SW Test Workshop
Semiconductor Wafer Test Workshop

Image Processing Solutions for Probe Card Manufacturing, Inspection and Optimization

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June 4-7, 2017

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- The Challenges of Measuring Guide Plates
- Performance of the Imaging System
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Oxford Lasers

- Turn-Key Advanced Laser Systems and Tools, for Industry and R&D
- Contract Laser Micromachining Services

More than 1000 lasers / systems in 27 countries, headquarters in Oxfordshire (UK) and Boston (US)

15 years experience in vertical guide plate production

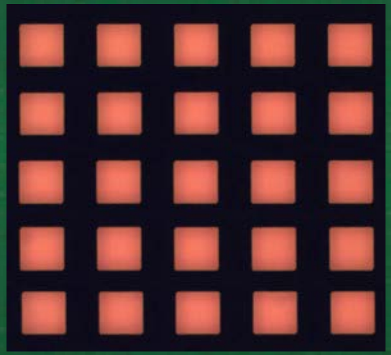
ProbeDrill Tool

- ✓ High aspect ratio hole drilling
- ✓ Fine Cutting, Dicing, Scribing
- ✓ Selective Laser Patterning

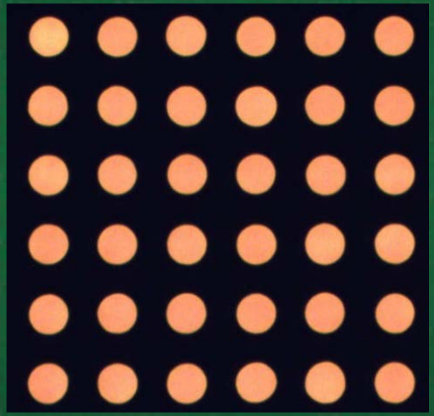
Guide Plates for Probe Cards

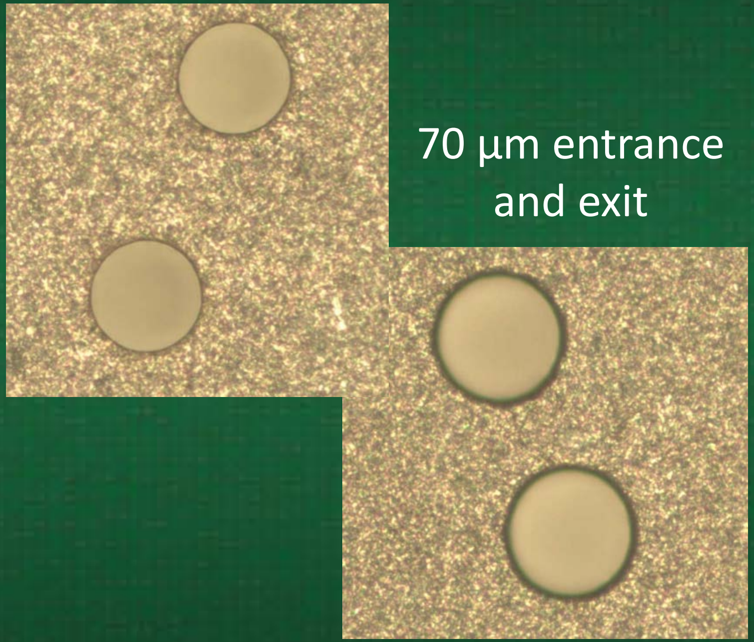
- **What are Guide Plates ?**
  - Consist of a mechanically stable substrate with 1000's of micro-holes, through which probes are fitted, ensuring accurate location of each probe
  - A typical probe card uses several guide plates

62.5 X 60 µm



55 µm





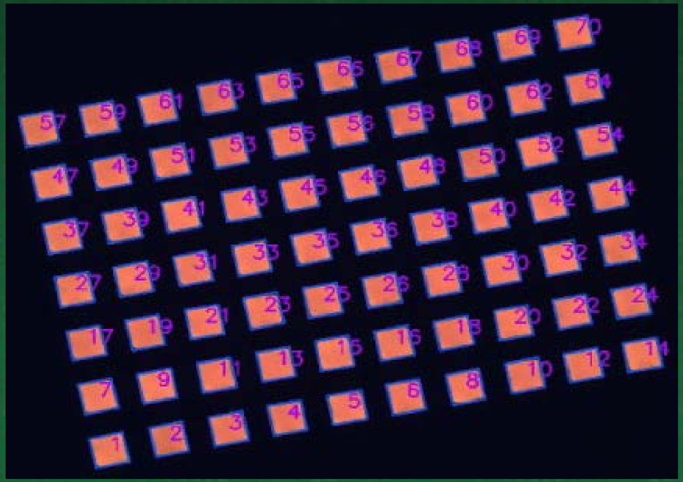
70 µm entrance and exit

- **Guide Plate Features**
  - Accurately locate probe pins
  - Probe size and pitch to accurately match DUT
  - Provide appropriate guiding/sliding of probes, scrub, wear, cleaning etc.
  - Material is chosen accordingly (Si_3N_4, Alumina, Macerite, Photoveel, Polyimides - Kapton, Vespel, Cirlex etc..)

SMART Project

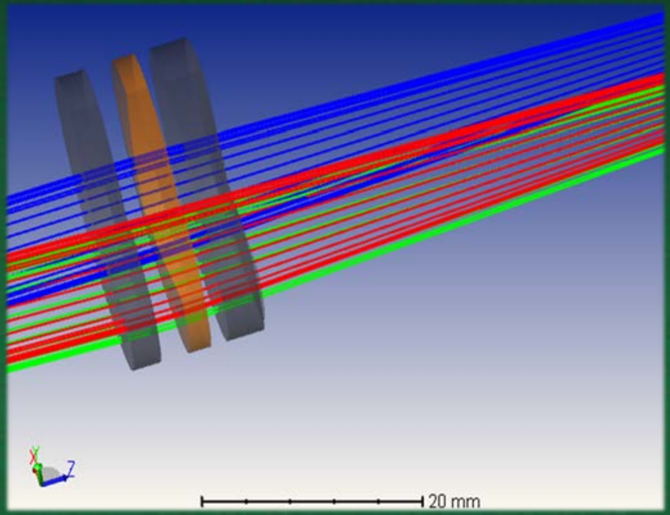
(Innovative UK, grant agreement 700495)

Measuring Algorithm, Software, Graphic Interface

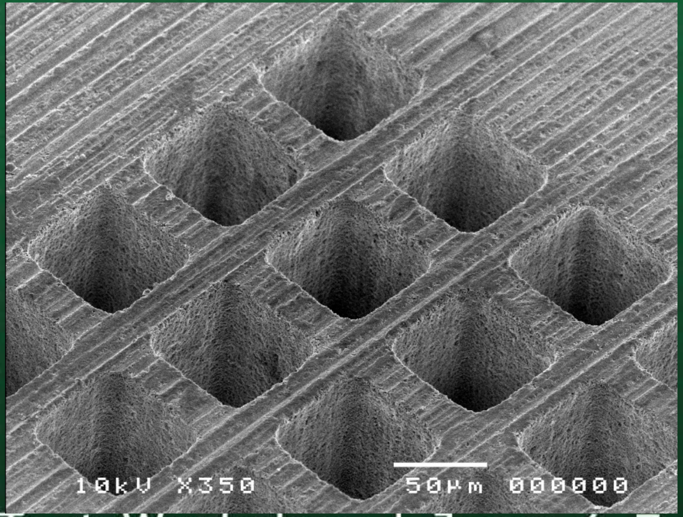


Drilling smaller, more precise holes, quicker

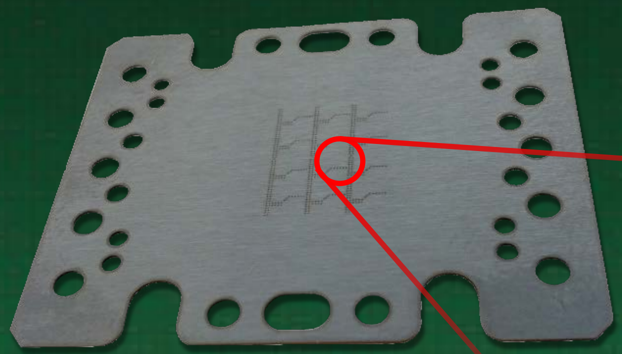
Optics, Beam Delivery, Mechanical Design



