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The fabrication of small molecule organic light-emitting diode pixels by laser-induced forward transfer

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Laser-induced forward transfer (LIFT) is a versatile organic light-emitting diode (OLED) pixel deposition process, but has hitherto been applied exclusively to polymeric materials. Here, a modified LIFT process has been used to fabricate small molecule Alq3 organic light-emitting diodes (SMOLEDs). Small molecule thin films are considerably more mechanically brittle than polymeric thin films, which posed significant challenges for LIFT of these materials. The LIFT process presented here uses a polymeric dynamic release layer, a reduced environmental pressure, and a well-defined receiver-donor gap. The Alq3 pixels demonstrate good morphology and functionality, even when compared to conventionally fabricated OLEDs. The Alq3 SMOLED pixel performances show a significant amount of fluence dependence, not observed with polymeric OLED pixels made in previous studies. A layer of tetrabutyl ammonium hydroxide has been deposited on top of the aluminium cathode, as part of the donor substrate, to improve electron injection to the Alq3, by over 600%. These results demonstrate that this variant of LIFT is applicable for the deposition of functional small molecule OLEDs as well as polymeric OLEDs.

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I. INTRODUCTION

The application of organic light-emitting diodes (OLEDs) in electronic displays has led to a large increase in research into OLED deposition and patterning techniques. Laser-induced forward transfer (LIFT) has been developed to enable fine patterned deposition of solid thin-films, such as those used in OLEDs. Additional advantages of laser-processing include high-throughput volumes, meaning the LIFT process is suited to large-scale applications. LIFT also transfers solid layers intact, meaning that layers on the donor substrates can be formed from processes that would be otherwise incompatible with other layers in the device. A final advantage is that the use of an intermediate polymer layer (dynamic release layer (DRL)) to absorb the laser light allows for the transfer of materials that would otherwise be sensitive to the laser radiation.

Whilst “direct-write” laser deposition techniques have been investigated for a number of years,1–3 scientific research into the process has really taken off in the past few years. In the field of OLEDs, this research is particularly important given that active-matrix OLED displays are already widely available on the market.4 LIFT is a term that encompasses a range of laser deposition techniques; the variant used in this article is summed up in Fig. 1, and an overview of the different LIFT technique classifications is shown in a previous article.3 Our variant of LIFT is unique in that it uses a thin sacrificial DRL of triazene polymer (TP) to propel the target layers across intact. OLEDs have been fabricated using our variant of LIFT,5,6 as well as another LIFT variant where the layer was not transferred intact, blister-actuated LIFT (BA-LIFT)7 and a commercially developed technique termed laser induced thermal imaging (LITI).8 The technique shown here, in Fig. 1, has previously only been applied successfully to polymeric light-emitting layers. With recent improvements to the technique,9,10 new approaches have been tried, such as transferring different types of pixels side-by-side11 and sequentially transferring the light-emitting layer and the cathode in separate steps.12

Here, we present the first transfers of small molecule OLED pixels using any form of LIFT (hereafter called LIFTed pixels, as opposed to conventionally fabricated devices), where the layers are transferred intact across a gap. Alq3 has been deposited using BA-LIFT,9 and small-molecule OLEDs using other materials were fabricated, but the organic layer was transferred as a powder, and the cathode was subsequently evaporated after the laser deposition process.7 Our group has also investigated Alq3 LIFT before, during the optimisation of the process,10 but functional pixels were not successfully fabricated. Alq3 was the first material used for low voltage, efficient OLED devices by Tang and Van Slyke in 1987.13 It is a small molecule material, in contrast to the polymeric materials used as the light-emitting layers in previous LIFT studies (see references for information on the polymers): MEH
PPV, PFO, and PFN. Because of the lower mechanical and thermal stabilities of small-molecule organic films relative to polymers, the functionality of these devices is of particular interest.

An improvement to the LIFTed Alq3 pixel performance has been demonstrated, in this article, with the use of tetrabutyl ammonium hydroxide (TBA), see Fig. 2. TBA was first proposed as a chemical base for the fabrication of a monolayer on indium-doped tin oxide (ITO), and was shown to reduce the work function of ITO significantly. At the time, it was not possible to test TBA as an electron injecting layer on the cathode because inverse architectures were not widespread, but it was used to block hole injection. Here, we use TBA on the cathode because the fabrication of the donor substrates allows for direct modification of the Al before the Alq3 is deposited (see Sec. II A).

