

Automatic Defect Inspection for LCDs Using Singular Value Decomposition



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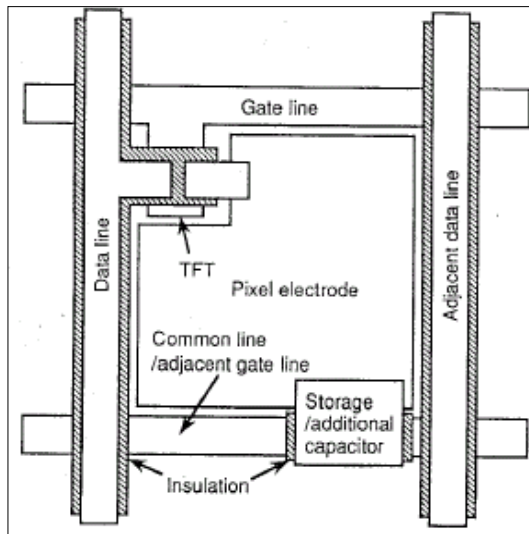
- **Introduction**
- **Singular Value Decomposition**
- **SVD Image Reconstruction**
- **Experimental Results**
- **Conclusion**

Introduction-TFT LCDs Array

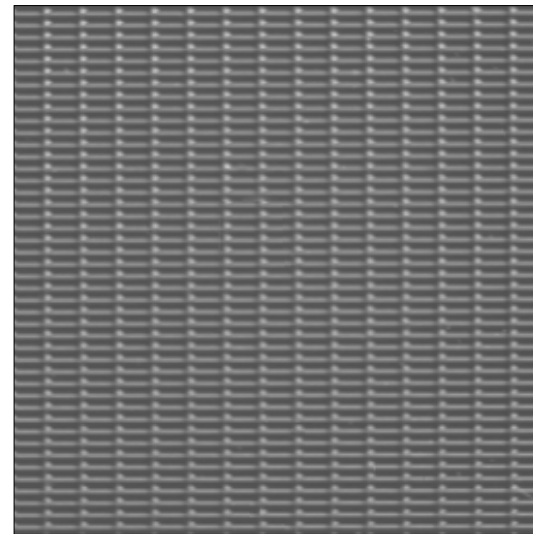
- LCDs are becoming increasingly important in recent years
- Manual activity of inspection could be subjective and highly dependent on the experience of human inspectors
- Most of existing methods of automatic inspection systems for TFT-array were based on conventional electrical methods

TFT Array Plate

- TFT-array plate surfaces comprise **horizontal and vertical structure**



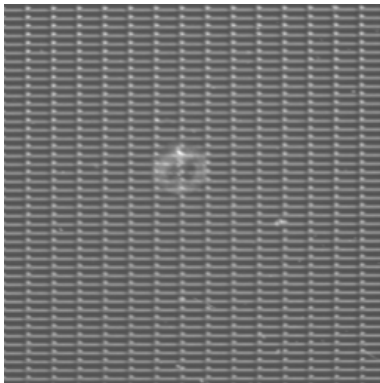
Schematic of a single unit of a TFT-array



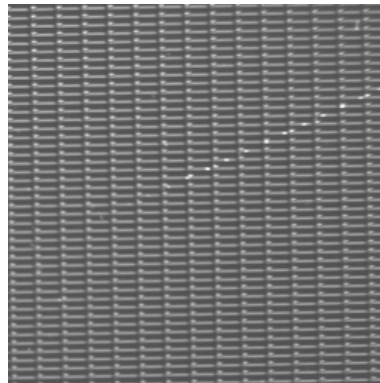
A surface of TFT-array plate

Micro Defects of TFT Array Plate

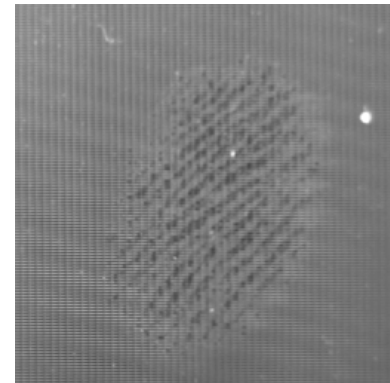
- Micro defects of TFT-array plate-**pinhole**, **scratch** and **fingerprint**



