Electroluminescent and Optoelectronic Properties of OLEDs with Bay-Extended, Distorted Perylene Esters as Emitter Materials

Joachim Vollbrecht, [a, b] Simon Blazy,[a] Philipp Dierks,[a] Samuel Peurifoy,[c] Harald Bock,[d] and Heinz Kitzerow*[a, b]

Three esters with a perylene, a unilaterally, and a bilaterally extended perylene core, respectively, were used as emitter materials for organic light-emitting diodes. The electroluminescent properties of these devices were studied. Different spectral shifts were found, which can be attributed to the formation of excited dimers (excimers) in the nanofilms of the emitter materials. Thermal treatment of the unilaterally extended derivative resulted in a red-shift of the electroluminescence owing to the formation of a denser nanofilm. The luminescence and efficiency of optoelectronic devices employing the extended perylene esters exceed those of devices using an emitter layer comprised of the perylene ester. Different deposition methods, limitations in the deposition process, and the role of hole-transporting materials are compared.

1. Introduction

Since the pioneering works of Tang and VanSlyke,[1] who showed that light-emitting diodes based on small organic molecules can be produced, and Burroughes et al.,[2] who depicted the suitability of conjugated polymers for organic light-emitting diodes (OLED), there have been major advances in the field of organic electronics (OE) in general. The commercial use of OLEDs in displays[3] and the emergence of planar lighting systems[4] are examples of an ongoing technological progress. Other notable applications of organic semiconductors (OSC) include, but are not limited to, organic photovoltaics (OPV),[5] organic field-effect transistors (OFET),[6] flexible electronics,[7] and sensors.[8] Increasing the performance of OE devices is also coupled with the promise of low-priced production due to the use of printing techniques.[9]

One important avenue to create market-ready OE devices is the improvement of manufacturing processes. Additionally, the synthesis and characterization of new OSC materials are also a necessary prerequisite for OE devices to leave their current niche. The orientation and ordering of the OSC molecules when deposited onto a substrate are crucial to the performance of devices.[10] Thus, OSCs showing liquid crystalline (LC) behavior have been in the spotlight of materials scientists in recent years. Especially calamitic[11, 12] and discotic[13–21] compounds are promising owing to their self-organizing properties, which can enhance the charge carrier mobility μ due to an improved π–π-stacking.[22] Another advantage of LC-OSCs is the possibility to remove defects by annealing the nanofilms, a process that is also known as self-healing.[23] The impact of LC-OSCs is underscored by the wide variety of devices implementing these compounds.[24–26] Among others, these include OLEDs—both for display[27, 28] and lighting applications,[29, 30] OPVs,[31, 32] OFETs,[33, 34] and chemical or thermal sensors.[35]

In particular, the expansive group of perylene derivatives has shown to contain promising candidates for OE applications,[36, 37] Mainly compounds with different side chains,[38] hetero atoms[39] and functional groups[40] have been studied, but derivatives with extended arene cores have also garnered some attention.[41–43] Recently, perylene derivatives containing helicene fragments in their cores have been of special interest owing to their peculiar properties, among others showing liquid crystalline behavior with minimal side chains due to distortions in the arene core.[44, 45] The electronic and spectroscopic properties of extended perylene derivatives with distorted cores are also noteworthy.[46–48]

Hence, the focus of this study will be to investigate the properties of OLEDs containing perylene-3,4,9,10-tetracarboxylic tetaethyl ester (1), the unilaterally extended perylene derivative phenanthro[1,2,3,4,ghi]perylen-1,6,7,12,13,16-hexacarboxylic hexaester (2) and the bilaterally extended perylene derivative dinaphtho[1,2-α:1',2']coronene-8,9,18,19-tetracarboxylic 2-ethylhexylester (3) as emitter materials. The derivatives of...
compound 3 with different side chains (4–6) were also considered (Figure 1). Compounds 1 and 3 have been used successfully in OLEDs in prior studies. While compound 1 has been investigated thoroughly, compound 3 has only been shown to work as emitter material as a proof of concept. Furthermore, 2-ethylhexyl side chains were chosen, because derivatives of compound 3 could either be used to prepare OLEDs only in little numbers due to a lack of supplies of that derivative (4) or only via solution processes such as spin-coating (5). In case of compound 6, no functioning devices could be produced at all. In summary, OLEDs with compound 1 as emitter layer (EML) were used as a reference for OLEDs using compounds 2 and 3 in the EML. All emitter materials were deposited via thermal vapor deposition (TVD), unless specifically mentioned otherwise.

