A Novel Image Trimming Algorithm for IJP Fabrication in Line Width and Layer Thickness Compromise

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Abstract

To brew ink-jet printing (IJP) technology instead of traditional processes like spinning, screen printing, photolithography, and laser printing, used for semiconductor and display field, what is the obstacle before make mass production? The tunable resolution for image compensation and thickness control is the highest priority due to they dominate the device performance and need carefully control. For examples, the metal circuit will be in tunable resolution up to ± 3 um for high level IC carrier board, to correct the image deterioration caused during prior layering process. However, the innate characteristics of IJP transfer the raster image data format restrict its development due to the resolution is non-tunable in such fine resolution, or it need overlap drop-to-drop in ultra accuracy, to complete the narrow line width requirement. But this strategy conflicts with the layer thickness while highly drop-to-drop overlay, it will increase the layer thickness and spreading the line width synchronously, make it is hard to control the line and layer quality expected. This paper proposed a novel image trimming method to transfer original image to trimmed image based on the spreading factor between the liquid-solid interface and the assumption of linear superposition for drop-to-drop overlapping , as well as versatile filtering function built as look-up table in auxiliary to modulate layer thickness. In details, the trimming method included the procedure of pattern identification and locating, image separation, seamless image merge, image boundary compensation, image trimming on spreading factor, and image reconstruction, and the filtering method included the local characteristic of boundary inspection with defined correcting function and varied filtering pattern applied to inner field of boundary. The test pattern found the resolution can be step tuning of ± 5 um at 100um line width requirement for 10 pl IJP dispensing, and got satisfactory thickness as expectation.

Introduction

Ink-jet printing (IJP) technology has many advantages over traditional process of mask-pattern fabrication, such as material saving and nimble pattern variation, but the upgrading from traditional process to IJP process has some issues to overcome. In the photolithography process, the standard protocol is Gerber RS274X for conventional PCB to be processed. Gerber format belongs to a kind of description language used for plotting lithography mask aligner is simply adjusting the mask size for modulation of line width by zooming the map. For example, the metal circuit can be in tunable resolution up to ± 3 um for high level IC carrier board to correct the image deterioration. However, the innate characteristics of IJP printing technology transfer the raster image data format restrict its development due to the resolution is non-tunable in such fine resolution [1]. It will need overlap drop-to-drop in ultra accuracy which results to the need of construction a huge bitmap data, and the impact is the over loading on system memory and CPU. Besides, high density of drop overlap will increase the layer thickness and spread the line width synchronously compared with raw printing data. The printing process will be uncontrollable on material diffusing and get unexpected results, likes line overlap, plug on hole, and pattern position shift, etc.

This article proposed the concept of modifying the raw printing data to reduce data format converting mismatch and constrain the increasing of layer thickness and spreading the line width, by trimming the original raw printing bitmap. This trimming method included the procedure of pattern identification and locating, image separation, seamless image merge, image boundary compensation, image trimming on spreading factor, and image reconstruction, and the filtering method included the local characteristic of boundary inspection with defined correcting function and varied filtering pattern applied to inner field of boundary.

Algorithm Flow

Generally, an image data compressed in certain format can't directly process for ink-jet printing. It needs first converting to matrix format, likes BMP or TIFF. A lot of image formats in common use, but the difficulty is the resolution reduction occurs during different format transfer. The BMP format needs high storage space but easier dealing with large image data reading, compares with the TIFF format. For industrial standard requirement, the description language Gerber format is popular, so the transferring from Gerber format to matrix format needs re-sampling, and generally a resolution loss occurs that should be carefully operated.

After the conversion of data format, a matrix data can be used for ink-jet printing. However, the resolution of original image just defined the landing position of each dot, but not included the wetting behavior between dots. The wettability will cause the printing pattern different with the origin one, especially present at the line width. Therefore, a compensation scheme is described in Fig. 1 and the detail will discuss below.

For example, for a printing region of 20inchs × 24inchs with 800 DPI resolutions will generate a 16000 × 19200 pixels image, which is huge data for image process and an image segmentation step is needed [2]. The size of segmented sub-images can be set by a computable magnitude, and it related to the adopted number of printing nozzles in order to consistent with the swath printing operation.

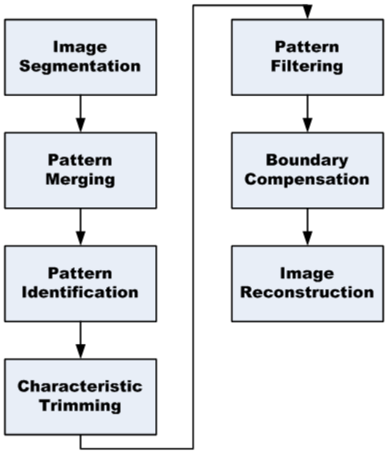


Figure 1. *Flow of Process*

After image segmented, some characteristic sub-pattern (for example, a circle has the chance to be semicircle) will be deteriorated and it is hard to be identified. The merge step is to detect the adjoining image and identify sub-pattern characteristic. Said region or grouping of pixels is referred to as cluster. The cluster consists of contiguous region of nonzero pixels.