pinhole



scratch



fingerprint

Introduction-SVD

- TFT-array plate surfaces comprise **horizontal and vertical structure**
- We propose a global approach using SVD image reconstruction for inspecting micro-defects on the TFT-array surface
- SVD involves horizontal and vertical basis functions
- **For defect inspection**- set the larger singular values to zero and preserve the smaller singular values to reconstruct an image
 - Remove the background texture
 - Retain the defect

Singular Value Decomposition

Assume an input image X is an $M \times N$ matrix with rank $= r$

$$X = USV^T$$

where

U is an orthogonal $M \times r$ matrix

V is an orthogonal $N \times r$ matrix

S is a $r \times r$ diagonal matrix with singular values σ_i

where $\sigma_1 \geq \sigma_2 \geq \dots \geq \sigma_r \geq 0$

Singular Value Decomposition

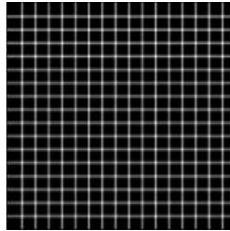


- The larger singular values represent the main information of the matrix.
- Singular values can describe the horizontal and vertical structures
- SVD uses proper orthogonal bases to pile up the image

SVD for Horizon/vertical Structured Image

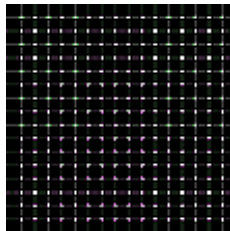
Example:

Horizontal/vertical intersection lines image

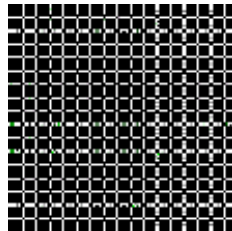


Singular value	σ_1	σ_2	σ_3	σ_4	σ_5	σ_{256}
value	68974	26106	397	372	353	0

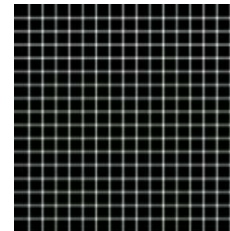
Reconstructed image **from** σ_i



Reconstructed image from σ_1

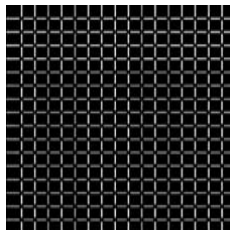


Reconstructed image from σ_2



Reconstructed image from $\sigma_1 + \sigma_2$

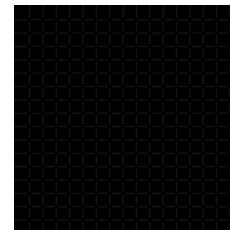
Reconstructed image **exclude** σ_i



Reconstructed image exclude σ_1



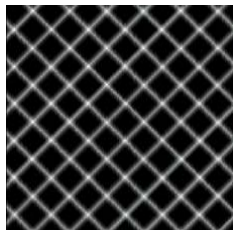
Reconstructed image exclude (σ_1 to σ_2)



Reconstructed image exclude (σ_1 to σ_5)

SVD for Obliquely Structured Image

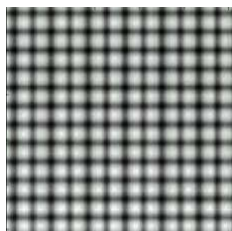
Example:



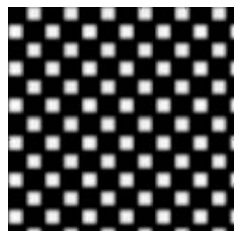
Obliquely intersection lines image

Singular value	σ_1	σ_2	σ_3	σ_4	σ_5	σ_{256}
value	54369	45354	31555	17521	7572	1

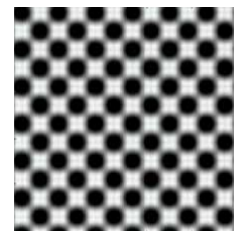
Reconstructed image **from** σ_i



Reconstructed image from σ_1

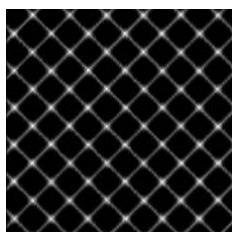


Reconstructed image from σ_2

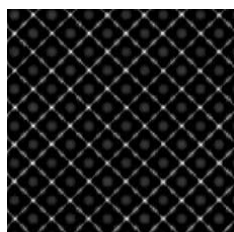


Reconstructed image from $\sigma_1 + \sigma_2$

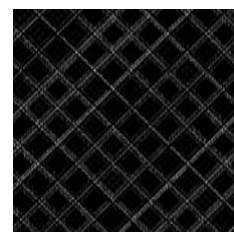
Reconstructed image **exclude** σ_i



Reconstructed image exclude σ_1



Reconstructed image exclude (σ_1 to σ_2)



Reconstructed image exclude (σ_1 to σ_5)

SVD Image Reconstruction

Use SVD to decompose the image
and gain the singular values



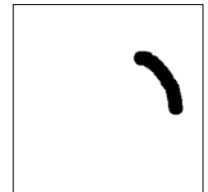
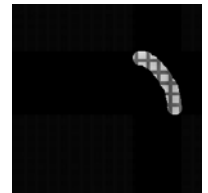
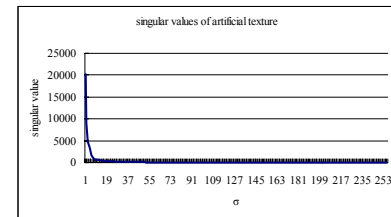
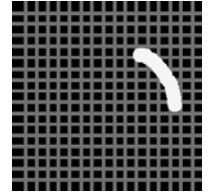
Select the proper number of singular values to
represent the orthogonal structure features



Set the selected singular values to zero
and reconstruct the image



Use simple statistical process control principle to set up the
control limits for distinguishing defects from regular regions

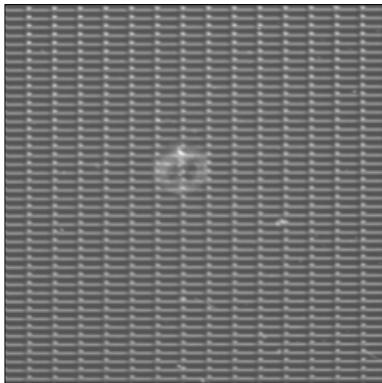


Experimental Results

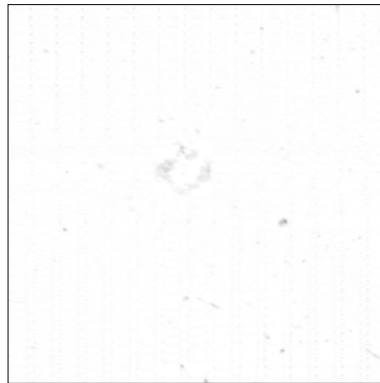
- Detect micro-defects including **pinhole**, **scratch** and **fingerprint** on TFT-array plate surface
- The images are 256×256 pixels wide with 8-bit gray levels