II. EXPERIMENTAL

A. Substrate preparation

The donor substrates use UV-transparent fused silica slides (25 mm × 25 mm × 1 mm), cleaned thoroughly with solvent and detergent baths, and UV-ozone treatment. The fused silica substrates are spin-coated at 1500 rpm with 3 wt. % solutions of TP, first synthesised in 1993. Profilometry shows that this gives a thin film thickness of 190 nm ± 10 nm. The cathode was made by thermally evaporating 90 nm films of aluminium onto the TP films at pressures below 10⁻⁵ mbar, with the thickness measured using a quartz-crystal microbalance. Finally, 80 nm aluminium tri-8-hydroxyquinoline (Alq3, sublimed grade, Sigma Aldrich) was deposited under the same conditions, on top of the Al. For the addition of TBA onto the Al, the substrates were removed from the vacuum chamber and a 10⁻⁴ M TBA in methanol solution was spin-coated at 1500 rpm before the substrate was placed back into the vacuum chamber for the Alq3 deposition.

The receiver substrates use pre-patterned 140 nm thick ITO glass slides (25.4 mm × 25.4 mm × 1 mm). These were spin-coated with two hole-transporting layers (HTLs): 60 nm poly[3,4-ethylene dioxythiophene] blended with poly[styrene sulfonate] (PEDOT:PSS) (Clevios P AI4083) and 40 nm of poly[N-vinylcarbazole] (PVK, Aldrich, Mw = 1100 000).

The receiver substrates were also used as the base for conventionally fabricated devices, where the Alq3 was evaporated using the same conditions as above, but directly onto the PVK. Al was then evaporated through a shadow mask which defined the shape (7 and 3.5 mm² circles) of the resultant devices with the architecture: ITO/PEDOT:PSS/PVK/Alq3/Al.

B. LIFT setup

The samples were kept in an inert nitrogen environment throughout the preparation process, and only removed briefly to be placed into, and removed from, the LIFT vacuum chamber. The receiver substrate was placed opposite the donor substrate with a 10⁻³ m steel spacer between which gave a gap width of 15 μm from interferometry. Both the donor and receiver substrates are shown with the spacer in Fig. 1(a).

The LIFT procedure including the details of the laser setup and optimization of the gap width and environmental pressure for the LIFT process are explained in detail elsewhere. The resultant LIFTed pixels, shown in Fig. 1(b), have the architectures: ITO/PEDOT:PSS/PVK/Alq3/(TBA)/Al. The pixel area is ~0.6 × 0.5 mm (0.3 mm²), but smaller would be possible.

C. Device characterization

The LIFTed pixels were kept in an inert nitrogen environment, and contacted using a specially designed sample holder with contacting pins. To line up the cathode contacts with the contacting pins, silver was evaporated onto the samples, helped with silver paste where they may have been misaligned.

A Keithley 2400 sourcemeter was used to apply a bias across the OLEDs, as shown in Fig. 1(b), and measure the I-V characteristics. A Minolta LS-110 light-meter was linked...
to the sourcemeter by a home-built LABVIEW programme to allow synchronous luminance measurements, and the process has been outlined in detail in a previous article.\textsuperscript{6} Electroluminescence (EL) spectra were obtained using a Jobin Yvon Horiba FL-311 Fluorolog, profilometry measurements were taken using an Ambios XP-1 profilometer, and the pixels were looked at through standard light microscopes (Zeiss Axiovert and Stemmi).

III. FABRICATION OF Alq$_3$ PIXELS

A. Alq$_3$ pixel fabrication results

90 nm Al/80 nm Alq$_3$ stacks have been transferred in the way shown in Fig. 1, and the fluence dependence of the pixels deposited by the LIFT process is shown in micrographs in Fig. 3. The Alq$_3$ pixels can be deposited at a range of fluences as wide as that observed for polymeric OLEDs in previous research.\textsuperscript{11,12} This is remarkable for two reasons: first, Alq$_3$ is a small molecule, meaning that the films are likely to have less internal cohesion than polymers, making them more brittle and susceptible to fragmentation; and second, Alq$_3$ typically sublimes at fairly low temperatures, around 300°C.\textsuperscript{14} The fact that both of these effects are mitigated suggests that the organic layer is protected from both large thermal and mechanical loads.

