# Methods for Minimizing Slot Die Coating Edge Effects and Patterned Coating

*Miguel Friedrich, Greg Gibson*
*nTact (FAS Holdings Group LLC)*
*10480 Markison Road, Dallas, TX*
*m.friedrich@nTact.com* • *214.343.5387*

***Keywords:*** *Slot Die Coating, Patterned Coating, Selective Coating, Patch Coating, Selective Removal, Edge Effect, Leading Edge, Trailing Edge, Active Area.*

***Abstract:***

The slot die coating method is typically used for coating essentially the entire area of the substrate. A new method of slot die coating has been developed by nTact which allows the "macro patterning" of a slot die coated film to produce an array of rectangular shapes (active areas) over the area of the substrate. When coating on larger substrates which may contain various smaller device structures, this technique is proving to be a useful way of depositing the material only in the active area where the devices are located. In addition, with some of the stricter edge exclusion requirements emerging from new device structures and designs, the historical 10mm edge exclusion used in the LCD industry is no longer acceptable for many newer applications.  While the latest slot die coating software controls and hardware allow for a reduced 5mm edge exclusion for many materials, in some cases this is still not sufficient. To meet these very small edge exclusions, a low cost (by comparison) thin film removal method known as Selective Removal was developed, which can be used to essentially eliminate leading (beginning of the coating) and trailing (end of the coating) edge non-uniformities and reduce the edge exclusion to less than 1mm.

***Background:***

Historically, slot die coating has been regarded as a very effective method for depositing films over large areas of the entire substrate surface, other than a small uncoated parameter of a couple of millimeters from the edges. Those familiar with the art understand the most challenging aspect of sheet-to-sheet / discrete panel slot die coating is minimizing the edge exclusion/edge effect, in particular for the leading and trailing edges.  The edge exclusion refers to the area around the edges of a coated surface that is required for the coating process to achieve steady states thickness and target uniformity, which is typically ±3% to ±5%.  In the past, for LCD manufacturing processes, an edge exclusion of up to 10mm was acceptable.  In other words, having a non-uniform area of 10mm (or less) in the leading, trailing or side edges of the coated film was acceptable.  But for many new applications, this is no longer allowable. For example, many new display applications and designs (for OLED and others) now have very thin or almost non-existent bezels, which require a much thinner edge exclusion of often less than 5mm. System developers frequently are then faced with the decision whether to use a subsequent, often expensive removal process, such as laser ablation, or to identify an alternate way to deposit these films. These alternative deposition methods usually also involve more expensive process options such as inkjet printing processes (significantly more complex and expensive equipment, and still at somewhat developmental stage) or vacuum deposition (expensive equipment and with poor material utilization) processes.

In addition, in most cases, a single substrate is used to manufacture numerous devices. So operators end up processing several "active areas" within a single larger pane. Ideally, material would be deposited only on those active areas, but it has always been challenging to use slot die coating to do any sort of patterned deposition on the substrate, such as a coating an array of rectangular shapes to cover only the active areas. The use of masks has not been an effective way to do this for solution based processing, and if the starting (leading edge) and stopping (trailing edge) control is the most challenging part of the slot die coating process, doing this numerous times throughout the coating process of a single substrate to define multiple coated areas on that surface increases the difficulty of achieving an acceptable coated film.

***Approach:***

To address the challenge of coating only on desired active areas of a substrate, nTact developed the technique of Selective Coating, often referred to as "Patch Coating", which gives operators the ability to coat an array of rectangular shapes on a discrete substrate surface in a single pass (see Figure 1 and Figure 2 below).

