Encapsulation of Small Molecule Organic Solar Cells for Improved Stability and Lifetime

In cooperation with NanoSYD center, Mads Clausen Institute, University of Southern Denmark, Sønderborg

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Preface

This report holds my bachelor’s thesis for the completion of my Bachelor of Science (B.Sc.) in Mechatronics from the University of Southern Denmark (SDU). All the work has taken place at NanoSYD center of Mads Clausen Institute at SDU, Sønderborg.

The objectives of this bachelor thesis was to encapsulate and optimize working lifespan of organic solar cells, increasing the effectiveness eventually. This includes fabrication, investigation, optimization and testing of inverted small molecule based organic solar cells with tetraphenyldibenzoperiflanthene (DBP) as donor and fullerene (C_{70}) as acceptor materials.

I would like to thank my supervisors, Morten Madsen (Associate professor, NanoSYD, MCI, SDU) and Bhushan Ramesh Patil (PhD Student, NanoSYD MCI, SDU) for their guidance to me towards the development and construction of my thesis. Furthermore, I would like to thank all the PhD students of NanoSYD center, who have been coordinating and helping me to understand, fabricate and work out my thesis. It is their upmost understanding and kindness that I was able to use such sophisticated and delicate equipment facilities available at NanoSYD center labs.
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1. Project formulation

1.1. Project background

Organic solar cells (OSC) are considered as a cost effective flexible PV technology using fast printing process, simple equipment and easy-to-synthesize materials \(^1\). Much hope is that the vision would become a reality, and this bring a massive increase in the scientific literature with ever increasing power and wonder of processability.

![Best Research-Cell Efficiencies](image)

*Figure 1: Record research cell efficiency chart created by National Renewable Energy Laboratory (NREL), USA \(^{12}\)*
OSC\textsuperscript{s} are potential candidates for future energy generation due to their appealing features such as mechanical flexibility, light weight and roll-to-roll fabrication compatibility\textsuperscript{2}. The strong potential of the technology has led to an increased focus on OSC\textsuperscript{s} from many researchers around the globe, who are constantly progressing towards achieving high power conversion efficiency. Owing to these efforts, the power conversion efficiency (PCE) of OSC\textsuperscript{s} has successfully managed to reach 13.2\%\textsuperscript{3} recently for tandem solar cells and 11.7\% for single junction\textsuperscript{4}.

Figure 1 shows the progress of solar cells since last four decades. Orange curves in the bottom right region shows the progress in emerging PV technologies. It represents that in term of efficiency, there has been a massive progress in the field of organic solar cells.

In spite of the efficiency progress of OSC\textsuperscript{s}, the device lifetime and stability still remains a concern. Compared to the inorganic counterparts, which typically last more than 20-25 years, OSC\textsuperscript{s} has strongly reduced lifetimes, mainly since the organic materials tend to degrade rapidly in ambient exposure\textsuperscript{5}. Moisture and air, in combination with sunlight, are considered to be the primary reason for the degradation of OSC performance over time. These external degradation mechanisms for OSC\textsuperscript{s} can to some extent be prevented by sufficient encapsulation of the devices, in order to protect them from the ambient exposure.

### 1.2. Problem Formulation

The main challenge in this project is the degradation of OSC\textsuperscript{s} which eventually results in short lifetime. The core objective of this thesis is to encapsulate and optimize the inverted small molecule based OSC\textsuperscript{s} to which one of my supervisor Bhushan Ramesh Patil, has been working on. This report not only holds my theoretical aspect but also the fabrications, challenges encountered, experimental data and result analysis.

This project focuses on incorporating different types of encapsulation techniques for small molecule based OSC devices. Small molecule OSC\textsuperscript{s} were fabricated using a pre-established procedure (fabricated at NanoSYD center at Mads Clausen Institute) and the cells were characterized by J-V measurements under standard conditions in order to determine their efficiency. The variation in performances over time was investigated for different encapsulation materials, with the aim to establish a procedure that could improve the stability of the investigated cells. In the project, a systematic study of the encapsulating properties of different materials was conducted, and different encapsulation techniques were carried out in practice.

The task in this project to be:

- Literature research
- Encapsulating organic donor/acceptor materials
- Optical characterization of encapsulated and non-encapsulated organic materials
- Delimitation will be set
- Fabrication and characterization of organic solar cells
- Implementing various encapsulations on organic solar cells
- Measurement of lifetime/stability and performance of encapsulated and non-encapsulated organic solar cells
• Comparison and documentation of lifetime/stability and perform of encapsulated and non-encapsulated organic solar cells

2. Theoretical
2.1. What is a solar cell?

Photovoltaic (PV) effect: The process in which two different materials, when brought in close contact produces an electrical energy when struck by photons from solar radiation and generates either excitons or positive/negative charges [6].

A solar cell is a device that generates electricity directly from the radiant energy from the sunlight through photovoltaic effect. In order to generate necessary power, number of solar cells are connected together to form a PV Modules also known as solar panels [7].

2.2. Types of solar cells

There are different kinds of solar technologies in the market, each having features that works for certain applications [8]. Solar cell technology is categorized in terms of generations, where the first generation technology is known widely, and implements crystalline Silicon solar cells. Second generation technology is thin-film solar cells, which aim to surpass crystalline Silicon solar cells in output power in terms of reduced costs. Organic solar cells (OSCs) fall under ‘third generation’ OSC technology [9].

2.2.1. Silicon (Si) Solar Cells

Silicon (Si) is what is known as semi-conductor, this means that it shares some of the properties of the metals and some from an electrical insulator [10]. In Si solar cell two layers of Si are doped so that one is electron rich (n-type layer) while one is hole rich (p-type layer). When photons are absorbed near the junction the electron and holes are separated and the electrons flow away from the cell towards the load (in to the circuit). Finally, the electron return through the circuit and recombine with the holes [11].

Figure 2: Working mechanism of Silicon solar cell

Figure 3: Image of Silicon solar cell [15]
The basic steps in the operation of a Si solar cell are:

- Absorption of light photons across the p-n junction
- Generation of positive/negative charges
- Charge collection via external circuit.

2.2.2. Thin-film Solar Cells

It is a second generation solar cell technology in which one or more thin layers of PV materials are stacked to fabricate a solar cell. As it is designed to hold reduced amount of PV material, each layer’s thickness ranges from a few nm to μm scale [13]. Therefore, they can be made light in weight, flexible and temperature resistant [14].

![Image of a flexible thin-film solar cell][17]

2.2.3. Organic Solar Cells (OSC)

Organic solar cells (OSCs) have gained attention due to their potential of being light in weight, semi-transparent and environmental friendly energy-converting devices [15].

An OSC is an electricity-generating device consisting of thin layers of organic semiconducting materials hence, named ‘Organic’ solar cells. The basic structure of an OSC is formed by a photoactive layer sandwiched between two thin-film electrodes where at least one electrode is semi-transparent, letting the sunlight enter into the device.

![Basic structure of an organic solar cell][16]
Photoactive Layer (PAL) is composed of two different types of organic semiconducting materials namely, donor (hole rich) and acceptor (electron rich). The concept of using these donor and acceptor materials together is termed as heterojunction, which is equivalent to the p-n junction in inorganic solar cells.

