Characterizing Features of Silicon Wafers

using Fourier Transforms and Delaunay Triangulation

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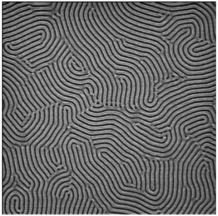
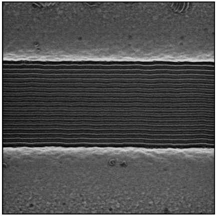
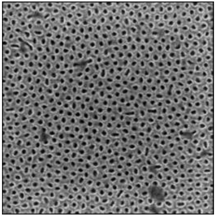
AZ Electronic Materials

- Manufacturer of materials for chip makers (processors etc.)
- Also do R&D in new methods of chip design
- Internship with R&D team to build a method for reliably characterizing research samples

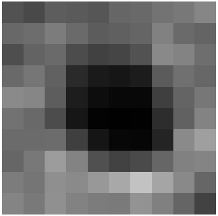
Self Assembly

- Traditionally wafers are patterned using lithography
- Self assembly is a different approach
- Two immiscible monomers polymerize to create a **Block Co Polymer (BCP)** with two distinct ends
- Given opportunity system assembles to **minimize energy**

Data Set

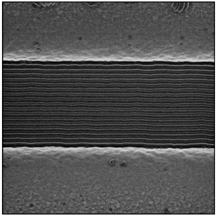
- Images of wafers from an Electron Microscope
- Typically 480 x 480 pixels with known field of view (nm)
- Can think of as just a matrix of intensity values (0-255)



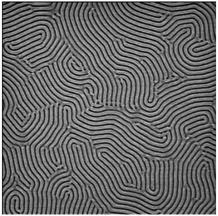
82	73	93	90	86	102	105	115	120	134
104	109	124	106	92	96	101	129	106	100
78	99	106	76	65	69	82	137	131	110
105	118	97	42	26	22	28	91	112	103
138	134	93	29	13	8	8	63	100	119
114	105	76	22	3	1	2	45	97	131
107	107	108	63	21	7	6	36	138	159
102	120	156	131	80	66	74	102	129	132
124	117	143	138	152	168	194	165	137	102
132	121	144	130	124	122	147	128	101	66

Characterizing

- Characterized by the distance between the lines L_0
- Easy to think of a method to measure Directed Assembly



- Unguided assembly (finger print pattern) is more tricky



Fourier Theorem

Any well behaved function can be expressed as a combination of sine and cosine waves.