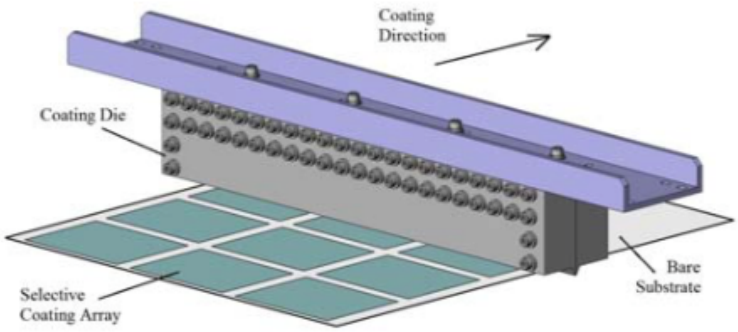



*Figure 1: Illustration of Selective Coating Process*

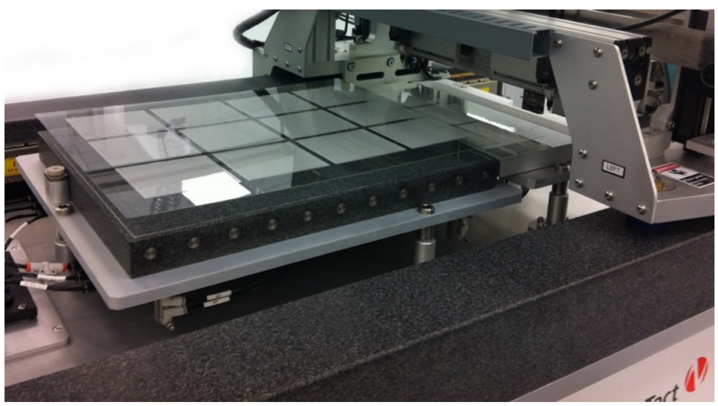


*Figure 2: Example of Selectively Coated Panel*

The Selective Coating method uses a specially designed slot die with multiple openings to define coated and uncoated areas (stripes) across the width of the substrate. The stripes are typically of uniform width and spacing, although asymmetrical arrangements are also possible. The stripe array is generally designed to coat the desired width on the final device, plus a small amount of extra width on each side. This extra width, or "side edge exclusion", is needed to compensate for thickness non-uniformities at the edge of the coating and for potential overlay inaccuracies where multiple layers must be aligned. The stripe coating is combined with precise and proprietary software controls giving the system the ability to precisely start and stop the coating multiple times down the length of the substrate, thereby enabling the deposition of an array of rectangular shapes. The start / stop operation involves the careful control of numerous coating parameters, including the flow of material through the die and the position of the die with respect to the substrate. The position of the coating start and stop locations can be precisely controlled and the locations are typically programmed to correspond to the desired coated areas, along with a small amount of additional coating length to compensate for edge thickness non-uniformities and overlay inaccuracies. The combination of this specifically designed slot die and nTact's optimized proprietary software and controls scheme gives the operator not only the ability to selectively coat a patterned array of rectangular shapes on a substrate surface, but also typically achieve a better than 5mm edge exclusion for the deposition of most films.

However, although achievable for some processes, limiting the edge effect below that 5mm threshold is still quite challenging. Today's small bezel display designs and other application requirements often call for an edge exclusion of less than 2mm, which is quite difficult to attain with materials through the use of slot die coating. To achieve this, the operator is typically forced to use a subsequent removal step/process.

nTact developed a low cost (by comparison) material removal method called Selective Removal, which allows developers to limit the edge exclusion to less than 1mm in most cases. The Selective Removal technique implements a proprietary mechanism to remove portions of the coating material, such as the leading and trailing edge, after deposition. The removal mechanism is a jet spray nozzle that uses a solvent that is compatible with the coating fluid to dissolve the coated layer, while simultaneously removing the solution from the surface of the substrate. The nozzle does not touch the substrate, the z-axis controlling the height above the surface, along with the x-axis and y-axis motion of the device, is controlled to ensure process reliability and repeatability. As the nozzle is moved along a programmed path, the coating material is removed, leaving a coated area of precise shape and dimensions. The nozzle mechanism is designed so that the dissolved solution is completely contained and removed from the substrate with no yield impact on the coated panel. Through the use of Selective Removal, the operator is able to eliminate the unwanted, non-uniform edge effect at the leading, trailing and/or side edges, leaving nearly the entire coated area within target uniformity. The technique could also be used to create complex, non-rectilinear shapes of coated materials. The removal mechanism can be configured to remove a narrow band of material (less than 1 mm as shown in *Figure 3*), or a much wider band (20 mm or more), providing further flexibility in the way that the final coated pattern can be generated.