Sunlight consist of radiant particles called Photons. When these photons hit the PAL of an OSC, a tightly bound electron-hole pair is generated which is known as an exciton. Although these excitons are useless until a potential imbalance is created within the system to separate the excitons into electrons and holes and create a steady flow of both electrons and holes. Usually in OSC this imbalance is created via the usage of two electrodes (cathode and anode) of the materials having different work functions. Majority of these excitons, after the bombardment of the photons, are created in the donor layer, after the separation of excitons into charges, the acceptor layer attracts electrons giving an initiate flow of charges [16].

2.2.4. Working mechanism

Working principle of the OPV can be described in just few point as mentioned below
1. Absorption of photons from sunlight into photoactive material
2. Generation of excitons – tightly bound electron-hole pair
3. Separation of excitons into charge carriers
4. Collection of charges at relative electrodes
5. Electricity generation due to steady flow of charges into to the external circuit.

Figure 6, is a simple approach to explain the operation of an OSC. It shows that when a photon of light is absorbed in the donor material, it generates an exciton. These excitons move towards the Donor-Acceptor (D-A) interface and get separated into electrons and holes at the interface. After separation holes move through the donor material and electrons move through electron acceptor material to anode and cathode respectively.

The absorption of photons majorly happens in the donor material. The photons with the energy equivalent or greater than the band gap energy of the photoactive material are absorbed. The built-in electric field variance amongst the work function of the two thin-film electrodes used causes separation of an exciton into charge [18, 19]. Thus, it is critical to choose two electrodes with enough
difference of work functions for OSC \[19\]. Transportation of charges can further be enhanced by using the dedicated electron transport layer (ETL) and hole transport layers (HTL) \[18, 20\].

Work function is an experimentally obtained parameter and is most simply determined from the photoelectric effect experiment. Since in metals electrons are filled up to the Fermi level, and there is no band gap, the minimum energy required to extract an electron from a metal is assigned as its work function \[21\].

2.2.5. Energy level diagram

For open-circuit voltage \(V_{OC}\) of an OSC is directed by the energy levels of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of donor and acceptor materials \[22\].

A best situation is where the LUMO of the donor is lower than the LUMO of the acceptor, and the HOMO of the donor is lower than that of the HOMO of the accepter \[23\]. It is a necessary but yet not a sufficient condition for separation of exciton binding energy \[23\].

**Figure 7**: Operation schematic of the organic solar cell demonstrating energy levels \[24\]

Figure 7 demonstrates the working principle of OSC at the energy levels. Photons are absorbed in donor material majorly and tightly bound electrons-hole pair (exciton) is generated. These excitons travel further to reach the donor-acceptor interface where they get separated into charges i.e. electrons and holes. Now separated electron jumps from LUMO of donor material to LUMO of acceptor material which is attracted by cathode while hole travels to anode from HOMO of donor material \[60\].
2.2.6. Structures of Bulk and Planar heterojunction

A heterojunction is an interface that occur between two semiconductor layers of donor and acceptor of the solar cell [25]. These semiconducting materials have unequal band gap [25].

**Planar Heterojunction (PHJ):** It contain two individual layers of donor-acceptor in between the conductive electrodes. As of different electron affinity and ionization energies of these layers, electrostatic forces are generated at the interface of both layers. Which is also known as Donor-Acceptor (D-A) interface. In figure 8(1) the structure of the planar heterojunction has been demonstrated.

**Bulk Heterojunction (BHJ):** It contains one absorption layer, which is a fine blend of donor and acceptor material. The difference of electron affinity is still there making it more usable. Adoption of this technique allow us to even capture weaker excitons, eventually giving us a higher output. In figure 8(2) the structure of the bulk heterojunction is demonstrated.

Figure 8: Two basic structures of the organic solar cell; (1) Planer heterojunction - two separate donor and acceptor layers are deposited on top of each other to have a photoactive layer and (2) Bulk heterojunction - photoactive layer of donor and acceptor mixed together as one layer.

2.2.7. Buffer layers

Buffer layers are based on materials which have the capability of being able to primarily transfer either electrons or holes due to a suitable positioning of the energy levels. OSC device structures include buffer layers, both at the anode and at the cathode interface, primarily to gain high charge collection and extraction, which also improves the device’s overall performance and respectively optimizing the output. Buffer layers are actually essential for achieving highly efficient OSCs and
can no more be considered as “optional” [26]. Electron transport layer (ETL) attracts electrons from acceptor layer and hole transport layer (HTL) attracts holes from donor layer after separation of exciton.

Some of the basic most used and popular as electron transport layers (ETL) are; Zinc Oxide (ZnO) [63], Titanium dioxide (TiO₂) [64] and Bathocuparoine (BCP) [27]. The basic most used and popular as Hole transport layer (HTL) are; Molybdenum trioxide (MoO₃) [28], Poly(3,4-ethylenedioxythiophene): Polystyrene sulfonate (PEDOT:PSS) [29].

Figure 9: Structure of an organic solar cell with buffer layers.

2.2.8. Two geometrical structures

Figure 10: Non-inverted structure of organic solar cell

Figure 11: Inverted structure of organic solar cell
Figure 10 shows the geometrical structure of an OSC with non-inverted cell structure. In this structure the holes travel to the transparent electrode through HTL and electrons to the metal electrode through ETL. To increase the transportation of the hole HTL is sandwiched between PAL and electrode.

Figure 11 shows the geometrical structure of an OSC with inverted cell structure. In this structure the hole travel to the metal electrode through HTL and the electrons to transparent electrode through ETL. The positioning of HTL and ETL is reversed in inverted compared to the non-inverted structure of OSC.

2.3. Donor and Accepter materials

Fullerene based acceptor materials and small molecule based donor materials are commonly researched materials for OSC. These small molecules offer advantages over their polymeric counterparts, their structures are well defined and display no molecular weight dependence, leading to improved purity and they normally display more organized nanostructures, leading to higher charge carrier mobility [30]. Whereas, on the other hand fullerenes have comparably high electron affinity, which makes them suitable to extract electrons from excitons [31].

Acceptors are the materials that accept electrons from the donor and thus encourages charge separation [31]. The most important acceptors are fullerene based materials such as C₆₀ and C₇₀ for small molecule based organic solar cells. C₆₀ and C₇₀ molecular structures are shown in figure 14 and 15 respectively.

Donors are the materials that absorb photons of light and generate excitons, thus transferring electron from the pair of charge in exciton to accepter materials. The most common donors for small molecule based materials are Copper (II) Phthalocyanine (CuPC) (figure 12) [33] and tetraphenyldibenzoperiflanthene (DBP) (figure 13) [32].

