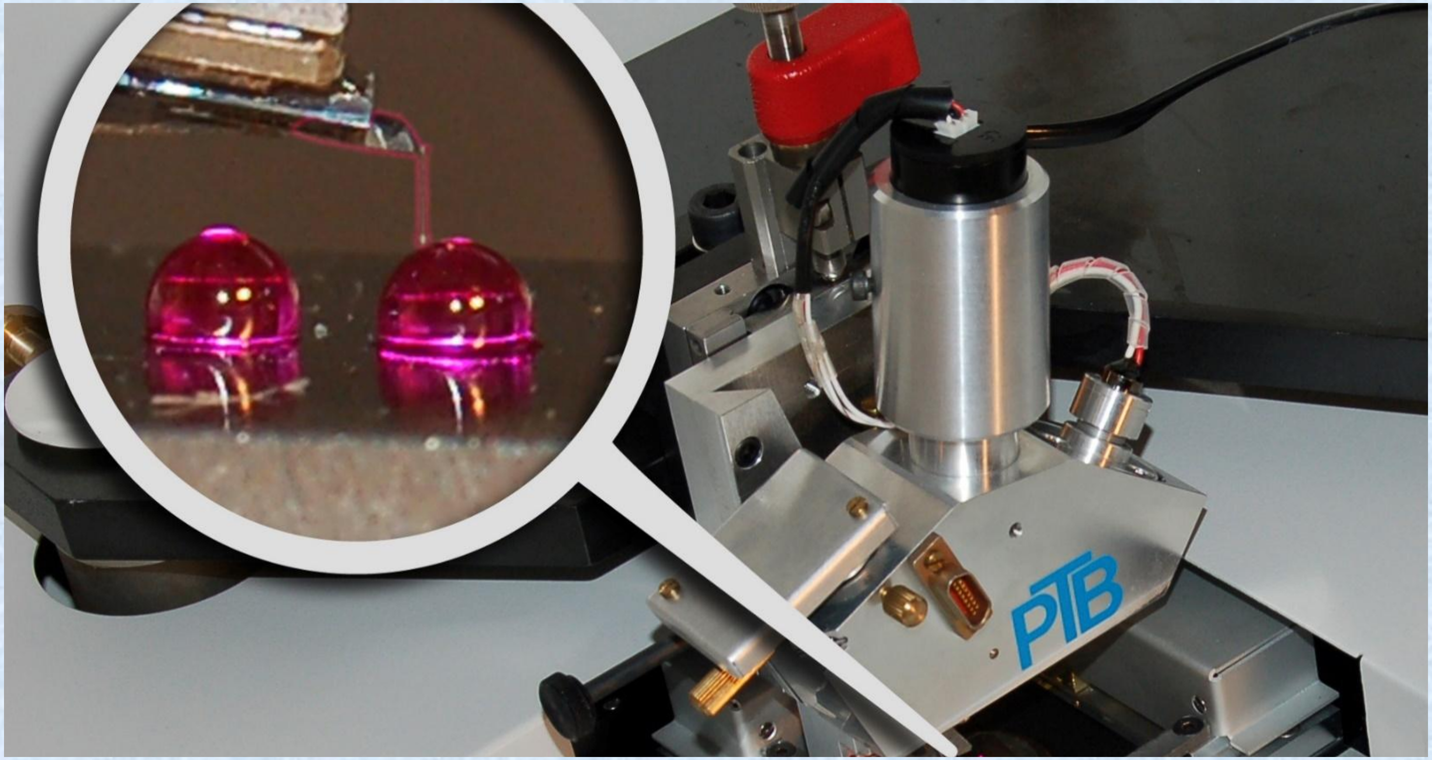
Unit V:
Micro/Nano Measurement systems



Course Content

Unit I: Introduction to Mechanical Micro Machining: Principle Micro Machining techniques, micro turning, micro milling, micro drilling, micro grinding, micro Tool geometry and tool materials, cutting forces and measurement, micro tool and tooling management.

Unit II: Components of micro manufacturing systems: Micro linear stage, rotary stage, air spindle, air bearings, magnetic bearings, servo motors and micro actuators, micro positioning systems, Micro robots, micro grippers, micro parts handling systems - selection criteria

Unit III: Non conventional micro machining technique: Micro EDM, Ion Beam machining, Laser micro machining, Laser Assisted Mechanical Micro Machining, Abrasive micro machining, Electron beam machining – process mechanics, capabilities and Applications

Unit IV: Micro forming: Micro forming processes- ultra fine punching, imprinting, extrusion, incremental forming, micro forming of sheet metals, micro-deep drawing.

Unit V: Micro/Nano Measurement systems: Micro sensors, laser measurement systems, capacitance sensors, micro optical sensors, feedback sensors, 2D and 3D surface profiling.

Text Books and References

10. Text Books:

1. Joseph Mc Geough, Micromaching of Engineering Materials, Marcel Dekker Inc, New York, 2002.
2. Yi Qin, Micro-Manufacturing Engineering and Technology, Elsevier Inc., Oxford, UK,2010.

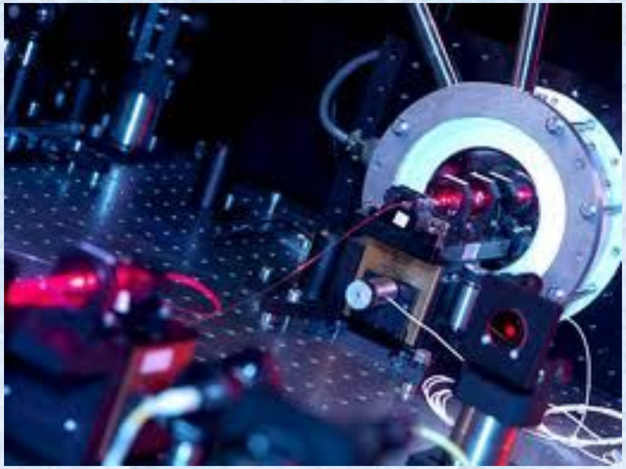
11. References:

1. V. K. Jain, Introduction to Micromachining, Narosa Publishing House Pvt Ltd, New Delhi, 2010.
2. J. Paulo Davim and Mark J. Jackson, Nano and Micromachining, John Wiley & Sons, London, UK., 2013.
3. P.C. Pandey and H. S. Shan, Modern Machining Processes, Tata McGraw Hill, New Delhi, 2009.
4. Richard S. Muller, Microsensors, New York: IEEE Press, 1991.
5. Frank Vollertsen, Micro Metal Forming, Springer-Verlag, Berlin Heidelberg, Germany, 2013.

What is Metrology?

Metrology is the science of measurement

- ***The Science Behind Quality Control on a Manufacturing Shop Floor***



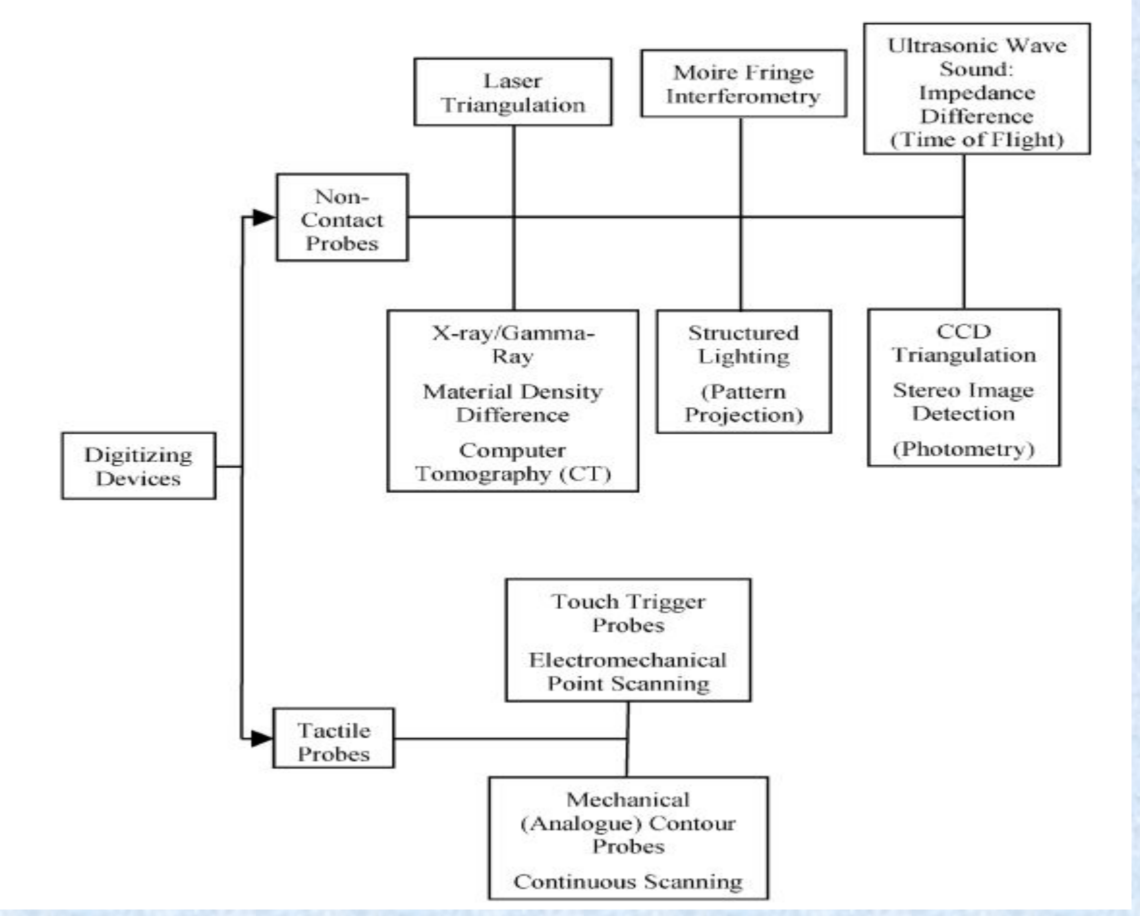
- **Metrology** is the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology. ”International Bureau of Weights and measurements (BIPM)”

Need of Measurements:

- ✔ To ensure that the products supplied to the customer are within the agreed specifications.
- ✔ To monitor the process performance.
- ✔ To ensure that the purchased materials are confirm to the purchaser's specifications.
- ✔ To meet the interchangeability concept.
- ✔ To evaluate the possibility of rework of defective parts.
- ✔ To exclude sources of errors and deficiency in the process
- ✔ To establish limit gauging. To achieve reverse engineering.
- ✔ To augment the reputation of manufacturer and to help him to become a world class manufacturer

Modern Inspection Devices

1. **Contact Inspection devices**
2. **Non-contact Inspection devices.**



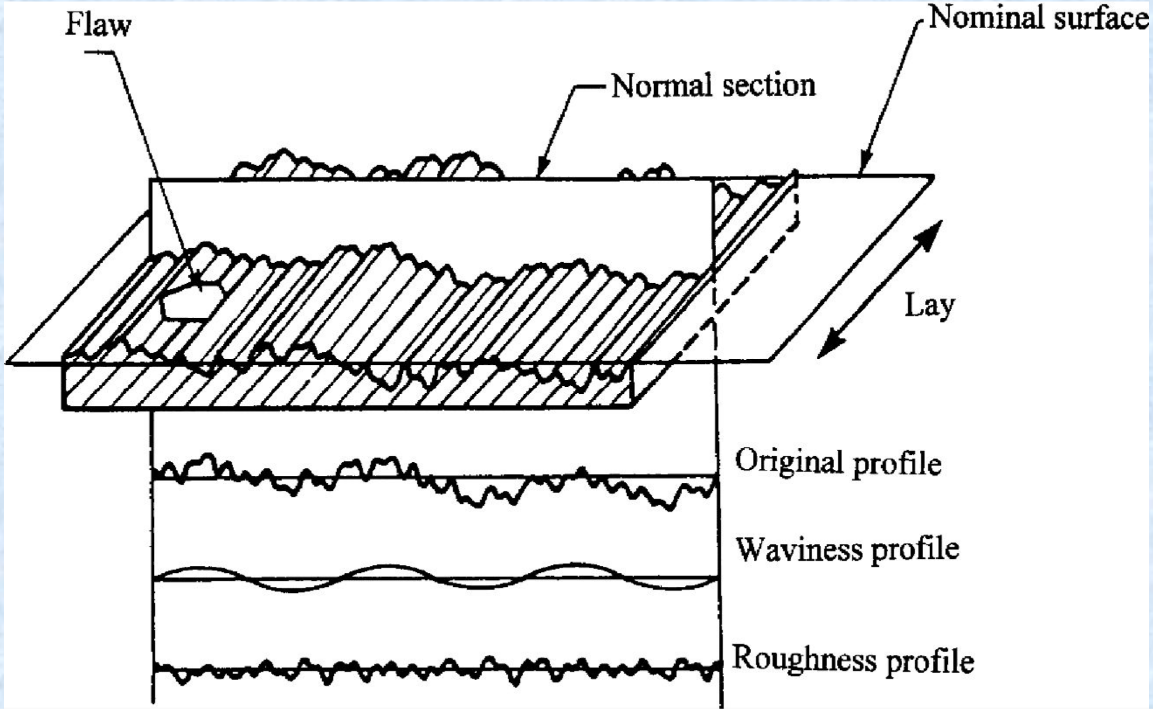
Measurements

- Surface Characteristics
- Dimensions
- Form

Surface texture is the combination of fairly short wavelength deviations of a surface from the nominal surface.

Roughness: Roughness includes the finest (shortest wavelength) irregularities of a surface.

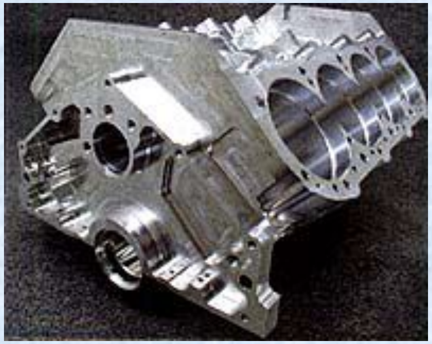
Waviness: Waviness includes the more widely spaced (longer wavelength) deviations of a surface from its nominal shape.



Ref: ASME B46.1. Surface texture (surface roughness, waviness, and lay), 1995.

Micro – Nano Surfaces and devices

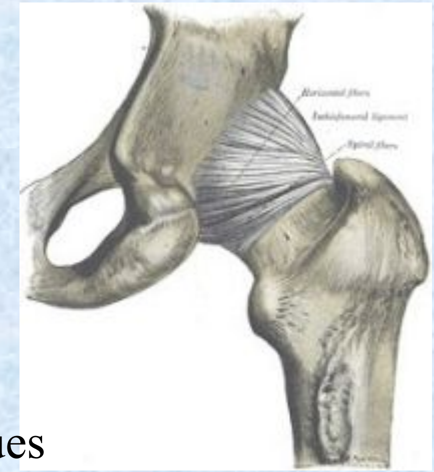
- Surface metrology plays an important role in the functioning of machined, etched, molded parts in different market areas like
  - automotive/aerospace
    - bearing surfaces
    - shafts
    - dynamic seals
  - high-brightness LED
  - solar
  - Semiconductor
  - medical device markets



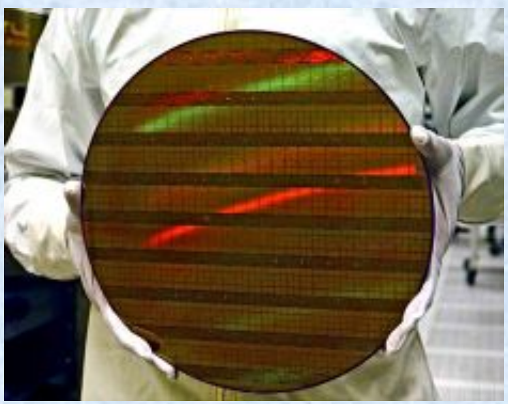
"If you can't measure it, you can't make it"

Applications

Wear-resistant coatings
TiN, TiC, DLC, WC
Cutting tools

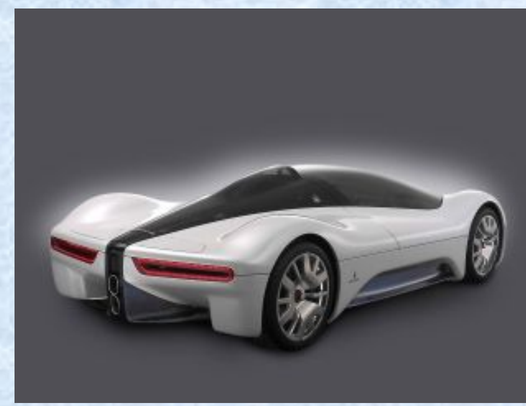


Biomedical
Tablets and pills
Implants and Tissues



Semiconductors
Low K materials
Interconnects
Passivation layers

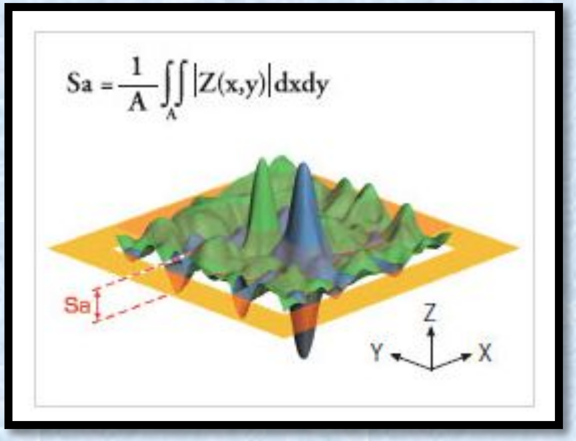
Optical components
Window Glass
Lenses
Optical coatings



Automotive & Aerospace
Paints and intermediate layers
Windows Engine components

Surface Finish - 3D parameter

1. Arithmetic mean height (Sa)

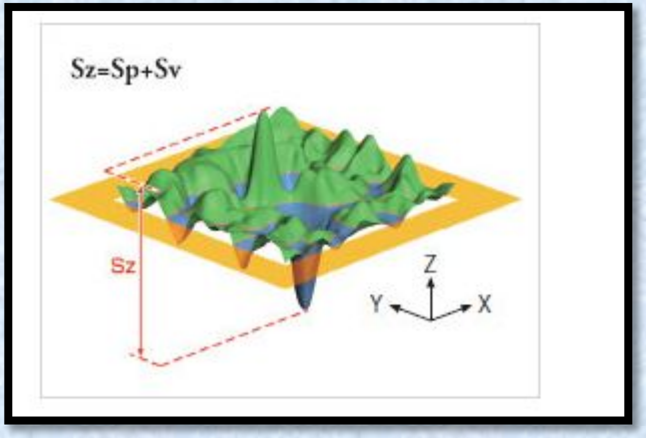


This is a 3D parameter expanded from the roughness (2D) parameter Ra. It expresses the average of the absolute values of Z(x,y) in the measured area.