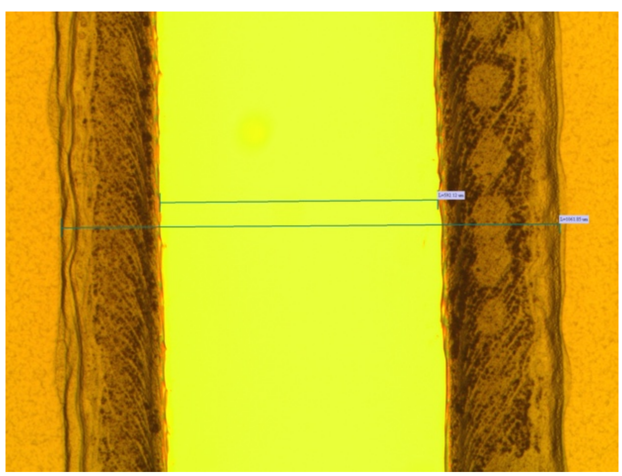


*Figure 3: 592µm line removed from 9µm thick Fluoropolymer film. Edge effect of 235µm*

***Implementation:***

Selective Coating and Selective Removal provide process flexibility that allows an optimized approach to creating the desired shape and edge profile of a coated area. Selective Coating alone allows the deposition of a defined array, though with some edge effects around the perimeter of each coated area. Selective Removal can be used with Selective Coating to more precisely define both the coated area and the coating edge profile. Selective Removal can also be used to create an array of shapes from a single coated area, independent of Selective Coating.

Selective Coating can be implemented as an additional feature and capability of the slot die coater system. It is a combination of a specifically designed coating die and die components which give you the ability to coat stripes in the coating direction (x-axis) and software controls which provide the operator the parameter inputs and capability to start and stop the coating process in the y-axis direction. The combination of these two features and functions can generate a film with an array of rectangular shapes.

The implementation of Selective Removal can be done either in-situ, directly on the coater, or as a separate process station. For many research and development applications, a single mechanism system installed on the coater system provides adequate throughput. In this case, the Selective Removal mechanism is installed on the cross bar and takes advantage of the already existing linear motors of the coater to move the nozzle in the “X” direction. Additional motors and controls are added to give the Selective Removal nozzle the ability to in the Y-axis move along the coater cross bar as well as Z-axis motion. For production applications, multiple mechanisms as well as the implementation of a separate Selective Removal station(s) or module(s) can be used to increase system throughput.

***Results:***

Selective Coating has been tested and successfully implemented with a variety of materials ranging from very low viscosity to much more viscous materials. *Table 1* shows uniformity date of a selectively coated PEDOT:PSS film, a typical OLED Hole Injection material, coated at 70nm. The material was deposited using a coat velocity of 45mm/sec to generate 18 segments on a Gen2 (370x470mm) borosilicate display glass substrate. An overall uniformity of better than ±4% was achieved, and target uniformity/steady state was reached with an edge exclusion on the leading and trailing edges of less than 5mm and better than 2mm on the side