2.3.1. Molecular structures

![Figure 12: Structure of CuPC (Donor)](image)

![Figure 13: Structure of DBP (Donor)](image)

![Figure 14: Structure of C₆₀ (Accepter)](image)

![Figure 15: Structure of C₇₀ (Accepter)](image)
3. Fabrication Techniques

3.1. Small molecule OSCs
In terms of implementation, OSCs are basically divided in two categories: small molecule and polymer based [34]. Both the materials have good film-formation ability; have wide and efficient energy absorption, a planar structure that leads to good charge carrier mobility. Polymer based materials are used in solution processing as they are easily soluble in suitable solvents [35]. On the other hand, small molecule based materials are evaporated using sophisticated vacuum deposition techniques and thus does not involve the use of harmful solvents that are used in solution processing [36, 37].

3.2. Photolithography

3.2.1 Introduction
Photolithography, is a process used in microfabrication to pattern parts of a thin film or the bulk of a substrate [38]. The process involves light exposure through a mask to project the image of a geometric pattern on the substrate which has light sensitive material on it known as photoresist. The substrate then go several chemical processes to remove unwanted resist [61].

3.2.2 Schematic

![Simplified photolithography schematic describing the working principle of photolithography](image)

3.2.3 Process
There are several steps that are to be taken to go through photolithography:

- Photoresist Coating (Spin Casting):
Wafer is held on a spinner chuck and resist is applied on the wafer. Then vacuum underneath the chuck holds down the wafer while it rotates at a very high rpm to get a uniform layer on the wafer. Figur-17 demonstrate the spin coating.

![Diagram of spin coating](image)

**Figure 17: Diagram of spin coating**

- **Pre-Bake (soft Bake):**
  This is done to harden the resist on the substrate or the sample.
- **Alignment:**
  Mask is aligned with substrate in the machine to get wanted pattern the exact way it is required. As shown in figure 16.
- **Exposure:**
  After alignment UV light is bombarded onto substrate through mask to get wanted pattern.
- **Pattern of development**
  This process is done to stabilize and develop photoresist, removing any remaining traces of the coated resist.
- **Etching**
  This is done to etch away the area exposed which was exposed to the UV light and is unwanted. Etching agent is mixture of different ratio of solution
- **Photoresist stripping**
  This last step is done to remove photoresist, if its positive photoresists, acetone is used. If its negative photoresist methyl ethyl ketone (MEK) is used.
3.3. Organic Molecular Beam Deposition (OMBD)

Organic Molecular Beam Deposition (OMBD) is used for deposition of organic materials inside the vacuum chamber. OMBD allows to obtain organic layers of only a few nm thickness with several quantum well structures \[42\]. Although OMBD is compatible with inorganic and organic semiconductor materials but there is an important difference of output between these two. In inorganic materials it requires lattice matching and high substrate temperatures. In comparison, the molecules of the organic compounds have weak Van der Wall forces \[42\].

To avoid any contaminations of oxidation, this chambers base pressure is set to \(10^{-8}\). For thin film on the substrate, ovens are at the temperature up to ca. 100°C to 500°C depending on the materials \[42\]. This deposition is controlled by the shutter in front of the sample and sometime on the face of the oven. The deposition rate varies from material to material which is then measure by the thickness monitor.

3.4. Thermal evaporation

In thermal evaporation deposition technique, the material is heated until evaporated, this is achieved by high electrical current passing through filament or metal plate where the material is placed \[43\]. The chamber is in vacuum to allow vapor particles of material to travel directly to the substrate where the material condenses back to solid state, forming a smooth layer. The evaporated materials are then condensed on the substrate. See figure -20 on the next page for demonstration. This technique is a common method for thin-film deposition \[44\] and is useful for depositing many layers of different materials without chemical interaction between different layers.
To conclude it have two basic steps:
1st: Material evaporation
2nd: Material condensing on the substrate

For thermal evaporation to work optimally, usually a vacuum of $<10^{-5}$ mbar is applied. In addition, contaminants like oxygen and water are reduced and can be eliminated further by the ultra-high vacuum $<10^{-9}$ \[45\].

![Image of boat source in thermal evaporation chamber](image)

Figure 19: An image of boat source in thermal evaporation chamber \[44\]

![General schematic of a thermal evaporation chamber](image)

Figure 20: General schematic of a thermal evaporation chamber \[43\]

3.5. Characterization
Solar cells behave as a diode when there is no incident light present. As the intensity of the light increases, it generates current. It can be imitated as current source in parallel with a diode \[46\].

3.5.1. Current - Voltage (I-V) characteristics
The figure 21 on the next page shows the dark and illuminated characteristics of the OSCs. Most commonly current density ($J$) which is nothing but the current divided by active area of the solar cell, is measured according to standards.
**Isc (Short circuit current):**
Short-circuit current is the current through the OSC when the voltage across the OSC is zero \[^{47}\].

**Voc (open-circuit voltage):**
The open-circuit voltage is the maximum voltage available from a solar cell, where current is zero \[^{48}\].

**Fill Factor (FF):**
Fill Factor is another important performance parameter in the measurement of solar cells, which is given by the formula below:

\[
FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}
\]

$I_{MP}$ and $V_{MP}$ are the maximum current and voltage respectively from the solar cell \[^{49}\]. Ideally, FF is unity (1) and usually it is represented in a percentage (%) value.

**Power Conversion Efficiency (PCE):**
PCE is defined as the ratio of power output from the solar cell to the power of input radiation energy of sun or the solar simulator lamp. It is given by the formula below:

\[
PCE = \frac{(V_{OC} I_{SC} FF)}{P_{in}}
\]

Where $P_{in}$ is the input power of the radiation source. PCE is expressed in percentage (%) value.
3.5.2. Solar simulator

Solar simulator is a device that provides illumination resembling natural sunlight. Its purpose is to provide a controllable indoor test facility, used for testing solar cells and other devices [51]. The output is a uniform beam that closely matches the sun's radiation spectra for a given air mass.

The light intensity for all solar simulators is one sun (1,000 W/m²) as per air mass (AM) 1.5G standard [52]. Each solar simulator has a shutter that can be operated from designed software. The shutter can also be programmed to open from 0.1 second to 999 seconds via the help of the same software.

As ground level spectrum of natural sun varies from location to location around the earth, plus the location of the ground level effect this effect further. For any location to get sunlight it has to pass through the atmosphere which modifies its course before it falls on the surface of earth. To simulate all these natural occurrence factors, a simulator is built [52].

3.5.3. Photoluminescence

Photoluminescence (PL) is characteristic of the material in which light is emitted from the material after the absorption of photons of electromagnetic radiation [62].

Photoluminescence (PL) spectroscopy is a contactless nondestructive method to probe the electronic structure of organic semiconductors. It also measures the spectral distribution from the
semiconductor and analyze vitally important material parameters influencing OSC devices efficiency \[^{[54]}\].

3.5.4. **Photo-bleaching**

Photobleaching is an effect, which causes a material to lose its fluorescence permanently over the period of time. Also causing complications in observing fluorescent molecules since they are destroyed to the exposure of the light.

PL spectroscopy is a good tool to measure the photo-bleaching of the semiconductor materials like DBP.

4. **Encapsulation**

4.1. **Introduction**

Small molecule materials such as DBP particularly is vulnerable to photo degradation induced by oxygen and moisture which is photo-bleaching. Ellipsometry studies showed that during exposure to air and light, the thickness of the active layer in OSC rises while its absorption coefficient significantly decrease \[^{[55]}\]. As materials used in the electrodes of OSCs are rapidly undergo oxidation when exposed to air. This leads to the formation of thin barriers acting as insulation of oxide \[^{[56]}\], hindering electric conduction and collection of the charge carriers.