In merge step, the algorithm is: (A) to identify a certain cluster on a segmented image. (B) to find all pixels have connected with this cluster on this segmented image. (C) to find extra pixels connected with said cluster on other segmented image. (D) to iterate of (A)-(C), to collect all connected pixels within a cluster (may be not on same segmented image). After (A)-(D) operation, all the connected pixels separated at different segmented image will be identified.

The completed clusters then will compare with the characteristics pre-determined [3-5]. Most characteristics like circle via, horizontal line, slant line, and vertical line are concerned, especially for some square pad or circle pad that connected with line, should be identified [6] to further trimming and filtering to enhance its printing performance.. Fig. 2 showed a partial example of printing circuit board.

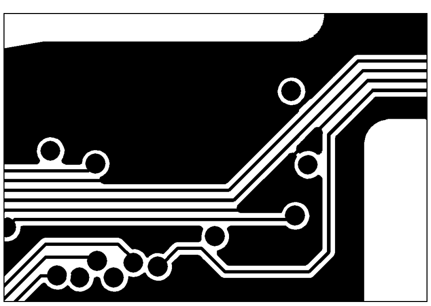


Figure 2. *Appearance of a printing circuit board*

To detect the edge across the line boundary, a popular Canny method is used to obtain the edge information. Operation this algorithm will get the gradient magnitude and direction information to locate the edge presented at a binary image. If any part of the images contained at least one characteristic, then it will be abstracted to further modify by trimming algorithm, to combine with the need of surface wetting property. Different characteristic need versatile processing strategy, for example, a slant line will extra detect the edge with slope at ±45°, a circle (hollow or solid) will compare the reminding tolerance by r-theta scanning with default circle pattern. Sometimes, the circle have a protruding part (connect with line). the strategy is to isolate the circle and leave the connect part first, and then treat the circle and connect part at different criterion

The trimming step aims for correcting the inconsistence between the original image and printed image, due to the wetting spread of jetting materials on substrate. The concept is to shrink the pattern detail in original image by typical scheme like eroding, to against its landing spread as jetting on substrate, which acts to dilate the pattern different with desired [7]. Key factor is the spreading factor for ink-substrate interface, the drop volume, and the desired printing resolution (or call it as overlap of dot density). However, it is difficult to treat each characteristic (circle, line, square, etc.) in the same trimming algorithm, and individual trimming procedure for each characteristic is needed. For example, a drop with 110 um diameter is discharged in resolution of 2540 DPI. We will adopt different trimming ratio (defined as the cancellation pixel / original pixel to be printed) for different characteristic in an original image. As shown in Fig.3, four rows of pixel along the horizontal line direction were cancelled to avoid the spreading toward the perpendicular of line direction (the up direction in paper). But for the slant line, to be compromised with the resolution consistence, five columns of pixel along with the slant line direction were cancelled. Especially, some area characteristics (like circle, square) need higher trimming ratio compared with line characteristic, due to its 2-dimension overlapping in area. In our example, six columns of pixel along with the rim of area characteristic were cancelled.

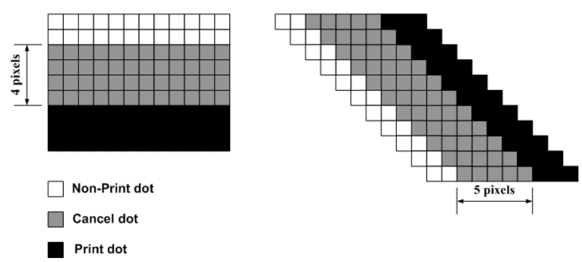


Figure 3. *Line trimming and slant trimming is different*

Even though the trimming procedure can be effective corrected the difference between the original image and printed image, which caused by ink-substrate spreading behavior. However, for high viscosity or low wetting ink, likes the use of ink-jet printing of legend on printed circuit board, its strategy is discrepant. Those kinds of ink are care more about the thickness presence than line width, for its innate characteristic. The overlap of landing drop has minor effect on line width variation, but it will dramatically make the difference on the line thickness presence. For this concern, in this article, we also developed a filtering scheme to screen the overlap density on keeping same resolution criterion. There are many classic space filters skeleton can be applied to modulate the layer thickness, as shown in Fig.4, where the black square indicated a block to be mask data for printing, and the white square presented as a block of allowing data for printing.