![Molecular structure of the emitter materials perylene-3,4,9,10-tetracarboxylic tetraethylester 1, phenantheno[1,2,3,4,ghi]perylen-1,6,7,12,13,16-hexacarboxylic hexaester 2, dinaphtho[1,2-a:1′,2′-j]coronene-8,9,18,19-tetracarboxylic alkylesters (3–6), the hole transporting materials N,N'-bis(3-methylphenyl)-N,N'-diphenylbenzidine (TPD) and poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) (7).](attachment:structure.png)

**2. Experiments**

In principle, OLEDs consist of a substrate, an anode, a layer of organic semiconductor material(s), and a cathode. Since the purpose of an OLED is to emit light, either the cathode or anode has to be transparent in the visible region of the spectrum, to allow the generated light to leave the device. Usually, a glass substrate coated with a layer of indium tin oxide (ITO) is used. While OLEDs containing only a layer of a single OSC can work, multi-layered devices with at least one hole-transporting layer, an emitter layer and an electron-transporting layer are most commonly used.

In this study, up to 36 OLEDs on a single substrate were fabricated at once. This was possible due to the matrix-like arrangement of the anodes and cathodes (Figure 2). The substrates were patterned with up to six, parallel ITO stripes (0.6 × 6 cm²), which would later be used as anodes. These patterns were achieved by etching the ITO with Zn-powder and an HCl-solution. The areas that would later become the anodes were masked with scotch tape. The patterned substrates were then cleaned with detergent solutions and annealed at 250 °C over 24 h, thus enhancing the conductivity of the ITO. Then, the ITO was activated in an ozone plasma for 30 min. Directly afterwards, poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) was spin-coated as a hole injection layer onto the substrates. A commercial PEDOT:PSS-solution was used (Clevios-P, Heraeus).

The substrates with a PEDOT:PSS layer were then annealed for 1 h at 60 °C to remove traces of solvent. In a subset of the manufactured OLEDs, a layer of N,N'-bis(3-methylphenyl)-N,N'-diphenylbenzidine (TPD) was thermally evaporated on top of the PEDOT:PSS layer. The pressure in the vacuum chamber for the evaporation of organic compounds was p < 1 × 10⁻⁵ mbar. Both, PEDOT:PSS and TPD were used as hole transporting/electron blocking layers. However, TPD was used to facilitate the transport of holes into the emitter layer due to the lower energy of its highest occupied molecular orbital (Figure 3). The influence of TPD on the OLED performance is another subject of this study. The thickness of the TPD layer was varied (dTPD = 10–40 nm). Depending on the type of OLED, the respective emitter material—compounds 1, 2 or 3—was thermally evaporated on top of either the PEDOT:PSS or TPD layer. Typically, the thicknesses of the emitter layers were d_emitter = 30–80 nm. After depositing the organic layers, up to six parallel aluminum stripes (0.6 × 6 cm²) were thermally evaporated at a pressure p < 1 × 10⁻⁵ mbar on top of the organic layers. The cathodes were perpendicular to the ITO anode stripes. Thus, a matrix of 6 × 6 single OLEDs with an area of 36 mm² was created. The OLEDs could be addressed one at a time by applying a voltage on the respective anode and cathode. Furthermore, the variations in the layer thickness across the surface of the substrates owing to the nature of the thermal evaporation process were taken into account. Consequently, each OLED was comprised...
of organic layers of slightly different thicknesses $d_{\text{org}}$. Layers dedicated only to the injection and transport of electrons were not used. Perylene diimides are known to be good electron acceptors and are thus suitable for electron transporting purposes.\cite{36, 46} While the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) of perylene esters and their derivatives tend to be at higher energies than their diimide counterparts, they are still considered to be viable electron transporting materials.\cite{28, 50}

The focus of this paper is to compare compounds $1$, $2$, and $3$ as emitter materials for OLED applications. While compounds $1$ and $3$ were used earlier,\cite{29, 47, 49–51} compound $2$ has not been used in organic light emitting devices so far. The electroluminescent behavior—in particular the spectral properties and color perception—and the optoelectronic behavior—current–voltage–luminance characteristics and the role of hole transporting materials such as TPD—are examined for the three emitter materials. Especially the direct comparison in performance is a subject of investigation.