Radiation - Matter Interaction, Laser Process Development

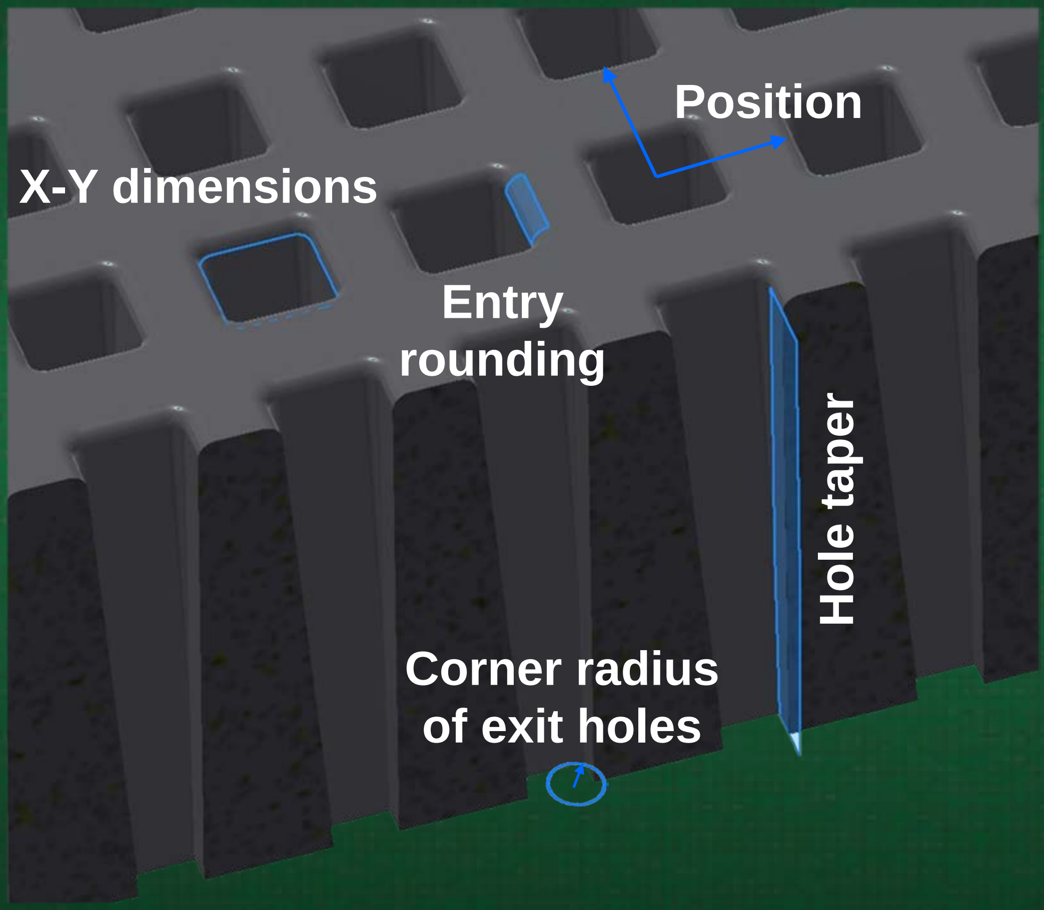


Measurement Challenges



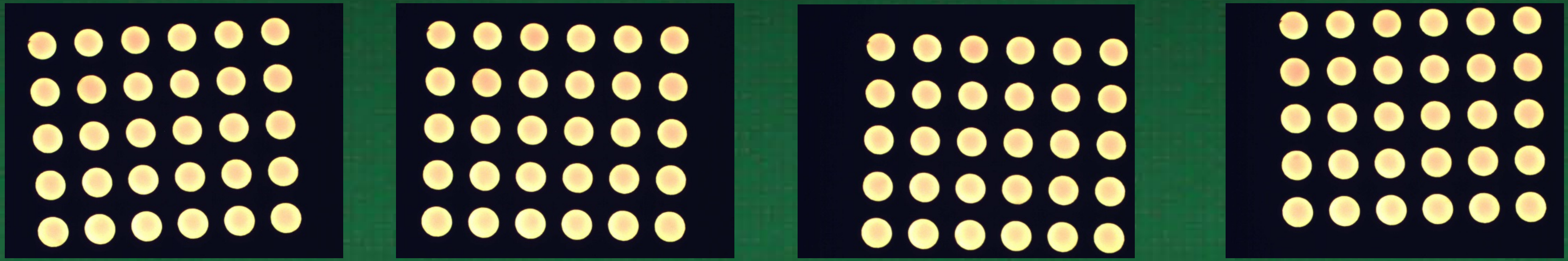
- Non conventional features : for typical image processing software
- Niche market : no investment appeal for an industrial solution from large image processing software companies
- Lack of well defined standards
- A real need for a solution for quality control, optimization, customer support and R&D

Tailored, in-house development of an image processing solution

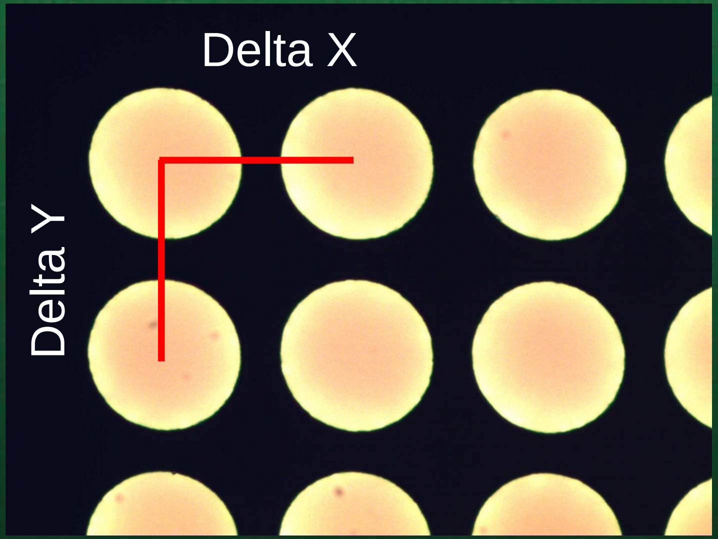


Defining the Imaging System Performance

For several combinations of NA and pixel size, multiple pictures of the same sample have been taken.
The standard deviations of each group of pictures defines the repeatability