4.2. **Types of encapsulation**

4.2.1. **Meltonix 1170-60 (Foil)**

![Figure 23: Animation of hot-melt thermoplastic sealing film \[^{[57]}\)](image)

Meltonix 1170-60 (Solaronix SA, Switzerland) is a 60 micron thick hot-melt thermoplastic sealing film suitable for laminating dye solar cells, by applying heat and pressure. Meltonix 1170-60 is chemically compatible with most electrolyte compositions used in dye solar cells. It ensures a robust with confinement of the electrolyte, even in extreme operating condition \[^{[57]}\]. See the Appendix-A for the technical information provided by the company.
4.2.2. DELO-KATIOBOND LP655 (UV-curable Glue)

DELO-KATIOBOND LP655 is light/UV curing adhesive with high barrier against vapor. Due to high permeation resistance against water vapor, this glue is especially suitable for the sealing of sensitive components, such as in this case OSCs. Check Appendix B for the technical information provided by the company.

Figure 24: Image of the glue used for initial testing of encapsulation. Which was changed midway with a newer version of the same glue (name mentioned in the heading)

4.3. Photo-bleaching of DBP using PL measurement

4.3.1. Experimental

The samples of the size 6×18 mm of BK-7 glass were cut using dicing saw from the square wafer of 4 inch. The glass samples were then put in Acetone, to clean any dust particles and impurities for 20 minutes in an ultrasonic water bath. As Acetone is really quick to dry, leaving unwanted traces on the glass sample, it was rinsed immediately with Isopropyl Alchohol (IPA) taking it out of sounication. Glass samples were then dried by nitrogen gas. Later they were transported inside the glovebox which is connected to the cluster system.

40 nm of DBP was deposited on the glass samples using Organic Molecular Beam Depositon (OMBD) at a growth rate of 0.03 nm/s and base pressure of 3×10^{-8} mbar. The layer structure is shown in figure 25.
Samples were then encapsulated using foil and glue as described below. Samples without encapsulation were kept as reference samples.

**Foil:**

Starting the encapsulation, first thing done was to cut similar size of foil as the substrates. Then the samples were placed onto the hotplate, with foil sandwiched between DBP and external glass substrate, which was at 90° C for 5 minutes. Very slight pressure was applied from the top of the glass pressuring the air trapped to escape out.

**Glue:**

Starting the encapsulation, first thing done was to cut similar size of foil as the substrates. Then the samples were placed onto the hotplate, with foil sandwiched between DBP and external glass substrate, which was at 90° C for 5 minutes. Very slight pressure was applied from the top of the glass pressuring the air trapped to escape out.
A small syringe of 10 ml was used to transport and apply glue on the glass/DBP substrate. After the application of glue was done on the DBP layer, another glass sample of same size was applied on the top and was left for UV exposure for 60 minutes. A mercury lamp used had wavelength ranging from 300-800 nm. Whereas requirement for curing glue was wavelength range from 365-460 nm (See Appendix B).

All the samples were left overnight under nitrogen gas in glovebox after they were fabricated and encapsulations were applied. PL measurements were taken for all these samples taking out of glovebox one by one giving the same exposure time to each of them, to have the best optimal comparison. As glue solution reacted with the DBP layer we weren’t able to record its PL reading. Using PMMA or Silver (Ag) as protective layer against the chemical reaction of DBP and glue

**PMMA:**
PMMA is an organic polymer and also known as Plexiglas, it is flexible, light weighted, low in cost and easy processed by spin coating [58]. The purpose of using PMMA layer was to protect DBP layer from reacting with encapsulation glue. PMMA was spin coated on DBP sample at 1000 rpm for 5 seconds and 8000 rpm for 1 minute.

**Silver:**
Silver was used as a protective layer between DBP and glue because it does not react with encapsulation glue [59]. 40 nm of DBP was evaporated on the plain glass substrate as per the parameter mentioned above and 50 nm of silver was deposited, at 1 Å/s by thermal evaporation technique at base pressure of $5 \times 10^{-7}$ mbar, as a second layer on top of DBP. Thus all other experiments were repeated with Ag layer to ensure best comparison of the results.

![Figure 28: Structure of DBP/Ag on glass substrate – with glue encapsulation](image)

![Figure 29: A sample of glass was coated with 40 nm DBP and then 50 nm of Silver. Left image is of the top Silver side. Right image is of the back side covered by the glass](image)
PL measurement were done for all the samples by using a fluorescence microscope having mercury short arc lamp with wavelength of 380 nm as light source. The peak of the PL intensity at 632 nm of DBP PL spectrum was recorded using spectrometer at every 6 seconds from 1 hour to 23 hours.

4.3.2. Results and discussion

Figure above shows PL spectrum of 40 nm DBP. Which shows that PL of DBP material is between the range of 600-850 nm wavelength. It also shows that the highest PL intensity of DBP is in red region of visible light spectrum with the maximum PL intensity observed for 632 nm wavelength. Therefore in order to measure photo-bleaching of DBP over the time, PL intensity at 632 nm wavelength was recorded for all the samples fabricated. Measurements were performed every 6 seconds for the time period of 1 hour to 23 hours.

As for the test initially DBP was deposited on the sample size of 6×18 mm. The reasoning’s were, this was the exact size for the cell on our OSC structure. The figure below presents the structure of small sample with 40 nm DBP deposited on it without any encapsulation.
Results of PL measurement for a non-encapsulated DBP layer of 40 nm was recorded and the results are shown in the graph above. As can be clearly observed from the PL Intensity/Time graph for DBP, the photo-bleaching rate is quite high. Within the time period of couple of hours the DBP is losing up to more than 50% of its ability to generate exciton. This is mainly due to the oxidation when it is exposed to the air. This degradation effect heavily effect the efficiency and life-span of the OSCs.

Initially smaller samples was prepared with 40nm DBP deposited on it, to experiment with glue and foil encapsulation for the purpose of measuring PL.

Foil encapsulated was attempted first with smaller glass samples. As can be seen in figure 33, there are air bubbles trapped inside of encapsulated sample.
These bubbles have a huge impact on foil encapsulation, causing its degradation almost same as DBP. The graph below represents the comparison of plain DBP and DBP-foil encapsulated.

The rate of degradation of plain and encapsulated samples is almost same concluding the foil encapsulations is not the better solution than plain sample but not to be considered the best.

Next came encapsulation with glue. As the drop of glue was put directly onto DBP layer, it started to change its color from purple to pink. This clearly was an indication of a chemical reaction between DBP and the glue. As PL measurements were required to see the photo-bleaching of the element after encapsulation a solution was required. On the figure below a sample of DBP with glue encapsulation is given.
While applying pressure manually during glue encapsulation, it caused sliding and displacement of the encapsulated glass which damaged the entire DBP layer as it had already reacted with glue and dissolved. This was the reason that a protective layer on DBP was needed in order to have glue encapsulation without any further reaction.