- Pixel data is discretized
- We will use a 2D DFFT

Fourier Transform
Example

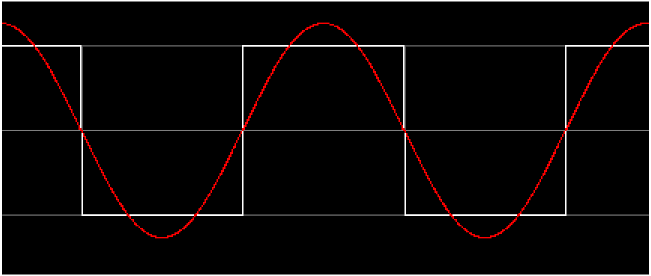


Figure: N=1

Fourier Transform
Example

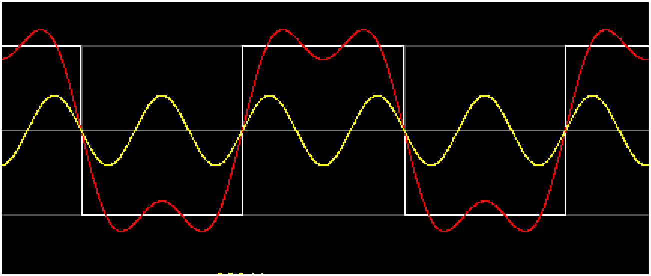


Figure: N=2

Fourier Transform
Example

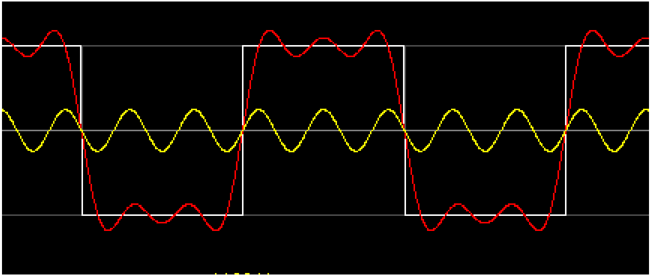


Figure: N=3

Fourier Transform
Example

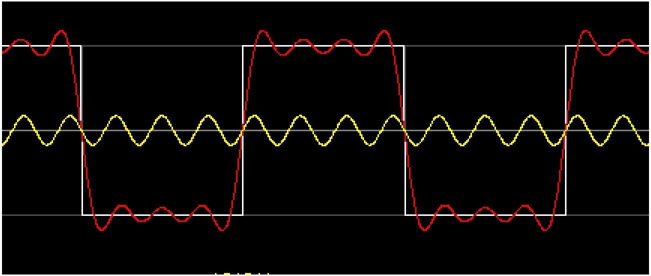


Figure: N=4

Fourier Transform
Example

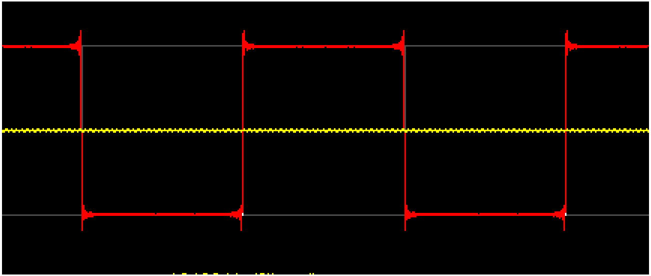
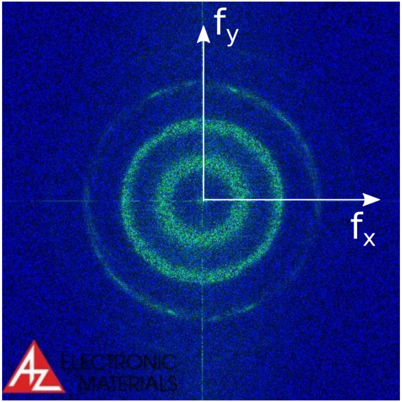


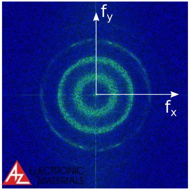
Figure: N=Lots!

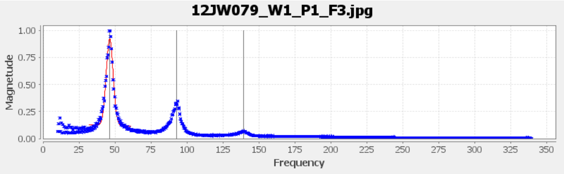
Power Spectrum - 2D

- Output is a map of amplitudes
- Frequencies which best fit the image in x and y axis
- Circular spectrum confirms the same frequency in all directions
- $f = \sqrt{f_x^2 + f_y^2}$

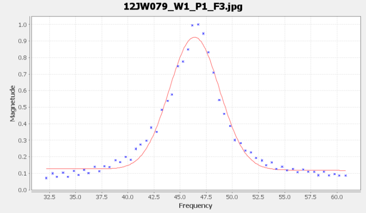


Frequency Distribution





- Multiple peaks - harmonics
- Gaussian fit gives the peak frequency and associated error f_0

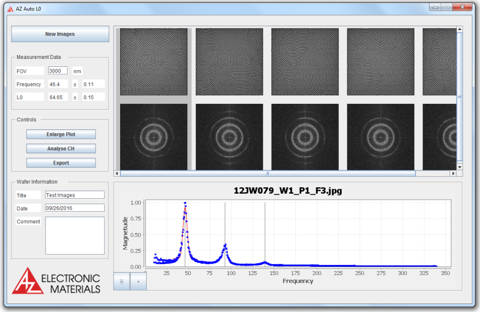


Calculating L_0

- Measure peak frequency for multiple images
- Calculate the mean ($\bar{f}_0$) and combine errors

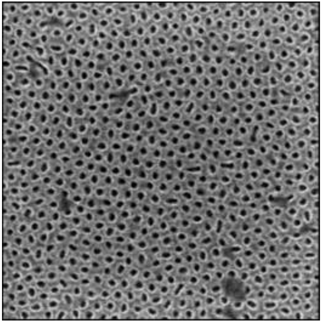
$$\Delta f_0 = \frac{\sqrt{\sum_{i=1}^{N} \Delta f_{0_i}}}{N}$$

$$\bar{L}_0 = \frac{FOV}{\bar{f}_0}$$

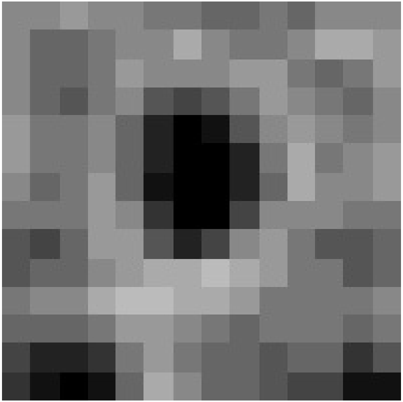


Finding Holes

- First need to define holes in the image
- Simple idea - focus on darkest pixels and expand out to find a hole
- Stop when next change to next pixel is above a specific threshold