Experimental Results

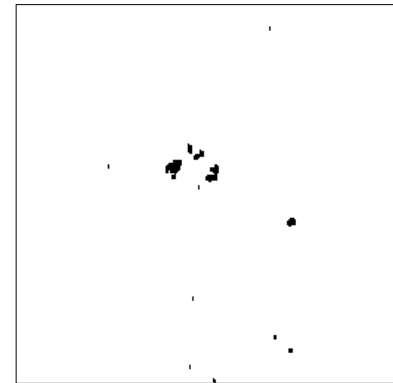
■ Pinhole



The defective image
with pinhole



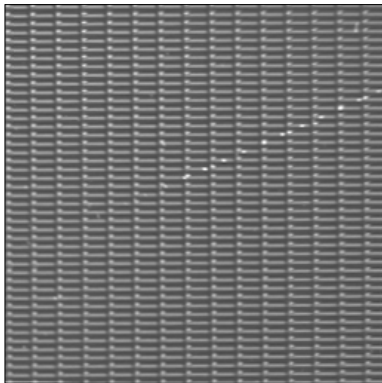
Restored image
by remove (σ_1 to σ_5)



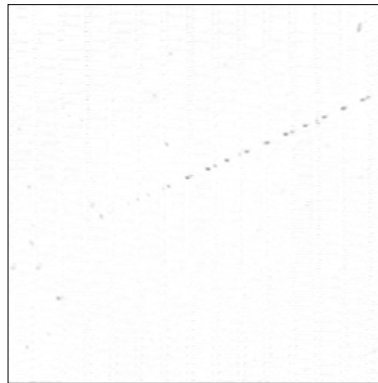
Resulting binary image
for defect segmentation
($\mu \pm 4s_f$)

Experimental Results

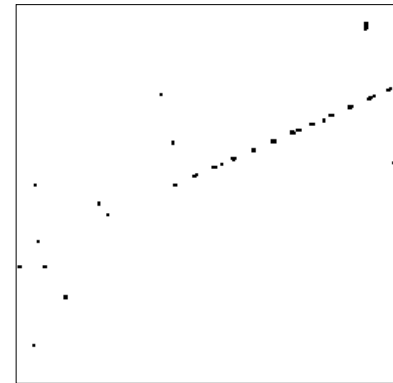
■ Scratch



The defective image
with scratch



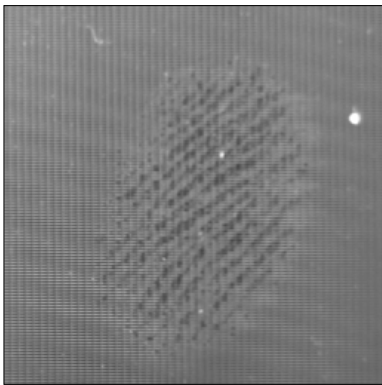
Restored image
by remove (σ_1 to σ_8)



Resulting binary image
for defect segmentation
($\mu \pm 4s_f$)

Experimental Results

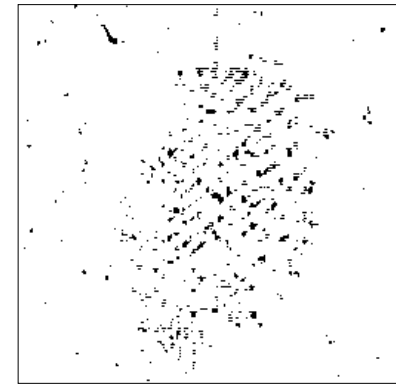
■ Fingerprint



The defective image
with fingerprint



Restored image
by remove(σ_1 to σ_6)



Resulting binary image
for defect segmentation
($\mu \pm 4s_f$)

Conclusion



- We have proposed a global approach using SVD for inspecting **micro-defects** on the TFT-array surface.
- The proposed SVD image reconstruction scheme has shown promising result for LCD micro-defect inspection including **pinhole, scratch and fingerprint**



The END

normalized

plot

SVD Image Reconstruction

■ *SVD for defect detection*

The restoration technique process

$$\hat{X} = \sum_{j=k}^r U_j \sigma_j V_j^T$$

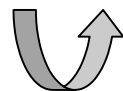
where \hat{X} is restored image

U_j and V_j are the j th column vector of U and V , respectively

σ_j is the j th singular values of S

k is the steady - state point of singular values

r is the rank of the matrix



SVD Image Reconstruction

■ *SVD for defect detection*

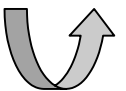
Simple statistical control limits process

$$\mu_f \pm ks_f$$

where

k is a control constant

μ_f and s_f are the mean and standard deviation
of gray levels in the restored image $f(x,y)$