The best pixel morphology in Fig. 3 came from transfer at a fluence of 85 mJ/cm$^2$. This fluence was used to fabricate functional pixels, shown from both above (a) and through the substrate (b) in Fig. 4. The quality of these Alq$_3$ pixels, particularly when compared to the attempted LIFT of Alq$_3$ pixels at atmospheric pressure,\textsuperscript{10} demonstrates the significant improvement in transfer that the following factors have: (1) the removal of air resistance by reducing the pressure, and (to a lesser extent) (2) the introduction of a gap.

Some length bars have been added to Fig. 3 to highlight how the pixel size differs with LIFT. For 110 mJ/cm$^2$, a white bar is drawn, measuring 425 $\mu$m. This highlights how transferring a pixel across a 15 $\mu$m gap significantly reduces the pixel size by folding/crumpling/ripping at the edges (see a previous article by Shaw-Stewart et al.\textsuperscript{10}). A second aspect shown by the yellow bar, of 500 $\mu$m, is how higher fluences create marginally larger ablation craters.

Fig. 4 shows the same pixel from above, onto the aluminium (a), and from below, through the glass, ITO, HTLs, and Alq$_3$ (b). This not only shows the small cracks in more detail than Figs. 3 and 5 but also shows how defects may be visible from above that are less obvious through the substrate and, more importantly, vice versa. Examples of defects more obvious at the Alq$_3$/Al interface than at the Al/air interface are shown circled in red. The pixel in Fig. 4 and other Alq$_3$ devices have had their device characteristics tested in Sec. IV.

A direct comparison between Alq$_3$ and polymeric PFN pixels (from an earlier article by Shaw-Stewart et al.\textsuperscript{12}), transferred at the same fluences with the same Al thickness is shown in Fig. 5. This confirms that the small molecule Alq$_3$ pixels are more prone to morphological defects such as cracks and folds than the polymeric PFN pixels.

B. Alq$_3$ pixel fabrication discussion

The observation that the Alq$_3$ does not decompose at fluences below 150 mJ/cm$^2$ indicates that at the laser fluences less than 100 mJ/cm$^2$, used for the optimised transfers such as the pixel in Fig. 4, the temperature in the organic layer over the aluminium is certainly below 300°C.\textsuperscript{17} Despite the fact that this is probably higher than the decomposition...
temperature of the polymeric materials investigated (MEH-
PPV, PFO, and PFN), any onset of Alq3 sublimation is likely
to have a greater effect upon pixel morphology than poly-
meric decomposition, due to the faster kinetics of sublima-
tion, and this is not observed. However, there are fine cracks
or folds which are particularly obvious when compared with
PFN in Fig. 5.

The fine cracks and folds in the Alq3 in Figs. 3–5 are
similar to those obtained when LIFT of Alq3 pixels at atmos-
pheric pressure was attempted.\textsuperscript{10} Like the polymeric cracks
obtained, for MEH-PPV\textsuperscript{8} and PFO,\textsuperscript{10} the cracks are probably
the result of the brittleness in the film, probably from me-
chanical stress in the transfer process. If the brittle fractures
were from rapid heating and cooling, then it may be expected
that the small molecule Alq3 would be less affected than the
large molecules of polymers. Given that the polymers are
typically more ductile in response to mechanical stress than
the small molecule Alq3, the observation that Alq3 pixels
have more cracks in it than the polymeric PFN in Fig. 5
backs up the hypothesis that the brittle fractures come from
mechanical stress.

IV. Alq3 small-molecule OLED (SMOLED)
FUNCTIONALITY

A. Conventional Alq3 device results

Due to the ubiquity of Alq3 in the OLED literature, it is
easy to compare the devices to devices fabricated by other
groups. The conventionally fabricated devices were made to
act as a control for the LIFTed pixels, as there could be vari-
ation in material purity and film-forming apparatus, among
other variables. Without a control, any responsibility for
abnormal features of the LIFTed pixel device characteristics
may be mistakenly attributed to the LIFT process.

