Method of Patching Element Defects by Ink-Jet Printing for Polymer Light Emitting Diodes

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Abstract

The innate character of ink-jet instability causes the device defect in manufacturing for polymer light emitting diodes (PLED). This study develops image process skill to identify defect location; these skills include the filtering, color processing, background subtraction, dilation etc. Combination with the defect information and the predetermined head library, the ink-jet amount to patch defects can be appropriately estimated. Besides, an optimal printing route has designed with a special head driving of pre-oscillation during motion intermission. By this methodology, a 60 pL drop size from ink jet nozzle can precisely patch the PLED panel with pixel resolution of 240*73 μm, the QCIF standard. This ink-jet manufacture skill use for patch defects can increase the yield rate on line.

Introduction

Polymer light emitting diodes (PLED) technologies offer many attractive properties for use in a display. The discovery of electroluminescence in organic molecules and semiconducting polymers has generated considerable interest in display applications based on these materials.[1-2] In past years, many groups have focused on the challenge to overcome the technical hurdles to realize high-resolution passive displays of PLED.[4-6] However, some important technical issues still leave to be resolved for applications, for example, the coffee ring behavior, the ink-jet stability control,[7-8] the bank pattern design[9] and the crosstalk issues.[10] The mask-patterning method has been developed for low weight molecular type organic EL multicolor displays in past years. For single color of PLED, a spin process is feasible. But for a full color process, the spin method is limited by the solving problems occurs between different colors spinning. Therefore, an ink jet patterning method has been developed for PLED multicolor displays due to the good matching between polymer solution and the ink jet patterning method.[11-12]

However, the film flatness problem arose in the direct printing method especially around the drop edge. Thus ring-type edge behavior causes the film has different film thickness between pixels. The thick periphery will lead to low efficiency of PLED and thin center will breakdown by current leakage. How to keeping uniform film thickness is the key obstacle to be solved. In addition, the surface treatment of the substrate is critical. If the surface is not well treated, the hydrophilic and hydrophobic of the surface will cause the ink droplet to separate on the surface to form the defects. Ink-jet instability is another key factor to induce the defect forming, especially when the print head has large drop deviation or bad nozzle-to-nozzle stability. These intangible behaviors deteriorate the yield rate in fabrication and cause low lifetime of panel.

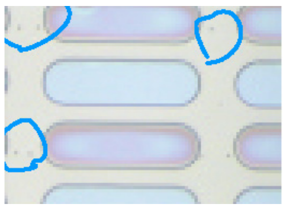
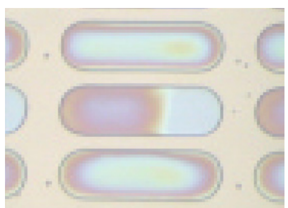
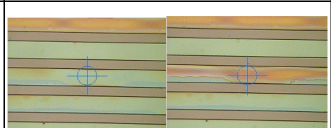
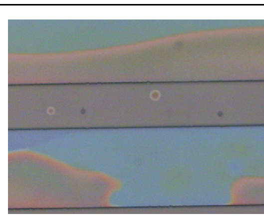
Therefore, this study designs a patching process in ink-jet platform. By image identification scheme, versatile defects are recognized. These defects are established and transferred into ink patching amount by half-toning technique. To maintain patching process stability, we also design a low driving energy to oscillate the ink refilling to keep from ink kogation at nozzle.

Defects Observation

Many factors can induce a defect occurrence on PLED pixel. Typical examples like: (1) Ink-jet instability, not appropriate driving waveform makes satellite drops present. (2) Non-uniform surface property on substrate, it caused the different wettability on pixels. The hydrophilic and hydrophobic properties of the surface difference lead to fluid separation. Some typical problems came from the plasma treatment uniformity, the substrate cleaning and roughness, as well as the difference at the exposure of photo bank. (3) A clogging at nozzle occurs as jetting, especially for polymer blended in high evaporation solvent. The continuous jetting behavior will become unstable after the nozzle has stopped printing. It is because the high evaporation rate of ink will cause the kogation at the opening of nozzle, for the local concentration will increase with time. For our experience in ink-jet printing PLED, 3-5 minutes non-printing will make the beginning of instability. In worst case, the head can't even discharge. Appropriate driving modulation and stirring the ink chamber to refill ink to the opening of nozzle is needed. (4) Non uniform layer of PEDOT by ink-jet printing at bottom, and caused the PF ink flowing accumulated at local. (5) Over long printing time, surface property of bank had changed.