These are commonly-used parameters. The influence of a single injury on the measurement value becomes extremely small, so stable results can be obtained.

Roughness (3D) parameter

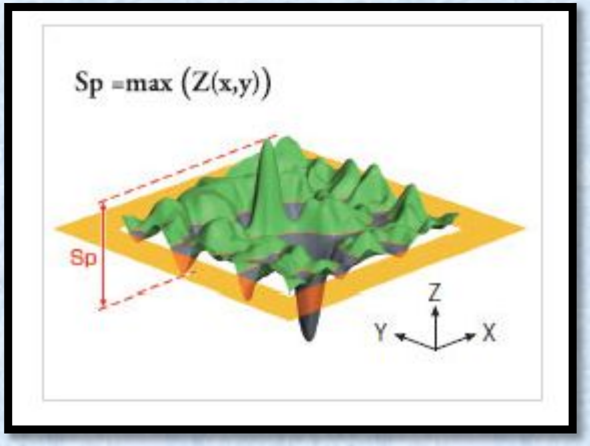
2. Maximum height (Sz)



This is a 3D parameter expanded from the roughness (2D) parameter Rz. It expresses the sum of the maximum value of peak height Zp and the maximum value of valley depth Zy on the surface within the measured area

They are used for evaluation of gloss and luster, surface strength, surface treatability, frictional force, electrical contact resistance, etc.

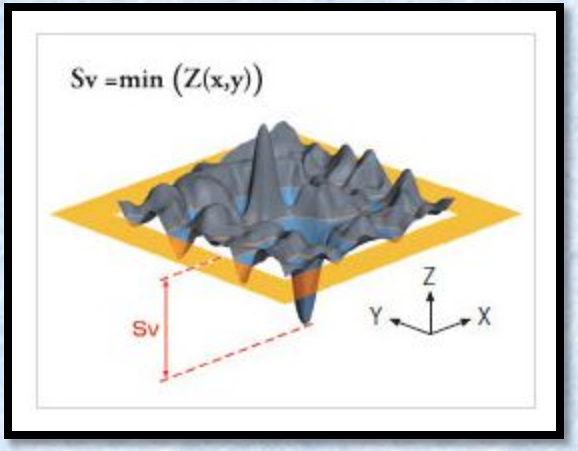
3. Maximum peak height (Sp)



This is a 3D parameter expanded from the roughness (2D) parameter Rp. It expresses the maximum value peak height Zp on the surface in the measured area.

These are often used for evaluation of frictional force and electrical contact resistance.

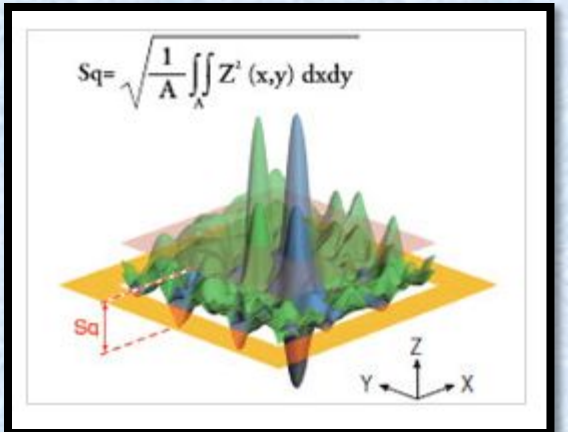
4. Maximum valley depth (Sv)



This is a 3D parameter expanded from the roughness (2D) parameter Rv. It expresses the maximum value valley depth Zv on the surface in the measured area.

These are often used for evaluation of surface strength and corrosion resistance.

5. Root mean squared height (Sq)



This is a 3D parameter expanded from the roughness (2D) parameter Rq. It expresses the root mean squared of Z(x,y) in the measured area. It is equivalent to the average mean squared of the measured region on the three-dimensional display diagram when valleys have been changed to high peaks by squaring.

Evaluation methods using Rq are often used when expanded into 3D.

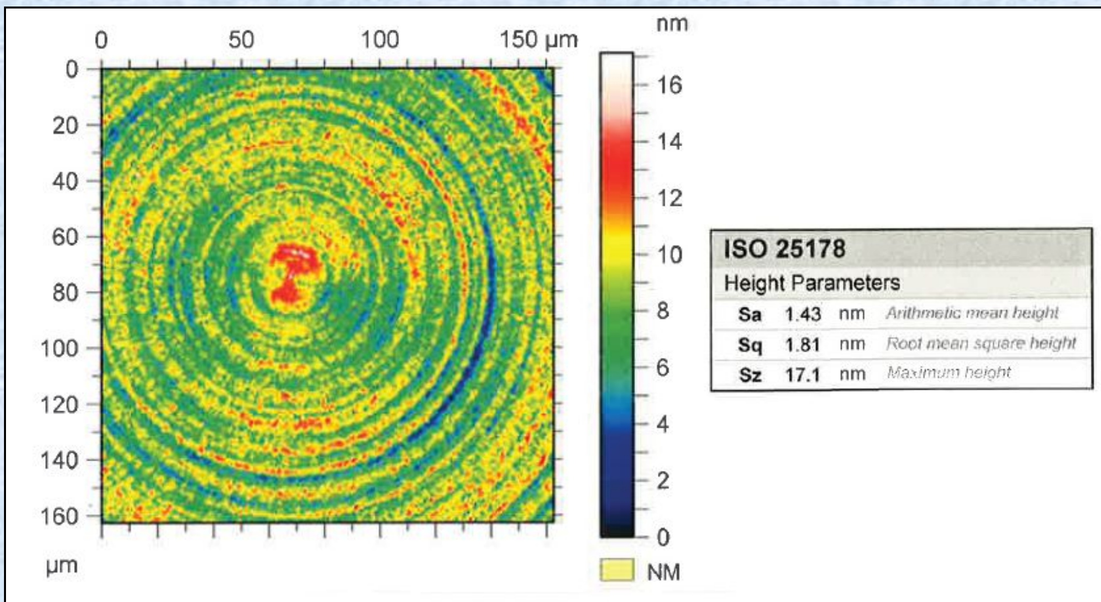
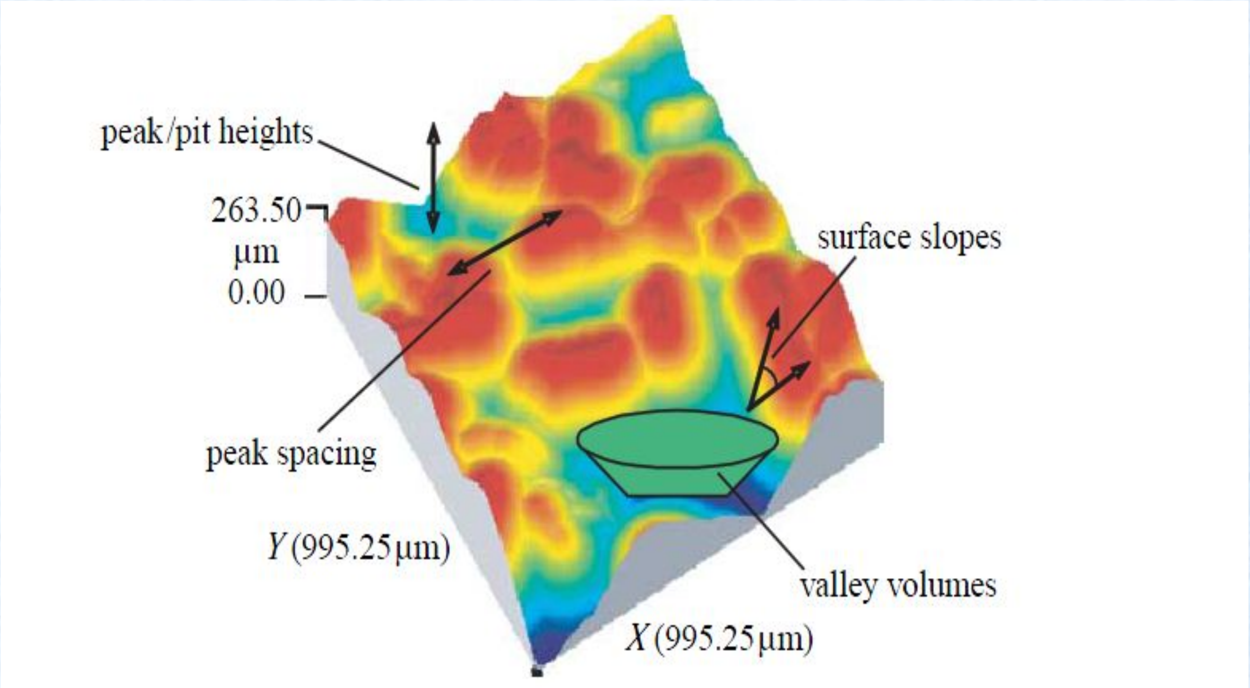
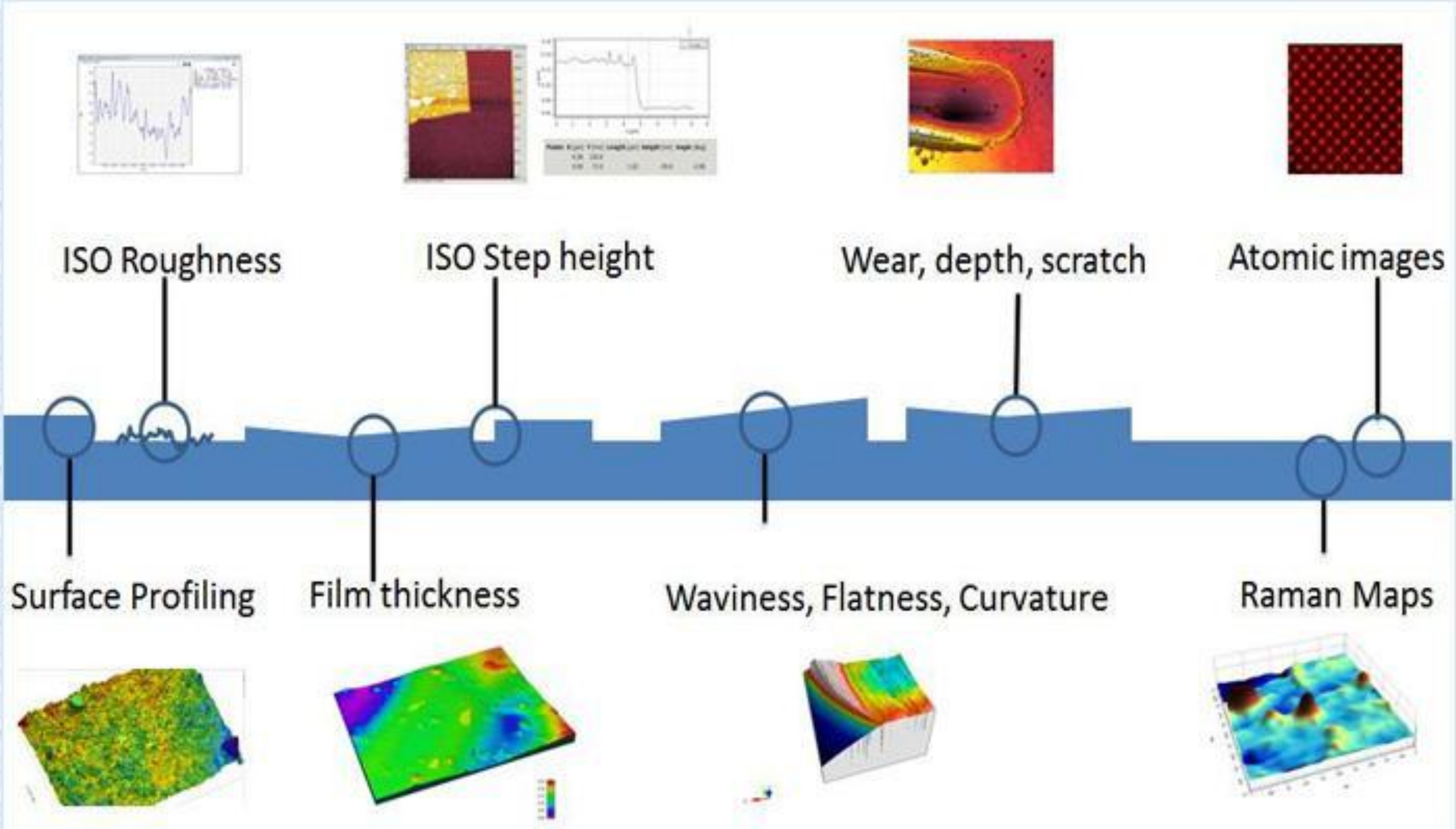


Fig: 3D surface profile of a Nano surface (courtesy AMETEK, Precitech Inc.)

Attributes used for Characterization of 3D areal surface texture

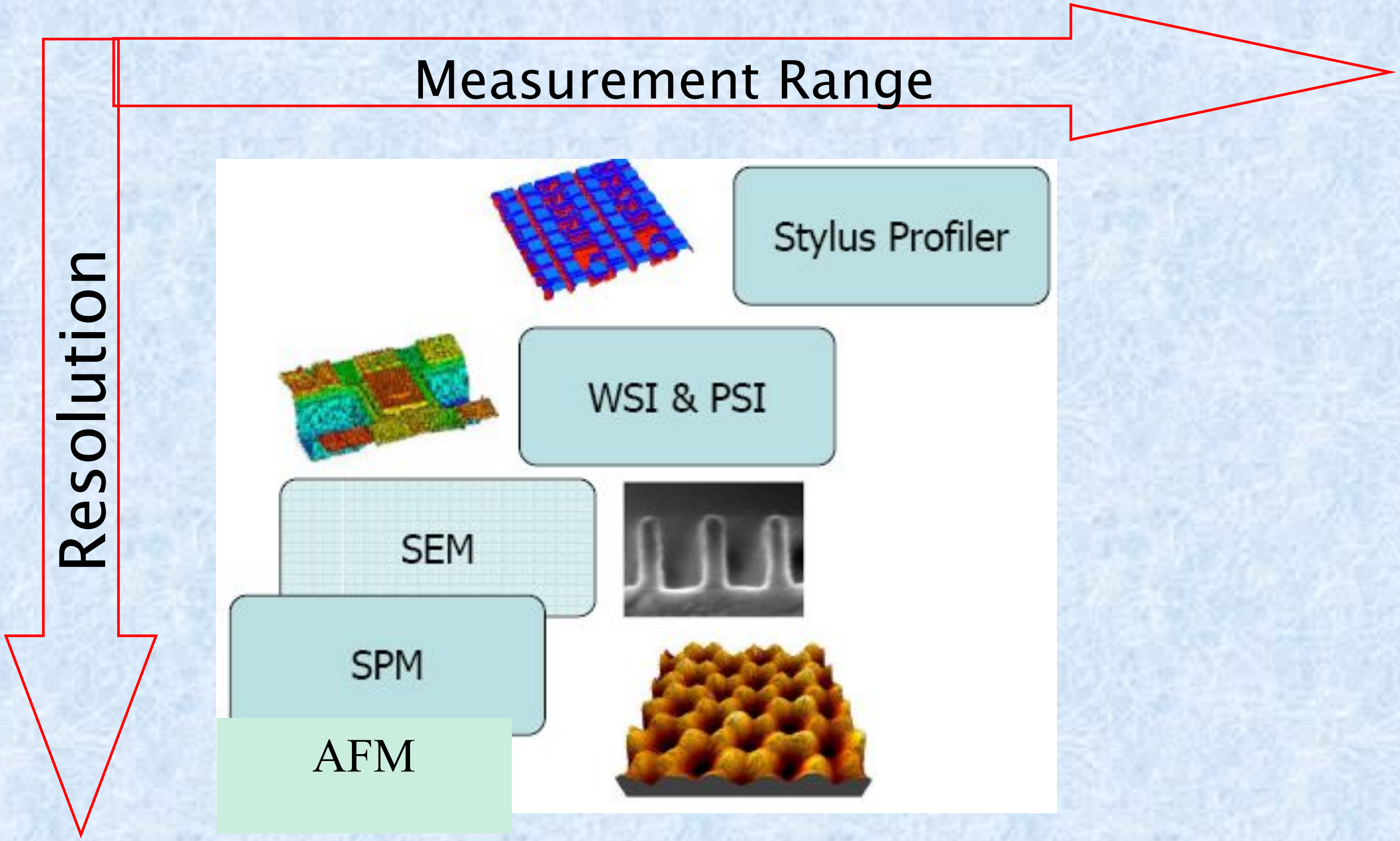


Profile characteristics in Micro Components



http://rtec-instruments.com/profilometer.htm

Surface Measurement Technology



WSI - White-light Scanning Interferometry
PSI - Phase Shifting Interferometry

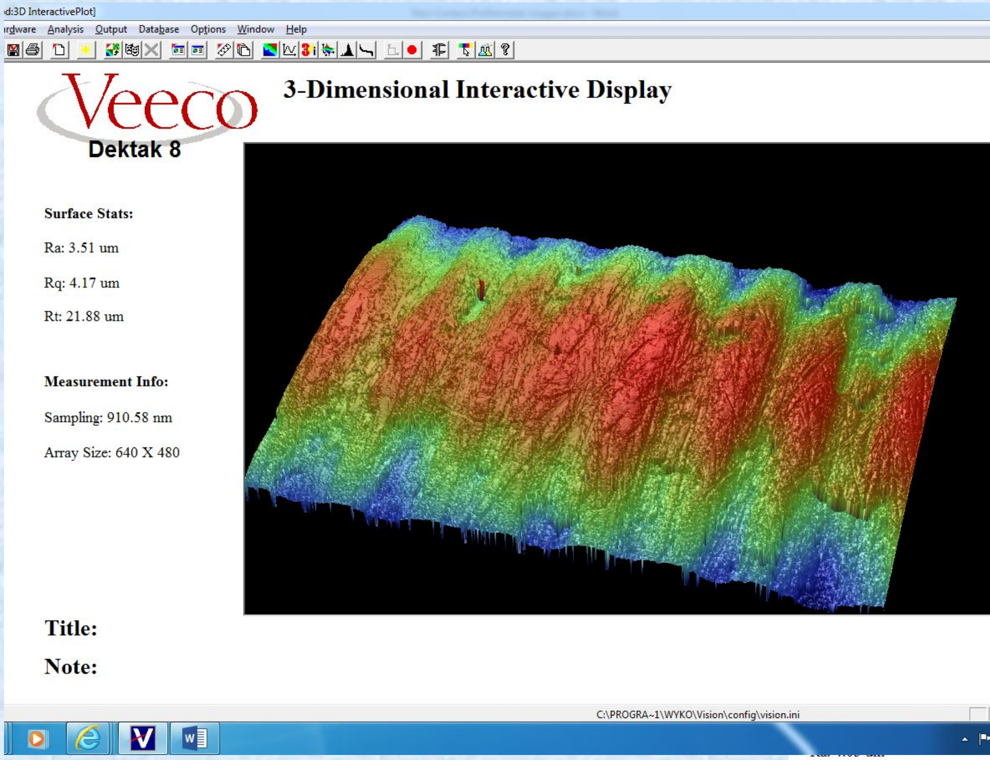
SEM- Scanning Electron Microscopy
SPM - Scanning Probe Microscopy