*Table 1: Selective Coating of PEDOT:PSS*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 470mm | | | | | |
| STRIPES | | | unit: nm | | | | | |
| 6 | 73.48 | 73.74 | 74.19 | 72.56 | 73.04 | 71.81 | | |
| | 72.45 | 73.78 | 74.18 | 73.06 | 72.85 | 72.23 | | |
| 5 | 69.99 | 73.09 | 75.70 | 73.29 | 72.92 | 72.84 | | |
| | 72.53 | 73.45 | 72.33 | 73.91 | 72.65 | 72.42 | | |
| 4 | 72.60 | 73.11 | 74.40 | 73.78 | 72.85 | 73.20 | | |
| | 73.90 | 73.17 | 72.49 | 73.79 | 72.73 | 72.07 | | |
| | | | | | | | | 370mm |
| 3 | 71.50 | 71.19 | 71.33 | 72.97 | 72.11 | 72.76 | | |
| | 73.28 | 72.35 | 70.99 | 71.84 | 72.71 | 72.19 | | |
| 2 | 71.80 | 72.05 | 71.57 | 72.88 | 72.49 | 72.89 | | |
| | 71.38 | 72.51 | 72.65 | 71.74 | 72.77 | 73.25 | | |
| 1 | 72.05 | 72.62 | 73.00 | 72.19 | 72.46 | 71.87 | | |
| | 72.57 | 72.33 | 72.12 | 71.37 | 71.92 | 71.56 | | |
| Trailing Edge | 5mm | | | | | 5mm | Leading Edge | |
| | Max | Min | Range | Avg | Unif. (+/-) | | | |
| | 75.70 | 69.99 | 5.71 | 72.64 | 3.92% | | | |
| | Lateral measurements taken 3mm from edges | | | | | | | |

edges. This proved to be adequate for the OLED Lighting application for which this process was optimized.

Selective Removal provides for the elimination of the coating material as the mechanism travels along a defined path. The duration of the removal process depends on the path length and the velocity of the mechanism, the latter of which is heavily influenced by the coating material and removal solvent. Some materials are much easier to dissolve with a given solvent and therefore quicker to remove, while other materials will dissolve at a slower pace taking longer to eliminate.

*Figure 4: ~46µm Edge Effect*

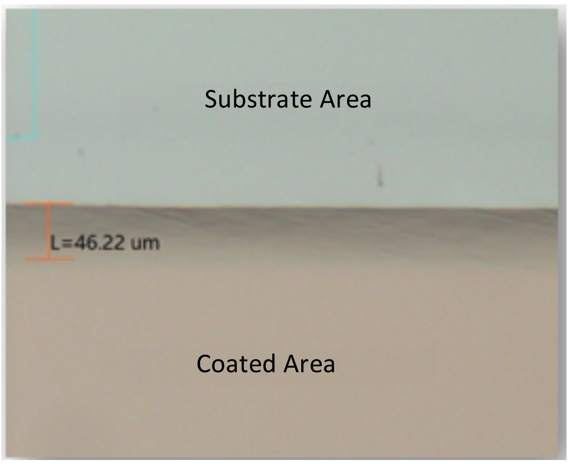
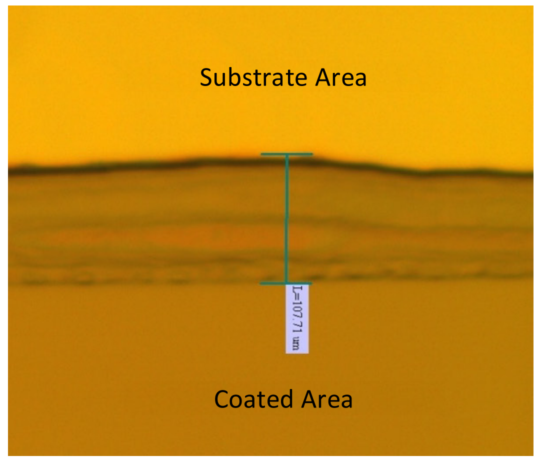



*Figure 5: ~108µm Edge Effect*




nTact tested the removal process under various conditions, including removal of a wet film (immediately after coating) a semi dry film (after soft bake or vacuum dry process) or a dry film after a more thorough thermal curing process. Results have varied and been very material specific, with some materials performing better when removed wet immediately after coating, and others benefiting from some solvent evaporation process, such a vacuum dry, to improve performance. However, Selective Removal on a mostly dry film generally proved to be the least effective. While it worked in some cases, the removal process proved to be significantly slower than under wet film or a semi-dry film conditions.