Fig. 6(a) shows the external quantum efficiency (EQE)
plotted against current density of the conventionally fabri-
cated PVK/80 nm Alq3/Al device with the some EQEs
reported from the literature for comparison. The device is
better than older PVK/Alq3 devices from the 1990 s.\textsuperscript{19,20} It is
easy to speculate on differences, but one difference noted in
the articles is that all the measurements from Jiang \textit{et al.}\textsuperscript{19}
and Berthelot \textit{et al.}\textsuperscript{20} were undertaken in ambient conditions
(unlike Tang and Van Slyke\textsuperscript{13} and Li \textit{et al.},\textsuperscript{18} which were
kept in inert oxygen-free atmospheres). It is particularly
interesting that the EQE value from Jiang \textit{et al.}\textsuperscript{19} is so close
to the value obtained here (0.25% vs 0.4%). The original
OLED by Tang and Van Slyke\textsuperscript{13} has a good efficiency,
partly not only because it was made under a very well
controlled oxygen-free atmosphere but also because the
charge-injection was optimised using a hole-transporting dia-
nine and a low work-function Mg:Ag alloyed cathode.

Whilst a different hole-transporting layer may have helped a
bit, the main limitation is probably the lower work function
cathode helping electron-injection.

Fig. 6(b) shows the current density and luminance as a
function of voltage. As can be seen, the luminance reaches
very high brightness levels above 1000 cd/m\textsuperscript{2} at relatively
low current densities. The operating voltage is fairly high
which is partly due to the high thickness of the Alq3 (80 nm),
and partly due to the charge injection at the electrodes which
is probably not quite ideal. The J-V and L-V curves in
Fig. 6(b) are in very good agreement with those in Ref. 19.

B. LIFTed Alq3 pixel results

The main aim of this study is to demonstrate the versa-
tility of the LIFT process. After the fabrication of conjugated
polymer MEH-PPV OLED pixels, the research has continued to focus on polymeric materials; PFO and PFN. The fabrication of SMOLEDs by LIFT demonstrates that this variant of LIFT with a TP DRL is potentially applicable to all solid thin-film OLED materials.

In addition to just demonstrating a proof of principle, TBA was added onto the aluminium cathode to improve electron injection (as was done with the PFO in an earlier study by Shaw-Stewart et al.). Fig. 7 shows a comparison of the conventional and LIFTed pixel device performances. Whilst the LIFTed pixels are clearly not quite as good as the conventional device, they appear to have a similar turn-on voltage in Fig. 7(b), and not too high operating voltages (they are comparable to the PFO and PFN devices). In terms of efficiency, in Fig. 7(a), the LIFTed pixels exhibit good external quantum efficiencies above 0.05%.

When comparing the LIFTed pixels with and without TBA, the Alq3 devices show a significant difference. The pixel device characteristics in Fig. 7(b) show that the peak EQE increases from about 0.06% without TBA to 0.19% with TBA. This improvement with Alq3 is even more marked than for PFO in Shaw-Stewart et al.). The operating voltage is also improved significantly in Fig. 7 with a reduction (at ~50 mA/cm²) from 31 V without TBA to 26 V with TBA. LIFTed pixels shown in Figs. 8(a)–8(c) show a pixel without TBA, and d-f show a pixel with TBA. The uniformity of the pixel electroluminescence in Figs. 8(b) and 8(e) demonstrates that there is no distinct difference in the pixel morphology with and without TBA.

The pixels before, during, and after operation is shown in Fig. 8, and demonstrate that the morphological defects mainly come from the transfer rather than operation. Whilst this may appear to be a disadvantage with the LIFT process, the pixels do not exhibit significantly more defects than the polymers in previous studies, typified by the PFN pixels in Fig. 5(a), and show the potential to be optimised. In fact, the lack of black-spot defects in the OLEDs from operation due to oxygen or water contamination reflects positively upon LIFT.21 Alq3 appears to transfer as well as any of the other materials with the optimised LIFT conditions of 1 mbar and a 15 µm gap. The electroluminescence spectra all match very well, and the LIFTed pixel efficiencies are only just below the conventional device efficiencies, which perhaps perform better than polymers because the detrimental effects of aluminium evaporation on polymers are not so marked with Alq3.