3. Results and Discussion

3.1. Electroluminescence Spectra

At first, the electroluminescent properties (EL) of working OLEDs using compounds $1$–$3$ as emitter materials were measured. These three emitters show distinctly different EL-spectra, with compound $1$ showing the maximum emission at $\lambda_{\text{max}} = 589$ nm with a full width at half maximum of FWHM = 91 nm, compound $2$ exhibiting the maximum emission at $\lambda_{\text{max}} = 568$ nm with FWHM = 70 nm and compound $3$ showing the maximum emission at $\lambda_{\text{max}} = 538$ nm with FWHM = 45 nm (Figure 4a and Table 1). This comparison indicates that compounds with a bigger arene core—$2$ and $3$—emit light in narrower spectra and show a blue shifted emission compared to compound $1$, which has a relatively small arene core.

The emission spectrum can be explained with the formation of excimers. The existence of excimers in nanofilms of compounds $1$–$3$ and the relationship of the interplanar distance between the molecules and the resulting excimeric red shift were studied earlier.\cite{48} However, the EL-spectra demonstrate that one has to take into consideration the effects of excimer formation, when choosing compounds such as $1$–$3$ for OLED applications.
applications. Photoluminescence (PL) spectra of nanofilms deviate from the PL spectra of solutions of compounds 1–3, but are very similar to the respective EL spectra (Figure 4b). As mentioned above, the effects of excimer formation on the PL-spectra of nanofilms of compounds 1–3 were already established and discussed in preceding studies. [48] Consequently, it is reasonable to assume that the same process is responsible for the observed EL-spectra.

The nanofilms of compounds 1–3 are mainly polycrystalline,[29, 54, 55] but compound 2 is of particular interest, because it can form a glassy liquid crystalline phase with a denser packing after annealing, resulting in a smaller interplanar distance and a more pronounced excimeric red shift in the PL-spectra.[44, 48]

We compared two OLEDs with compound 2 as the emitter material. The emitter layers were obtained via spin-coating from a CHCl₃-solution at room temperature and via evaporation at \( T = 230^\circ C \), the temperature necessary to obtain the denser glassy liquid crystalline phase. As a result, we can observe noticeable changes in the EL-spectra (Figure 5a).

The OLED with the spin-coated nanofilm shows the maximum emission at \( \lambda_{\text{max}} = 536 \text{ nm} \) with FWHM = 89 nm, while the OLED with the evaporated nanofilm exhibits the maximum emission at \( \lambda_{\text{max}} = 568 \text{ nm} \) with FWHM = 70 nm. So, a shift of the EL-spectrum of \( \Delta \lambda_{\text{TVD}} = 32 \text{ nm} \) can be observed. Another OLED was produced with a spin-coated layer from a CHCl₃-solution of compound 2, the EL-spectrum was measured and subsequently this very same OLED was annealed at \( T = 230^\circ C \) and the electroluminescent behavior was measured again (Figure 5b). Before annealing, the OLED shows a maximum emission at \( \lambda_{\text{max}} = 540 \text{ nm} \) with FWHM = 83 nm and after annealing at \( \lambda_{\text{max}} = 556 \text{ nm} \) with FWHM = 66 nm. The red-shift due to annealing of the nanofilm is not as pronounced as in OLEDs with an EML which was deposited via TVD (\( \Delta \lambda_{\text{annealed}} = 16 \text{ nm} \) and \( \Delta \lambda_{\text{TVD}} = 32 \text{ nm} \)). This can be explained due to the on-going reduction of luminance of OLEDs that occurs after multiple measurements at higher voltages (\( U > 8 \text{ V} \)). The measurement of the EL-spectra starts at the lower wavelengths. Therefore, an on-going reduction of luminance will result in an artificial blue-shift of the EL-spectrum in the region of \( \Delta \lambda \approx 5–10 \text{ nm} \).

Since the polarity of the solvent neither changes the absorption nor the photoluminescent behavior of compounds 1–3 in solution,[48] the most likely explanation for the observed red-shift of the EL spectra is the variation of the interplanar distance of the molecules.

As was conjectured in earlier studies,[48] these results underline the influence of the interplanar distance on the excimeric red shift and the color perception of the emitted light of OLEDs using this compound as emitter material.

For OLEDs with compound 3 as emitter material, a similar change in the EL-spectra can be observed (Figure 6b). However, in this case the formation of a denser film and a subsequently stronger excimeric red shift is most likely not taking place. If a nanofilm of compound 3 is spin-coated as a CHCl₃-solution

---

Table 1. FWHM’s and maxima \( \lambda_{\text{max}} \) of the EL and PL spectra shown in Figures 4–6.

