TRANSMISSION SPECTROSCOPIC AND IV CURVES ANALYSIS OF SEMITRANSPARENT ORGANIC PHOTOVOLTAIC MODULES

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ABSTRACT: To harness the benefits of organic over conventional inorganic photovoltaic technology, further investigations about optical and technical characteristics are required. Especially for building integrated photovoltaic (BIPV), it is interesting to obtain precise information on optical specifications such as the transmission-, reflection and absorption spectrum. For the integration of semi-transparent, organic modules in windows, for example, it is of great importance, which fraction of the sun light will be sensed by the residents and how it effects the sense of comfort for the inhabitants. In this work an analysis of transmission spectra of organic photovoltaic (OPV) modules and the dependency of the spectra on different load conditions in short-and long-term experiments is shown. In addition the outdoor behaviour of organic photovoltaic modules is evaluated over a longer period.

Keywords: Building Integrated PV (BIPV), Organic Solar Cell, Spectroscopy

1 ORGANIC PHOTOVOLTAIK – INTRODUCTION

Organic photovoltaic (OPV) represent the youngest generation of solar cells. They consist of semiconducting organic hydrocarbon materials in form of polymers or dendrimers to convert solar radiation into electricity. Organic semiconducting molecules have the ability to absorb light and induce the transport of electrical charges between the conduction band of the absorber to the conduction band of the acceptor molecule.

Thinking of photovoltaic's as a connection between the biggest and inexhaustible, natural power station -the sun- and our electrical grid, OPV emphasizes the idea of an environment-friendly energy transforming technology. There are many promising advantages of OPV compared to conventional inorganic solar cells especially for building integrated photovoltaic (BIPV) (Figure 1).

Figure 1: Example for semi-transparent BIPV, PV-Modules as laminated safety glass (ECN, office and laboratory building)

1.1 COMPARISON OF TECHNOLOGY

FLEXIBILITY
An important advantage of organic materials used in solar cell manufacturing is the ability to tailor the molecule properties in order to fit the application. Molecular engineering can change the molecular mass, bandgap, and ability to generate charges, by modifying e.g. the length and functional group of polymers. Moreover, new unique formulations can be developed with the combination of organic and inorganic molecules, making possible to print the organic solar cells in any desirable pattern or colour.

SUSTAINABILITY / ECOLOGY
The energy consumption needed to manufacture organic cells is far less than the energy required for conventional inorganic cells [1]. Furthermore there are less rare earth compounds and heavy metals needed than the amount used within thin film photovoltaic's.

FABRICATION / COST
Organic solar cells can be easily manufactured compared to silicon based cells, and this is due to the molecular nature of the materials used. Molecules are easier to work with and can be used with thin film substrates that are 1,000 times thinner than silicon cells (order of a few hundred nanometers). This fact by itself can reduce the cost production significantly.
Since organic materials are highly compatible with a wide range of substrates, they present versatility in their production methods. These methods include solution processes (inks or paints), high throughput printing techniques, roll-to-roll technology and many more, that enable organic solar cells to cover large thin film surfaces easily and cost-effectively. All above methods have low energy and temperature demands compared to conventional semi conductive cells and can reduce cost by a factor of 10 to 20. [2] The following figure 2 shows the energy consumption of production.

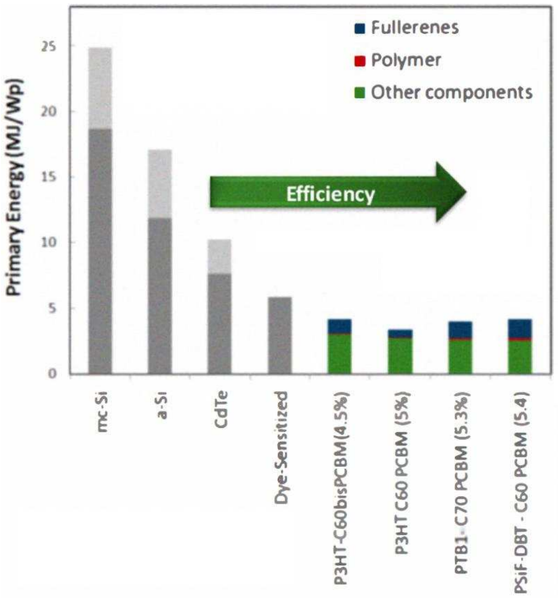

Figure 2: Energy consumption of production [3]

SPECIAL PROPERTIES

Compared to heavy and brittle anorganic photovoltaic modules, these cells are flexible and much lighter, which makes them easy to be stored (rolled), transported and installed and thus less prone to damage and failure. They fit to complex surfaces, and because of their transparency even to windows. Figure 3 shows some examples of these semi-transparent and flexible solar cells with different colours.