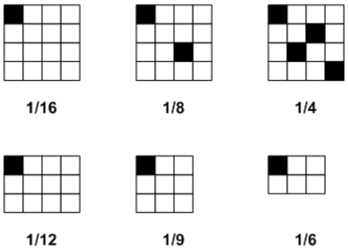


Figure 4. *Classic space filter example*

The filter procedure is significant to modulate thickness presence, depends on the ratio of black square / white square adopted. Higher ratio means thinner thickness due to less deposition after filtering. The design of filtering needs careful consideration of the symmetry of skeleton to avoid the inconsistence with characteristics in image. Besides, the sharpness near the boundary for each characteristic will be vague. It makes rough line edge or saw profile for the circle.

To solve it, a compensation scheme is proposed to recover the boundary sharpness after filtering step. After filtering, a seeking scheme is applied to reconstruct the boundary, and then following a filtering description along this boundary, to fine tuning its thickness presence, as indicated in Fig.5 (a)-(d). Fig.5(d) is an advance scheme to deal with slant line depends on its local characteristics by convolution of a 3 × 3 matrix, after operation, a boundary in interlace arrangement was performed. However, those filtering scheme can't process the arc boundary well for a circle characteristic. In current state, we leave the circle characteristic only dominate by printing resolution, no further boundary compensation was suggested. Instead of boundary compensation, we described the circle pattern by a calculation of r-spiral path from outside toward to the center of circle, to generate its pixel grids. The printing result shown the circles will present good smooth edge, as indicated in Fig.6. In final step, each characteristic has been identified, trimmed, filtered, and compensated, then reconstructed all the characteristics according to its original position to form a completed image ready to print.

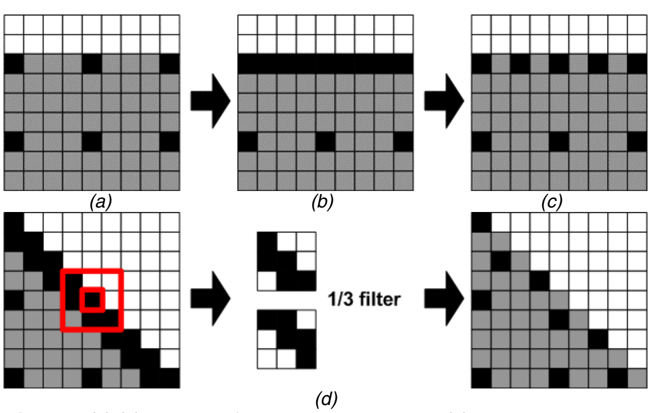


Figure 5. *(a)-(d) Example of boundary compensation (a) Image has processed by filtering (b) Boundary reconstruction (C) Boundary filtering. (d) Boundary filtering for slant line.*

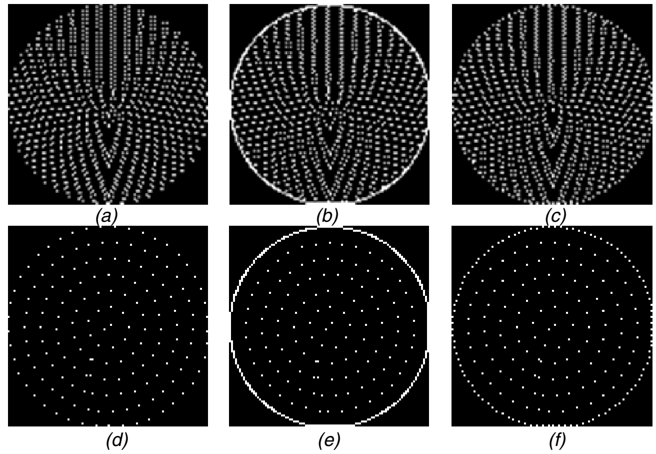
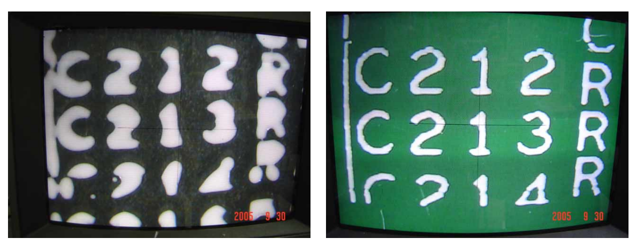


Figure 6. *(a)-(e) Schemes for circle characteristic, in different methodology. (a) only by one-dimensional filtering (b) one -dimensional filtering and boundary reconstruct boundary (c) one -dimensional filtering, boundary reconstruct boundary and boundary compensation. (d) two-dimensional filtering (e) two -dimensional filtering and boundary reconstruct boundary (f) two -dimensional filtering, boundary reconstruct boundary and boundary compensation.*

Result & Discussion

Fig. 7 shown the results of white legend ink printed with 600 DPI resolutions. The left one was original image without any processing, and the right one was the original image with trimming procedure as mentioned before. Compare with these two images, it is obviously the trimming result is clearer than non-trimming result. The non-trimming case will congregate ink and make vague presence.