× …*n*



Reference guide plate under best achievable conditions

- High quality 70 µm round holes as an example
- Pitch between the micro holes centre of mass, is used as a relative measure of linear distance
- Samples have been cleaned
- Homogenous illumination conditions

Defining the Imaging System Performance

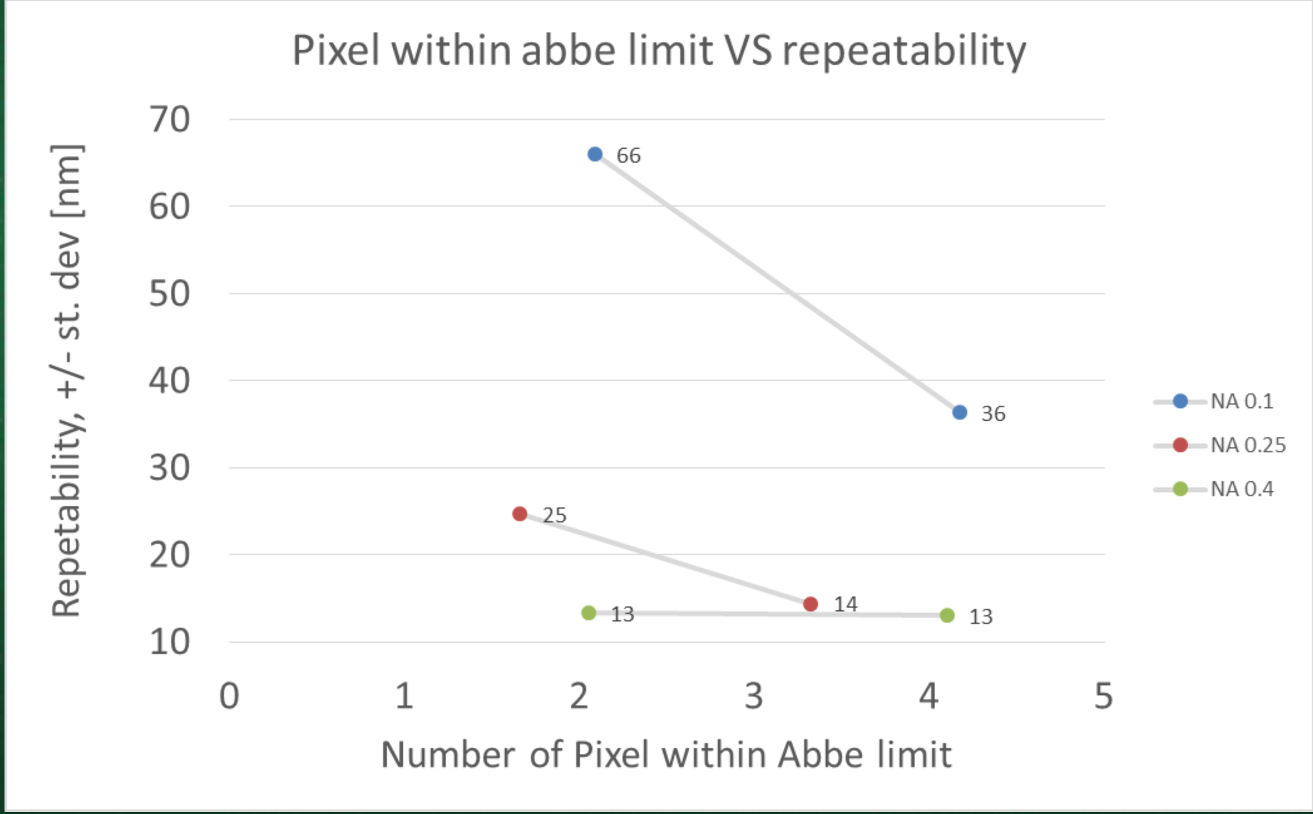
- For a given NA, we can determine the repeatability for a chosen pixel size
- System performance can be optimized with respect to hole dimensions
- After this study, we set the system to have a **repeatability of +/- 50 nm** for feature dimensions **above 25 µm**

Abbe/diffraction limit:

$$d = \frac{\lambda}{2\,NA}$$

Pixels within Abbe limit:

$$N = \frac{d}{pixel\ size}$$



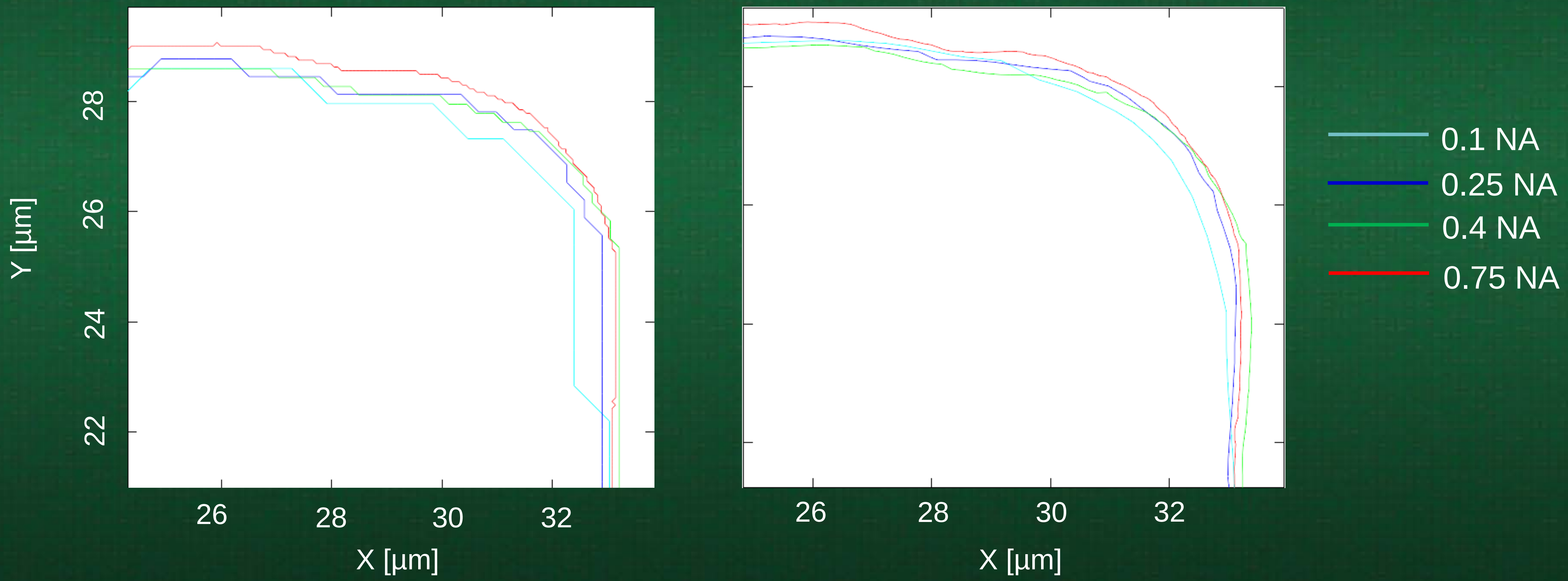
Edge Detection, Sub-Pixel Resolution

- With Sub-pixel resolution we can extract more information from lower NA and larger field of views

The software looks over several pixels along the contour to provide a smoother transition between adjacent pixels