Therefore, thin layer of PMMA was spin coated on DBP layer which could act as protective layer. However, as seen in the figure 39 below PMMA totally dissolved and destroyed DBP layer while spin coating itself. It can be seen in the figure 39 (right) that sample is almost transparent and there in no trace of DBP layer on it.

As there was no sample of plain DBP-glue encapsulation, the comparison of its PL degradation was not done. The failure of PMMA as protective layer resulted in finding another solution which could help prevent DBP-glue reaction. For the purpose 50 nm thermal evaporated silver was tried.
Figure 40 demonstrates the glue encapsulated sample of DBP with silver as protective layer.

All the samples either with DBP layer, glue or foil encapsulation were repeated with silver layer deposited over DBP layer protecting it from reacting with encapsulation glue as shown in figure 41 to 43.
Concluding from the graph above, the sample with no encapsulation is degrading faster than the any of the encapsulated samples. Where DBP plain or DBP/Ag is less effective and is more likely to degrade at faster rate than the being encapsulated with foil. Although it seems that foil encapsulation is better than non-encapsulated sample, but as the gradient of both curve seems similar, there might not be that big or effective difference in between them. But Glue encapsulation is showing very promising difference from DBP/Ag and DBP/Ag-foil encapsulation. Showing that the purpose of glue encapsulation is playing its role of preventing any moisture and oxygen from the air to reach DBP. The test was perform over a period of 23 hours and glue encapsulation still held its primary curve slightly descending over time.

Figure 44: Comparison between DBP/Ag, DBP/Ag-foil encapsulation and DBP/Ag-glue encapsulation
This percentage graph gives us a very nice prospective of the degradation rate. It can be concluded from figure 45 that glue encapsulation is best amongst the rest of the samples, where it is degrading only 10-15% over the time of 23 hours. Glue encapsulation is also degrading but in a much slower rate.

4.3.3. Conclusion

As the conclusion, PL spectrum of 40 nm DBP was measured by illuminating samples with UV light having the wavelength of approximately 380 nm. The PL spectrum of DBP lies in red region of the visible light spectrum that is from 600-850 nm range. The highest PL intensity was observed at the wavelength of 632 nm. Hence, for measuring the photo-bleaching of DBP PL intensity at 632 nm was recorded over the time for the samples with and without encapsulations.

40 nm DBP sample without any protection layer or encapsulation degraded very fast, with PL intensity going down to approximately 70% only within an hour. Photo-bleaching of DBP was prevented by using different types of encapsulations that prevented oxygen and moisture to diffuse into DBP layer. In order to prevent reaction between DBP and encapsulation glue a thin layer of PMMA was coated on the top of DBP layer however it totally dissolved DBP and sample was almost transparent. Therefore, later DBP with protective layer of silver was fabricated and encapsulations were tried on it because the glue reacted with DBP layer when there is no protective layer. Foil encapsulation and glue encapsulation on top of silver prevented photo-bleaching of DBP with glue encapsulation being the best solution to prevent photo-bleaching of DBP for the considerable amount of time.

Figure 45: Comparison of plain and encapsulated samples, taking PL Intensity in percentage over time
4.4. Organic Solar Cells (OSC) with and without encapsulation

Many different approaches were made to accomplish best OSC devices in regards to their encapsulation methods. As the final object was to achieve a process of encapsulation that would help sustain the lifetime of the OSC, stopping the degradation while in contact with the air. Inverted OSC configuration was used, as it was the most optimized OSC in fabrication at NanoSYD department of SDU. This chapter includes all the results gathered and a brief discussion on their performances.

4.4.1. Indium-Tin-Oxide (ITO) patterning by photolithography

Photolithography technique was implemented to pattern ITO electrodes. The desired patterns show in the figure 46.

The steps taken were:

- **Coating (Spin Casting):**
  Wafer was held on a spinner chuck and resist (AZ5214E) was coated. Recipe loaded was in three steps:
  - Step 1; time = 2.5 s, rotation = 0 rpm and Ramping = 100 rpm
  - Step 2; time = 5 s, rotation = 500 rpm and Ramping = 5000 rpm
  - Step 3; time = 30 s, rotation = 4000 rpm and Ramping = 5000 rpm

- **Pre-Bake (soft Bake):**
  This was done to harden the resist on the substrate or the sample. Substrate were baked on hotplate for 1 minute @ 90°C

- **Alignment:**
  Mask was aligned with substrate in the machine to get wanted pattern, the exact way it was required.

- **Exposure:**
  After alignment UV light was bombarded onto substrate through mask to get wanted pattern. Substrates were exposed to UV light for time $t = 9s$, with Alignment Gap = 50 $\mu$m, Exposure Gap = 5 $\mu$m

- **Development**
  This process was done to stabilize and develop photoresist, removing any remaining traces of the coated resist. Several step were taken to ensure the developing of the substrate:
  - 1$^{st}$ Dipped in Developer (AZ3518) for 1 minute
  - 2$^{nd}$ Rough rinsing in DI water for 1 minute
  - 3$^{rd}$ Fine rinsing in DI water for 1 minute

- **Etching**
  This is done to etch away the area exposed to UV light was unwanted. Etching solution was a mixture of different ratio of Hydrochloric acid (HCl): Nitric Acid (HNO$_3$): Water (H$_2$O) was chosen to be at 1:0.08:1 which was then heated up to 60$^\circ$ for 5 minutes. First the substrate was dipped in this etching solution for 5 minutes and then rinsed by DI water and dried by nitrogen.

After the patterning was done, the samples were then cut using a dicing saw in the size of 20×15 mm.
After the patterning was done the patterned ITO was bought to nano-lab, where it was left in Acetone and was covered with an aluminum foil. The beaker was left over night to remove any reaming resist and dust particles on the ITO. Then the beaker filled with acetone and ITO samples in it were moved to the ultrasonic bath for at least 30 minutes. The ITO substrate were then rinsed with IPA, as acetone evaporated really fast it leave stains on the samples, and then dipped for cleaning again for another 30 minutes but this time in IPA. This was the last step to ensure maximum cleaning of the ITO patterned samples.

Patterned samples were then moved to the cluster deposition machine which is connected to the nitrogen glovebox, where BCP, C\textsubscript{70}, DBP, MoO\textsubscript{3} and Ag were coated on Patterned ITO.

Firstly the samples were inserted in OMBD chamber, where organic materials were deposited on it:

- BCP was deposited at the rate of $0.03 \text{ Å/s}$ @ pressure of $3 \times 10^{-8}$ mbar
- C\textsubscript{70} was deposited at the rate of $0.5 \text{ Å/s}$ @ pressure of $3 \times 10^{-8}$ mbar
- DBP was deposited at the rate of $0.3 \text{ Å/s}$ @ pressure of $3 \times 10^{-8}$ mbar

The mask used for the OMBD was given in the figure 47 below:
Afterward deposition in OMBD, the samples were moved to the thermal chamber, where all the non-organic materials like MoO$_3$ and Ag

- MoO$_3$ was deposited at the rate of 0.5 Å/s at a pressure of $3 \times 10^{-7}$ mbar
- Ag was deposited at the rate of 1 Å/s at a pressure of $3 \times 10^{-7}$ mbar

The mask used for the thermal chamber is slightly smaller than the organic mask, which is given in figure 48 below:

![Figure 48: Mask for MoO$_3$ and silver in thermal chamber](image)

After the depositions were done the samples were taken out to the nitrogen glovebox with the active layer as shown in figure 49 below.