Types of Profilometer

- Contact Profilometer
  - ✔ Stylus Profilometer
  - ✔ Atomic Force Microscopy (AFM)
  - ✔ Scanning Tunneling Microscopy
- Non-Contact Profilometer

  <u>Optical Methods</u>
  - ✔ Vertical Scanning Interferometry
  - ✔ Phase - Shifting Interferometry
  - ✔ Differential Interference Contrast Microscopy

3D profiling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Veeco
Dektak 8
3-Dimensional Interactive Display
Surface Stats:
Ra: 3.51 um
Rq: 4.17 um
Rt: 21.88 um
Measurement Info:
Sampling: 910.58 nm
Array Size: 640 X 480
Title:
Note:
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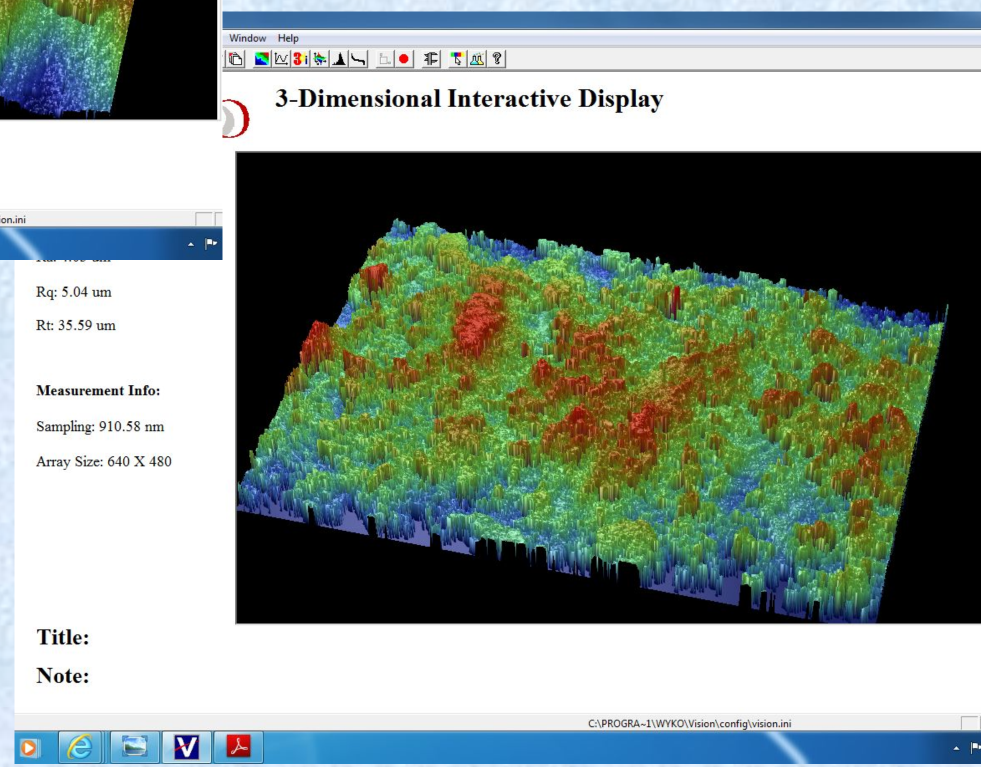
Window Help
3-Dimensional Interactive Display
Rq: 5.04 um
Rt: 35.59 um
Measurement Info:
Sampling: 910.58 nm
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Note:
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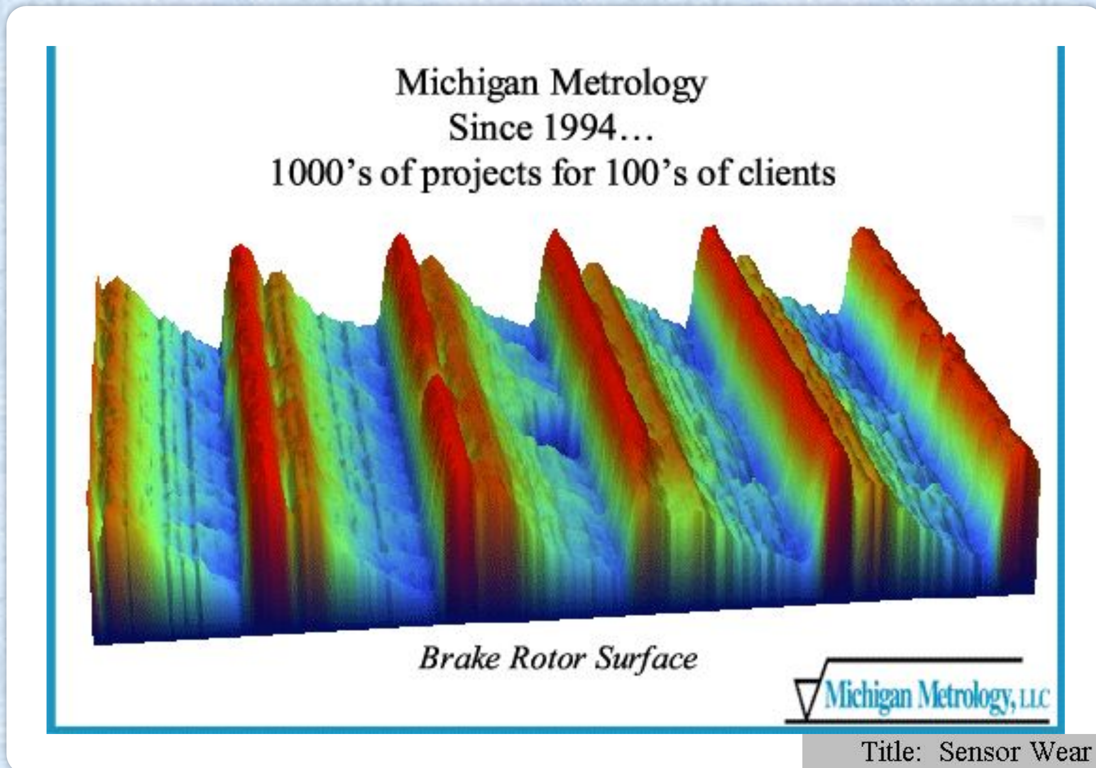
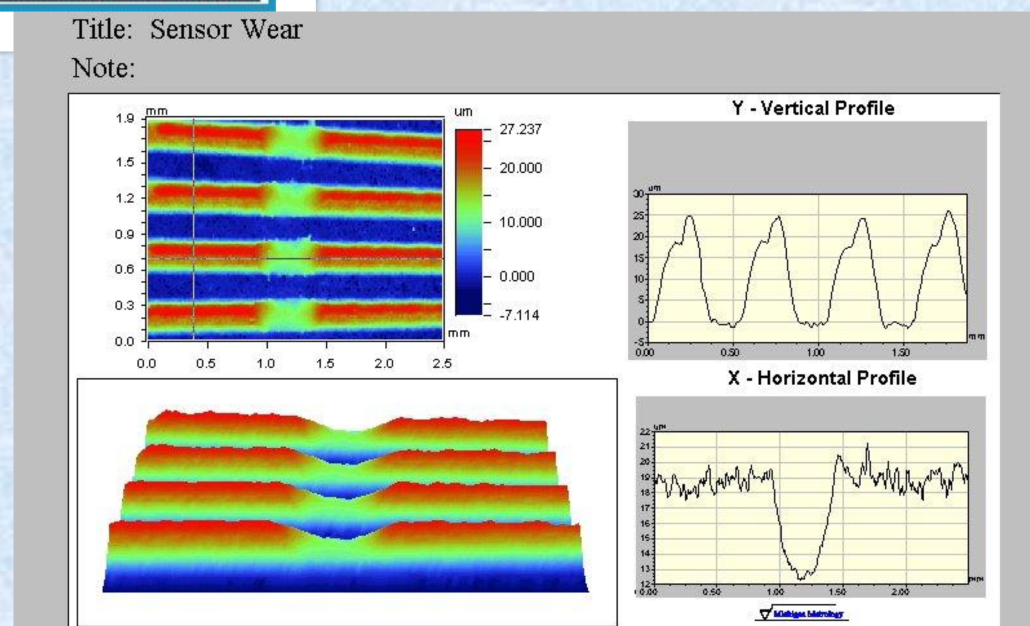

Michigan Metrology
Since 1994…
1000’s of projects for 100’s of clients
Brake Rotor Surface
Michigan Metrology, LLC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Y - Vertical Profile
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Key Technology

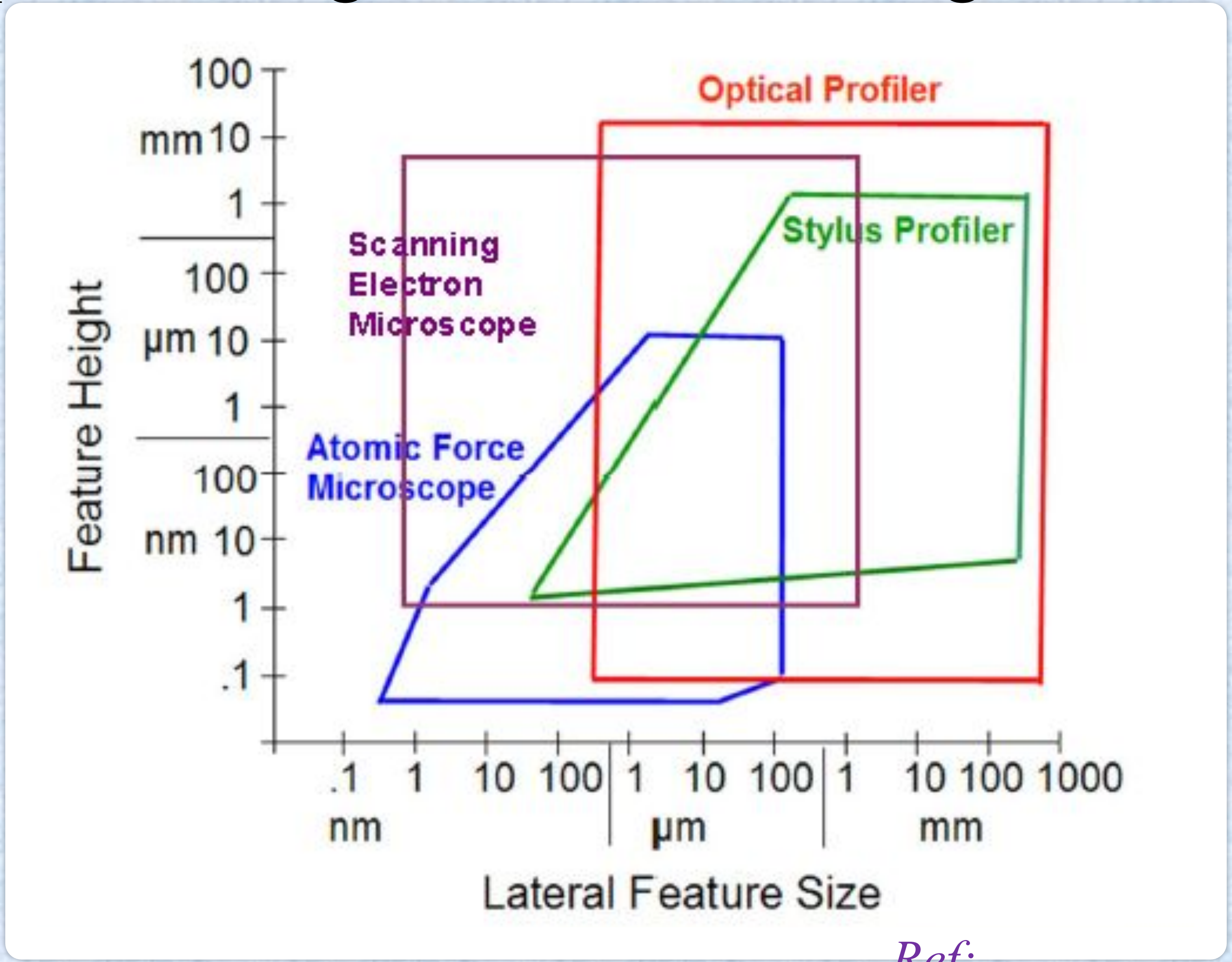
- AFM: Highest lateral resolution with multiple modes and applications
- 3D Microscopy using WLI: Highest vertical resolution, non-contact high-speed 3D measurements
- Stylus: Low noise contact profiling with excellent measurement repeatability

Atomic Force Microscopy
Nanoscale characterization of electrical, magnetic, compositional and material properties

Optical Profiling
Non-contact 3D measurement of surface texture and roughness

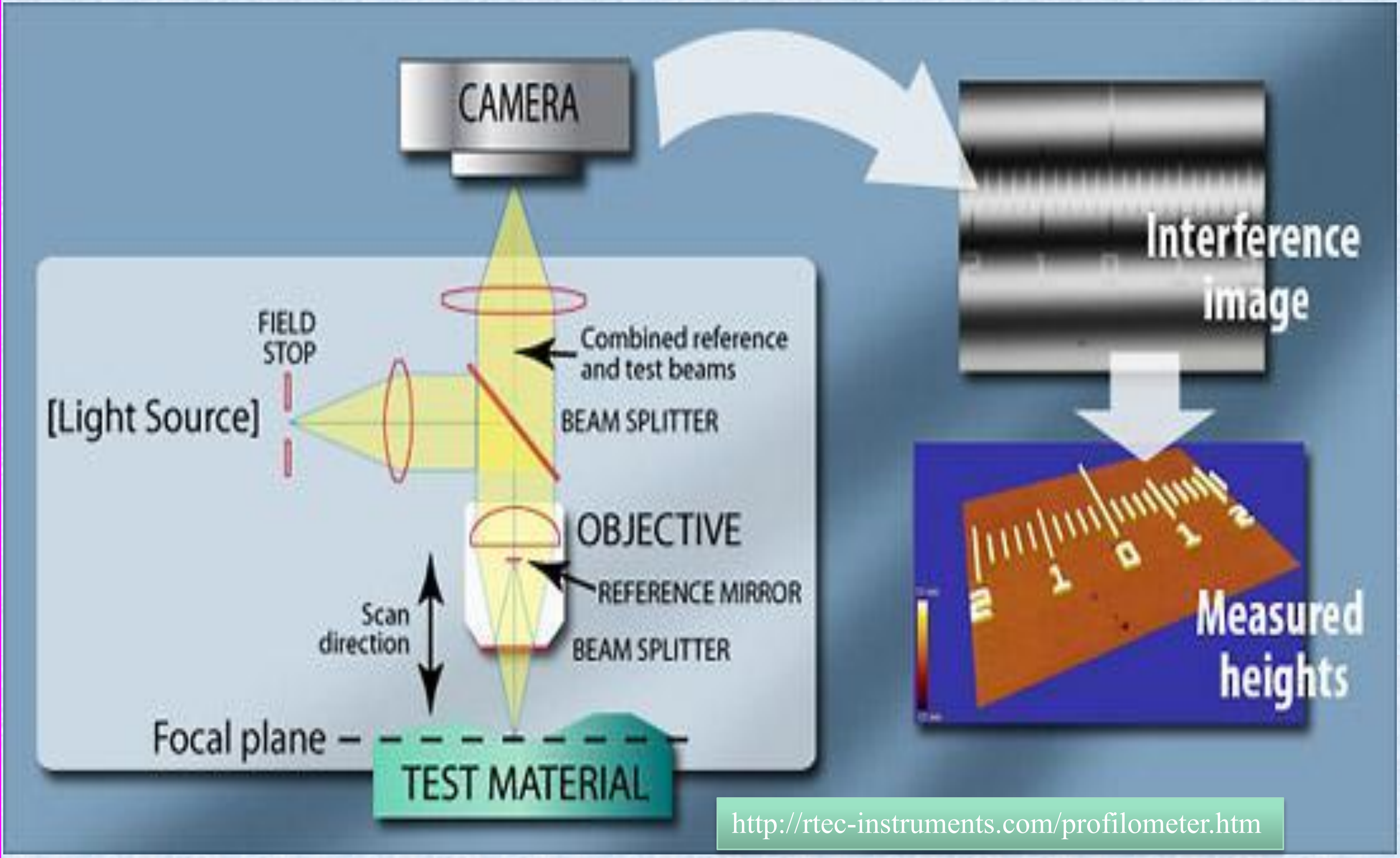
Stylus Profiling
Measure thin film step heights, stress and surface texture