<table>
<thead>
<tr>
<th>Compound</th>
<th>EL FWHM [nm]</th>
<th>( \lambda_{\text{max}} ) [nm]</th>
<th>PL FWHM [nm]</th>
<th>( \lambda_{\text{max}} ) [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>91</td>
<td>589</td>
<td>60</td>
<td>598</td>
</tr>
<tr>
<td>2</td>
<td>Spin-Coated</td>
<td>89</td>
<td>536</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>TVD</td>
<td>70</td>
<td>568</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Spin-Coated, not annealed</td>
<td>83</td>
<td>540</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Spin-Coated, annealed</td>
<td>66</td>
<td>556</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>TVD, pristine</td>
<td>45</td>
<td>538</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>TVD, used</td>
<td>42</td>
<td>582</td>
<td>–</td>
</tr>
</tbody>
</table>

---

Figure 5. a) Normalized EL spectra of OLEDs with compound 2 as emitter material deposited via spin coating (open, orange circles) and thermal evaporation (red circles), respectively. b) Normalized EL spectra of an OLED with compound 2 as emitter material deposited via spin-coating (open, orange circles) and after subsequently being annealed at \( T = 230^\circ C \) (red circles).
onto a glass substrate at room temperature and then annealed at \( T > 250 \) °C, a change in the absorption spectrum can be observed—specifically in the wavelength region of \( \lambda = 520–560 \) nm (red arrow in Figure 6a). This new peak coincides with the strongest absorption band of dianhydride 7. Thus, it is likely that compound 3 changes its chemical structure—namely from a tetraster to the corresponding dianhydride—due to the prolonged annealing process.

To confirm this hypothesis, the absorption of a film of pristine compound 3 was measured and this film was subsequently mixed with dianhydride 7. The absorption spectrum of the mixed phase shows a new peak at \( \lambda = 550–560 \) nm and the color of the mixed phase changes from yellow to orange (Figure S10 in the supplement).

These results have important implications for the deposition procedure of compound 3. The minimal temperature needed to evaporate compound 3 in a vacuum is \( T = 230 \) °C. However, if compound 3 is not in good contact with the ceramic crucible or if substance from prior deposition cycles remains in the crucible, then the necessary temperature for the evaporation can exceed the critical temperature range of \( T = 250–270 \) °C and a degradation of compound 3 can take place. This is also supported by a simple visual examination, where pristine samples of compound 3 are yellow, samples after one evaporation cycle are orange-red and after several evaporation cycles dark grey (inset of Figure 6a), which indicates at least some level of chemical decomposition and is in agreement with the simple experiment described in Figure S10 in the supplement. In contrast, the absorption spectra of nanofilms of compound 2 do not change after evaporation or annealing at \( T = 230 \) °C, indicating that the reduction of the interplanar distance is the reason for the red shift in the EL-spectra, rather than a changing chemical structure.\(^{48}\) However, if nanofilms of compound 2 are annealed at temperatures of \( T > 270 \) °C for several hours, then—similar to compound 3—a change in the absorption spectra can be observed. Moreover, the nanofilms of compound 2 annealed at \( T > 270 \) °C did not show any kind of photoluminescence (Figure S11 in the supplement).

The EL-spectra of OLEDs with an EML evaporated from pristine samples of compound 3 differ from the EL-spectra of OLEDs with an EML that was evaporated from samples that were used in prior evaporation cycles. OLEDs with a pristine EML of compound 3 have the maximum emission at \( \lambda_{\text{max}} = 538 \) nm with FWHM = 45 nm and OLEDs with an EML consisting of a used sample of compound 3 at \( \lambda_{\text{max}} = 582 \) nm with FWHM = 42 nm. Furthermore, the EL-spectrum is not simply red shifted, but the peak in the region of \( \lambda = 540 \) nm loses intensity—possibly due to self-absorption, quenching effects or the formation of exciplexes.\(^{56}\) The optical band gap of compound 7 is \( \Delta E_{\text{opt}} = 2.25 \) eV and the emission maximum of compound 3 is at \( \lambda_{\text{max}} = 538 \) nm or \( E_{\text{max}} = 2.31 \) eV. Since a homogeneous distribution of the different molecules—those of compounds 3 and 7—can be assumed and since the average distance of neighboring molecules in the nanofilm is \( s < 1 \) nm, it is reasonable to assume that an energy transfer from the tetraesters 3 to the dianhydrides 7 could take place (inset of Figure 6b). Thus, it is possible that excited tetraester molecules 3* could act as donors and transfer their energy via a Förster resonance energy transfer (FRET), Dexter energy transfer (DET) or a similar process to a neighboring dianhydride molecule 7, which would act as an acceptor (3* + 7 → 3 + 7*). Then, the excited dianhydride 7* would relax into the ground state and emit a photon of the energy \( E_{\text{max}} = 2.13 \) eV (\( \lambda_{\text{max}} = 582 \) nm).