![Figure 49: Image of ITO and substrate after OMBD deposition and thermal depositing](image)

The active area of the ITO is only around 3 mm$^2$. In each sample of the ITO, it had 7 cells which can produce PCE independent to each other.
4.4.2. Device structure

Figure 50 represents device structure of inverted OSC. In OSC light passes through the glass coated with transparent Indium-Tin-Oxide (ITO) and a BCP transport layer. A planner heterojunction is made with DBP and a C\textsubscript{70} and finally a bottom electrode made from Silver. In the heterojunction photons are absorbed and charge is separated due to the difference in work function of the electrodes.

![Diagram of inverted OSC structure with layers: Glass, ITO, BCP, C\textsubscript{70}, DBP, MoO\textsubscript{3}, Ag.]

Figure 50: The structure of Inverted OSC with layers of BCP/DBP+C\textsubscript{70}/MoO\textsubscript{3}/Ag

Figure 51-53 represent the stack formation of the OSC without and with encapsulation. The gray region in the diagram show the glue or foil in the stack.

![Stack of OSC diagrams with and without encapsulation.]

Figure 51: Stack of OSC with glue encapsulation
Figure 52: Stack of OSC with foil encapsulation
Figure 53: Stack of OSC
Characterization:  J-V characteristics of the fabricated OSCs were measured using the class AAA solar simulator (Sun 3000, Abet technology). In air using voltage sweep of +2 to -1V using keithley source meter. Lifetime of the OSC was measured by repeating the same measurement every 2 minutes for 3.5 hours.

4.4.3. Results and discussions
After the encapsulation of the DBP for measuring PL. Foil and Glue encapsulation were done on the ITO samples with 7 OSCs on it. The silver paste was applied on the contacts of the OSCs to have a definite contact point for measuring the characteristics of OSC.

The plain and encapsulated OSCs are shown in figure 54-56. As can be seen in figure 56 the foil encapsulation has some air bubbles trapped inside of the encapsulation. After trying several ways to avoid these occurrence in foil encapsulation, no favorable outcomes were gained. Due to these air bubbles, our foil encapsulated OSC did not work. There might be several reasons for this occurrence i.e. while putting in foil the top layer of silver might have been distorted. Several
attempts were made to fabricate a working foil encapsulation OSC. Although rest of the batch was working where only foil encapsulation sample was not working.

From the performance parameters shown in figure 58, $V_{OC}$ still remains comparable for with and without encapsulated OSCs. However, FF is lower in encapsulated OSC compared to one which is non-encapsulated and reason might be the reaction of glue with organic materials of OSC. Therefore there is also a tiny leakage current that is visible in the J-V characteristic of OSC with encapsulation, which shows current density little bit higher than that of non-encapsulated OSC. However the OSC with and without encapsulation were performing enough to be investigated for the lifetime measurement which is shown below.
From the figure 59 above it can be concluded that OSC without encapsulation is degrading at a very high rate, whereas glue encapsulated OSC have higher stability in terms of performance. The parameters at the beginning of testing for OSC without encapsulation were $V_{OC} = 0.854 \text{ V}$, $J_{SC} = 6.65 \text{ mA/cm}^2$, FF = 60 % and PCE = 3.42 %, however DBP without encapsulation degraded over the time period of 3.5 hours leaving its parameters to greatly decrease more than 50%, $V_{OC} = 0.3 \text{ V}$, $J_{SC} = 6.2 \text{ mA/cm}^2$, FF = 26.4 % and PCE = 0.49 %.

While the parameters at the beginning of testing for OSC with glue encapsulation were $V_{OC} = 0.84 \text{ V}$, $J_{SC} = 7.69 \text{ mA/cm}^2$, FF = 48 % and PCE = 3.11 %, whereas degradation over the time period of 3.5 hours didn’t caused glue encapsulated OSC devises to loss its characteristics over approximately 15%, $V_{OC} = 0.83 \text{ V}$, $J_{SC} = 9.07 \text{ mA/cm}^2$, FF = 44.7 % and PCE = 2.98 %.
From all the graphs in figure 6 we can conclude that glue encapsulation is working, optimizing the lifespan of the OSC. Where for glue encapsulation all the characteristics of the OSC are very stable and are decreasing in over the time except JSC (%) graph this might be due to crystallization of organic layer and changes in the morphology of the active layer. The graph shows increase in JSC, which expected to eventually start decreasing over the time. Over the period of 3.25 hours the results are very conclusive and sustainable. These experiments were fabricated several times to ensure there accurate results.

4.4.4. Conclusion

Initial performance after optimizing OSC layers thicknesses was promising with OSC without encapsulation showing VOC = 854 mV, JSC = 6.65 mA/cm², FF = 60 % and PCE of 3.42 %, as encapsulation techniques were tried with foil and glue, the performance of OSCs showed descend considering the fact that while encapsulating first with foil the layers OSCs were peeled off because of manual pressure and not having control over the melting duration of the foil and therefore the OSCs with foil encapsulation didn’t work at all.
Secondly for the glue encapsulation, as the glue reacts with organics it could be one of the reasons that the performance of the OSC with glue encapsulation was comparatively lower than the reference OSC without encapsulation. The performance parameters of OSC with glue encapsulation were: $V_{OC} = 842$ mV, $J_{SC} = 7.69$ mA/cm$^2$, FF = 48 % and PCE = 3.11 %. As said before this might be because the glue might have penetrated the OSC from the edges of silver layer and might have reacted with organic layers close to the edge of the silver and hence it shows leakage in the J-V curve.

In spite of performance variation in the OSCs with and without encapsulations lifetime measurements were performed by measuring J-V curve every 2 minutes for 3.5 hours. From the lifetime measurements it was seen that power conversion efficiency of OSC without encapsulation decrease by 90 % within 3 hours, while the power conversion efficiency of OSC with DELO LP655 glue encapsulation drops less than 8 %. This proves that DELO LP655 glue has a significant impact on the stability of OSCs.
Bibliography

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Appendix A
Meltonix 1170-60

Hot Melt Sealing Film with Protective Foil

Meltonix 1170-60 is a 60 micron thick hot melt sealing film suitable for laminating Dye Solar Cell electrodes and closing filling holes, by applying heat and pressure. The material chosen for Meltonix 1170-60 is chemically compatible with most electrolyte compositions. It ensures a robust confinement of the electrolyte, even in extreme operating conditions.

Meltonix 1170-60 does not come with any protective foil.

In the opposite, its equivalent Meltonix 1170-60PF comes with a protective foil on one side. This foil is comparable to the additional film that comes with most popular brands of double-stick tape. It lets the user conveniently apply the tape one sticky side at a time. Meltonix 1170-60PF is used the same way except that it only adheres when heat is applied. With the protective foil, the lamination is completed in two easy steps.