Typically, the plasma treatment can keep the surface hydrophilic properties about 3-4 hrs. Over the time period, the bank will repel the PF ink and form defects. (6) Environment control problem: Moisture is the major problem for defects. It will change the bank and PEDOT surface characteristics, and deteriorate the device. Table.1 listed these common defects.

Table 1. Defects Take Place in Ink-Jet Printing Processes

No.	Common	Defect observation
1	Satellite drop occurred during ink-jet printing	
2	Ink drop deposited not uniform in pixel or the bank surface is not well treated.	
3	Pixel omission: some print head nozzles was clogged	
4.	Layer by layer problem: non-uniform printed PEDOT layer caused upper RED-PF layer defect	
5.	PEDOT and PF: bad bank and bottom ITO layer surface treatment	
6	Environment moisture deteriorated device	

The disclosed patching process is mainly for under-filled of pixel. The method includes steps of identifying all defects of the element by image analysis and obtaining an optimal ink-jet printing path of the ink-jet head. The ink-jet head repairs all defects of the element at a shortest distance along the optimal patching path. The detection and patching are automated so as to improve the quality and yield of the element.

Surface Interface Behavior

The deposition of a liquid on a solid generates new interfaces between dissimilar materials and involves considerations of wettability, spreading, interface evolution, and adhesion. The wettability of a solid by a liquid is characterized in terms of the contact angle that the liquid makes on the solid. The contact angle, q, is obtained from a balance of interfacial tensions and is defined from Young's equation, according to which slv.cosq + sls = ssv , where slv, sls, and ssv are the interfacial tensions at the boundaries between liquid (l), solid (s), and vapor (v). Here, s represents the force needed to stretch an interface by a unit distance. The condition q < 90° indicates that the solid is wet by the liquid, and q > 90° indicates non-wetting, with the limits q = 0 and q = 180° defining complete wetting and complete non-wetting, respectively.[20]

Contact angle indicates the wettability of liquid on solid surface. For some application like PLED by ink-jet printing, a polymer ink drop will contact two different interfaces. Typically, for ink-jet PEDOT, the PEDOT drop will contact ITO film with hydrophilic interface and hydrophobic interface for photo bank. Similarly, for ink-jet PF, it contacts with PEDOT film with hydrophilic interface and hydrophobic interface for photo bank. However, the surface interface will dramatically change because some treatment method like the plasma last only a short time duration, for example, 3-4 hrs. If the overall full color ink-jet printing and related processes take more than the time limit, it is possible that the number of pixel defects will increase.

Ink-Jet Instability

The innate character of ink-jet instability causes the device defect in manufacturing process mainly due to the mechanical inertia force acceleration, the head start-driving instability, and individual nozzle behavior difference. The mechanical inertia force causes an exponential decay with the printing distance, and it presented a landing position variation. Another instability is at beginning of printing. The head start-driving instability is caused by unstable ink refilling, and it manifests variable drop size. The most challenge in printing stability control is the nozzle-to-nozzle variation. Due to the flow channel length for each nozzle is different, it is found the drop size and its break-off behavior was different, when the driving energy for each nozzle is the same. More detail and solution strategies can refer Song et al.[21]

Image Identification for Defects

An image identification methodology for defect recognizing is shown in Fig. 1. The step included: setting hardware and its optical characteristic for capturing image, image process of captured image and recognizing the defects in the image through image comparison.