Normalization proceed

➤ Normalization proceed

$$\sigma'_i = \frac{\sigma_i - \mu_\sigma}{S_\sigma}, \text{ for } i = 1 \dots r$$

where

$r = \text{rank}(X)$

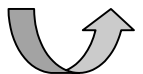
σ_i is the value of the j th singular value

μ_σ is the mean of singular value

S_σ is the standard deviation of singular value

➤ First-order difference of NSV

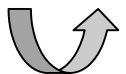
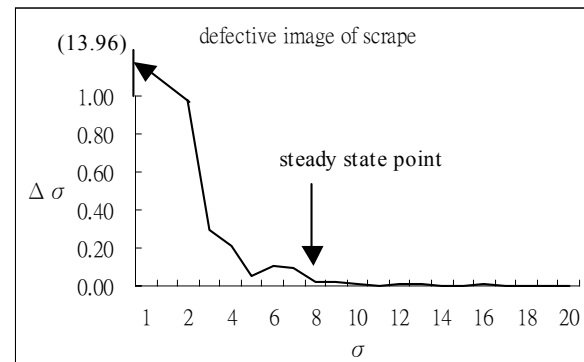
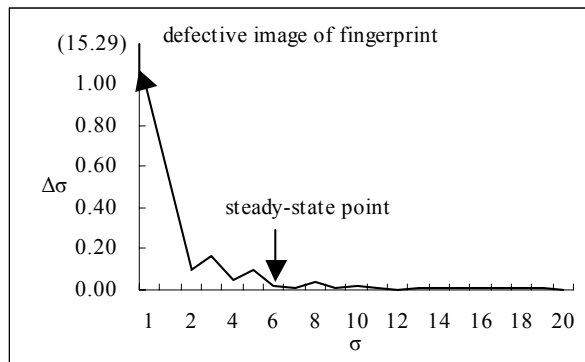
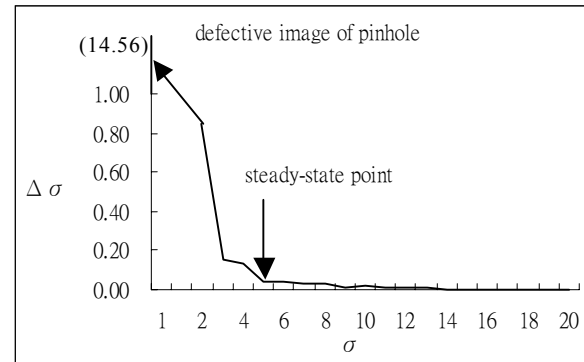
$$\Delta\sigma_i = \sigma'_i - \sigma'_{i+1}$$



The Plots of First-order Difference

- The plots of first-order difference $\Delta \sigma$ of defective images

➤ **Steady-state point: $\Delta \sigma < 0.05$**



SVD Image Reconstruction

Use SVD to decompose the image X
and gain the singular values



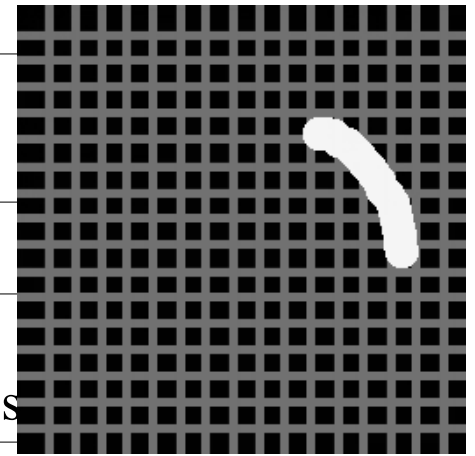
Select the proper number of singular values to
represent the repetitive orthogonal structure features