To describe the color perception of all the relevant EL-spectra that were shown in Figure 4–6, the \( x–y \)-coordinates based on the 1931 CIE chromaticity formalism were determined (Figure 7 and Table S2 in the supplement).

Overall, the effects of a denser packed nanofilm (compound 2) and chemical degradation (compound 3) in terms of the perceived color cannot be ignored and should be incorporated in the production guidelines, if these compounds are to be used in light emitting devices. Furthermore, the relationship between the interplanar distances of the molecules and the re-
are depicted. More OLEDs were tested and these results are presented itself in a reduction of the threshold voltage from \( U_{\text{th}} = 8.6 \text{ V} \) to \( U_{\text{th}} = 4.3 \text{ V} \) and an increase of the maximal luminance from \( L_{\text{max}} = 26.1 \text{ cd m}^{-2} \) to \( L_{\text{max}} = 33.7 \text{ cd m}^{-2} \). However, OLEDs with compound 2 as emitter material benefit significantly more from a TPD layer. While OLEDs lacking this additional hole transporting layer have a maximal luminance not exceeding \( L_{\text{max}} = 20 \text{ cd m}^{-2} \), devices with a TPD layer have a maximal luminance of up to \( L_{\text{max}} = 132.1 \text{ cd m}^{-2} \) (Figure 8 and supplement). The best performance could be observed for OLEDs having compound 3 as emitter material, although in this case, the addition of a TPD layer seems to be of less importance, since OLEDs with or without TPD layer show a maximal luminance of \( L_{\text{max}} = 166.1 \text{ cd m}^{-2} \) and \( L_{\text{max}} = 174.0 \text{ cd m}^{-2} \), respectively (Table 2).

To further investigate the role of a TPD layer, we have to take a look at the needed electrical parameters at a certain luminance \( L_0 \). Thus, the voltage, current and electrical power to achieve a luminance of \( L_0 = 100 \text{ cd m}^{-2} \) \((U_{100}, I_{100}, P_{100})\) were determined. OLEDs with compounds 1 or 2 as emitter materials and with a TPD layer, show considerably better values for \( U_{100} \), \( I_{100} \) and \( P_{100} \) than comparable devices without a TPD layer. Additionally, it is now possible to point out some improvements of OLEDs with compound 3 as emitter due to the presence of a TPD layer. In particular, a reduction of \( U_{100}, I_{100} \) and \( P_{100} \) could be observed. But it has to be stressed that these improvements of OLEDs with compound 3 due to a TPD layer are marginal if compared to the significant improvement of OLEDs with compound 2. Especially, since there are some cases of OLEDs with compound 3 lacking a TPD layer that still perform better than their equivalent counterparts with a TPD layer (see supplement, Table S1).

In Figure 9, the luminance-power and current-efficiency characteristics are depicted. First of all, the differences in performance that were mentioned above can also be easily seen in these diagrams. Furthermore, the formation of a plateau of the luminance and the maxima of the current-efficiency are good indicators at what voltages the studied OLEDs perform best in terms of electrical power consumption and luminance.