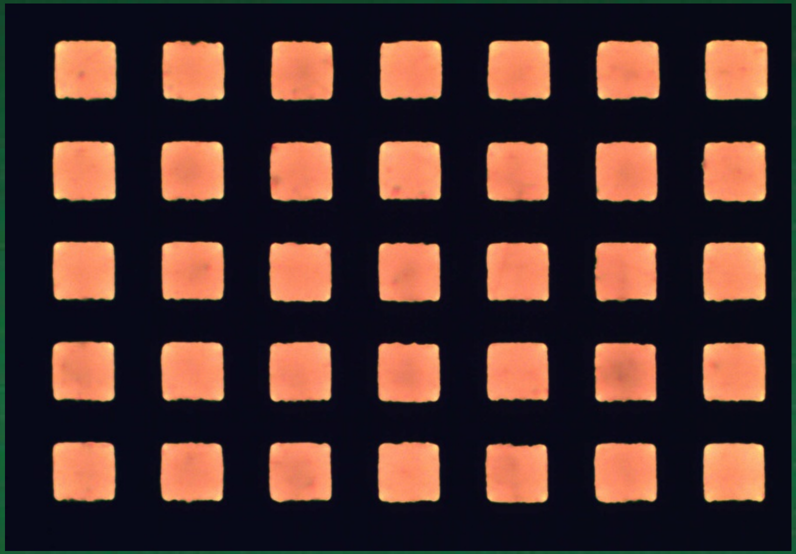
Before sub-pixel thresholding

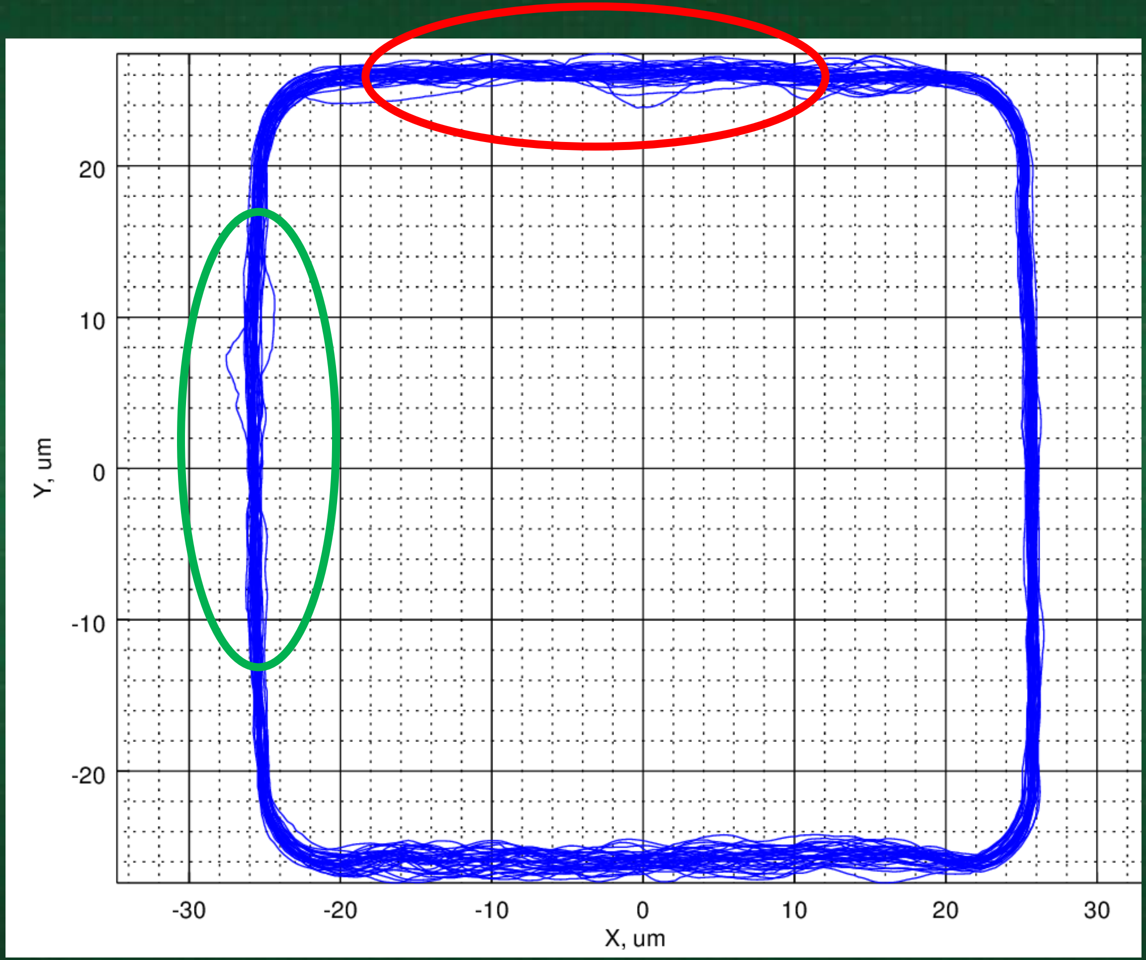
After sub-pixel thresholding



Edge Contour Overlap

50 X 60 µm square exit holes





- The edge contour overlap is an immediate and intuitive method to address process variability
- Example on the right: process with higher variability in Y with respect to X direction

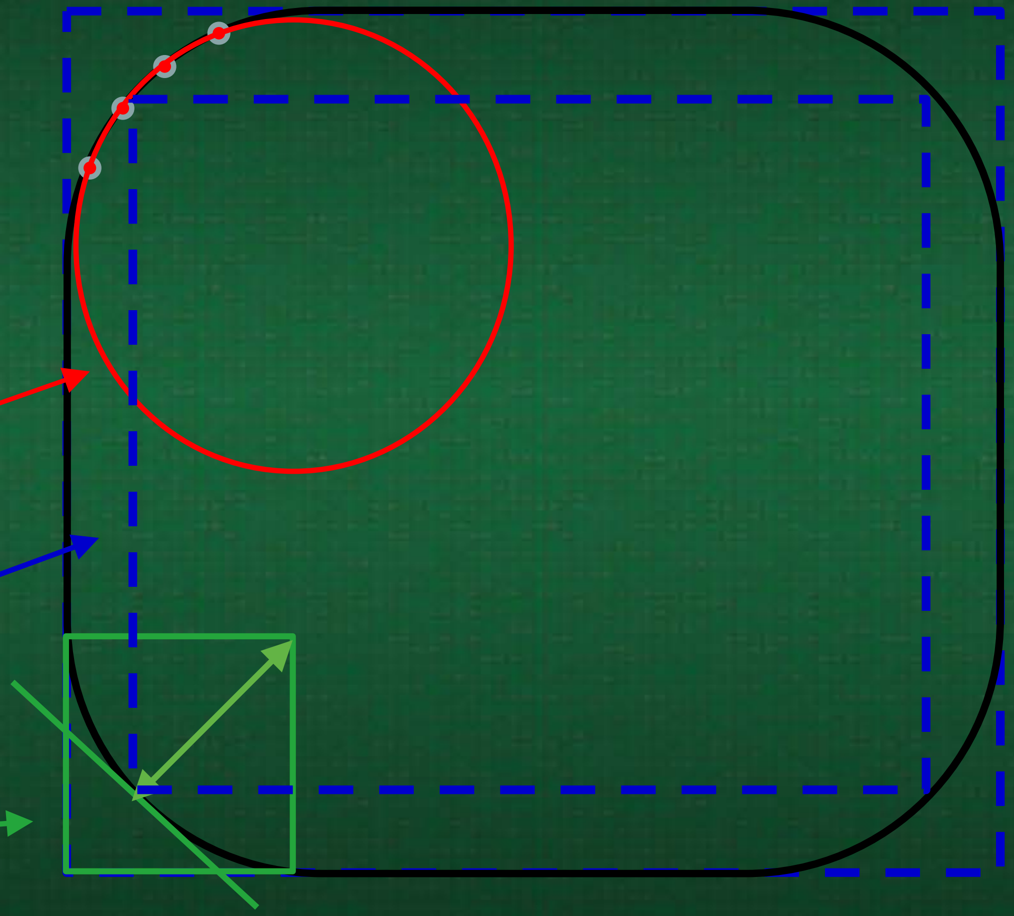
Searching for the Best Algorithm

Many different methods were studied during the SMART project :

- ➢ Holes dimensions, taper and position are easier to measure
- ➢ Corner radius and entry rounding are extremely challenging

CASE STUDY: Corner radius measurement

Software fitting of corner radius is much better than Operator fitting.