Characteristics

<table>
<thead>
<tr>
<th>Sealing Agent</th>
<th>DuPont Surlyn®</th>
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<tbody>
<tr>
<td>Film Thickness</td>
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</tr>
<tr>
<td>Sealing Temperature</td>
<td>~100 °C</td>
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<tr>
<td>Protective Foil</td>
<td>none</td>
</tr>
<tr>
<td>HS Code</td>
<td>3919.9000</td>
</tr>
</tbody>
</table>

Protected or Non-Protected Sealing Film

References

| 30 x 20 cm       | ref. 42232 |
| 30 x 20 cm, 10 pcs. | ref. 42210 |

Pricing on product page: solx.ch/meltonix60

How to Order

Please visit our webshop at shop.solaronix.com, or send us an e-mail or fax indicating your desired products.

Bulk Supply

In addition to the retail quantities listed above, Meltonix 1170-60 is also available in bulk for industrial purpose. Inquiries are welcome.
**USAGE**

Meltonix 1170-60 is a 60 micron thick hot-melt film specifically suitable for sealing glass electrodes. It is supplied in sheets from which virtually any shape of gasket can be cut out. Such a gasket is then laminated between two glass substrates by applying heat an pressure.

The resulting stack leaves an internal pocket in which a liquid electrolyte can be hosted. The interstice between the electrodes is slightly inferior to 60 microns after processing.

**Sealing Dye Solar Cell Electrodes**

Cut out a sealing gasket from a sheet of Meltonix 1170-60. The inner dimensions should correspond to, or be slightly larger than, the active area of the cell to be laminated, but not smaller. The outer dimensions should be 2-3 mm larger on all sides in order to ensure a good confinement of the electrolyte. Make sure the overall size of the gasket leaves room for electrical contacts on the electrodes after sealing. Watch out for wrinkles, defects, and debris.

For solar modules (several cells interconnected on the same substrate), we recommend 1-2 mm of gasket between the cells, and at least 2-3 mm on the outer perimeter of the module.

Position the gasket on the conducting side of the anode so that it matches up with the active area. There should be one or more edges of the electrode that are not covered by the gasket to leave room for electrical contacts.

Place the counter-electrode, conductive side facing down, on top of the gasket to form a glass sandwich. Consider shifting slightly the two electrodes to leave room for electrical connections.

Apply heat and pressure with the help of a hot press or a similar tool set at 110°C. A domestic iron set to synthetic fabric can be advantageously turned into a hot press for small works. After about ten seconds, the hot-melt material should seal the electrodes together. If not, repeat this operation until the whole surface of the gasket has melted onto both electrodes.

Be careful not to apply too much pressure. This can cause the gasket to spread out, resulting in uneven gasket thickness.

**A good adhesion of the sealing film to the glass plates can be confirmed by a careful visual examination. The hot-melt material should match the refractive index of the glass and look very transparent all over the gasket surface.**

The degradation of finished Dye Solar Cell is typically due to leaks from imperfect sealing. Temperature and pressure adjustments may be necessary to find the optimal conditions for your setup.

Remember that stained titania electrodes are sensitive to air, light, and high temperature when the electrolyte is not present. Even when the electrodes are sealed, air can still enter the cell thought the electrolyte filling holes. To avoid degradation of the cell proceed directly to electrolyte filling if required.

**Sealing Electrolyte Filling Holes**

Electrolyte filling holes can be sealed in a similar fashion, by laminating a glass disc onto the hole on the external side of the electrode. The process is similar to the procedure explained above.

First, cut out a piece of Meltonix 1170-60 the size of the glass circle or bigger. Position the piece of Meltonix 1170-60 over the hole, and center the glass disk on top of it.

Apply heat and pressure for a few seconds to adhere the Meltonix to the glass surfaces. The hole is now sealed.

**Gently nudge the sealed glass disc with a sharp tool, the disc shouldn’t pop out too easily when the hole is properly sealed.**

**Common Pitfalls**

A faulty seal will eventually lead to electrolyte leakage and allow the cell to dry out. Insufficient pressure, and/or insufficient temperature for a too short time can prevent a proper sealing. Although the resulting imperfections may not be instantly visible, such defects are absolutely detrimental for the long term performance of Dye Solar Cells.

In the opposite, over pressure can spread the sealing film too thin and allow both electrodes to touch each others, causing internal short circuits. This is possibly traced by a slight conductivity between the electrodes prior to adding the electrolyte, or a very low open-circuit voltage under illumination.
Too high a temperature can also generate defects, such as forming bubbles in the sealing film, which could in turn allow the electrolyte to permeate through the gasket. Here is a series of close up views of the sealing gasket between adjacent cells in a DSC module:

**EXAMPLE**

A Dye Solar Cell Sealed With Meltonix 1170-60

A 36 mm² titania photo-anode was prepared with 2 prints of Ti–Nanoxide T/SP and 1 print of Ti–Nanoxide R/SP on a piece of TCO22–7 glass substrate. The electrode was treated with TiCl₄, and stained in a solution of Ruthenizer 535–bisTBA with chenodeoxycholic acid (1:10) as a co-adsorbent. A platinum coated cathode was prepared on another TCO22–7 substrate with a layer of Platisol T. The two electrodes were laminated together using Meltonix 1170-25 and the solar cell was filled with Mosalyte TDE-250 through a hole in the cathode. The filling hole was then sealed with Meltonix 1170-60 and a thin glass circle of 6 mm diameter.

The resulting solar cell was placed under continuous 1 sun illumination using a Solaronix Solixon Class-A solar simulator. The efficiency of the solar cell was monitored yielding the following stability plot.

In this accelerated aging test, 1000 h of continuous full sun illumination corresponds approximately to the amount of light received in 1 year outdoor. The sample cell monitored here demonstrates an excellent stability after 9000 h, whereas an improperly sealed solar cell would drop within the first hundred hours.
STORAGE AND SAFETY

Storage

Store the film in its original envelope or similar on a flat surface. Prevent from bends and wrinkles. Keep in a dry place at room temperature, away from light exposure.

The product is not known to suffer from degradation when stored properly.

Safety

Meltonix 1170-60 is for research and development use only and is intended to be manipulated by knowledgeable personnel.

For a complete description of safety measures, please refer to the Material Safety Datasheet (MSDS) of Meltonix 1170-60.

solaronix.com/msds/

RELATED PRODUCTS

Cited in This Document

- TCO22–7, FTO coated glass substrates.
- Ruthenizer 535–bisTBA, industry standard photo-sensitizer.
- Chenodeoxycholic Acid, staining additive.
- Ti–Nanoxide T/SP, screen-printable titania nanoparticle paste.
- Ti–Nanoxide R/SP, screen-printable reflective titania paste.
- Platisol T, platinum precursor paint.
- Solixon, continuous illumination solar simulators.

Consider Also

- Meltonix 60PF, 60PF micron sealing film with protective foil.
- Meltonix 25, a 25 micron thick variant.
- Meltonix 100, a 100 micron thick variant.