Specific Height and Lateral Ranges



Ref: www.bruker.co

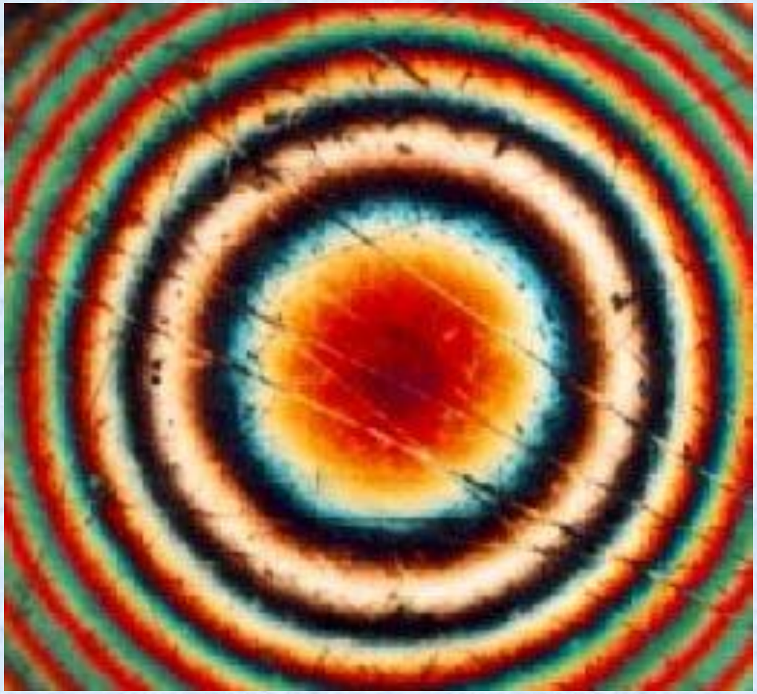
Optical profiler Basic principle



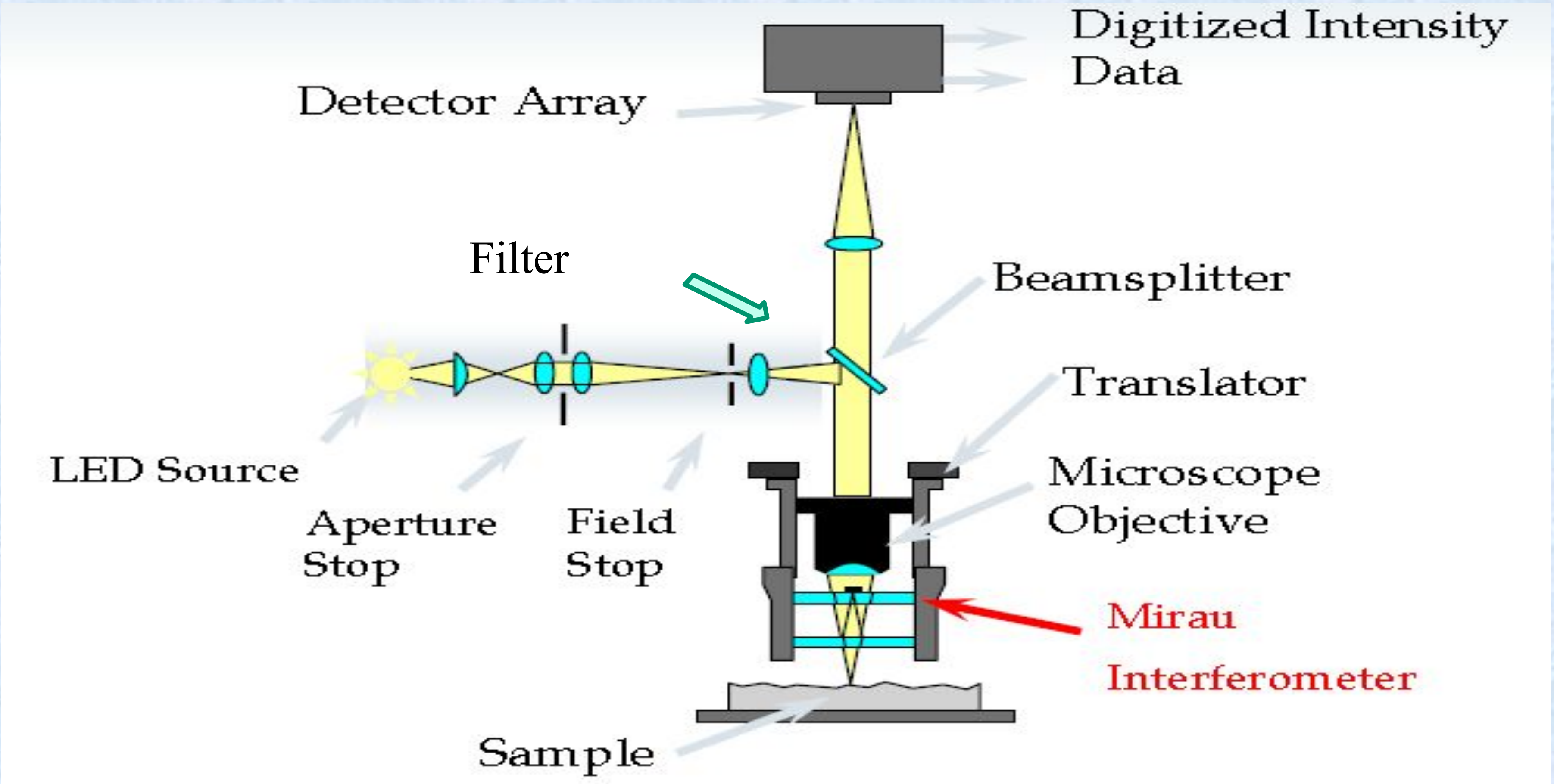
Optical Path Difference (OPD) - difference in optical path lengths that beams travel in Reference and Test arms.

Principle of Interferometry

- Difference in optical paths will cause a difference in phase
- Interference will be constructive at some points, destructive at others, forming an interferogram



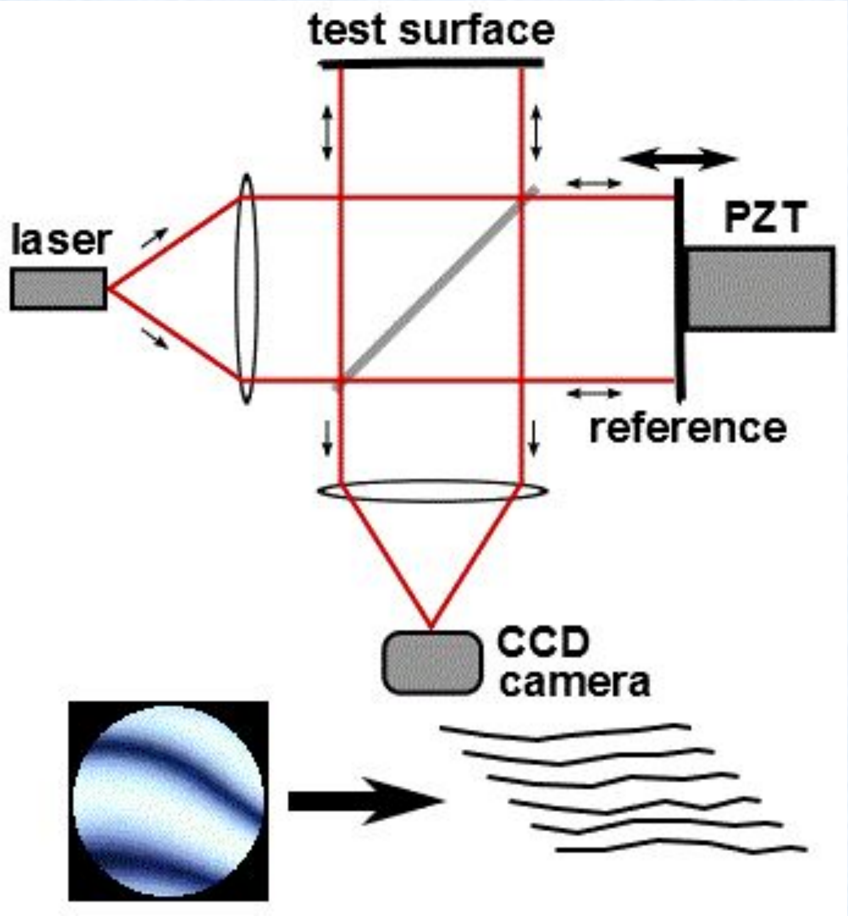
- Two Techniques
  - Phase Shifting Interferometry (PSI)
  - Vertical Scanning Interferometry (VSI)



- Scan special objective in a predefined fashion to change optical path between sample and reference
- CCD camera captures the intensity changes over multiple frames
- Best focus determined from captured Intensity - phase calculated from the fringes or COM of signal envelope used to build height information

Phase Shifting Interferometry(PSI)

- Piezoelectric transducer (PZT) linearly moves the reference surface
- A small, known amount to cause a phase shift between the test and reference beams
- The intensity of the resulting interference pattern at many different relative phase shifts, and then converts the intensity to wave front (phase) data by integrating the intensity data.

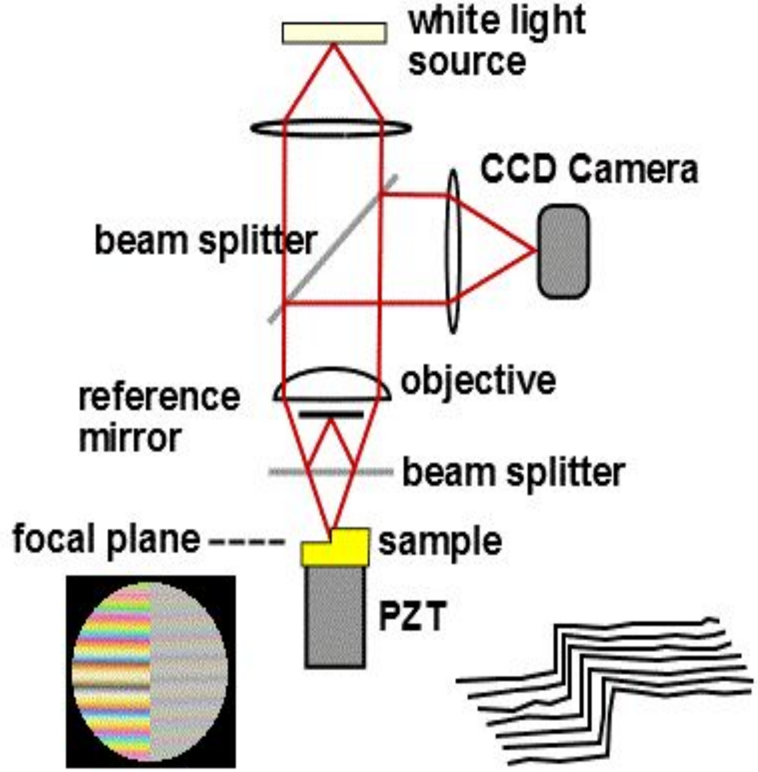


<u>*Ref:*</u>

Vertical scanning Interferometry (VSI)

- Light reflected from a reference mirror combines with light reflected from a sample to produce interference fringes.

- System measures the degree of fringe modulation, or coherence, instead of the phase of the interference fringes



Vertical Scanning Interferometer

Ref:

Coherence

- Two wave sources are perfectly coherent if they have a constant phase difference and the same frequency, and the same waveform. Coherence is an ideal property of waves that enables stationary (i.e. temporally and spatially constant) interference.

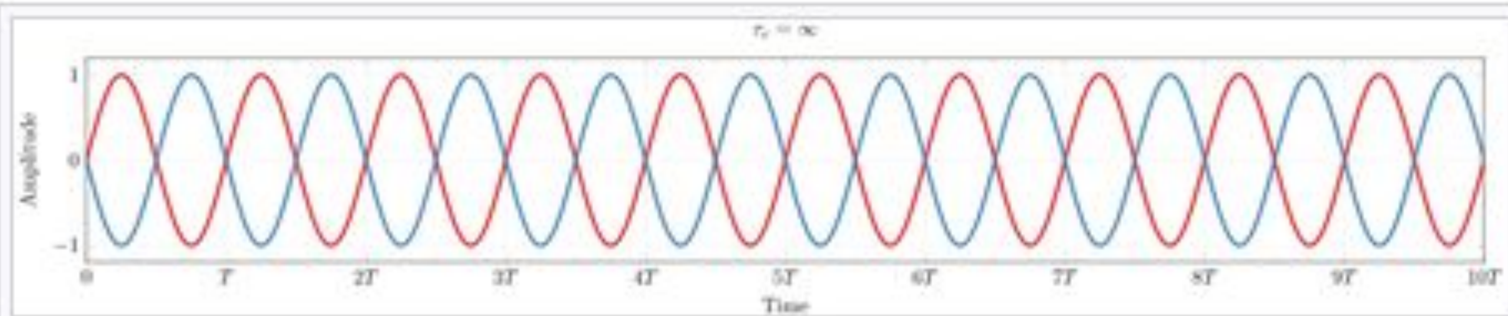


Figure 1: The amplitude of a single frequency wave as a function of time *t* (red) and a copy of the same wave delayed by τ (blue). The coherence time of the wave is infinite since it is perfectly correlated with itself for all delays τ.[11]:118

Compressions PSI Vs VSI

Phase Shifting Interferometry (PSI)	Vertical scanning Interferometry (VSI)
Narrow bandwidth filtered	Neutral density filter for white light
Phase-shift at a single focus point – the objective doesn't move	Vertically scans – the objective actually moves through focus
Processes phase data from the intensity signal to calculate surface heights	Processes fringe modulation data from the intensity signal to calculate surface heights
160nm	1mm (Range)
$3A^0$	3nm (Vertical resolution)

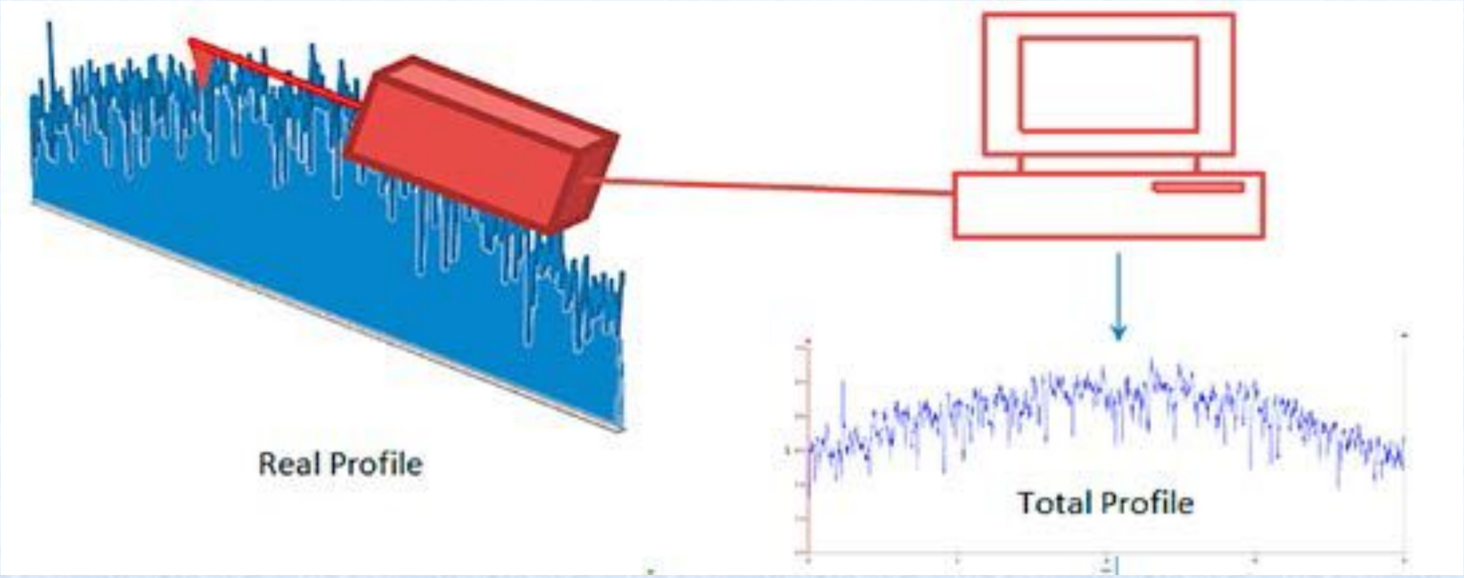
Ref: www.bruker.com

Stylus Profiler

Stylus Profiler: Collects data from the sample surface "Real Profile"

Total Profile: Unfiltered data produced by the stylus profiler

Primary Profile: Data after the short cut-off filter is applied (cut-off spatial frequency of λs to remove noise).