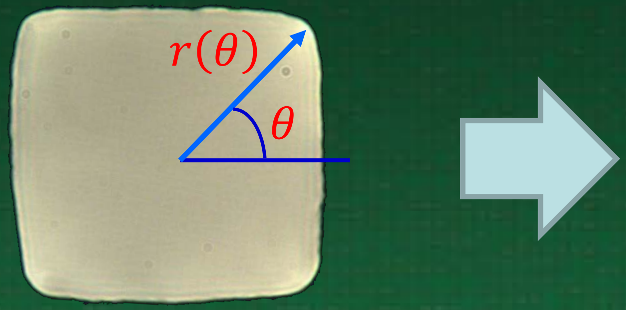


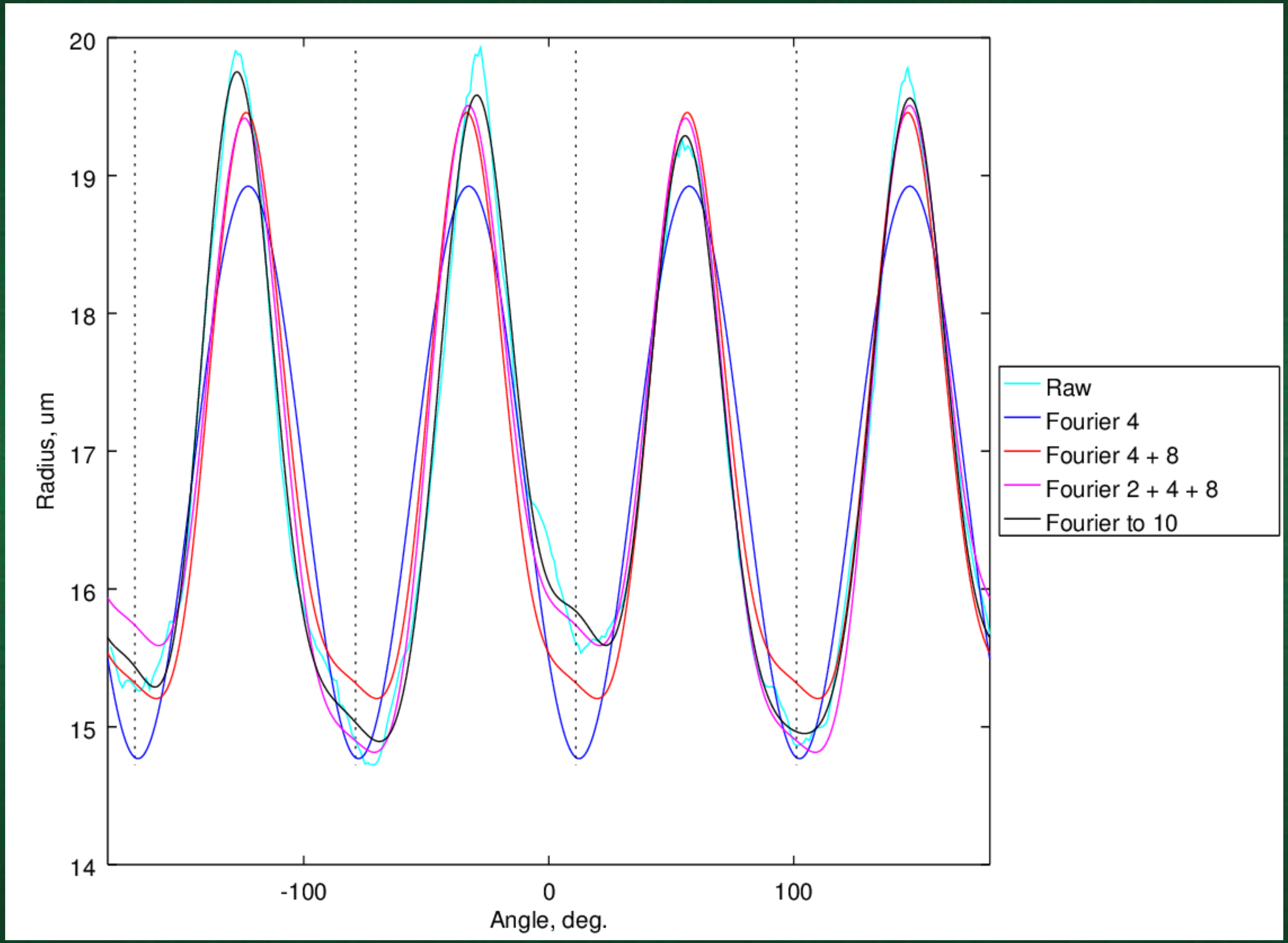
But which is the best method/algorithm to use ?

- Select a number of points and fit to a circle
- Relationship between largest inscribed square and smallest out-scribed square
- Measure distance at 45 degs

These methods rely on arbitrary assumptions: Where does the corner start? Which points do I take for the fit?