REFERENCES

People Using Meltonix Products

A selection of publications using Meltonix products:

Appendix B
**DELO-KATIOBOND® LP655**
Light-/UV-curing adhesive with high barrier function against water vapour

**Base**
- modified epoxy resin
- one-component, solvent-free, UV-/light-curing

**Use**
- due to the high permeation resistance against water vapor, the product is especially suitable for the sealing of sensitive components, e. g. flexible photovoltaic cells, E-Paper, barrier films
- for edge sealing and flat bonding
- for the bonding of glass, ITO-coated glass and other materials
- the product is normally used in a temperature range of -40 °C to +120 °C; depending on the application, other limits may be more reasonable
- compliant with RoHS directive 2011/65/EU
- recognized Photovoltaic Polymeric material certified by UL

**Processing**
- the adhesive is supplied ready for use; in case of cool storage, it must be ensured that the container is conditioned to room temperature before use
- the containers are conditioned at room temperature (max. 25 °C); the conditioning time is approx. 4 h for containers up to 1,000 ml and approx. 12 h for containers up to 10 litre; additional heat addition is not allowed
- the adhesive is usually applied by dispensing or roller application
- the adhesive can be processed well from the original container
- the surfaces to be bonded must be dry as well as free of dust, grease and other contaminations
- use DELOTHEN cleaners for the cleaning of bonding surfaces
- when using aqueous cleaners with alkaline properties, they must be removed from the bonding surface after cleaning through appropriate rinsing cycles
- dispensing valves and product-bearing elements must be carefully cleaned before use, residues of other products must totally be completely removed; DELOTHEN EP as well as acetone, isopropanol or a mixture of both are recommended to remove DELO-KATIOBOND residues
- for further information please refer to our instructions for use DELO-KATIOBOND
**Curing**
- curing with UV light or visible light in a wavelength range of 320 – 440 nm. DELOLUX LED curing lamps are especially suitable as per the chart below. All standard DELOLUX HID discharge lamps are also suitable.
- after irradiation curing until final strength within 24 h at room temperature
- increased temperatures accelerate the reaction, lower temperature decelerate it
- increased intensities shorten the required irradiation time, lower intensities prolong it

<table>
<thead>
<tr>
<th>Lamp type</th>
<th>DELOLUX 20 / 50 / 80</th>
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<tbody>
<tr>
<td>Wavelength [nm]</td>
<td>365</td>
</tr>
<tr>
<td>Suitability</td>
<td>++</td>
</tr>
</tbody>
</table>

- not suitable ++ suitable +++ especially suitable

**Absorption spectrum**
- photoinitiation system in epoxy resin basic matrix

**Curing parameters**
- dependent on material thickness and absorption, adhesive layer thickness, lamp type and distance between lamp and adhesive layer

**Technical data**

*Color*
cured in a layer thickness of approx. 0.1 mm yellowish

Density [g/cm³]
DELO Standard 13 at room temperature (approx. 23 °C) 1.4

Viscosity [mPas]
at 23 °C, rheometer, shear rate 10 1/s 10000

Processing time
at room temperature (max. 25 °C) 1 week

Minimal irradiation time [s]
DELO Standard 37, DSC UVA intensity: 55 - 60 mW/cm² DELOLUXcontrol, at 30 °C 16

Recommended irradiation time [s]
DELOLUX 03 S, UVA intensity: 55 - 60 mW/cm² DELOLUXcontrol 60

Curing time until final strength [h]
at room temperature (approx. 23 °C) after irradiation 24

Curable layer thickness [mm]
DELO Standard 20 curing lamp DELOLUX 03 S UVA intensity: 55 - 60 mW/cm² DELOLUXcontrol 0.5
Compression shear strength glass/glass [MPa]
DELO Standard 5
UVA intensity: 55 - 60 mW/cm², DELOLUXcontrol, irradiation time: 60 s
curing time: 24 h at room temperature (approx. 23 °C)

11

Compression shear strength glass/Al [MPa]
DELO Standard 5
UVA intensity: 55 - 60 mW/cm², DELOLUXcontrol, irradiation time: 60 s
curing time: 24 h at room temperature (approx. 23 °C)

9

Compression shear strength glass/FR4 [MPa]
DELO Standard 5
UVA intensity: 55 - 60 mW/cm², DELOLUXcontrol, irradiation time: 60 s
curing time: 24 h at room temperature (approx. 23 °C)

9

Compression shear strength glass/PBT [MPa]
DELO Standard 5
UVA intensity: 55 - 60 mW/cm², DELOLUXcontrol, irradiation time: 60 s
curing time: 24 h at room temperature (approx. 23 °C)

4

Compression shear strength glass/PC [MPa]
DELO Standard 5
UVA intensity: 55 - 60 mW/cm², DELOLUXcontrol, irradiation time: 60 s
curing time: 24 h at room temperature (approx. 23 °C)

3

Tensile strength [MPa]
according to DIN EN ISO 527
layer thickness: 1 mm

36

Elongation at tear [%]
according to DIN EN ISO 527
layer thickness: 1 mm

1

Young’s modulus [MPa]
according to DIN EN ISO 527
layer thickness: 1 mm

4400

Glass transition temperature [°C]

170

Coefficient of linear expansion [ppm]
TMA, in a temperature range of +30 to +80 °C

43

Decomposition temperature [°C]

299

Shrinkage [vol. %]

2.5

Water permeation [g/m²·d]
ASTME96
at +60 °C and 90 % relative humidity
layer thickness: 1 mm

6.1

Dielectric constant
RF-IV method, 1 MHz, at 25 °C +/- 3 °C

3.1

Dielectric constant
RF-IV method, 10 MHz, at 25 °C +/- 3 °C

3.2

Dielectric constant
RF-IV method, 100 MHz, at 25 °C +/- 3 °C

3.1

Dielectric constant
RF-IV method, 1 GHz, at 25 °C +/- 3 °C

3.0

Storage life at 0 °C to +10 °C
in unopened original container

6 months
Instructions and advice

General
The data and information provided are based on tests performed under laboratory conditions. Reliable information about the behavior of the product under practical conditions and its suitability for a specific purpose cannot be concluded from this. Many product properties are subject to temperature and may change permanently, especially at high temperatures. It is the user’s responsibility to test the suitability of the product for the intended purpose and temperature range of use by considering all specific requirements. Type and physical and chemical properties of the materials to be processed with the product, as well as all actual influences occurring during transport, storage, processing and use, may cause deviations in the behavior of the product compared to its behavior under laboratory conditions. All data provided are typical average values or uniquely determined parameters measured under laboratory conditions. The data and information provided are, therefore, no guarantee for specific product properties or the suitability of the product for a specific purpose.

Instructions for use
The instructions for use of DELO-KATIOBOND are available on: www.DELO.de. We will be pleased to send them to you on demand.

Occupational health and safety
see material safety data sheet

Specification
The properties in italics are part of the specification. Ranges with clear limits are defined for them and others, where applicable. In the course of the QA test, each batch is tested for these properties and the maintenance of the limits is ensured. The measuring methods used can deviate from those specified in the data sheet. Details can be found in the QA test report.