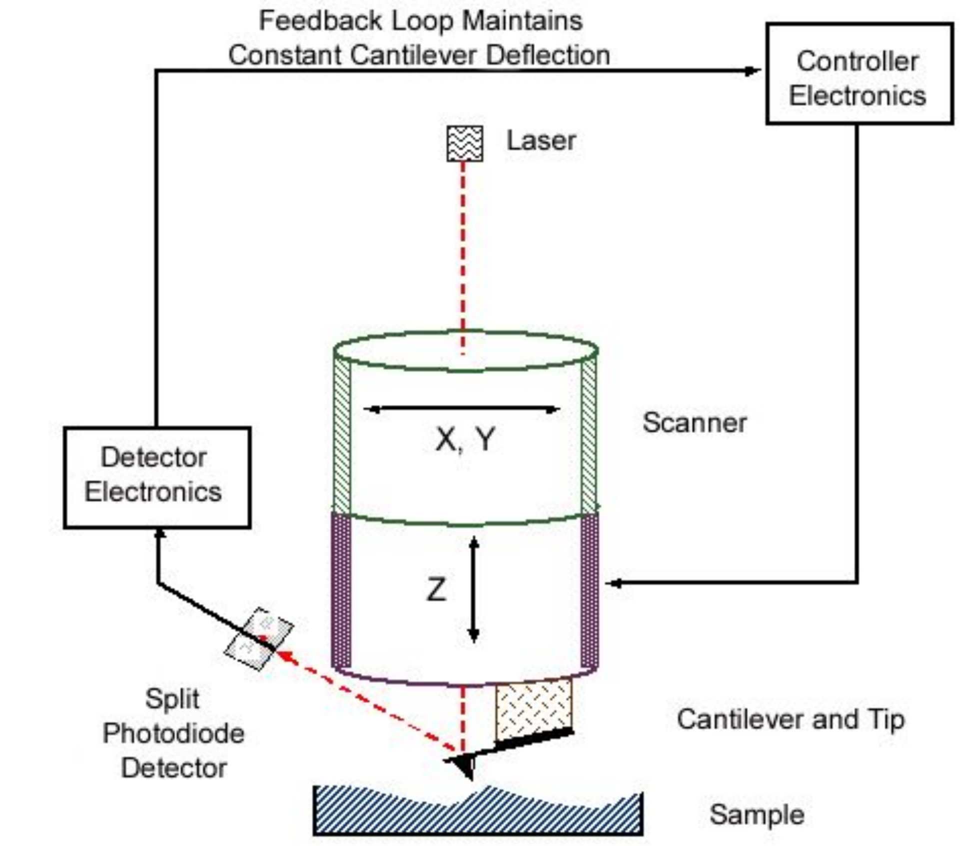
Atomic Force Microscope

- 3-dimensional topography.
- Roughness measurements for chemical mechanical polishing.
- Analysis of microscopic phase distribution in polymers.
- Mechanical and physical property measurements for thin films.
- Imaging of sub micron phases in metals.
- Defect imaging in MEMS failure analysis.
- Inspection of Mechanical, Material and Electrical Properties.

Atomic Force Microscope

- Feedback loop maintains constant deflection (force) of AFM cantilever

- Constant contact between the tip and sample surface facilitates:
  - • High resolution imaging
  - • Fast scanning speeds / fast data acquisition times



Ref: Bruker Nano Surfaces Division

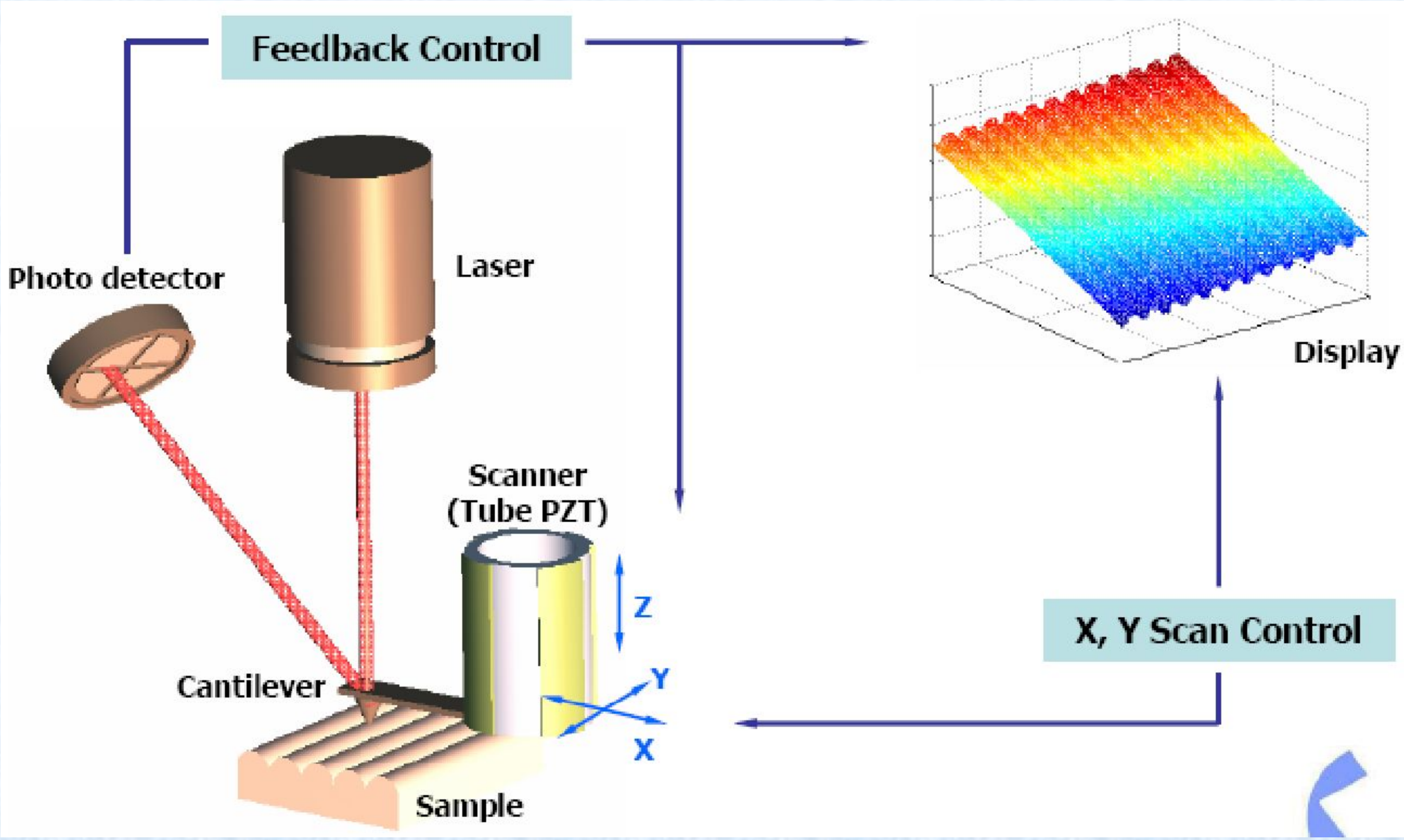
Atomic Force Microscope (AFM)

- It is a scanned-proximity probe microscopes
- AFM do not use lenses, so the size of the probe rather than diffraction effects generally limits their resolution
- AFM is being applied to studies of phenomena such as abrasion, adhesion, cleaning, corrosion, etching, friction, lubrication, plating, and polishing

Atomic Force Microscope …

- The Atomic Force Microscope is being used to solve processing and materials problems in a wide range of technologies:
  - Electronics
  - Telecommunications
  - Biology
  - Chemistry
  - Automotive
  - Aerospace and
  - Energy industries

Structure of AFM



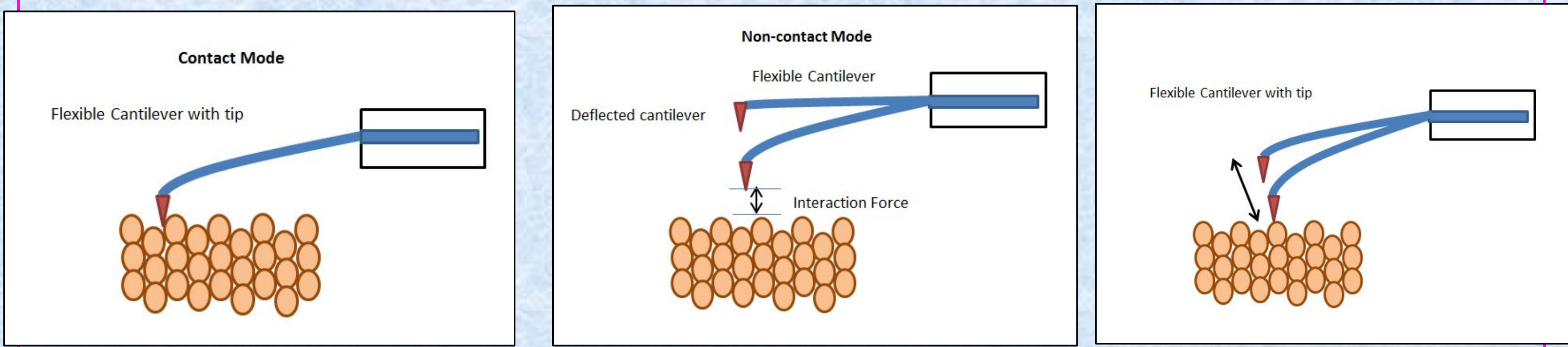
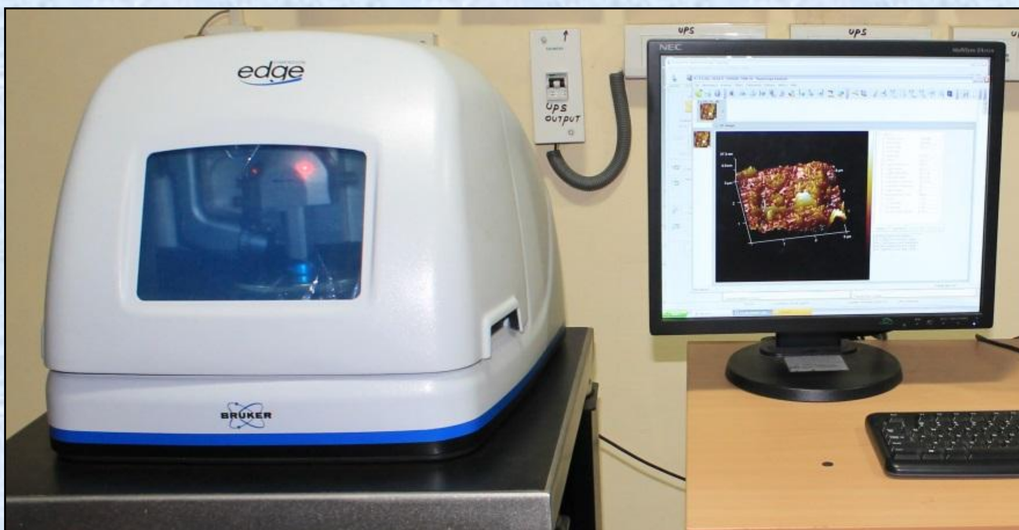


Fig: Schematic diagram of the different modes of AFM operation



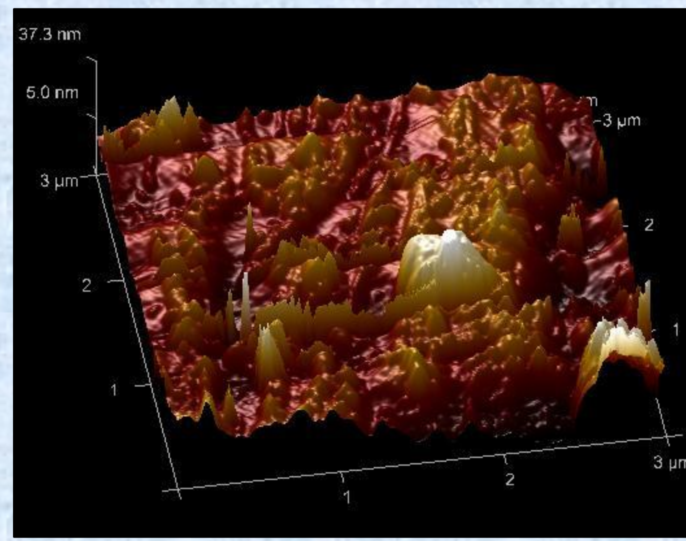
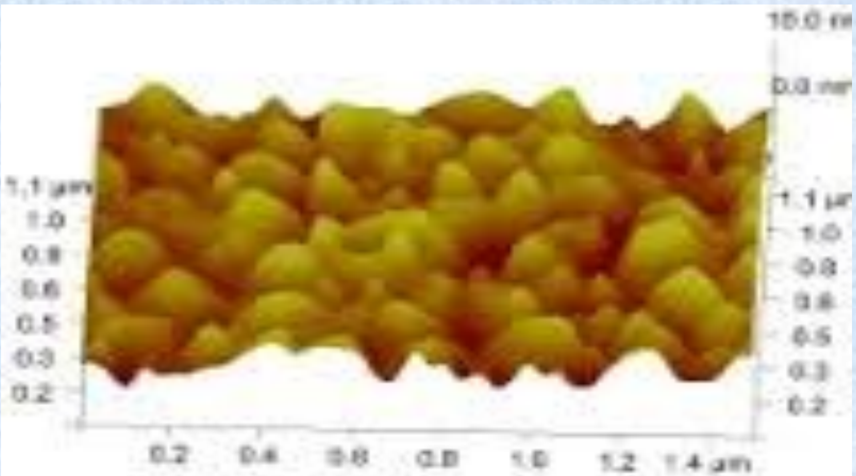
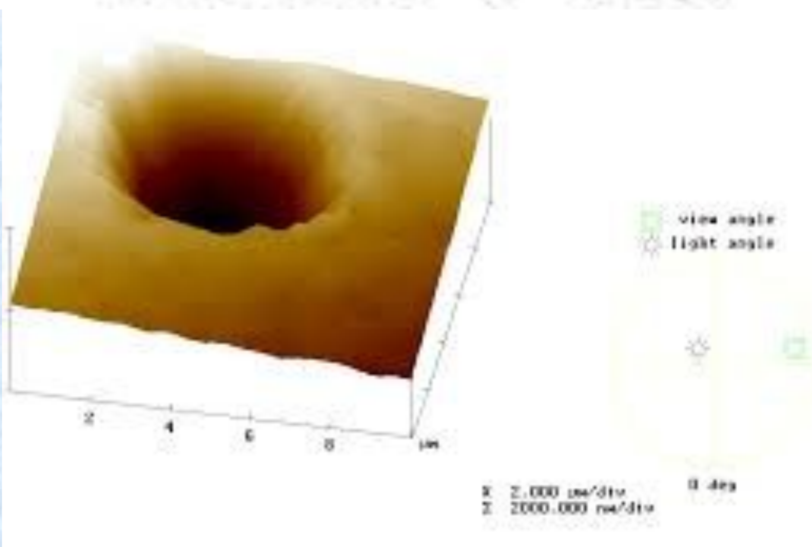
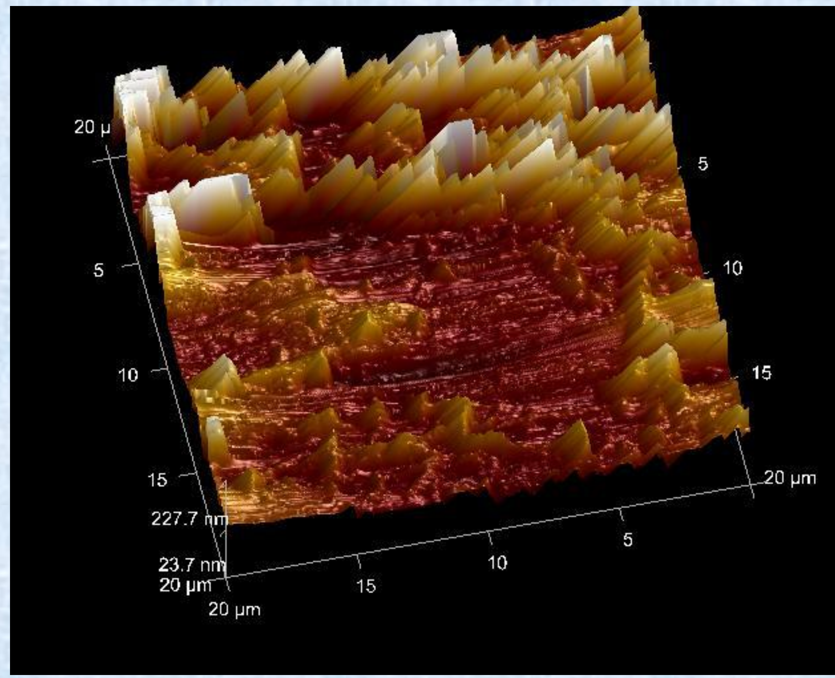


Fig: Profile of a surface measured using AFM

Images taken by AFM

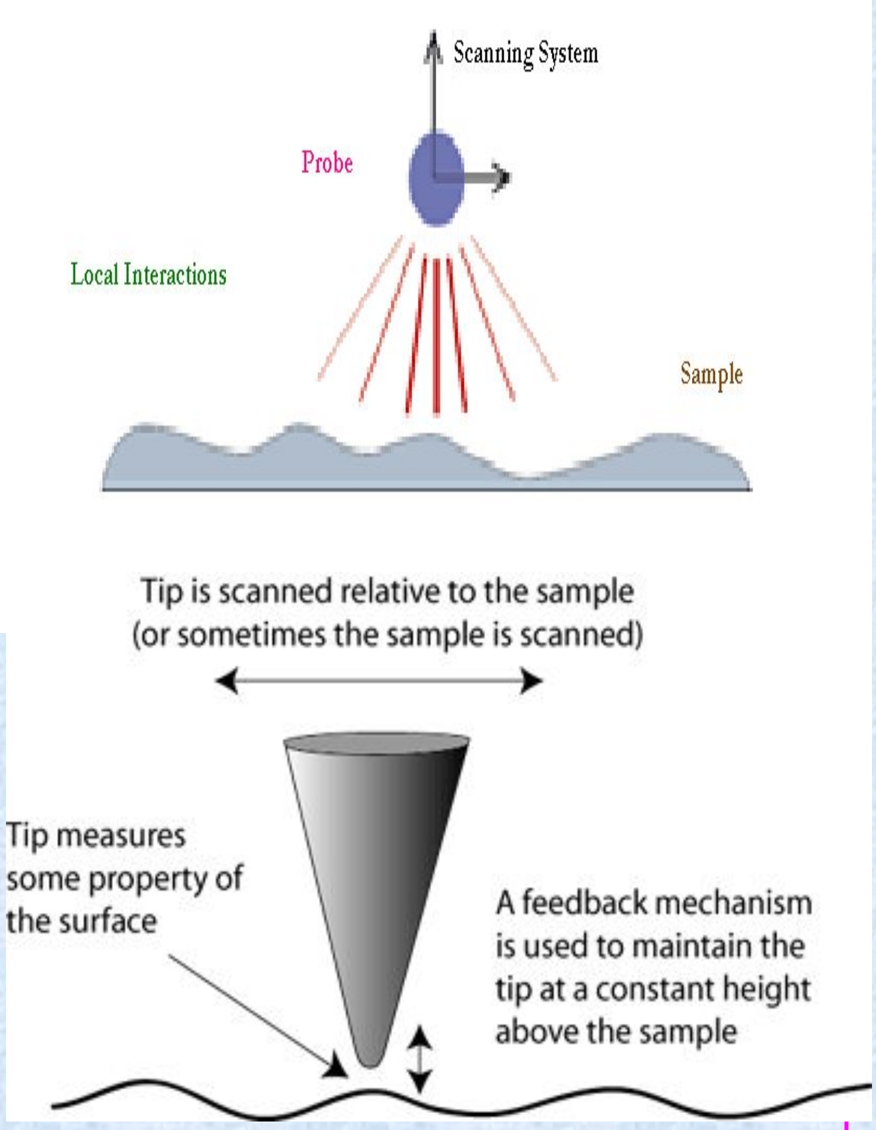






Scanning Probe Microscope

- Electron beam is focused in to a small spot, electro magnetically raster scanned across it.
- Images are focused by collecting the secondary electrons generated by the impact of impinging electron beams by detecting back scattered electrons, or by detecting the X-rays generated.
- Different aspects including morphology, composition etc. are characterized.