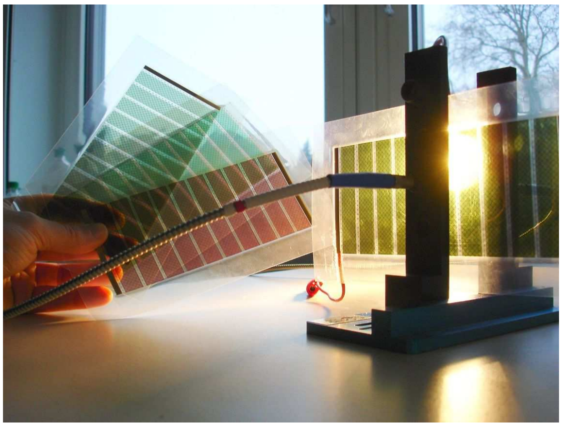

Figure3: Some examples of semi-transparent and flexible solar cells with different colours.

The tailoring of molecular properties and the versatility of production methods enable organic polymer solar cells to present a series of desirable properties:

- Adjustable band gap to harvest a large fraction of the solar spectrum
- High optical absorption coefficients
- Compatibility with flexible substrates
- Fabrication via low cost, high throughput printing techniques.

DISADVANTAGES

Organic Solar cells have certain disadvantages including their low efficiency (about 5% efficiency compared to the 15% of silicon cells) and short lifetime due to foil degradation. Nonetheless, their numerous benefits can justify the current attention and research in developing new polymeric materials, new combinations, and structures to enhance efficiency and achieve low-cost and large-scale production.

2. TRANSMISSION OF IRRADIATION AT WAVELENGTH OF 200 - 1100 nm

2.1 Transmission spectrum at real time conditions.

Semi-transparent organic modules installed in windows, change the intensity and colour of sunlight illumination for the rooms of the building. In this section the variation of the transmission spectrum at different weather situations, of a semitransparent organic solar panel was determined by means of spectral analysis.

The first test series is about getting typical transmission spectra which can be expected for real BIPV installations. Therefore OPV Modules where installed at about south-orientation, with a 30 degree elevation angle. Several thousands of spectra where taken during changing weather conditions. The spectra were recorded over a week in July and August (28.07.2011 to 03.08.2011) with an interval of one minute. To evaluate the spectra, the centroid of each spectrum was calculated with the following rule (2.1) (2.2) and (2.3).

$$A = \int_{\lambda_1}^{\lambda_2} S d\lambda \tag{2.1}$$

$$\lambda_C = \frac{1}{A} \int_{\lambda_1}^{\lambda_2} \lambda S d\lambda \tag{2.2}$$

$$S_C = \frac{1}{2A} \int_{\lambda_1}^{\lambda_2} S^2 d\lambda \tag{2.3}$$

with

A: Area of the spectrum between λ_1 and λ_2 calculated with the integral calculus

λ_C: Wavelength value of the centroid

S_C: Spectral irradiance value of the centroid

With this method one can determine whether the relative fraction of blue or rather the relative fraction of red spectrum predominates. Figure 4 shows some selected spectra at different irradiances and in two different states of the relative diffuse fraction F_D. The relative diffuse fraction indicates the share of diffuse radiation relative to the global radiation. For example the value 1 of F_D means the global radiation consists completely of diffuse radiation. Consequently there is no direct radiation and the sky is overcast. On very sunny days the diffuse fraction decreases to 0.1. The following formula shows the calculation of F_D.