Fig. 9 shows a final interesting feature of the data on LIFTed Alq3 pixels, where a slight trend in device performance was observed as a function of laser fluence. The lower the laser fluence of deposition, the higher luminance for a given current density/voltage (i.e., the higher the efficiency). Fig. 9 serves to show both this increase in efficiency at lower laser fluences, and to show the absolute values for luminance: over 300 cd/m². The insets also give some idea of the
pixel morphologies. All three pixels show some defects, like those in Fig. 8, but the lowest fluence, 75 ml/cm², is clearly the pixel with the most defects. This does follow the pattern set by the polymers, particularly observed in the LIFT optimisation study.\(^\text{10}\)

C. Influence of TBA layer on LIFTed pixels

For the LIFTed Alq₃ pixels shown in Fig. 7, there is a distinct improvement in the device performance when the TBA layer is added onto the Al cathode. The explanation for this effect has been attributed to the formation of a dipolar layer creating a significant negative work function shift to the electrode surface.\(^\text{14}\) The LIFT process has allowed more investigation into the process by which the TBA aids electron injection, and a comparison of device characteristics of pixels made with two types of polyfluorenes, PFO\(^\text{11}\) and alcohol-soluble PFN,\(^\text{12}\) is shown in Table I.

As shown in Fig. 2, the pretext for using TBA was that it creates a dipolar layer on the cathode surface. The original hypothesis depended on the formation of a layer via some sort of reaction between the OH\(^-\) with the surface, giving the dipolar structure of the negative hydroxide ion (OH\(^-\)) and the positive counterion (\(\text{N(C}_4\text{H}_9\text{)}_4\)\(^{+}\)). The monolayer structure proved to be unlikely for TBA, despite the large reduction in the cathode work function.\(^\text{14}\)

A comparison between the results of different materials with TBA in Table I could aid understanding of how TBA works. Comparing just the LIFTed devices first, only Alq₃ exhibits a significant decrease in the operating voltage, although PFO appears to have a slight decrease. The presence of TBA significantly increases the EQE of Alq₃ pixels by over 600%, but only increases the PFO by ~50% and even causes the PFN pixel EQE to decrease. Evidently, TBA has the most positive effect on Alq₃. There are clearly numerous differences between the materials that could account for the bigger effect on Alq₃. However, one simple explanation is the deposition method; Alq₃ is evaporated and the polymers PFO and PFN are spin-coated. The spin-coating could remove some of the layer. PFN is spin-coated from a methanol solution,\(^\text{12}\) like the TBA, meaning that it may be able to redissolve a substantial amount of the TBA layer. In addition, the TBA could also hinder performance if it acts as a trap within the PFN layer. PFO is spin-coated from a toluene:xylene solution, still types of alcohol. This would be less likely to redissolve the TBA layer than methanol, but may still damage the layer significantly enough to reduce the improvement. However, it must be stressed that there could be other explanations based on the deposition process, or indeed based on other material differences between Alq₃, PFN, and PFO.

D. Discussion of Alq₃ SMOLED performances

The operation of LIFTed Alq₃ pixels demonstrates that LIFT may be applied to all types of OLED materials successfully. The LIFTed Alq₃ pixels exhibit efficiencies of about the same order of magnitude as the conventional devices, and generally show good device performance. In previous comparative studies using polymeric light-emitting layers,\(^\text{6,11,12}\) the LIFTed pixels have nearly always exhibited improved performance relative to the conventional devices. The main reason given for the improved performance of LIFTed devices was that aluminium evaporation onto the polymeric materials damaged the device performance.\(^\text{22}\) It is likely that although aluminium will still react with the Alq₃ when fabricating conventional devices,\(^\text{25}\) the consequence is not bad, and may possibly be positive for electron injection, and overall device performance.

TBA significantly improved the LIFTed pixel performances, and one proposed mechanism for the electron injection of TBA is well explained in Fig. 2: the OH\(^-\) reacts with acidic sites on the aluminium (assuming it is partly oxidised) to create negatively charged surfaces which will encourage the large positive counterions (\(\text{N(C}_4\text{H}_9\text{)}_4\)\(^{+}\)) to assemble as shown in Fig. 2.\(^\text{14,15}\) This creates a dipolar layer which has an internal electric field, effectively driving electrons through from the Al cathode improving electron injection (e.g., Ref. 24). However, unlike the original hypothesis,\(^\text{15}\) the TBA may not be forming a monolayer (in fact, it is very unlikely to be doing so), but it may form a thicker film which can still create a strong dipole, both at the Al/TBA interface, and within the TBA film.\(^\text{24}\) Nevertheless, this is not incompatible than the original idea that the adsorption starts with a weak acid-base reaction. The idea of a thicker than few-layer TBA supports the hypothesis that spin-coating a polymeric layer on top of the TBA will (partially) dissolve the TBA layer, outlined in Sec. IV C.