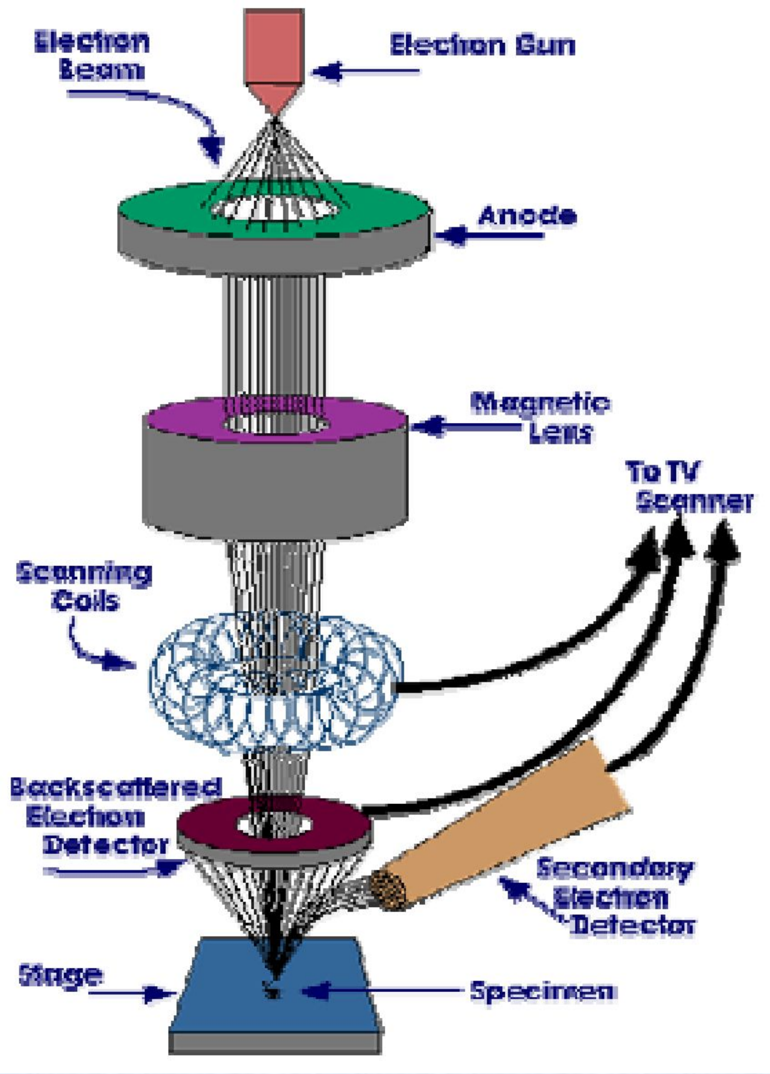
Scanning Electron Microscope (SEM)

- The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. There are many advantages to using the SEM instead of a light microscope
- The first modern scanning electron microscope, constructed by D. McMullan in the Cambridge University Engineering Laboratory in 1951
- The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time

Scanning Electron Microscope (Contd.)

- The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification
- Preparation of the samples is relatively easy since most SEMs only require the sample to be conductive
- The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research areas today

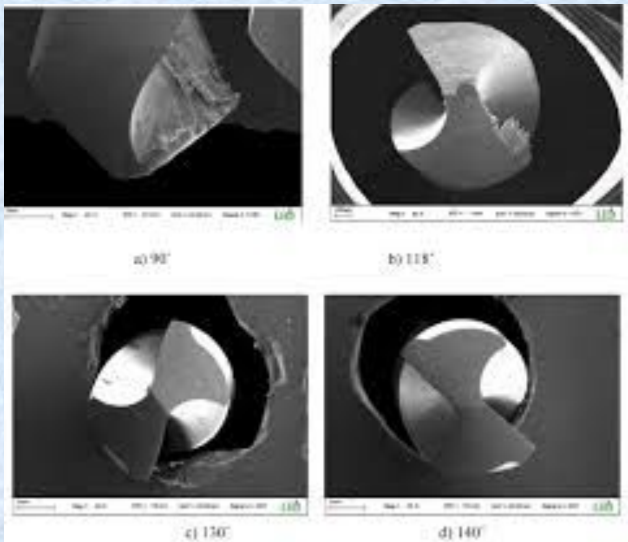
Scanning Electron Microscope

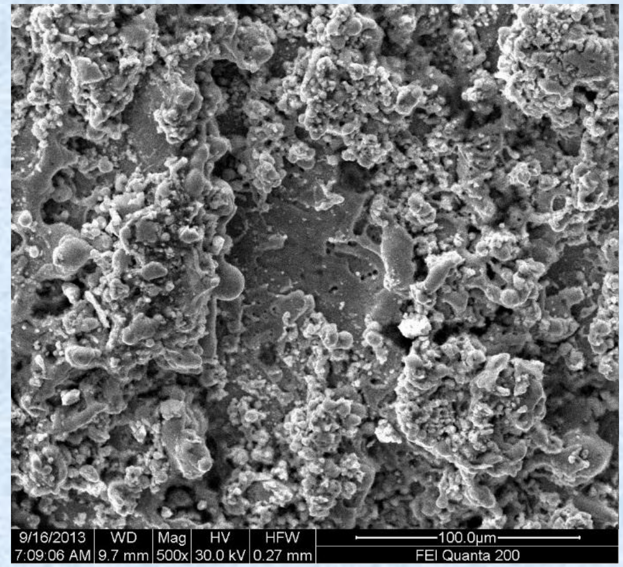


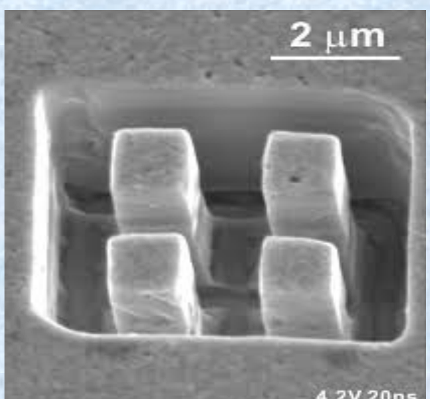
Working Principle of SEM (Contd.)

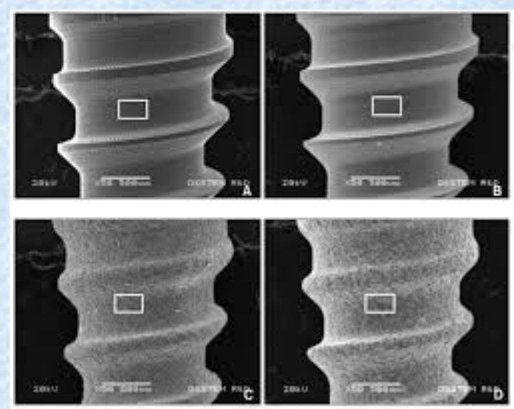
- SEM uses electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by heating of a metallic filament
- The electron beam follows a vertical path through the column of the microscope. It makes its way through electromagnetic lenses which focus and direct the beam down towards the sample
- Once it hits the sample, other electrons (backscattered or secondary) are ejected from the sample. Detectors collect the secondary or backscattered electrons, and convert them to a signal that is sent to a viewing screen similar to the one in an ordinary television, producing an image

Image taken by SEM









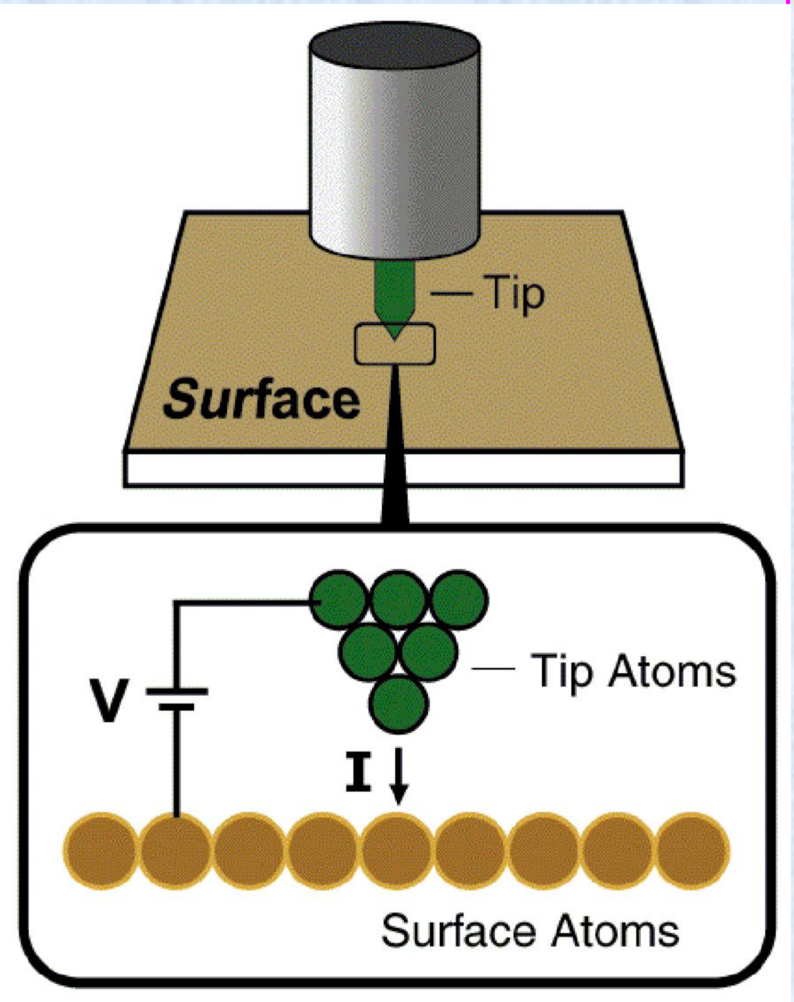
Scanning Tunnelling Microscope

- If a conducing surface is brought within 1 nm of the tip, tunneling current will be induced
- which is used for getting the topography of the surface

Modes of Operation:

1.Constant Current Mode

2.Constant Height Mode

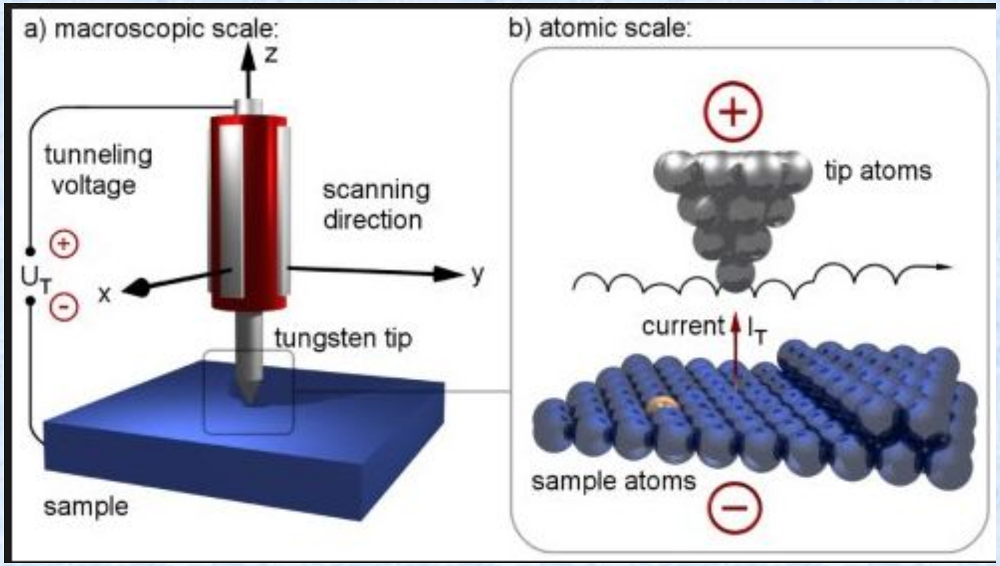


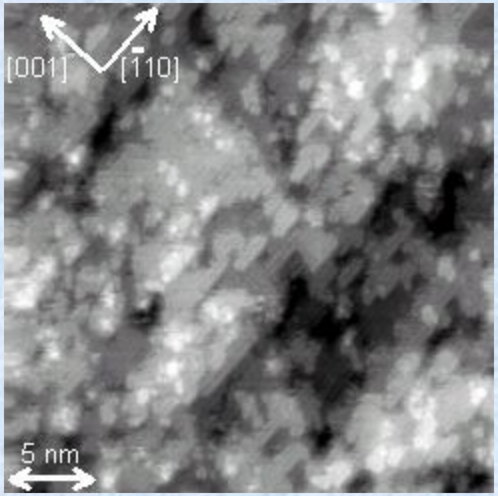
Scanning Tunneling Microscope

- Conceived in 1920’s but first developed in 1982 by G. Binning in IBM Zurich
- Lateral resolution capable of resolving protruding atoms
- Vertical resolution is 0.01 nm
- Operate in vacuum, oil, liquid nitrogen and water
- Applications in micro-topography of precision finished surfaces, microlithography

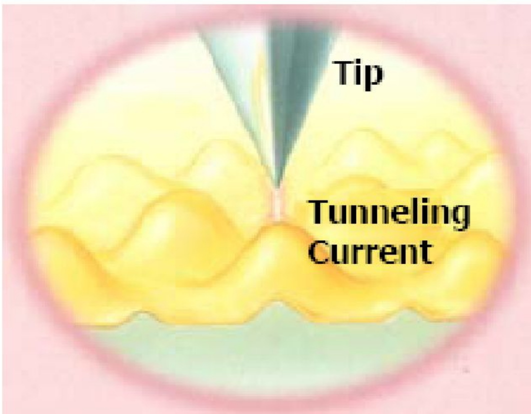
Operating Principle

- Quantum tunneling effect
- Electrons instead of bouncing pass through and current can be sensed
- Tunneling current is a function of local density of states