Set the selected singular values to zero
and reconstruct the image



Use simple statistical process control principle to set up the
control limits for distinguishing defects from regular regions



SVD Image Reconstruction

Use SVD to decompose the image X
and gain the singular values



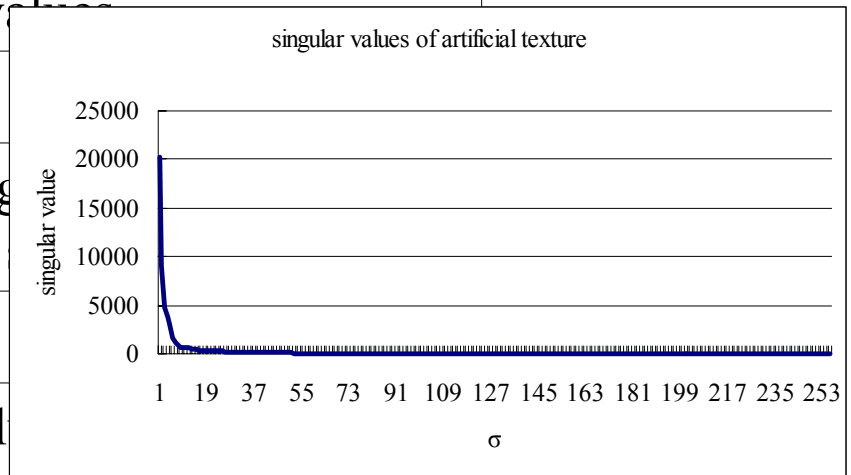
Select the proper number of singular values
represent the repetitive orthogonal



Set the selected singular values
and reconstruct the image



Use simple statistical process control principle to set up the
control limits for distinguishing defects from regular regions



SVD Image Reconstruction

Use SVD to decompose the image X
and gain the singular values



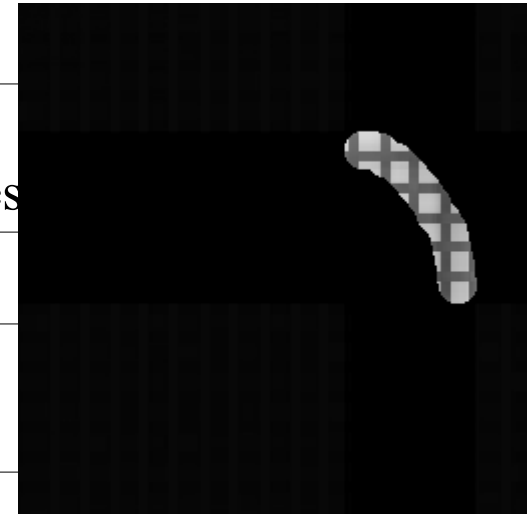
Select the proper number of singular values to
represent the repetitive orthogonal structure features



Set the selected singular values to zero
and reconstruct the image



Use simple statistical process control principle to set up the
control limits for distinguishing defects from regular regions



(remove σ_1)

SVD Image Reconstruction

Use SVD to decompose the image X
and gain the singular values



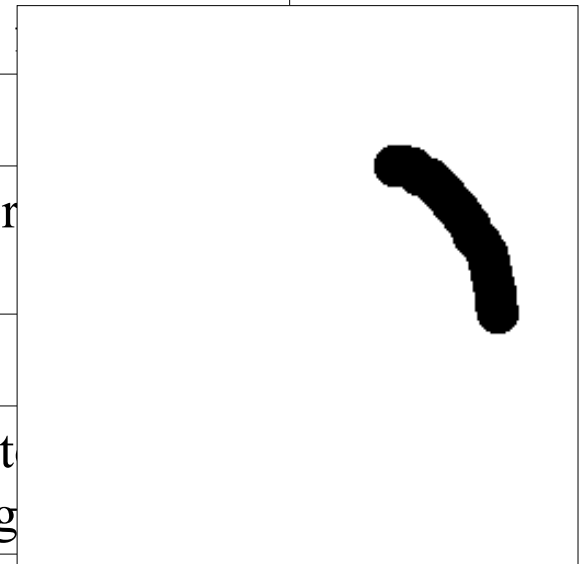
Select the proper number of singular values to
represent the repetitive orthogonal structure



