Manufacturing Sensor data Analytics: Spatial Data Modeling

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- Defects on semiconductor wafers
  - Spatial defect patterns contain useful information about issues during integrated circuit fabrication
  - Promptly detecting abnormal wafers is an important way to increase yield and product quality

- Objective
  - Develop an algorithm for detecting abnormal DRAM wafers more accurately in semiconductor manufacturing

- Binarized FBT maps
  - A generalized joint count-based statistics

$$T^{(k)}(g) = p^{(k)} c_{00}{}^{(k)}(g) + (1 - p^{(k)}) c_{11}{}^{(k)}(g)$$

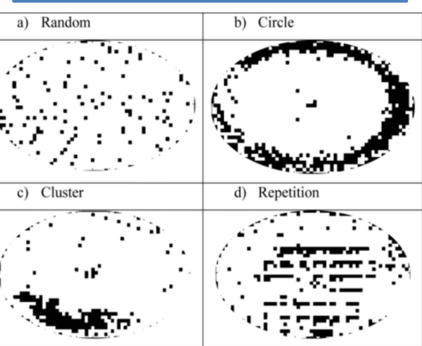
  - The test statistic corresponding to the spatial lag g

$$Z_T{}^{(k)}(g) = \frac{T^{(k)}(g) - c^{(k)}(g) p^{(k)} (1 - p^{(k)})}{\sqrt{c^{(k)}(g) (p^{(k)})^2 (1 - p^{(k)})^2}} \sim N(0, 1)$$

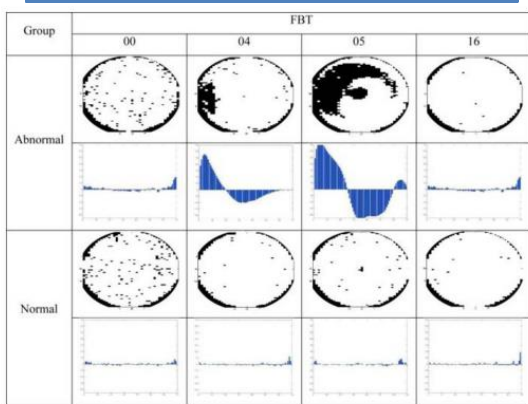
  - The orginial FTB value of i-th functional chip of k-th FTB map

$$\hat{f}_h^{(k)}(u) = \frac{1}{n_f * h^{(k)}} \sum_{i=1}^{n_f} K\left(\frac{u^{(k)} - u_i^{(k)}}{h^{(k)}}\right) \quad \text{where} \quad h^{(k)} = \left(\frac{4\hat{\sigma}^{(k)^5}}{3n_f}\right)^{\frac{1}{5}} \approx 1.06\hat{\sigma}^{(k)} (n_f)^{-\frac{1}{5}}$$

Binarized FBT maps



Selected denoised FBT maps



- Spatial Local Denoising
  - Case 1) De-Noising the Interior of the Binarized FBT Map

$$R^{(k)}(i, j) = \frac{1}{l^2} \sum_{m=-t}^{t} \sum_{n=-t}^{t} x_{i,j}^{(k)} x_{i+m,j+n}^{(k)}$$

  - Case 2) De-Noising the Edges of the Binarized FBT Map

$$R^{(k)}(i, j) = \frac{1}{N(i, j)} \sum_{m=-t}^{t} \sum_{n=-t}^{t} x_{i,j}^{(k)} x_{i+m,j+n}^{(k)} A(i + m, j + n)$$

- Step-down Randomness Test
  - Test statistics and Control limits

$$Z_1 = \boldsymbol{y_r}^{(1)T} \boldsymbol{S_r}^{(1)-1} \boldsymbol{y_r}^{(1)} \qquad CL_1 = \frac{(n-1)r}{(n-r)} F_{\alpha_1}(r, n-r)$$

$$Z_k = \frac{T_k^2 - T_{k-1}^2}{1 + T_{k-1}^2/(n-1)} \qquad CL_k = \frac{(n-1)r}{(n-kr)} F_{\alpha_k}(r, n-kr), k = 2, 3, \ldots, N$$

Comparison of Test performance

Test Method	*Procedure of the randomness test*			*Accuracy*		
	Binarization	De-noising	Test	Normal	Abnormal	All
A	No	No	Single test	0.50	0.56	0.52
B	Normal	Proposed denoising	Step-down	0.84	0.79	0.81
C	Otsu	Proposed denoising	Step-down	0.17	0.88	0.51
D	KDE	No	Step-down	0.78	0.79	0.78
E	KDE	Median Filter	Step-down	0.83	0.75	0.79
F	KDE	Proposed denoising	Bonferroni	0.92	0.71	0.81
G	KDE	Proposed denoising	Step-down	0.91	0.90	0.91

- "Step-Down Spatial Randomness Test for Detecting Abnormalities in DRAM Wafers with Multiple Spatial Maps", *IEEE TRANSACTIONS ON SEMICONDUCTOR MANUFACTURING* (2016)