Fourier Analysis



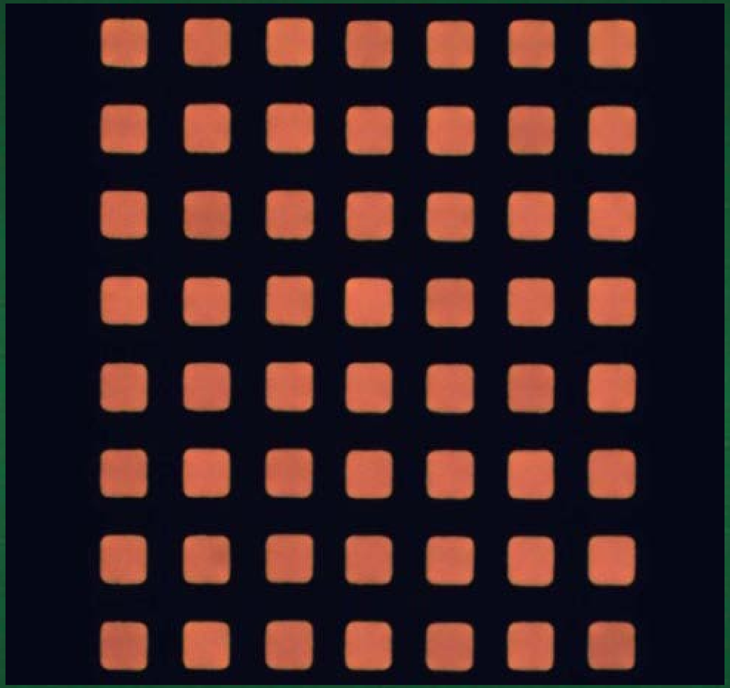


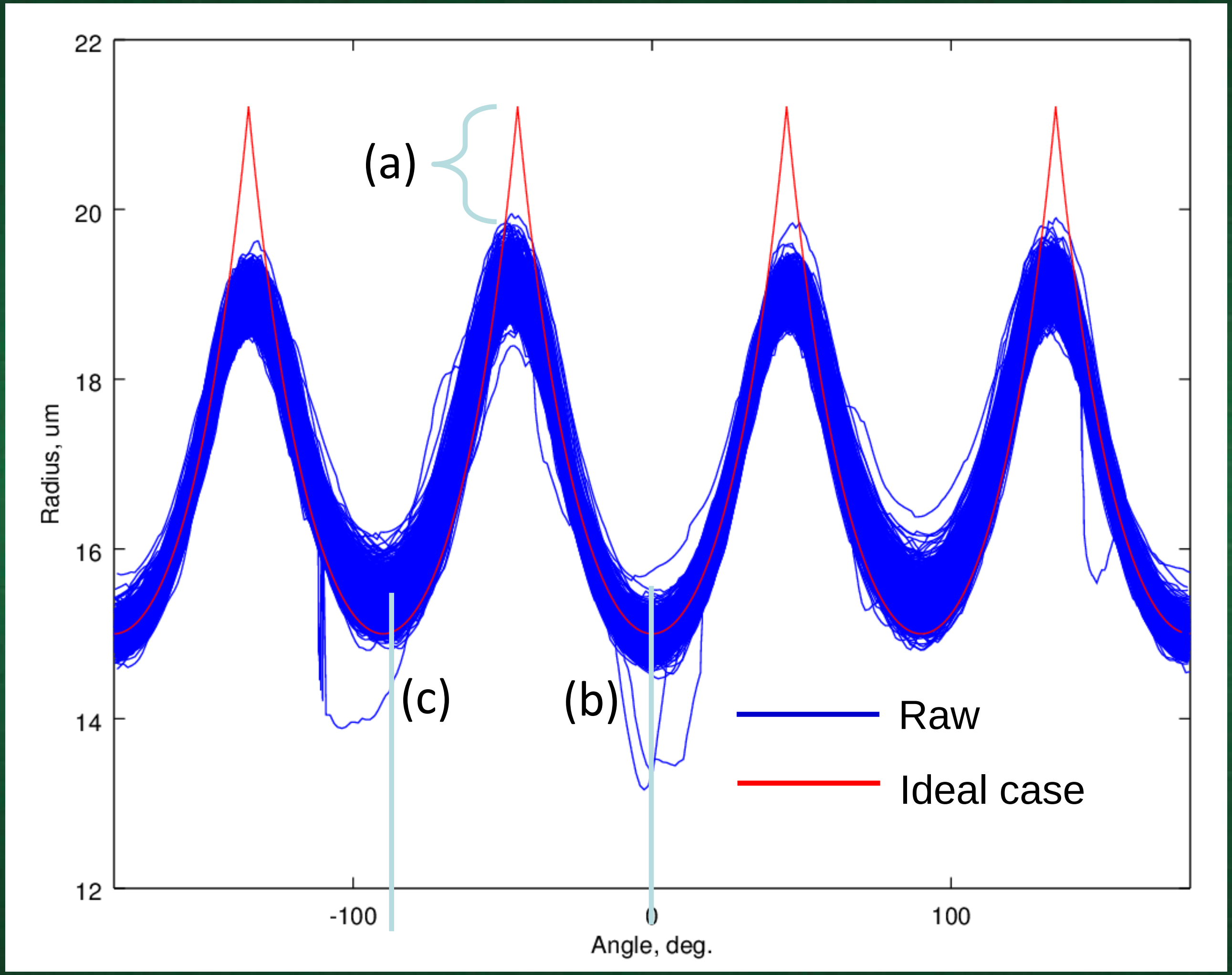
- **Plotting the distance from the centre of mass to the edge as a function of the angle** we can then extrapolate much information thru Fourier analysis
- **By fitting the series** with multiple terms we can evaluate corner radius, rotation, dimensions, parallelism etc...