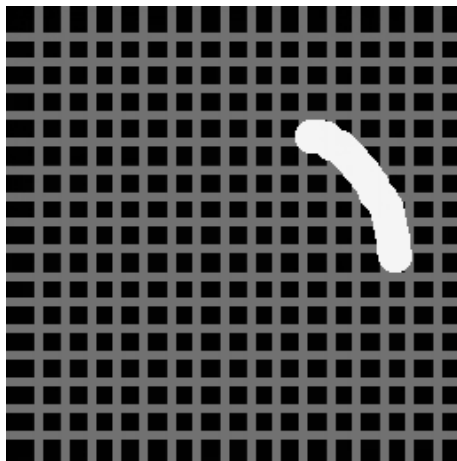
Set the selected singular values to zero
and reconstruct the image



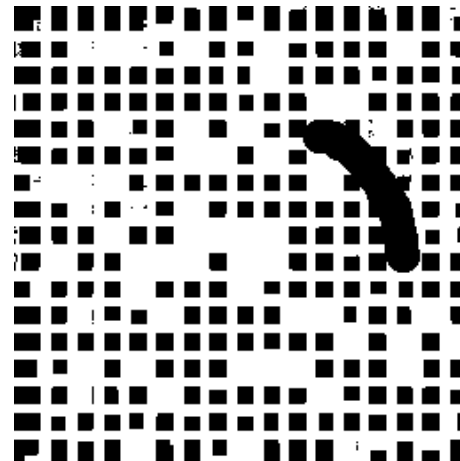
Use simple statistical process control principle to
control limits for distinguishing defects from regular



$(\mu \pm 1s)$

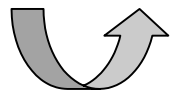


Original image



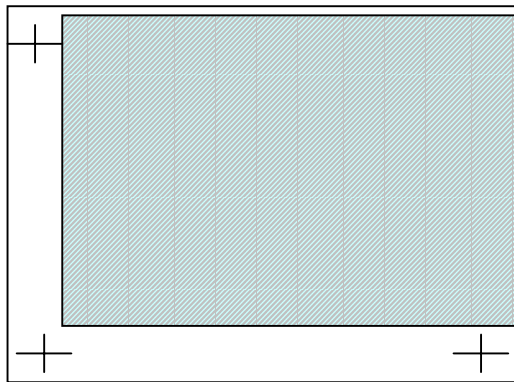
An image after SPC

$(\mu \pm 1s)$

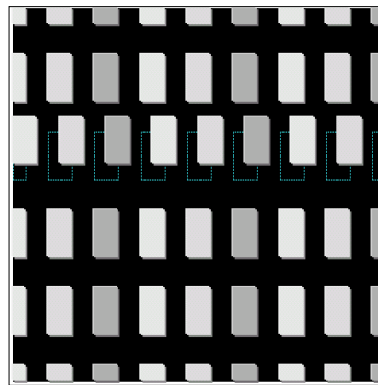


Macro Defects of TFT Array Plate

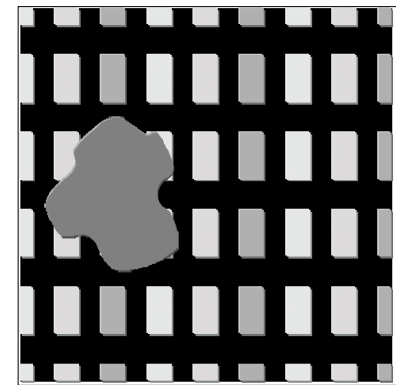
- Macro defects of TFT-array plate-**MURA**, **ZURE** and **SIMI**



MURA
(un-evenness)



ZURE
(mis-alignment)



SIMI
(stain)