$$F_D = \frac{G_D}{G} \quad (2.4)$$

with

G : Global irradiance

G_D : Diffuse irradiance

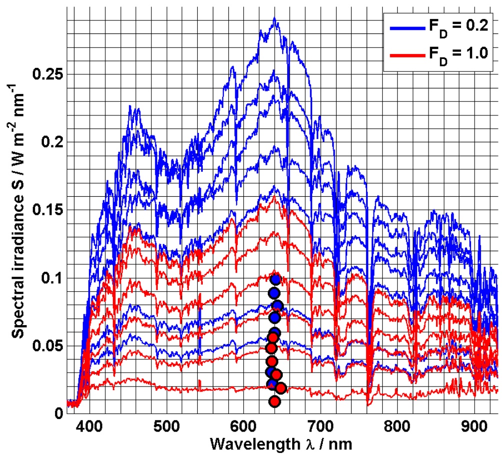

Figure 4: OPV transmission spectra at different irradiances and weather conditions (F_D = 0.2: high proportion of direct radiation, F_D = 1.0: no direct radiation). The points represent the centroid of the individual spectra.

As the centroid of the solar spectra varies with the weather conditions, this should also apply to the transmission spectra. This, at least is not the case for the selected spectra in Figure 4. The other measured spectra show little variation for the measured period. This means that the colour of the light behind the module is nearly constant and independent from the irradiation spectrum. Only the intensity of light varies. The different weather conditions have thus virtually no influence on the transmission spectrum.

2.2 Variation of Spectral-sensitivity within different operation conditions.

The absorbance of the OPV cell is, inter alia, dependent on the band gap between the HOMO (highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) Layers. This band gap is typically in the range of 1-4 eV [4] (see figure 5). When these materials absorb a photon, an excited state is created and confined to a molecule or a region of a polymer chain. The excited state can be regarded as an electron hole pair bound together by electrostatic interactions, i.e. excitons. In photovoltaic cells, excitons are broken up into free electron-hole pairs by effective fields. The effective fields are set up by creating a heterojunction between two dissimilar materials. Effective fields break up excitons by causing the electron to fall from the conduction band of the absorber to the conduction band of the acceptor molecule. While banding of the gap is possibly induced by electrical field within the cell [4], this investigation aims to find out, if there is a recognizable variation of transmission spectrum within different operation conditions. Such as open-circuit, short-circuit and mpp condition.

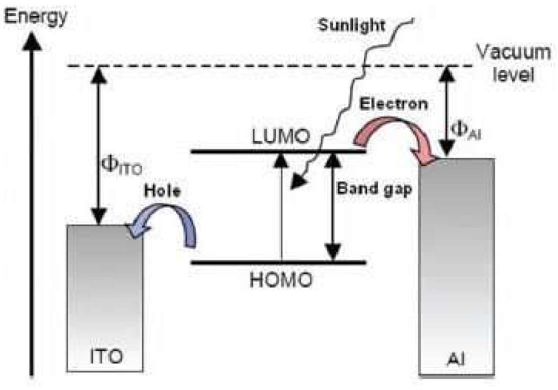

Figure 5: Band gap in an organic Cell [5]

Therefore the semi-transparent organic module is irradiated by a constant halogen light source. The spectrum of the light source is measured and named as reference spectrum. Taking a dark spectrum prevents from background noise. The following equation (2.5) shows the calculation of transmission rate:

$$T = \frac{S - D}{R - D} \cdot 100\% \quad (2.5)$$

with

T : Transmission rate

S : Spectrum behind the module

R : Reference spectrum

D : Dark spectrum

Several transmission spectra at different load conditions are measured indoors, to see if there is any noticeable change (figure 6 to 8).

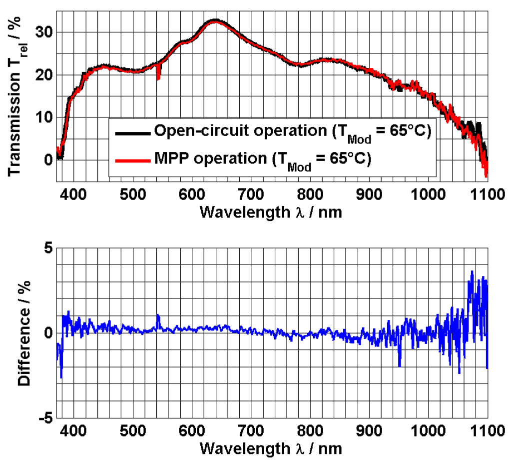

Figure 6: Transmission spectra comparison between open-circuit and MPP operation mode. Light source and module temperature were identical in both measurements. There is no significant difference between the two spectra.