$$r(\theta) = a_0 + \sum_{n=1}^{m} a_n \cos n\theta + b_n \sin n\theta$$

Fourier Analysis: Dimensions

30 X 30 µm square exit holes

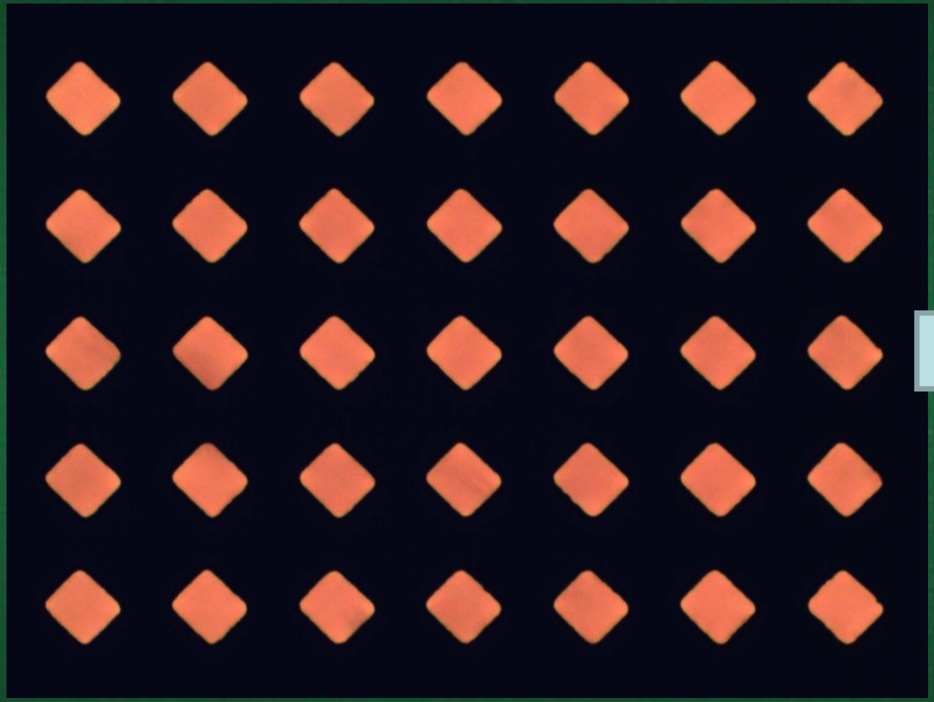


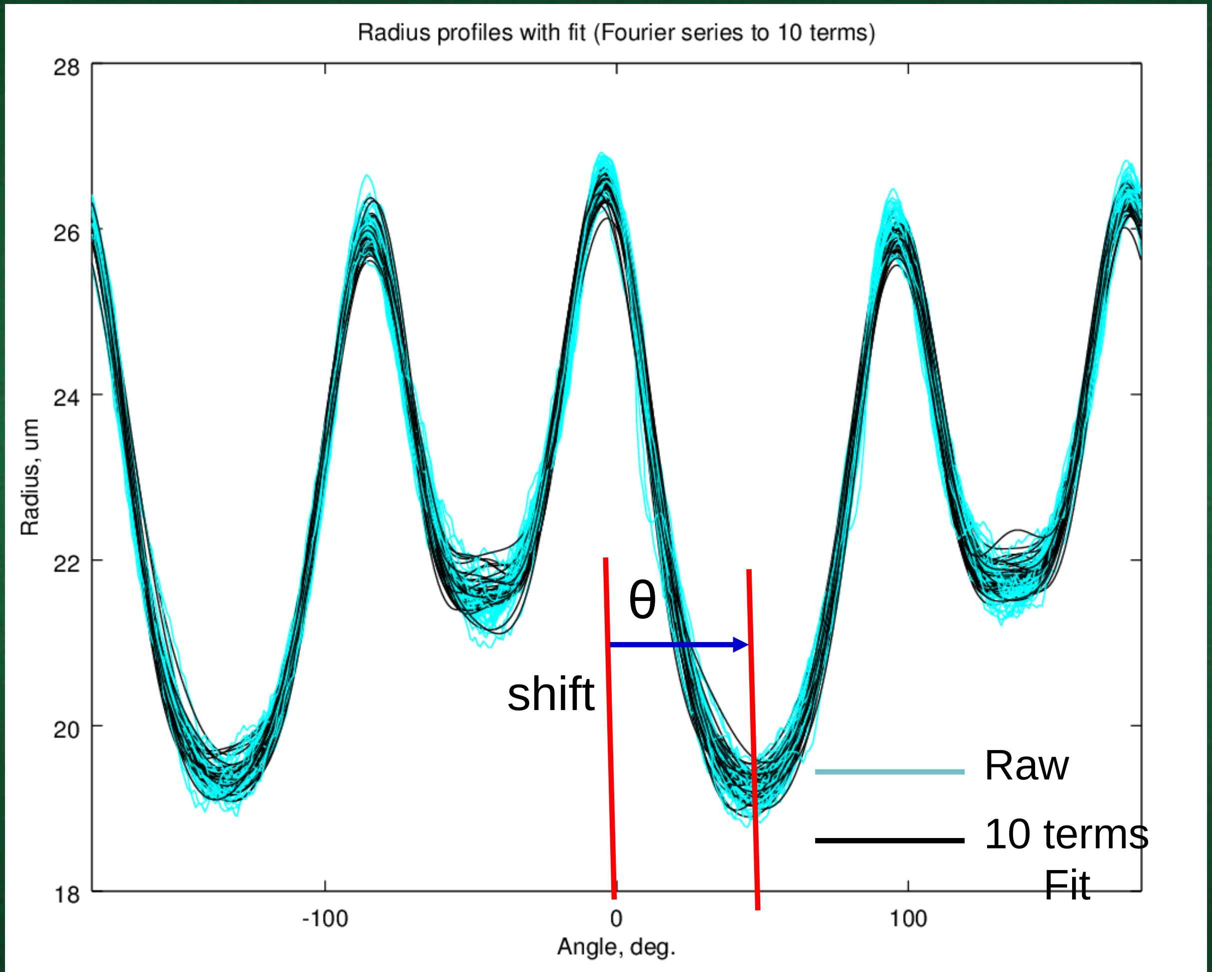


- Corner radius represented as the peak difference from ideal case (a)
- Dimension in X (b) and Y(c) are identified by the value at 0 and 90 deg.

Fourier Analysis: Hole Rotation

40 X 45 µm square exit holes rotated





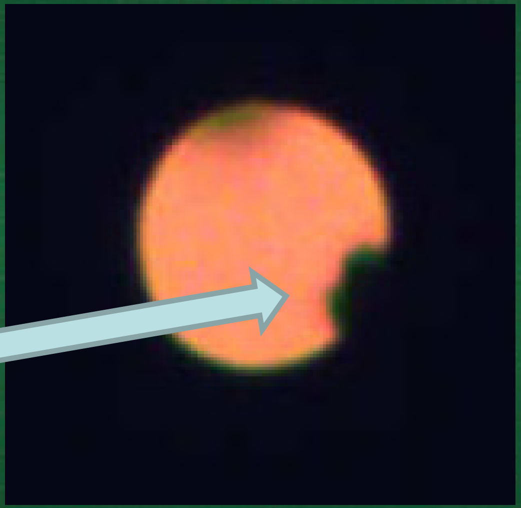
- Rotation is equivalent to a shift along the θ axis.
- This method can easily deal with rotated features (even within the same image frame)

Fourier Analysis: Debris Detection

- All the hole information is captured within the non-zero terms of the Fourier Series
- The method also allows for quick detection of residual debris

Holes #

-0.38	0.11	0.03	0.06	-0.06	0.02	-0.04	-0.02	0.01	0.02	0.03	-0.02	-0.01	0.00
-0.42	0.13	0.03	0.01	-0.03	0.03	-0.03	0.01	0.03	-0.01	0.02	-0.02	-0.02	-0.01
-0.33	0.09	0.04	0.04	-0.03	0.02	-0.01	-0.04	0.02	-0.02	-0.01	-0.01	-0.01	-0.01
-0.41	0.17	0.00	0.05	-0.01	0.06	-0.04	-0.03	-0.02	-0.01	0.00	-0.02	-0.01	0.01
-0.34	0.18	0.06	0.03	-0.04	0.04	0.01	0.02	0.00	-0.04	0.00	0.01	0.00	-0.01
-0.37	0.23	0.10	0.01	-0.01	0.04	0.01	0.02	-0.03	0.01	0.02	-0.01	-0.01	0.00
-0.40	0.18	0.06	0.06	-0.05	0.02	-0.01	-0.01	-0.01	-0.02	0.01	-0.01	0.02	-0.01
-0.66	0.84	-0.02	0.81	0.10	0.45	0.38	0.28	0.34	0.13	0.15	-0.01	0.09	-0.08
-0.36	0.14	0.07	0.07	-0.11	0.04	-0.02	-0.01	0.02	-0.01	-0.01	0.00	-0.01	-0.03
-0.36	0.07	0.08	0.02	-0.01	0.02	0.01	-0.02	-0.01	-0.03	0.00	0.00	0.01	0.00

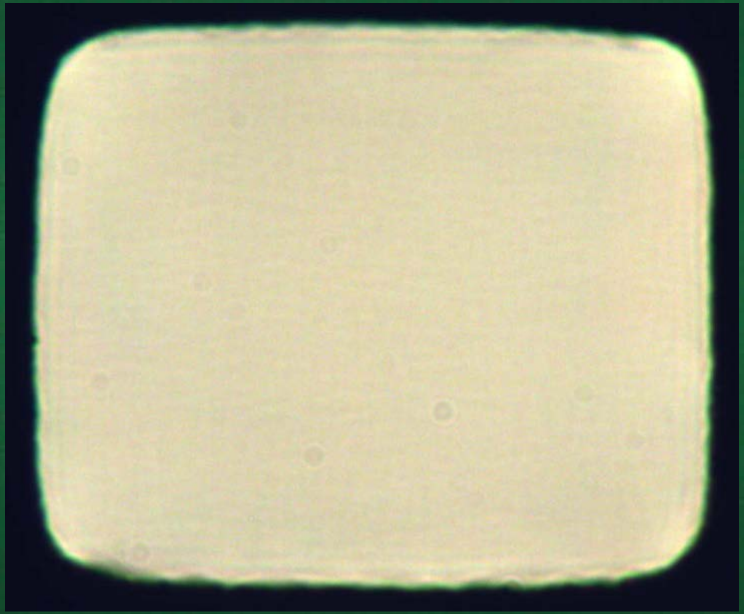


$$r(\theta) = a_0 + \sum_{n=1}^{m} a_n \cos n\theta + b_n \sin n\theta$$

Thresholding

In order to be interrogated - the picture must be converted into different formats depending on the application (grey scale, binary etc…)

- A threshold based on intensity level is needed to perform all the operations
- Different thresholds [from 0 to 1] can give drastically different dimensions, especially when close to 1 or 0
- What is the best threshold ?