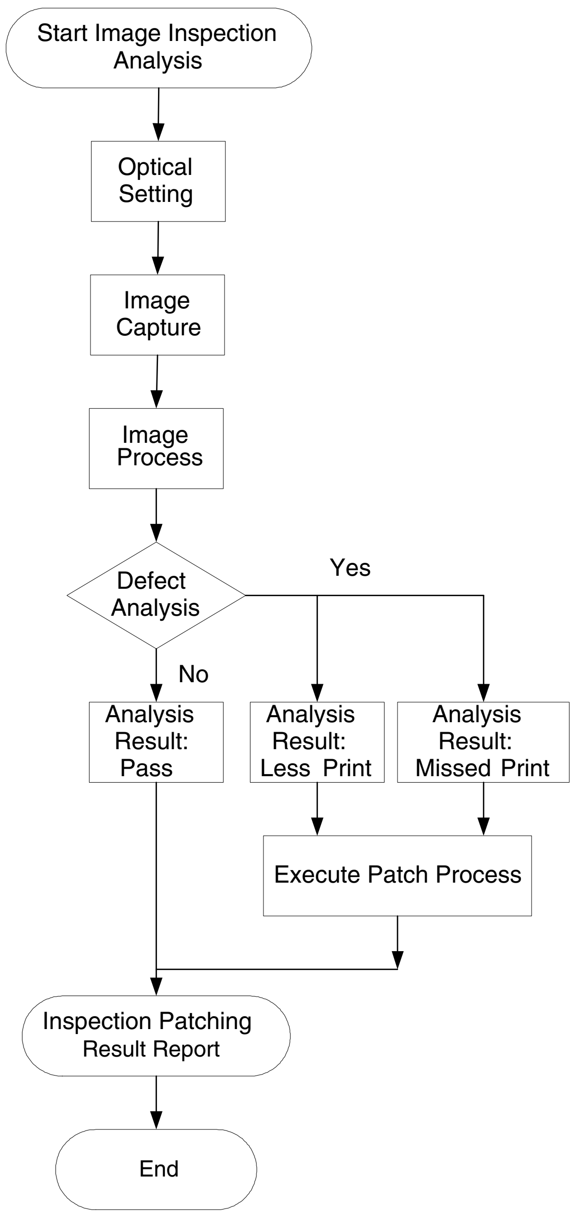


Figure 1. Illustration of image process flowchart.

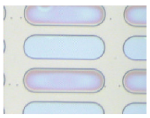
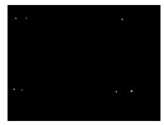
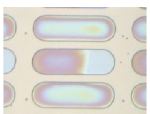
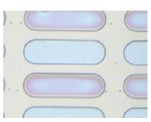
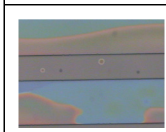
The optical hardware setting for the image analysis system includes fine-tuning of CCD color saturation, light source intensity and compensation,, magnification and optical focus tuning, etc. The image then requires a pre-process to establish an image template at the same hardware setting used for calibrating image distortion and enhance color intensity. For most case of polymer solution likes PEDOT and PF ink, they are high transmittance and hard to be observed in thin film thickness. Establish an image template as background before image process algorithm is critical. After that, a pixel to physical converting is for calculating the real size of image pixel.

The process of establishing an image template includes the following versatile strategies for different defects, as tabulated in Table 2. To save calculating time and improving the recognition rate, the image was segmented through a threshold filtering. Then the image was rotated and aligned to correct the image distortion in CCD capture. The corrected image is then compared with a standard image template, generally, by subtracting the background image, the to enhance the signal to noise ratio. After that, some pre-process includes noise removal, color range conversion, contrast enhance, binary transformation and extract color planes were used to further enhance the image. Details procedure for different type of defect was tabulated in Table 2. Where the white portion was the defect recognized.

Some key procedures like threshold processing, image operation, morphology, and filtering operation are discussed below. The threshold processing consists of segmenting an image into two regions: a particle region and a background region. This process works by setting to 1 for all pixels that belong to a gray-level interval, called the threshold interval, and setting all other pixels in the image to 0. Use threshold processing to isolate objects of interest in an image. Threshold processing converts the image from a grayscale image, with pixel values ranging from 0 to 255, to a binary image, with pixel values of 0 or 1. Threshold processing selects range of pixel values in grayscale and color images that separate the objects under consideration from the background.

Another important algorithm used here is the operator performing on images. It is a basic arithmetic and logical operations on images. Use operators to add, subtract, multiply, and divide an image with other images or constants. It can also perform logical operations, such as AND/NAND, OR/NOR, and XOR/XNOR, and make pixel comparisons between an image and other images or a constant. The concept of an arithmetic or logic operation between images is a pixel-by-pixel transformation. It produces an image in which each pixel derives its value from the values of pixels with the same coordinates in other images. If A is an image with a resolution XY, B is an image with a resolution XY, and Op is the operator, then the image N resulting from the combination of A and B through the operator Op is such that each pixel P of the resulting image N is assigned the value. It presented as pn = (pa)(Op)(pb), where pa is the value of pixel P in image A, and pb is the value of pixel P in image B. In this paper, these operators were used for identification of the union or intersection between images, correction of image backgrounds to eliminate light drifts, and comparisons between several images and a template.

Table 2. Versatile Image Identification Scheme Used for Defect Recognition.