Finding Holes - Example



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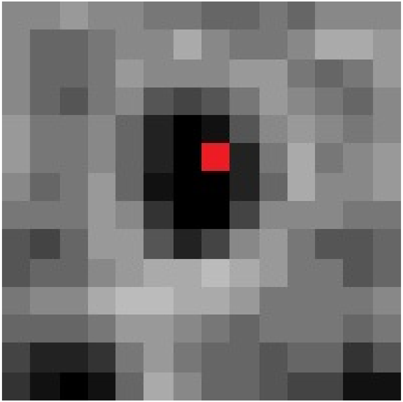
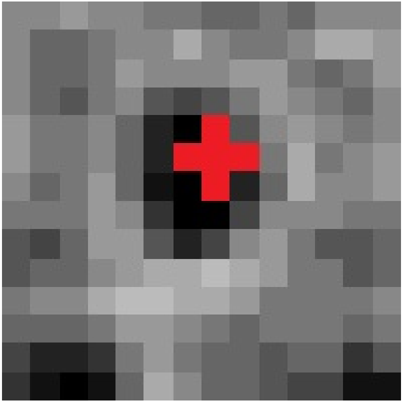


Finding Holes - Example



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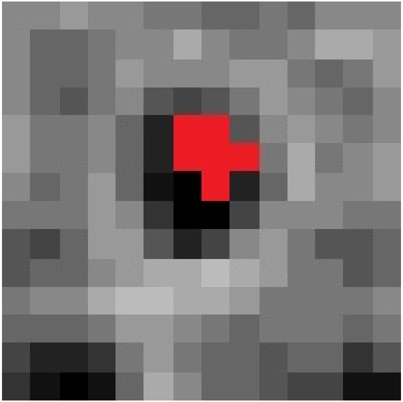
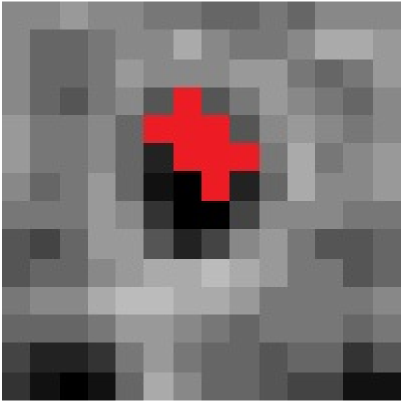
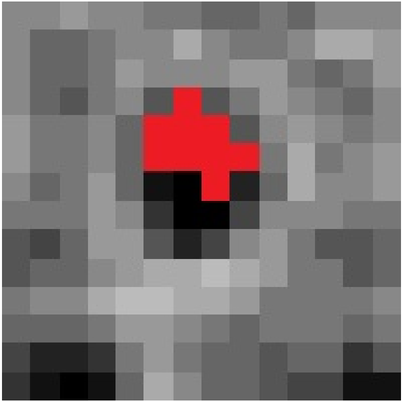