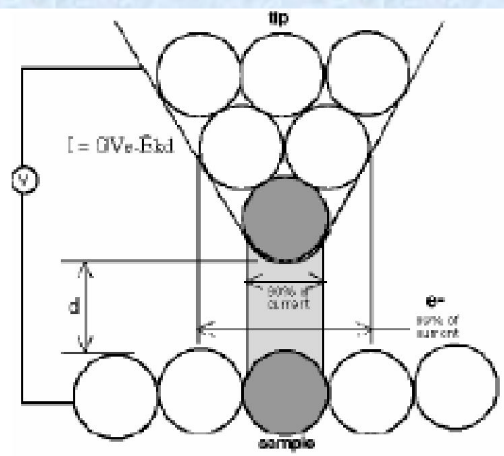


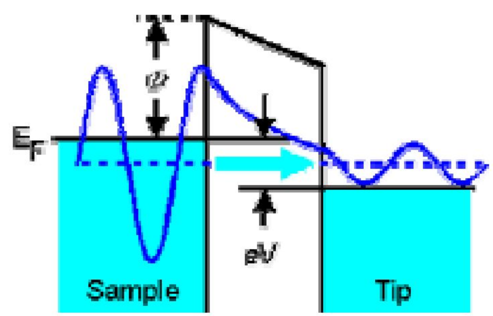
Electron Tunneling



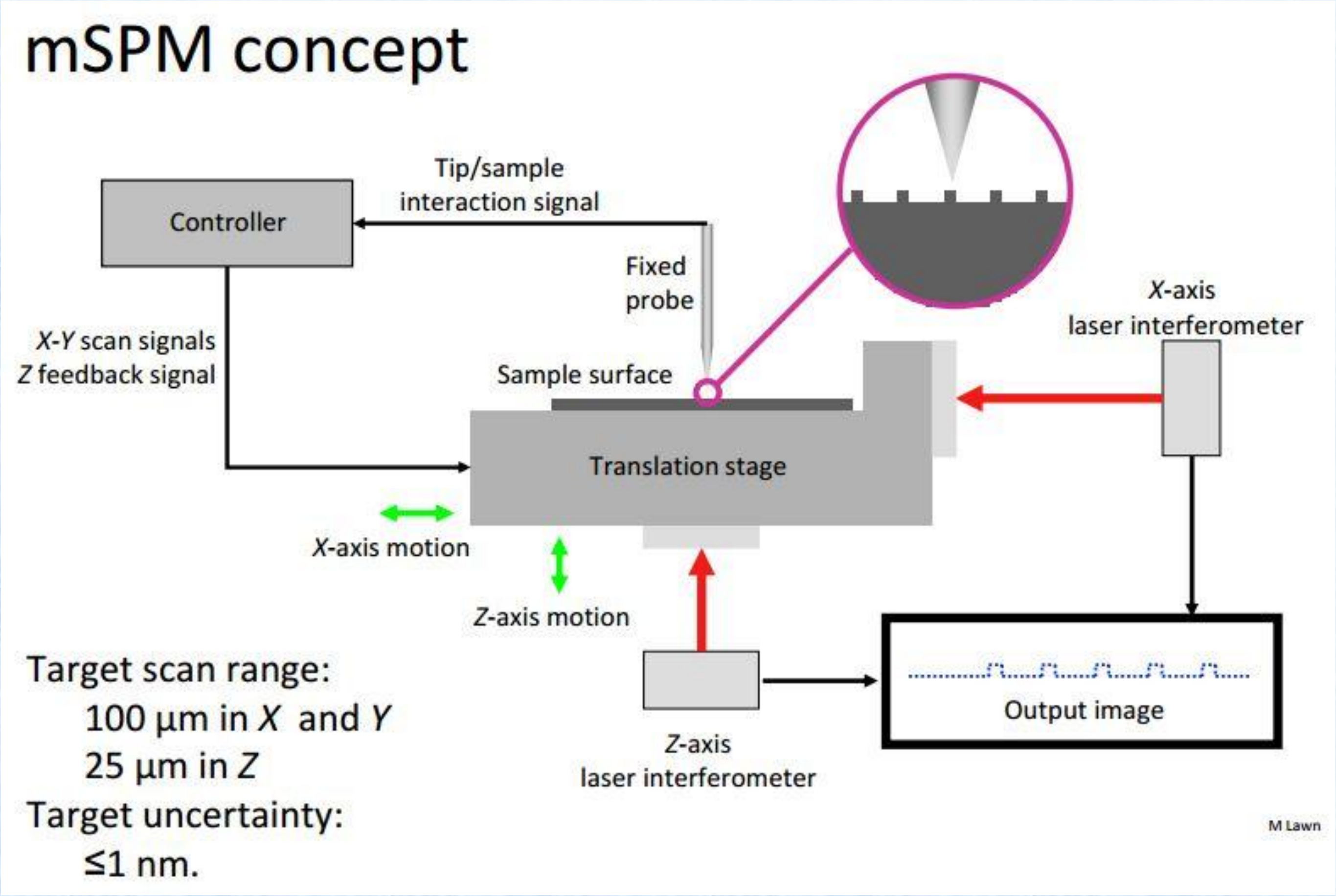
Electron tunneling

- Quantum mechanical principle
- Conductive sample to metal tip ~ a few Å
- Small voltage applied (< 4V)
- 0.01 nA-50 nA current output by electron tunneling

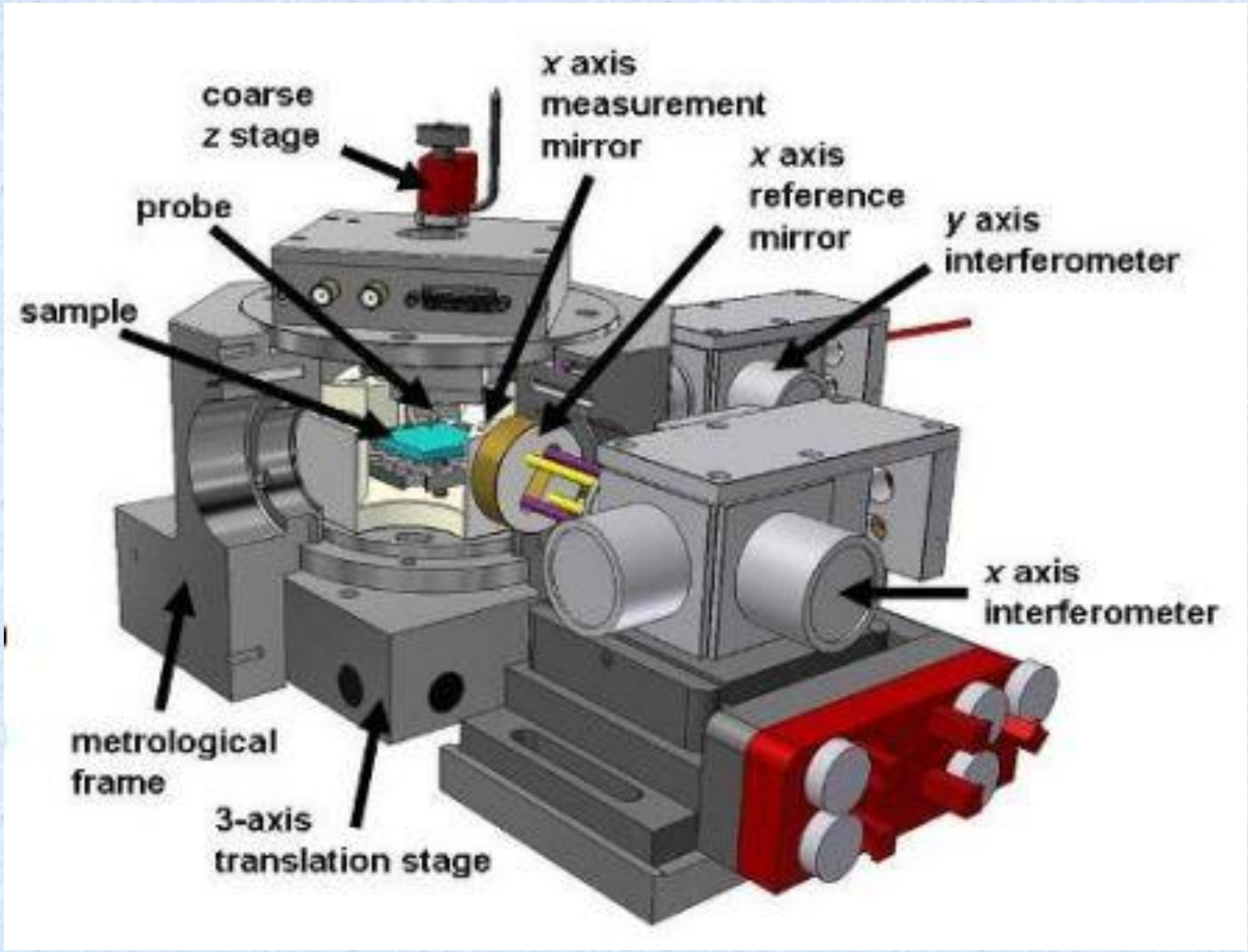


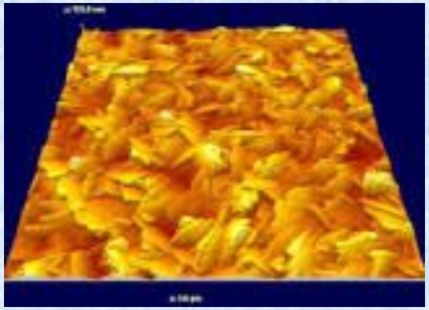


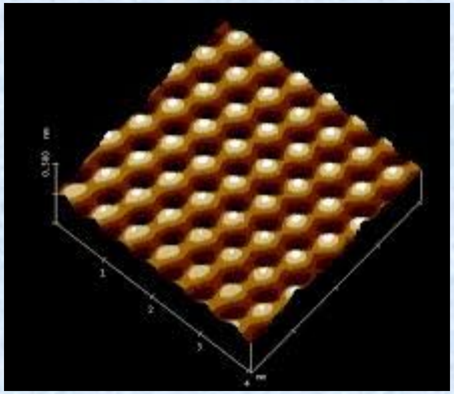
Metrological Scanning Probe Microscopy



mSPM


x axis
measurement
mirror
coarse
z stage
x axis
reference
mirror
probe
y axis
interferometer
sample
x axis
interferometer
metrological
frame
3-axis
translation stage





Confocal Microscope

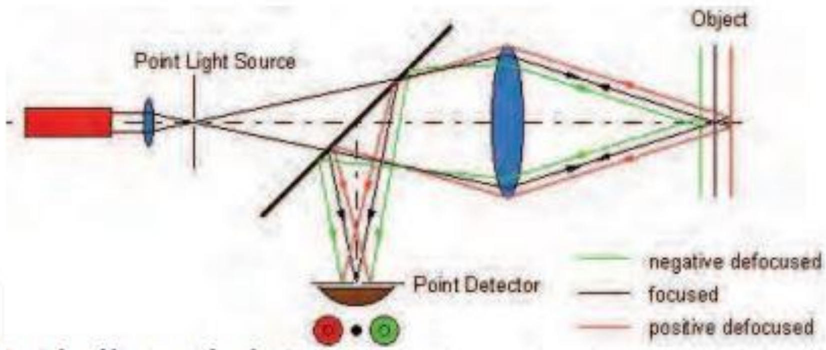


Fig. 5. Principle of laser confocal microscopy

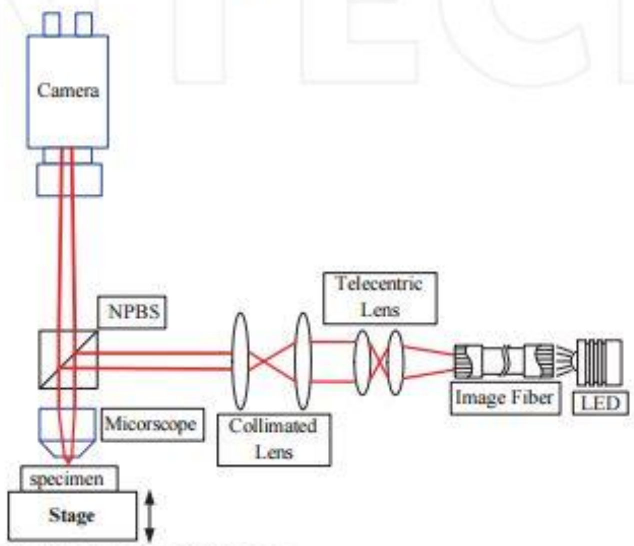
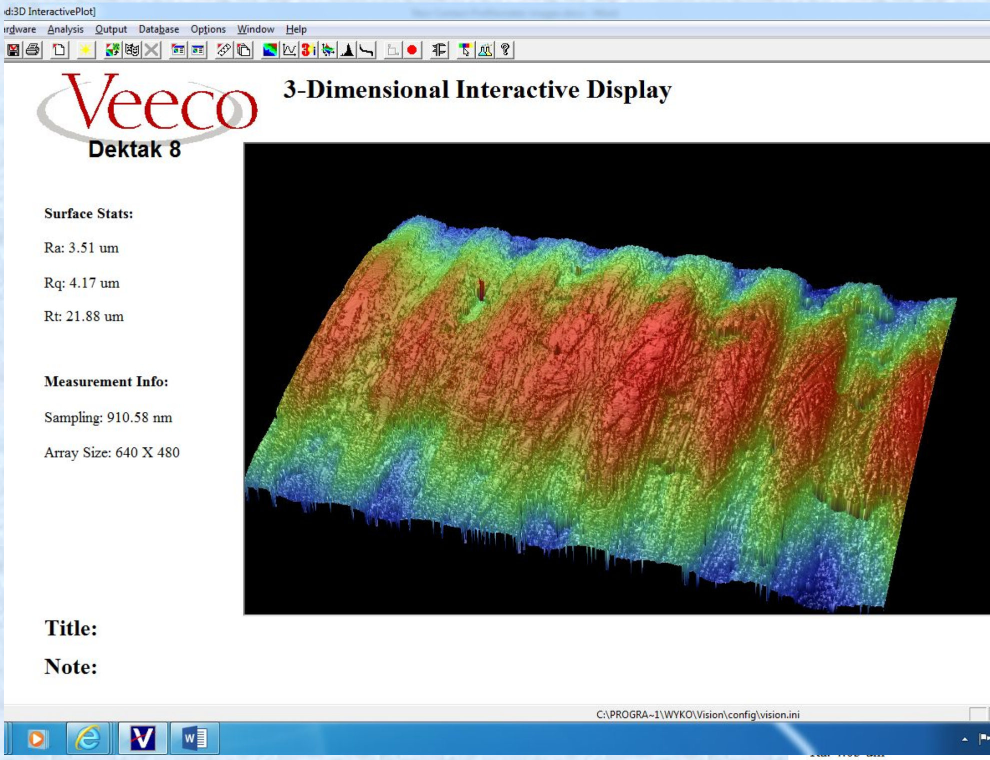
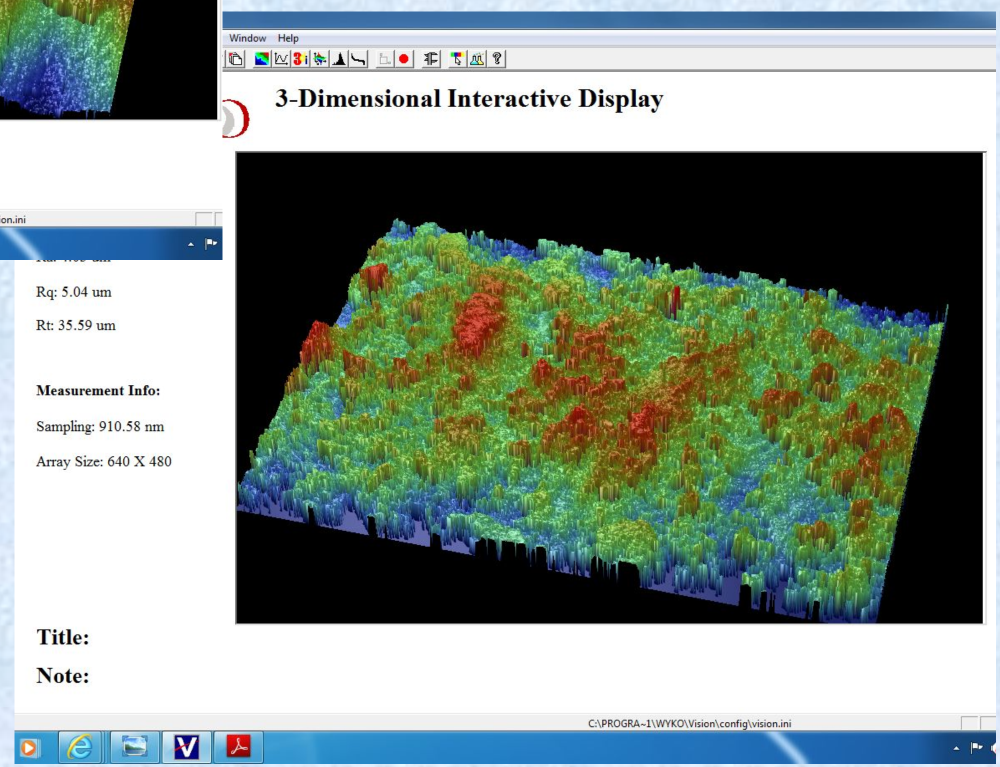


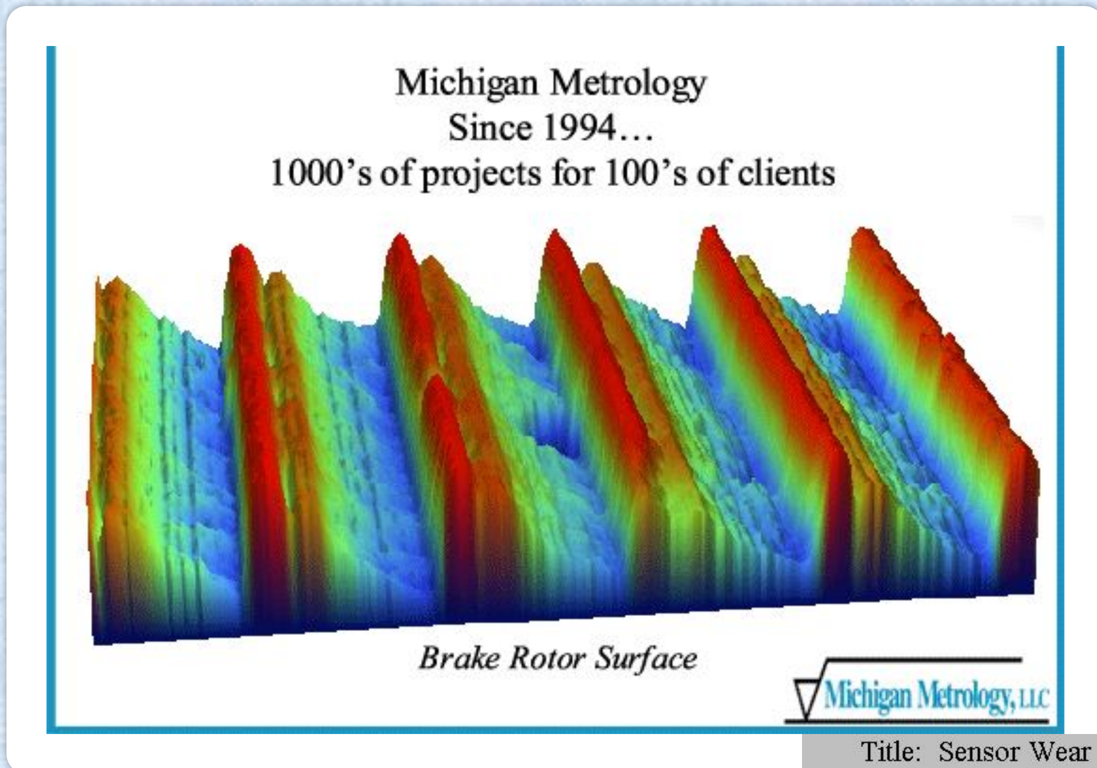
Fig. 6. Image fiber LED confocal microscope