Defects	Image processing	Result
 Satellite drop (PF)	1.Template Establish 2.Image Acquire 3.Operator:"AND" operation for original image & template 4.Color Conversion 5.Color Enhance 6.Thresholding: manual	
 Hole in Pixel (PF)	1.Template Establish 2.Image Acquire 3.Operator: "AND" operation for original image & template 4.Thresholding: manual 5.Filtering: smoothing (kernel size 3x3) 6.Morphology: Dilation (5x5) 7.Particle filtering: filter criteria "pixels" 8.Operator: "AND" operation for processed image & template	
 Pixel Omission (PF)	1.Image Acquire 2.Thresholding: manual 3.Morphology: Closing(5x5)	
 PEDOT and PF	1.Image Acquire 2.Extract color: HSL-Luminance plane 3.Threholdig: manual 4.Morphology: Eroding (5x5) 5.Morphology: Remove small particle 6.Morphology:Fill Holes	
 Environment moisture deteriorated device (PEDOT and PF)	1.Image Acquire 2.Extract color: HSL-Luminance plane 3.Thresholding: manual 4.Morphology: Remove small particle 5.Morphology:Fill Holes 6.Particle filtering: filter criteria "pixels" 7.Morphology: Dilating (5x5)	

The third important concept is the morphological operations work on binary images to process each pixel based on its neighborhood. Each pixel is set either to 1 or 0, depending on its neighborhood information and the operation used. These operations always change the overall size and shape of the particles in the image. Use the morphological operations for expanding or reducing particles appearance, smoothing the borders of objects, finding the external and internal boundaries of particles, and locating particular configurations of pixels. Also use these transformations to prepare particles for quantitative analysis, to observe the geometry of regions, and to extract the simplest forms for modeling and identification purposes.

The morphology functions apply to binary images in which particles have been set to 1 and the background is equal to 0. They include three fundamental binary processing functions erosion, dilation, and hit-miss. The other transformations are combinations of these three functions. The major morphology transformations used here are: erosion, dilation, opening and closing.

Erosion eliminates pixels isolated in the background and erodes the contour of particles according to the template defined by the structuring element. For a given pixel P0, the structuring element is centered on P0. The pixels masked by a coefficient of the structuring element equal to 1 are then referred as Pi. For example, (a)If the value of one pixel Pi is equal to 0, then P0 is set to 0, else P0 is set to 1. (b)If AND(Pi) = 1, then P0 = 1, else P0 = 0.

Dilation eliminates tiny holes isolated in particles and expands the contour of the particles according to the template defined by the structuring element. This function has the reverse effect of erosion, because the dilation is equivalent to eroding the background. For example, (a) For a given pixel P0, the structuring element is centered on P0. The pixels masked by a coefficient of the structuring element equal to 1 then are referred to as Pi. (b)If the value of one pixel Pi is equal to 1, then P0 is set to 1, else P0 is set to 0. (c)If OR(Pi) = 1, then P0 = 1, else P0 = 0.

The opening function is an erosion process followed by dilation process. This function removes small particles and smoothes the boundaries. This operation does not significantly alter the area and shape of particles because erosion and dilation are dual transformations, in which borders removed by the erosion process are restored during dilation. However, small particles eliminated during the erosion are not restored by the dilation. And similarly, the closing function is a dilation followed by erosion. This function fills tiny holes and smoothes boundaries. This operation does not significantly alter the area and shape of particles because dilation and erosion are morphological complements, where borders expanded by the dilation function are then reduced by the erosion function. However, erosion does not restore any tiny holes filled during dilation.

To enhance signal-to-noise ratio, the filtering scheme is used if necessary. Filters are divided into two types: linear (also called convolution) and nonlinear. A convolution is an algorithm that consists of recalculating the value of a pixel based on its own pixel value and the pixel values of its neighbors weighted by the coefficients of a convolution kernel. The sum of this calculation is divided by the sum of the elements in the kernel to obtain a new pixel value. The size of the convolution kernel does not have a theoretical limit and can be either square or rectangular (3 × 3, 5 × 5, 5 × 7, 9 × 3, 127 × 127, and so on). Convolutions are divided into four families: gradient (highpass), Laplacian (highpass), smoothing (lowpass), and Gaussian (lowpass). This grouping is determined by the convolution kernel contents or the weight assigned to each pixel, which depends on the geographical position of that pixel in relation to the central kernel pixel. Spatial filters serve a variety of purposes, such as detecting edges along a specific direction, contouring patterns, reducing noise, and detail outlining or smoothing. Filters smooth, sharpen, transform, and remove noise from an image so that one can extract the information need.