Threshold [0-1]	DimX [µm]	DimY [µm]
0.075	61.68	52.30
0.100	61.42	52.03
0.150	61.13	51.73
0.200	60.95	51.54
0.250	60.82	51.40
0.300	60.70	51.26
0.350	60.60	51.14
0.400	60.49	51.02
0.450	60.40	50.91
0.500	60.32	50.79
0.550	60.21	50.67
0.600	60.12	50.53
0.650	60.00	50.40
0.700	59.87	50.24
0.750	59.72	50.00
0.800	58.60	48.27

Thresholding and Illumination

Target dimensions 50 X 60 µm

Level	Dim X [µm]	Dim Y [µm]	Saturation?
1	60.08	50.65	No
2	60.08	50.59	No
3	60.09	50.63	No
4	60.09	50.64	No
5	60.12	50.69	No
6	60.27	50.84	Yes
7	60.60	51.26	Yes
8	60.99	51.71	Yes
9	61.31	51.93	Yes

Before saturation	
STD X [µm]	0.02
STD Y [µm]	0.03

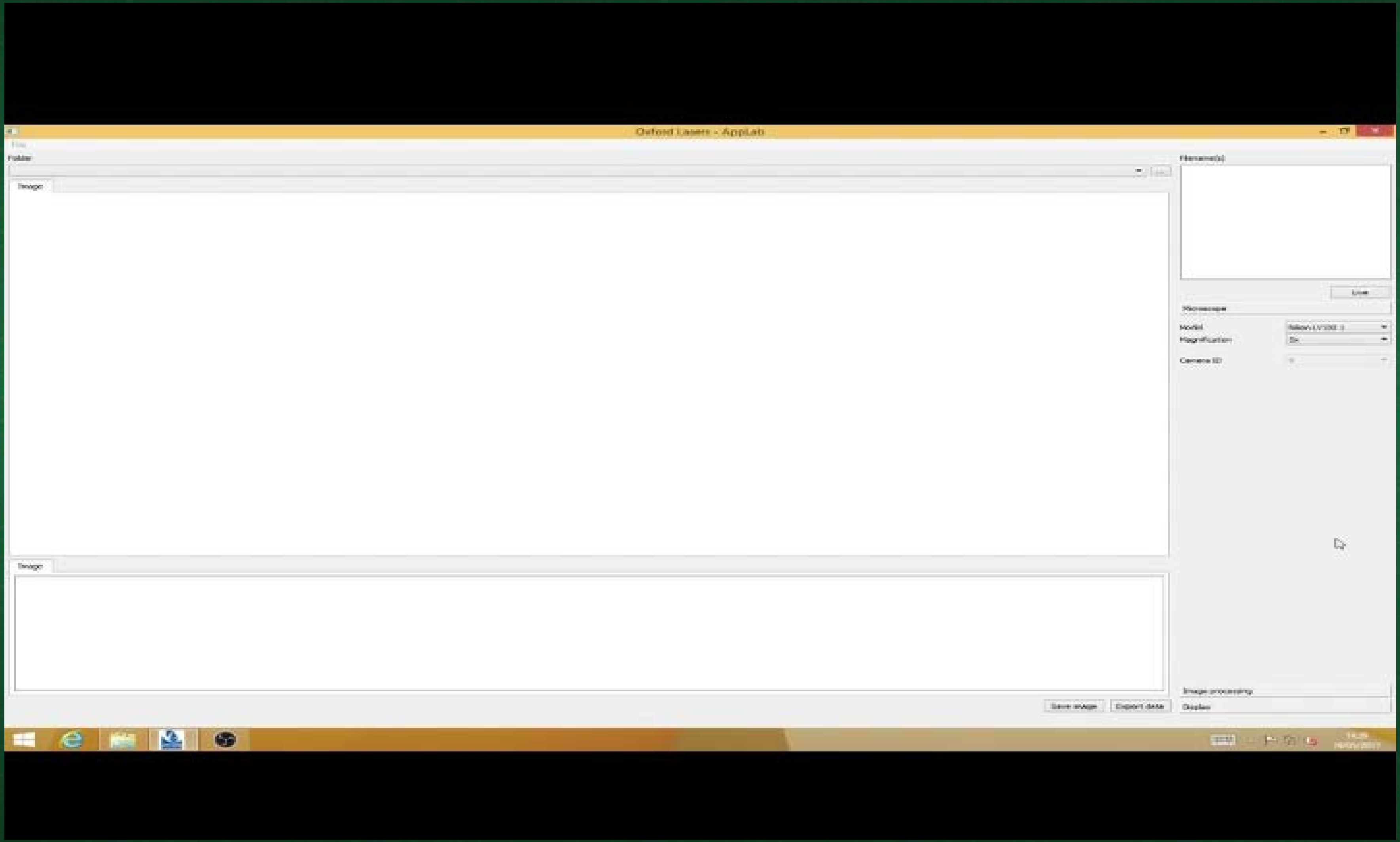
- Automatic thresholding provides stable results only when the image is not saturated
- Automatic illumination adjustment can avoid quality check failure due to operator error

Graphic Interface

Software Demo

1. Load and analyse all the pictures within a folder
2. Automatic shape recognition (circular or square) - measures position, XY dimensions etc etc
3. Magnification selection with consequent automatic adjustment of the measured parameters
4. Selection of optional operations e.g. plotting hole labels, contour or best shape fit
5. View analysed images e.g. Silicon Nitride and Kapton
6. Selection of intensity format options: real colours, grey scale and binary
7. Data export into an excel file, saves position, dimension, corner radius etc etc

Graphic Interface



Graphic Interface

Summary :

- Analysis of 150 square holes under same FOV (600 X 450 µm) in much less than 0.5 sec
- Corner radius, pitch and ellipticity (for circular holes) need to be added to the graphic version
- Valuable tool for both pre-production (fine adjustment of the drilling tool) and post-production phases (quality checks)

Future Work

SHORT TERM

- Complete analysis and coding of the Fourier method
- Finalizing the graphic interface

LONG TERM

- Automatic image grabbing
- Full mapping of the guide plate
- Real time analysis of samples during laser machining

Conclusion

- There is a real need for a standard measuring system/procedure for guide plates in the probe card community
- This in house developed, image processing system unlocks higher quality holes, rapid development/optimization and reduced time to market.
- System repeatability of +/- 50 nm has been achieved studying features from 25 to 70 µm
- Fourier analysis is a powerful and flexible method for measuring guide plates (dimension, corner radius, rotation, ellipticity etc…)
- Any imaging system will give you an output, but this output must be interpreted with a clear knowledge of the measuring system
- IF YOU CANNOT MEASURE IT, YOU CANNOT MAKE IT

Thank you for your time and attention