*Figure 6: Removal after soft bake, 70um Edge Exclusion*

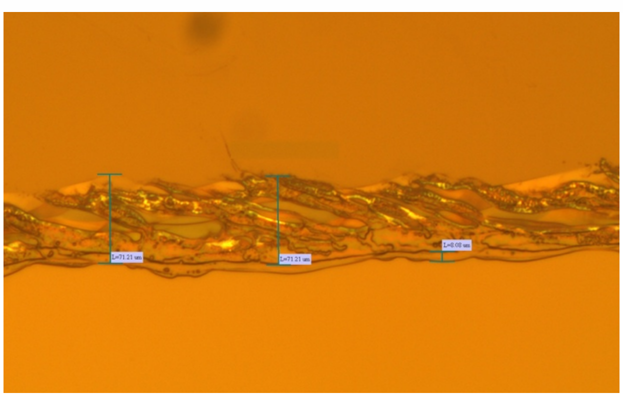
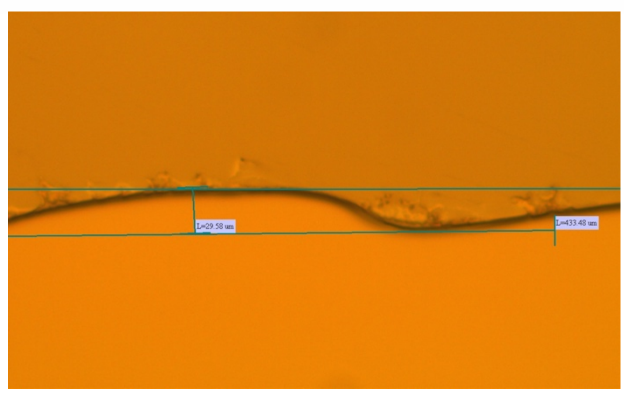


*Figure 7: Removal On Wet Film, 30µm Edge Exclusion*



Most films also benefitted from a second pass or subsequent additional Selective Removal, significantly minimizing the edge exclusion. Following you will find the removal of positive photoresist material with a single pass and a double pass of Selective Removal.

*Figure 8: Single Pass Removal*

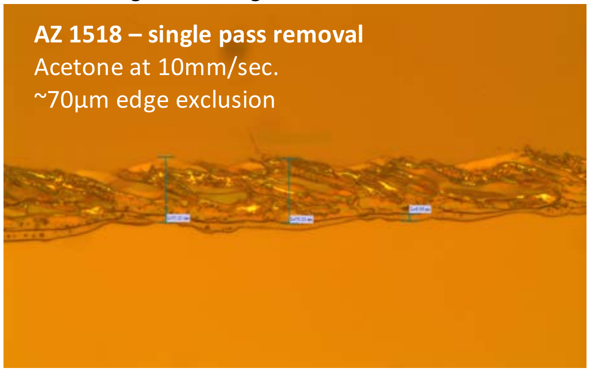



*Figure 9: Double Pass Removal*


With a double pass removal, an impressive edge exclusion of approximately 15µm was achieved. However, while double pass removal improved the edge exclusion by a factor of five (5), a 70-75µm edge exclusion is acceptable for many applications, and a single pass removal significantly improves throughput. For certain hard to eliminate materials, however, more than one pass may be necessary to achieve the desired removal performance.

In general, many of the same types of parameters which affect the outcome of a slot die coating process need to be adjusted for Selective Removal. Nozzle velocity, removal gap (meaning the space between the nozzle and the top surface of the film/substrate) and solvent dispense rate can all have an impact and influence Selective Removal results. And just as with slot die coating, each parameter needs to be optimized depending on the material/chemistry being removed.