Patching Routing & Refilling Oscillation

The defect analysis is to compare the template images with a standard template and to identify the defects of less print. When a defect is identified, the position coordinate and the type of defect are recorded for the patching afterward. The invention processes the defect positions into an optimal patching path so that the ink-jet head travels along a shortest path to finish the printing and patching. Figure 2 illustrates the optimal patch path. When applying in patching defects on polymer light emitter diodes, the highly evaporative and viscid ink is easy to dry in the nozzle during a longer idling time of non- printing. Because the solvent of the ink around the nozzle evaporates, the ink gets a higher viscosity and clogs the nozzle. Therefore, the invention provides the optimal patching path for shortening the idling time of the ink-jet head during traveling.

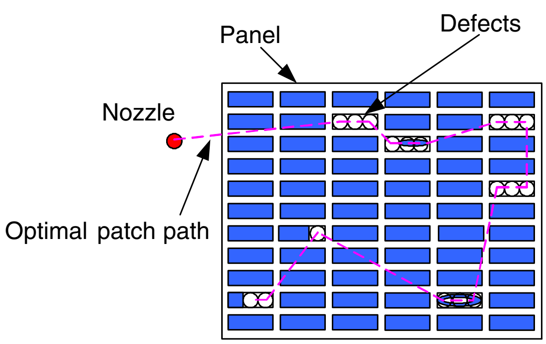


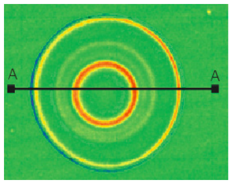
Figure 2. Illustrate optimal patch routine design after defect recognition.

Moreover, the invention provides a pre-oscillation control to the ink-jet head for oscillating the ink in the nozzle and stabilizing the ink-jet printing. The oscillation helps the ink in the nozzle move back and forth, but the energy is less than ejection, so as to prevent the ink drying and blocking the nozzle. During traveling of the ink-jet head from one patching position to another, there are oscillation voltage pulses applied on the nozzle of the ink-jet head. The oscillation energy moves the ink in the nozzle and prevents it from drying. When the nozzle reaches the patching position, the nozzle receives a firing voltage and ejects an ink droplet to the defect position. Even after the patching, the oscillation pulses are maintained to prevent the nozzle from being clogged.

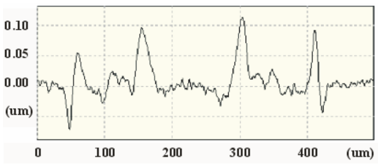
Multi-Rings Accumulation

Many studies have been performed on the evaporation of a drop of liquid on a substrate,[14-15] and discuss on the behavior of particles accumulate at the contact line and form ordered arrays. Some groups have focused on how particles are distributed after the drying process.[16-17] Adachi et al.[16] observed that circular stripe patterns, i.e. rings, form inside the dried drops, and further noticed that the three phase (water, air, glass) contact line exhibited stick-slip motion as the water evaporated. It is important to note that motion of the contact line really refers to the disappearance of water due to evaporation and not to the lateral physical movement of the particles at the contact line. Shmuylovich[18] studied more detailed features of multi-rings behavior for latex. They concluded that because the evaporation rate in a pinned drop is greatest at the edge, there is a flow of water toward the edge. They reported the results of experiments on concentric ring formation and contact line pinning, and discussed how particle size may affect the way in which the contact line gets pinned. An observation of the particles accumulating at the initial contact line presented as evaporation occurring, and the contact line moved and multiple rings formed. It is interesting that small drop volume made small ring area of the substrate and there was only one ring inside the drop. As the volume increases, the radius of the drop also increases, and bigger multi-rings forming.