The different impact of a TPD layer on the performance of devices with an EML using compound 2 or 3 can be explained with the HOMO and LUMO levels of the emitter compounds (Figure 3). Compound 3 has a higher LUMO energy \((−5.7 \text{ eV})\) than compound 2 \((−6.0 \text{ eV})\). Therefore, the addition of a TPD layer \((\text{LUMO}: −5.5 \text{ eV})\) as an intermediary level for the transport of holes from the PEDOT:PSS layer \((\text{LUMO}: −5.2 \text{ eV})\) into the EML comprised of compound 2 seems to be of more importance than for compound 3. To some extent, this interpretation also explains the impact of a TPD layer on OLEDs with an EML of compound 1 \((\text{LUMO}: −5.9 \text{ eV})\). Interestingly, earlier studies showed that OLEDs with a single organic layer of compound 3—namely with the following layers: ITO/50 nm 3/80 nm Al—work and display diode characteristics, already achieving a maximal luminance of \( L_{\text{max}} = 52 \text{ cd m}^{-2} \). This indicates that a sufficient number of holes can be injected from the ITO anode \((−4.8 \text{ eV})\) into a layer of compound 3 \((\text{LUMO}: −5.7 \text{ eV})\) even without a dedicated hole transporting layer at all. Consequently, the addition of TPD as second hole transporting layer—the first being the spin-coated PEDOT:PSS—should be less impactful for devices using compound 3 as EML.

Typically, the charge carrier mobility \( \mu \) is an important quantity that heavily influences the optoelectronic performance of...
Figure 8. Current–voltage and luminance–voltage characteristics of OLEDs with and without TPD layer (open and filled symbols, respectively). All OLEDs consist of the following layers: ITO/140 nm PEDOT:PSS/(TPD)/emitter/90 nm Al. The exact thickness of the TPD and emitter layers can be obtained from the insets.

Figure 9. Luminance-power characteristics (a) and current-efficiency (b) of the studied OLEDs with and without TPD layer (open and filled symbols, respectively). All the emitter materials (1: green; 2: red; 3: blue) were tested.
OE devices. Hence, the Mott-Gurney model was used to determine the mobility $\mu$ [Eq. (1)]:

$$J = \frac{9}{8} \varepsilon \varepsilon_0 \frac{d}{d \phi}$$

(1)

with $J$ as current density, $\varepsilon$ as dielectric constant, $\varepsilon_0$ as vacuum permittivity, $U$ as applied voltage and $d$ as distance between the electrodes.[55] The results for the average mobility have values of $\mu = 10^8 - 10^9 \text{cm}^2\text{V}^{-1}\text{s}^{-1}$ for all compounds, yet these values are not conclusive due to limitations of the used model (Figure S4–S9 in the supplement). Additional measurements have to be conducted in future studies to yield separate results for the mobility $\mu$ for both types of charge carriers.

4. Conclusions

This study demonstrates the viability of core-enlarged perylenes such as compounds 2 and 3 as emitter materials for OLEDs. Devices with nanofilms of perylene ester 1 and the derivatives 2 and 3 as emissive layer show significant differences in the electroluminescence spectra between each other, which results in a similarly varied color perception. At the same time, the electroluminescence and photoluminescence spectra of nanofilms of the same compounds differ only marginally, which indicates that the electroluminescent behavior is influenced by the formation of excimers in a similar way as observed for the photoluminescence.[46] This is further supported by the red shift of the electroluminescence that occurs after annealing nanofilms of compound 2—either due to the deposition process itself or due to a deliberate annealing step. In conclusion, it is demonstrated that the electroluminescent properties of an OLED can be changed simply by varying the interplanar distance of the emitter molecules.

The measurement of the optoelectronic properties of OLEDs with emitter layers of compounds 1–3 reveals that the core-enlarged derivatives 2 and 3 exhibit considerably better performances as emitter materials than compound 1 (2 & 3: $\eta = 160–170 \text{cd m}^{-2}$; 1: $\eta = 20–30 \text{cd m}^{-2}$). While devices employing compound 2 as emitter material require a hole transporting layer (TPD) to achieve the aforementioned performances, devices with compound 3 exhibit good performances independent of the presence of a hole transporting layer.

Furthermore, the limitations of the deposition methods (thermal evaporation and spin-coating) were also discussed, showing that compounds 2 and especially 3 can chemically degrade under excess deposition temperatures, resulting in changes in the electroluminescent properties.

These results may function as guidelines for the design of organic electronic devices using core-enlarged perylene derivatives as light emitting materials and future studies will focus on the role of liquid crystalline mesophases on the device performance.

Acknowledgements

We thank the German Research Foundation (DFG: GRK 1464, RISE 2015) for financial support.

Conflict of interest

The authors declare no conflict of interest.

Keywords: discotic liquid crystals · electroluminescence · excimer · nanofilms · organic semiconductors

Different perylene derivatives are tested as emitter materials in organic light-emitting diodes. After thermal treatment, the emission can be altered due to the formation of a denser packed nanofilm. This behavior can be explained by the formation of excited dimers and is in agreement with prior studies.