Another aspect of the Alq₃ pixels which is worth looking at in detail is the morphology of the pixels. The comparison with the polymeric OLED pixels in Fig. 5 is particularly revealing as it highlights how many fewer defects the polymeric pixels have. Rather than different mechanical properties, already mentioned in Sec. III B, one other explanation for the morphological differences between Alq₃ pixels and the polymeric material pixels comes from the sublimation temperature of Alq₃. A detailed analysis of the Alq₃ bought from Aldrich has shown an onset of sublimation at 300 °C.\(^\text{17}\) Even though this is roughly the same as the thermal

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**TABLE I. Device performances for various device architectures, at a current density (CD) of ~40-50 mA/cm².** The luminance (Lum), luminous efficiency (LE), and EQE are all shown for the Alq₃ SMOLEDS fabricated in this article as well as other OLEDs using polymeric materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Layer</th>
<th>Bias (V)</th>
<th>CD (mA cm⁻²)</th>
<th>Lum (cd m⁻²)</th>
<th>LE (cd A⁻¹)</th>
<th>EQE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alq₃</td>
<td>LIFT Al</td>
<td>30</td>
<td>46.3</td>
<td>44.4</td>
<td>0.096</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>LIFT Al/TBA</td>
<td>25</td>
<td>38.7</td>
<td>192.3</td>
<td>0.50</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td>Convent Al</td>
<td>19</td>
<td>34.9</td>
<td>448.7</td>
<td>1.29</td>
<td>0.21</td>
</tr>
<tr>
<td>PFNa</td>
<td>LIFT Al</td>
<td>16</td>
<td>43</td>
<td>44.9</td>
<td>0.11</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>LIFT Al/TBA</td>
<td>17</td>
<td>37.7</td>
<td>28.1</td>
<td>0.075</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>Convent Al</td>
<td>17</td>
<td>41.6</td>
<td>0.3</td>
<td>0.0007</td>
<td>0.0003</td>
</tr>
<tr>
<td>PFOa</td>
<td>LIFT Al</td>
<td>22</td>
<td>51</td>
<td>306.2</td>
<td>0.60</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>LIFT Al/TBA</td>
<td>21</td>
<td>48.32</td>
<td>540</td>
<td>0.89</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Convent Al</td>
<td>18</td>
<td>51.16</td>
<td>25.4</td>
<td>0.05</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>Convent Ca</td>
<td>13</td>
<td>49.23</td>
<td>102.3</td>
<td>0.21</td>
<td>0.17</td>
</tr>
</tbody>
</table>

\(^a\text{Partly in Shaw-Stewart et al.}\(^\text{12}\)\)

\(^b\text{From Shaw-Stewart et al.}\(^\text{11}\)\)
decomposition temperatures of standard light-emitting conjugated polymers,\textsuperscript{24,25} as a phase change rather than a thermal reaction (governed by Arrhenius kinetics), it is more likely to happen on the short time-scales of the laser pulse. An indication of the nature of pulse laser thermal degradation is indirectly shown via a recent study on the deposition of MEH-PPV, PFO, and Alq\textsubscript{3} by resonant infrared pulsed laser deposition (RIR-PLD) and resonant infrared matrix-assisted pulsed laser evaporation (RIR-MAPLE).\textsuperscript{26} Whilst Alq\textsubscript{3} could be deposited via RIR-PLD without significant damage to the material, this was not the case for the polymeric materials, which were all better suited to the “softer” RIR-MAPLE technique where the polymer is dissolved in a host matrix at a concentration of ~1%. This shows how the Alq\textsubscript{3} sublimes without any chemical structure damage, but the polymers will not sublime, or even melt without some chemical structure damage. This suggests that any effects of Alq\textsubscript{3} sublimation on the LIFT pixels could manifest themselves as morphological problems from small areas subliming.

This hypothesis is partly backed up by the data in Fig. 9, particularly by the low 90 mJ/cm\textsuperscript{2} vs 75 mJ/cm\textsuperscript{2} device per-
tion on the LIFT pixels could manifest themselves as the Alq\textsubscript{3} film, the main source of morphological defects is heterogeneity and defects in the pixel. This suggests that more efficient than the higher fluence pixel. However, the evaporation of the Alq\textsubscript{3} layer after the deposition of the TBA LIFTed pixels.

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