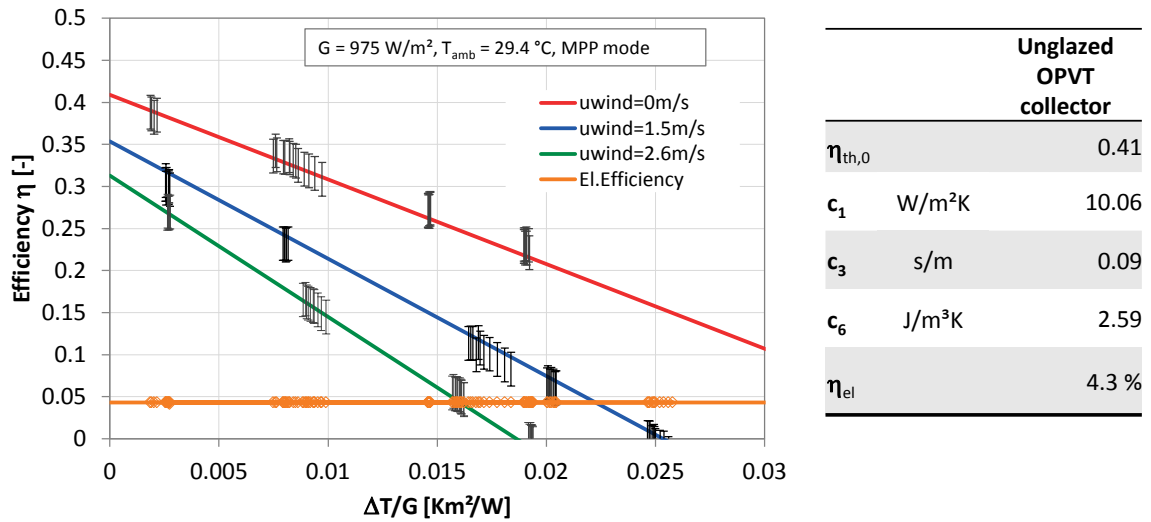


Fig. 7: Characterization of electrical and thermal performance of the unglazed OPVT collector in the solar simulator of the TestLab Solar Thermal Systems. Efficiency related to aperture area $A_{ap} = 1.21 \text{ m}^2$.

All tests were carried out applying an electrical load in the form of a MPP tracker. The electrical power is basically constant and amounts to $E_{OPV} = 50.5 \text{ W} \pm 0.3 \text{ W}$ for all steady-state test points. Neither the wind velocity nor the mean fluid temperature have an observable effect on the power output. This is a particularly interesting effect, as for conventional PVT collectors, the electrical and thermal operation are closely interlinked.

The measured electrical efficiency amounts to $\eta_{el} = 4.3 \%$. This corresponds to the rated electrical efficiency of the employed OPV module of $\eta_{el,STC} = 5.7 \%$ and the packing factor of $PF = 0.76$.

5. Conclusion and outlook

This paper presented a novel hybrid PVT collector combining organic PV modules and polymer absorbers. This combination promises synergies regarding materials, manufacturing process, and operating temperatures. The low-cost, low-weight OPVT collector aims at existing markets (stand-alone thermosiphon systems, façade integrated collectors) and novel applications (car washing station, bus station, car parking building).

The major development challenges concern the evaluation of ageing effects of the OPV module and adhesives, the development of a suitable bonding process for the OPVT absorber, and the high optical reflection losses of the OPV module.

A first unglazed OPVT collector was designed, built, and tested. The thermal performance is in the range of crystalline silicon PVT products that are commercially available ($\eta_{th,0} = 41 \%$). Nonetheless, an optimization of the absorptance of the OPV module is the key for an enhanced thermal performance. At the current early commercial stage of organic photovoltaics, the electrical efficiency is still comparably low ($\eta_{el} = 4.3 \%$) but a significant increase is expected for OPV modules from future production lines.

Test results of a glazed OPVT collector are pending and will be published subsequently.

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