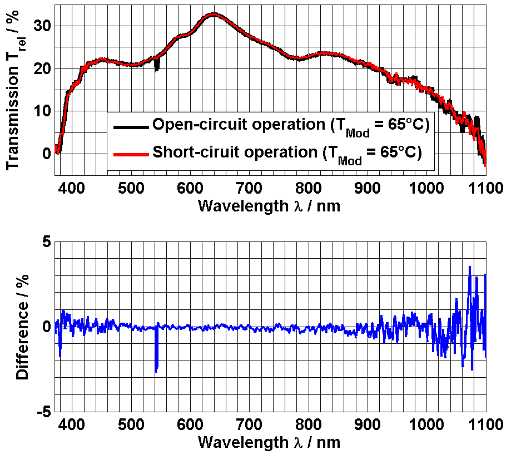

Figure 7: Transmission spectra at short-circuit and open-circuit operation mode. Light source and module temperature were identical in both measurements. There is no significant difference between the two spectra.

As to be seen in Figure 6 and Figure 7, different states of load don't change the quantum efficiency of the OPV cell in a way that fractions of the irradiated light would be absorbed more or less intense as at different operation conditions.
To extend this testing's, the influence of external thermal energy should be investigated. The temperature of the module has been varied in order to find influences on the spectrum. The result stays the same, even at higher temperatures.

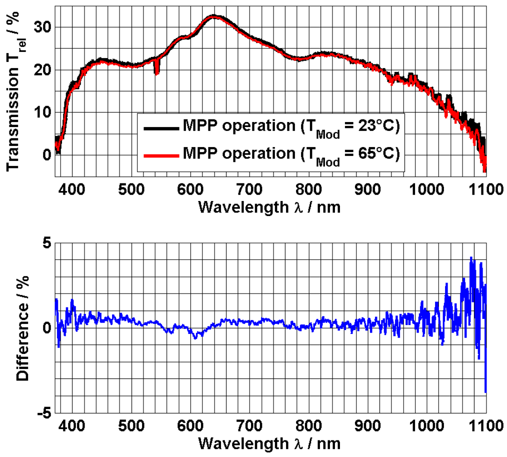

Figure 8: Influence of temperature for Transmission spectra measured in the laboratory. Light source and operation mode were identical in both measurements. There is no significant difference between the two spectra.

4. IV CURVES

During the same period in which the spectra were recorded, the IV curves of the module were recorded as well. Figure 9 shows exemplary some measured curves at different irradiances and weather conditions. In the future, with even more measured curves, further evaluations should be conducted. For example should be shown how the curves vary in comparison to crystalline technologies or how to behave OPV in weak light range. Furthermore, the curves should be simulated using different mathematical models, to see whether and which model for OPV cells and modules performs best (for example, one or two diode model).

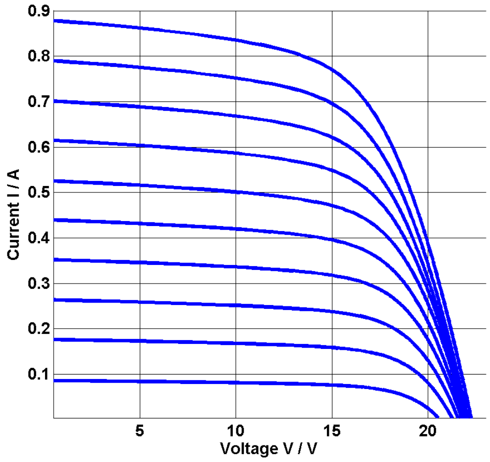

Figure 9: OPV IV curves at different irradiances and weather conditions.

5. SUMMARY

In this work the variation of the transmission spectrum at different weather situations, of a semitransparent organic solar panel was determined via using spectral analysis. To compare the spectra for each condition, the centroid has been calculated. It was found that the different weather conditions have virtually no influence on the transmission spectrum. Furthermore, it was investigated whether the electrical load state of the module has an influence on the transmission spectrum. This is also not the case.

6. REFERENCES

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