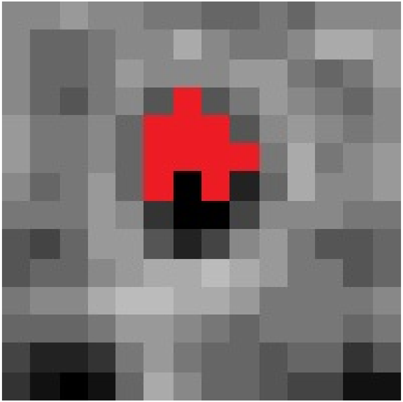
Finding Holes - Example



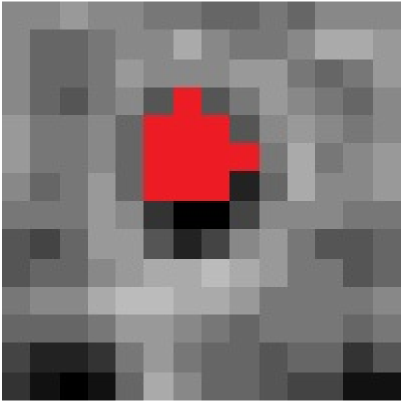
Finding Holes - Example



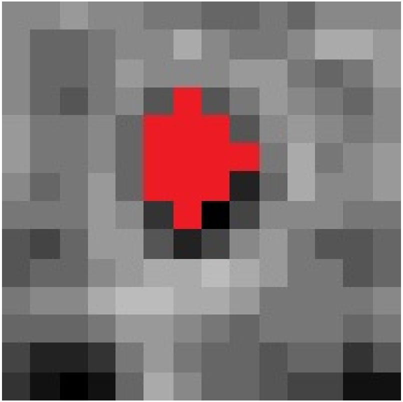
Finding Holes - Example



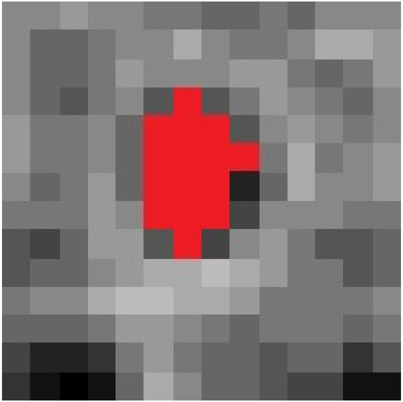
Finding Holes - Example



Finding Holes - Example



Finding Holes - Example



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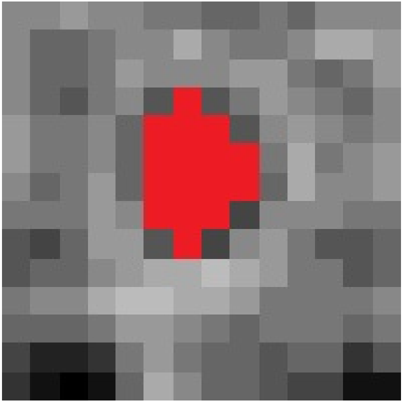

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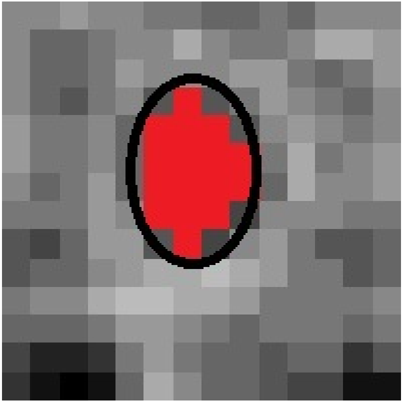
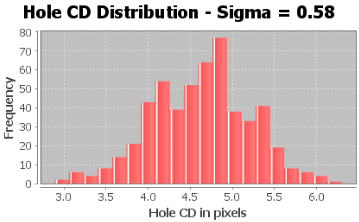
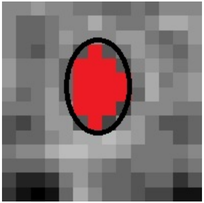
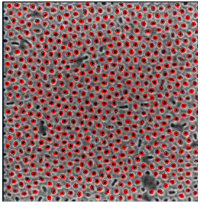


Characterizing Holes

- Once hole is found can fit a general ellipse
- Distribution of diameter and skew of holes tells us about quality

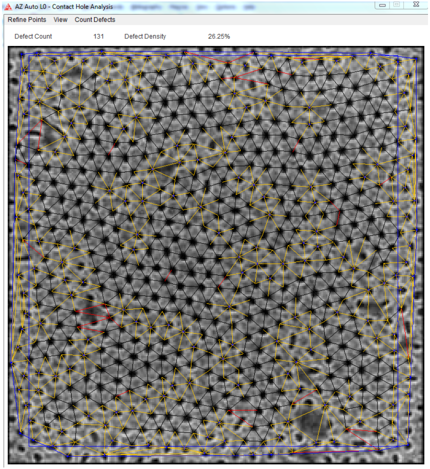






Triangulation

- By using triangulation we can find defects in the sample
- The number of neighbours highlights missing holes
- The neighbour - neighbour distance shows irregularities / smudges



Defect - Example

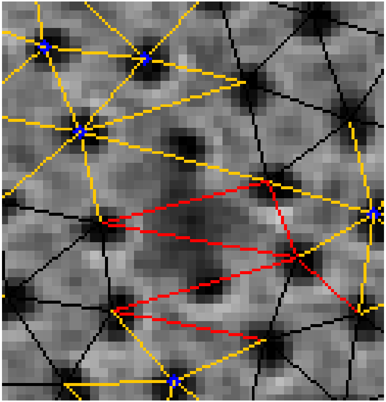


Figure: Example triangulation finding a missing hole

Summary

- A system was developed in Java to reliably characterize samples of patterned silicon wafers
- Both line and hole patterns were tackled
- The R&D team used this software to improve confidence in measurements and reduce time taken to analyse samples

Questions ?

Thank You