*Figure 10: Selective Removal at 10mm/sec*

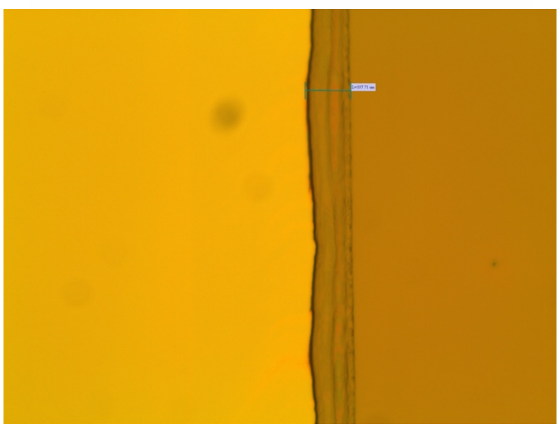
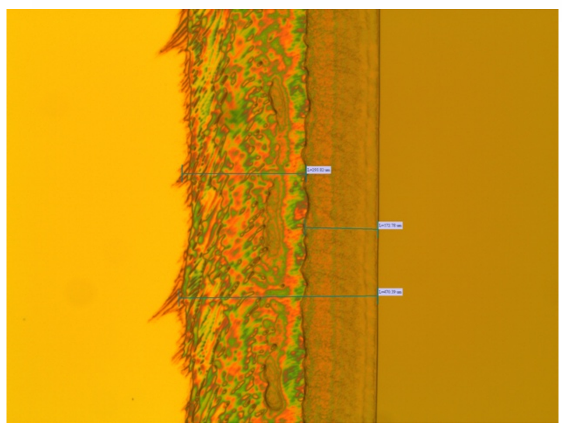


*Figure 11: Selective Removal at 20mm/sec*



Figures 10 and 11 show the results of Selective Removal at different removal speeds/nozzle velocities. Removal of a Fluoropolymer film at 10mm per second yielded an edge exclusion 108µm compared to a thicker 470µm edge exclusion using a faster nozzle velocity of 20mm per second. The slower nozzle and removal speed represents an edge exclusion improvement which is almost five (5) times thinner. However, an edge exclusion of less than 500µm may still be adequate for many applications. In this case, the overall process may benefit from a significantly faster nozzle speed, resulting in an overall improved throughput or TACT.

***Conclusion /Summary:***

These patent pending methods present process improvements and potential solutions to the challenges in slot die coating. The Selective Coating method improves upon the well-established and widely adopted use of slot die coating method to form thin film layers of polymers, addressing a historical limitation of traditional slot die coating techniques. Most microelectronic devices produced today require one or more selectively formed coated layers during the manufacturing process. Increasingly, those films are applied as patterns on larger substrates so that manufacturing efficiencies, economies of scale and overall cost reductions can be realized. With Selective Coating operators can now implement basic patterning by depositing an array of rectangular shapes in a single pass, each representing a device on a larger substrate. Selective Removal can complement and enhance Selective Coating as it addresses one of slot die coating's biggest challenges, minimizing the film edge exclusion, through the subsequent removal of non-uniformities typically found in the leading and trailing edges of a slot die coated panel. These techniques can be applied to a multitude of applications including flat panel display, Solid State Lighting, Smart Glass, and other organic and printed electronics applications.

While there is still ongoing research by nTact to continue to improve and further develop both of these techniques/methods, Selective Are Coating has already been successfully implemented on several pilot production lines with plans to move into full production in the near future. Both techniques show real promise as a cost effective way to expand the capability of using slot die coating process for numerous processes.

***References:***


[1] United States Patent number 7,169,229, "Moving Head, Coating Apparatus"

[2] G. Gibson, S. Snodgrass, "Selective Coating and Removal Technologies to Produce Patterned Films for Printed Electronics", LOPE-C Proceedings (2011)

[3] T.J. Faircloth, J.G. Innocenzo, C. Lang, "43.3: Slot Die Coating for OLED Displays", SID Symposium Digest **39** 645 (2008)

[4] Sonehara, et al, "48.3: Continuous Coating of Photo-Alignment Layer on a Flexible Color Filter for LCDs Using a Roll-to-Roll Manufacturing Process", SID Symposium Digest **37** 1579 (2006)

[5] J. Gabel, I. de Vries, R. Mandamparambil, A. Langen, R. Andriessen, "Progress in patterning technologies for R2R slot die coating for OLED and OPV application", European Coating Symposium (2011)