Figure 3 (a)-(b) was an observation of continuous ink-jet printing PF ink accumulation up to ten drops above PEDOT layer of glass substrate. Where a 0.7 mm glass substrate with 1500-2000 Å of deposited ITO is patterned into stripes to define the anode drive lines. The PEDOT buffer layer thickness was around 1000 to 2000 Å. All the process is fabricated environment in a low moisture and low oxygen content dry box. The drop-to-drop of PF ink has time period controlled at 1Hz. Figure 3 (a) was a top view of drop face to substrate, and it indicated the accumulated drop has diameter size of about 350 um. Fig.3 (b) was the profile along with the A-A section in Fig. 3(a). Multi-ring behavior was found in the image, and the peak value was about 0.1um. The multi-ring behavior will dominate the flatness in ink-jet patching process, and it must be assisted with complementary method to solve the problem. Recently, a vibration-induced method is proposed by Kevin et al.[20] that found the vibration-induced method substantially changed the polymer film ring edge behavior, shrink the polymer drop size, and control the film uniformity. It changed the flatness ratio (defined as profile peak / profile average) from 3.0 (with coffee ring) to 1.0 (nearly flat film) for non-improved and improved, respectively.



(a)



(b)

Figure 3. (a)-(b) Multi-ring behavior observed for continuous ink-jet printing accumulated up to 10 drops.

Discussion & Conclusion

In this study, we developed an image identification process for recognizing the pixel defect of PEDOT and PF. Due to the characteristics of PEDOT and PF were thin, high-transparent layer in low-contrast substrate (glass), generally, it was hard to find defect exist. This study successful observed and recognized these defects, and designed an optimal ink-jet printing route methodology and its driving control method to keep refilling oscillation. However, the multi-ring behavior occurs during ink-jet patching may be a challenge in this development. Their study verified a physical enforcement was helpful to solve this problem. Further focus study is expected in near future.

Reference

1. C. W. Tang and S. A. Vanslyke, Appl. Phys. Lett. 51, 913-915 (1987).
2. J. H. Burroughes et al., Nature, 347, 539-541 (1990).
3. P. May. Society for Information Display '96 Digest, San Diego, CA., 192-195 (1996).
4. R. F. Service, Science, 273, 878-880 (1996).
5. J. R. Sheats et al, Science, 273, 884-888 (1996).
6. A. Shen, P. E. Burrows and M. E. Thompson, Science, 276, 2009 (1997).
7. Kazunaga Suzuki et al., US Patent No.6431674.
8. Tsuyoshi Kitahara, US Patent No.6357846.
9. Shiuichi Ito , Katsuya Okumura, and Koutarou Sho, US Patent No.6162745.
10. D. Braun, "Crosstalk in passive matrix polymer LED displays", Synthetic Metals, 92, 107-113 (1998).
11. Hebner, C. Wu, D. Marcy, M. Lu, J. Strum, Appl. Phys. Lett. 72, 519 (1998).
12. K. Yoshimori, H. Onnagawa et al., Proc. Asia Display 98, 213 (1998).
13. Katsuyuki Morii and Tatsuya Shimoda, "Film Formation by Inkjet Behavior of Inkjet Droplets", Japan Surface Science, 24(2), 90-97 (2003).
14. Denkov, N.D.; Velev, O.D.; Kralchevsky, P.A.; Ivanov, I.B.; Yoshimura , H.; Nagayama, K., Nature. 1993, 361, 7.
15. Duskin, C.D.; Yoshimura, H; Nagayama, K., Chem. Rev. Lett. 1993, 204,5-6.
16. Adachi, E.; Dimitriov; Nagayama, K.; Kuniaki. Stripe pattern formed on glass. Langmuir.1995, 11, 1057-1060.
17. Deegan, R.D.; Bakajin, O.; Dupont, T.F.; Huber, G.; Nagel, S.R.; Witten, T.A. Contact line deposits in an evaporating drop. Phys. Rev. E. 2000, 62, 1.
18. Leonid Shmuylovich, A. Q. Shen & H. A. Stone, "Surface Morphology of Drying Latex Films: Multiple Ring Formation", Langmuir, 18 (9), 3441-3445 (2002)
19. Kevin Cheng , Wanda W. W. Chiu, Liang-Jiun Chen, Chun Fu Lu, Jane Chang, and Tai-Fa Ying, "Thin Film Morphology Controlled by Vibration Induced Method during Ink-Jet Printing", submitted to Applied Surface Science, 2004
20. M. Morra, E. Occhielo, and F. Garbassi, Prog. in Surf. Sci., p. 79.
21. Z.F. Song, F.K. Cheng, H.M. Tsai, J.P. Lu, J.P. Hu, Y.Z. Lee, Kevin Cheng, "Ink-jet instability behavior analysis for polymer light emitting diodes fabrication", accepted by NIP 20: International Conference on Digital Printing Technologies, 2004.

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