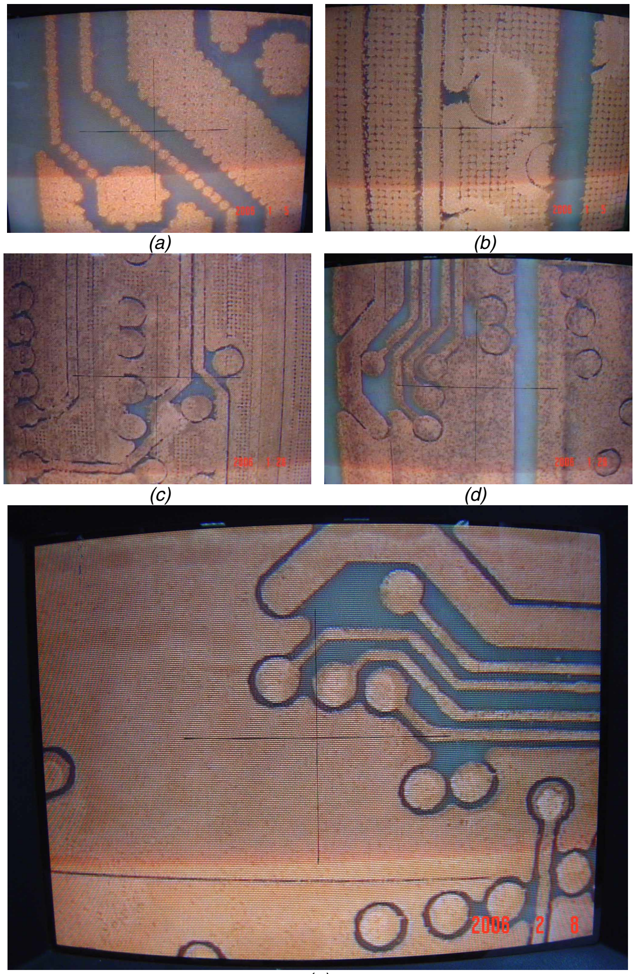


No trimming *With trimming*

Figure 7. *Results of trimming applying*

Fig.8 is another example followed Yang's [8-9] printing process, with image trimming and filtering in this article. The ink-jet dispensing material is catalyst, and then copper ion exchanged with catalyst to form metal pattern on the surface of the substrate by an electroless plating process. Fig. 8(a)-(d) presented the a series filtering and boundary compensating, for original image and it proved an excellent result in Fig.8 (d)

Fig. 8(a) adopted 1/5 space filter and the edge presented very rough. Fig. 8(b) changed to 1/7 space filter with full boundary compensated; it was found the edge little smooth compared with Fig. 8(a), but it also found the filter will create some chinks in pattern. Fig. 8(c) combined a 1/7 space filter and a 1/2 boundary compensated filter, and satisfactory result at gap between lines and pads. Fig. 8(d) further tried of a 1/5 space filter with boundary compensated for slant line in Fig.5 (d), almost all clinks will be smearing. The result of Fig. 8(e) was further refined by operating the circle correction step in Fig.6 (f), where the line width and line gap were excellent controlled at desired 100 m as original input pattern.



(a) (b) (c) (d) (e)

Figure 8. *(a)-(d) A series of filtering and boundary compensating for original image and their results*

Conclusion

An image modifying algorithm for ink jet printing is presented in this paper. This paper proposed a novel image trimming method to transfer original image based on the spreading factor between the liquid-solid interface and constructed at the assumption of linear superposition for drop-to-drop overlapping. Versatile filtering function built–in as look-up table in auxiliary to modulate layer thickness. The trimming method included the procedure of pattern identification and locating, image separation, seamless image merge, image boundary compensation, image trimming on spreading factor, and image reconstruction, and the filtering method included the local characteristic of boundary inspection with defined correcting function and varied filtering pattern applied to inner field of boundary. The printed pattern ideally matched with the original pattern requirement of 100 um line width in consideration of wetting spread effect, and got excellent thickness as expectation. This development is a powerful scheme for ink-jet printing, to increase the yield rate and printing quality in real fabrication.

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Biography

Chih-Hsuan Chiu received his M.S. from Institute of Biomedical Engineering of National Taiwan University, Taiwan, and then jointed the Print Head Test Section of OES/ITRI in 2002. He is now a system integration engineer in the Display Process Integration Technology Division, Display Technology Center of Industrial Technology Research Institute. His profession lies in the design of inspection & measurement systems for the inkjet printing technology.

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