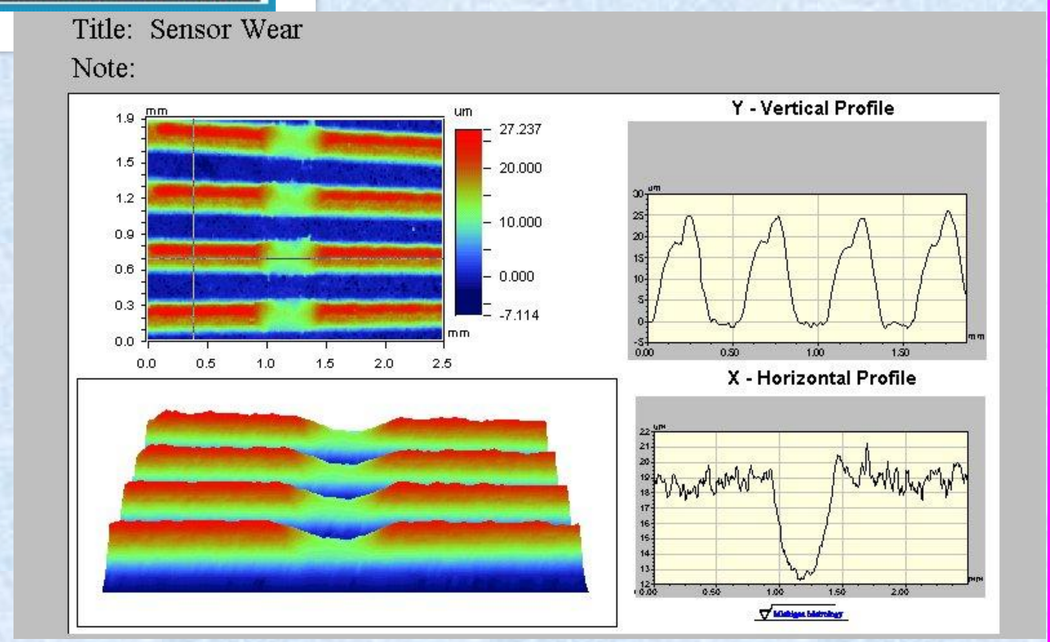
- It uses a high intensity LED to project light through an image fiber bundle onto the work surface.
- The fiber bundle consists of 80000 fibers with about 150µm in diameter each.
- The hexagonal grid pattern of the fiber bundle projected onto the work surface can be treated as a structural light.
- In the collected image frame the grey level change of the pixels is proportional to the distance out of focal plane of the probe

3D profiling


d:3D InteractivePlot]
rdware Analysis Output Database Options Window Help
Veeco
Dektak 8
3-Dimensional Interactive Display
Surface Stats:
Ra: 3.51 um
Rq: 4.17 um
Rt: 21.88 um
Measurement Info:
Sampling: 910.58 nm
Array Size: 640 X 480
Title:
Note:
C:\PROGRA~1\WYKO\Vision\config\vision.ini


Window Help
3-Dimensional Interactive Display
Rq: 5.04 um
Rt: 35.59 um
Measurement Info:
Sampling: 910.58 nm
Array Size: 640 X 480
Title:
Note:
C:\PROGRA~1\WYKO\Vision\config\vision.ini


Michigan Metrology
Since 1994…
1000’s of projects for 100’s of clients
Brake Rotor Surface
Michigan Metrology, LLC

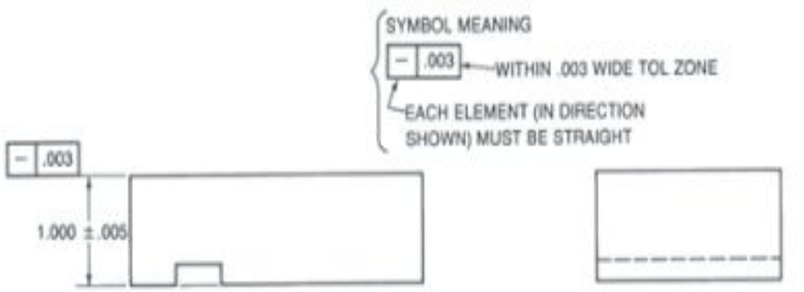

Title: Sensor Wear
Note:
mm
1.9
1.5
1.2
0.9
0.6
0.3
0.0
0.0
0.5
1.0
1.5
2.0
2.5
um
27.237
20.000
10.000
0.000
-7.114
mm
Y - Vertical Profile
X - Horizontal Profile

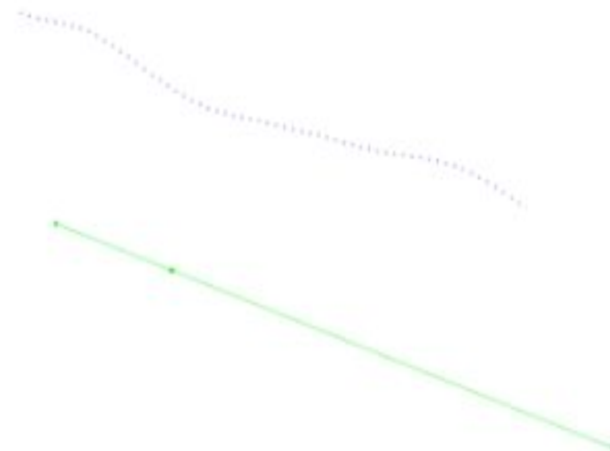
Form Measurement

- Straightness
- Flatness
- Roundness
- Cylindricity
- Sphericity

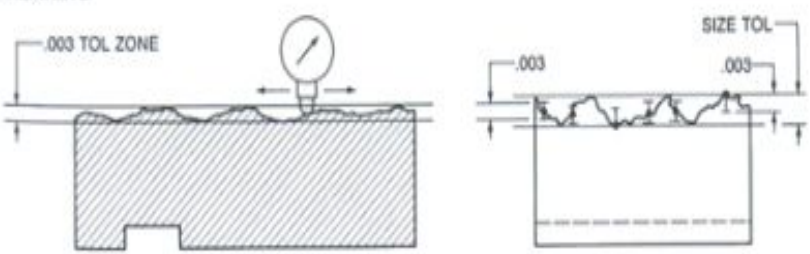
Straightness —

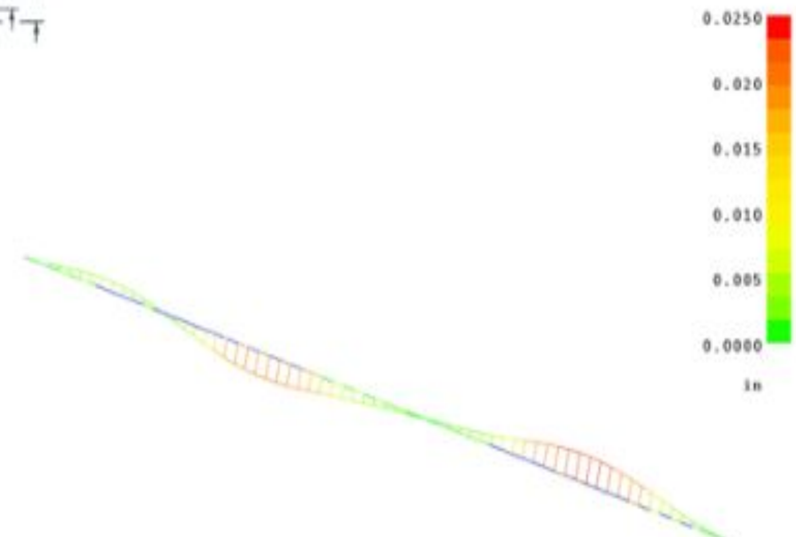
EXAMPLE





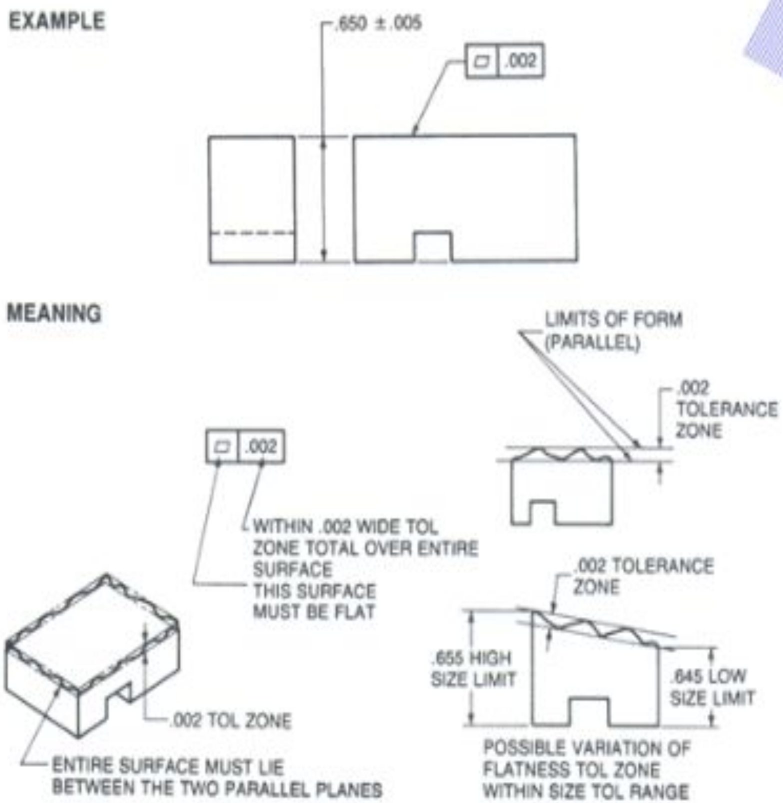
MEANING

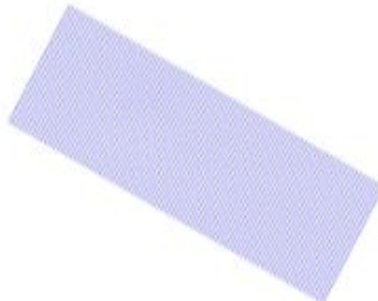


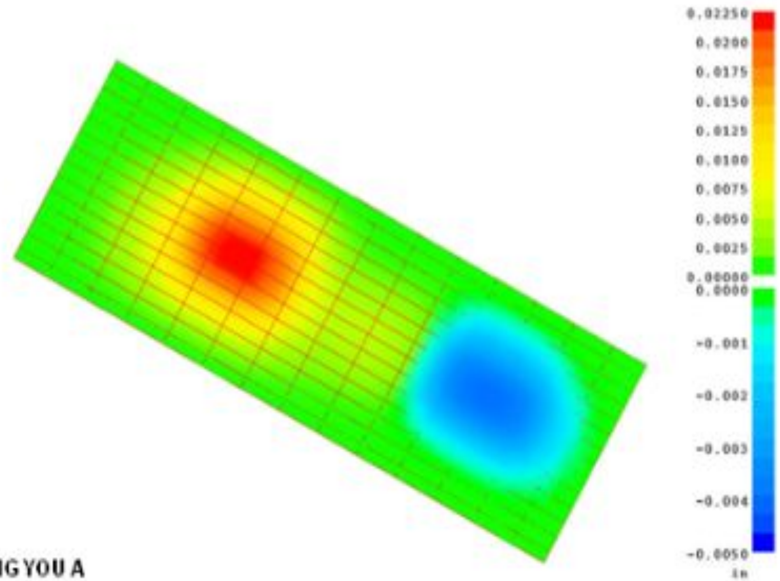


CROSS SECTION THE POINT CLOUD AND BEST FIT A LINE TO THE RESULTING POINTS. THEN COLOR MAP THE LINE TO THE POINTS FOR A STRIAGHTNESS REPORT

Flatness ⏥

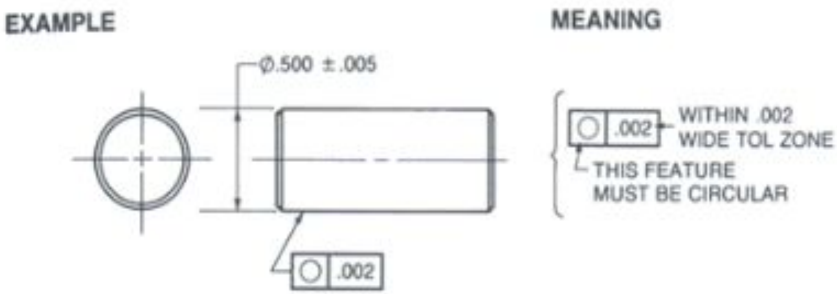


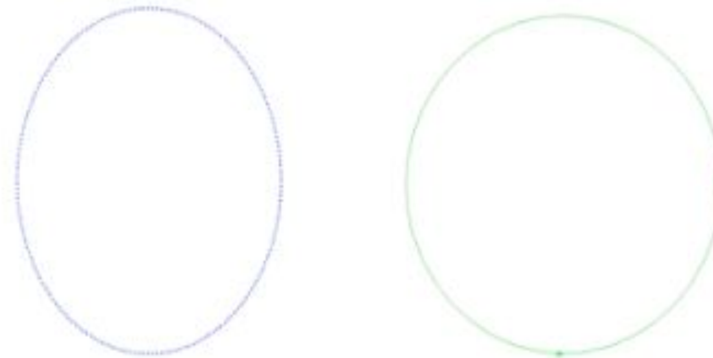


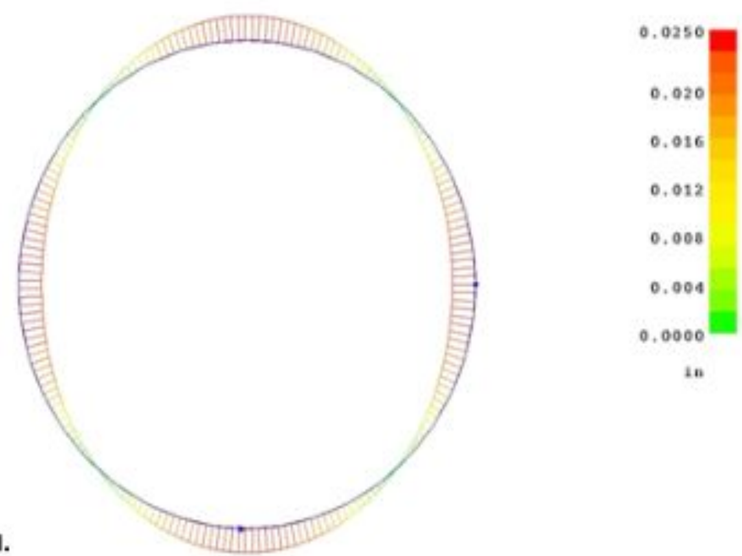


BEST FIT A SURFACE TO THE POINT CLOUD AND COLOR MAP THE RESULT,GIVING YOU A FLATNESS REPORT

Circularity (Roundness) ○





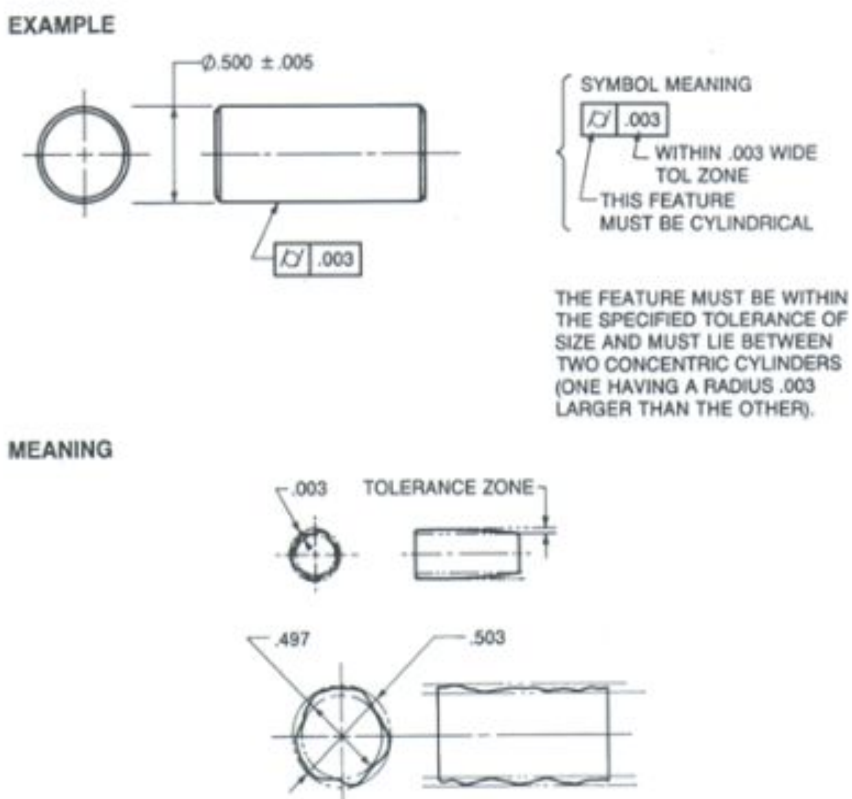


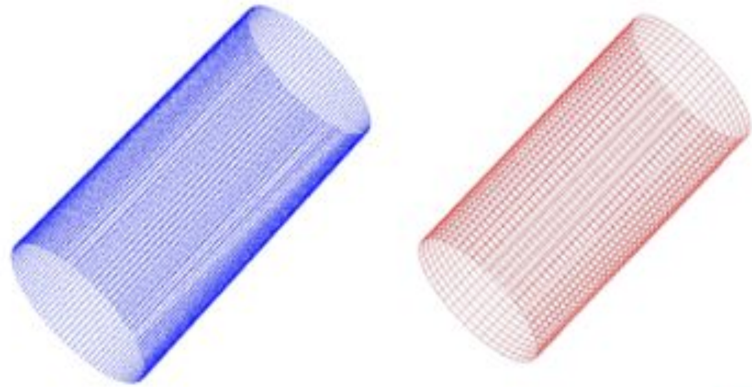
SURFACE PERIPHERY AT ANY CROSS SECTION PERPENDICULAR TO THE AXIS MUST BE WITHIN THE SPECIFIED TOLERANCE OF SIZE AND MUST LIE BETWEEN TWO CONCENTRIC CIRCLES, ONE HAVING A RADIUS .002 LARGER THAN THE OTHER.

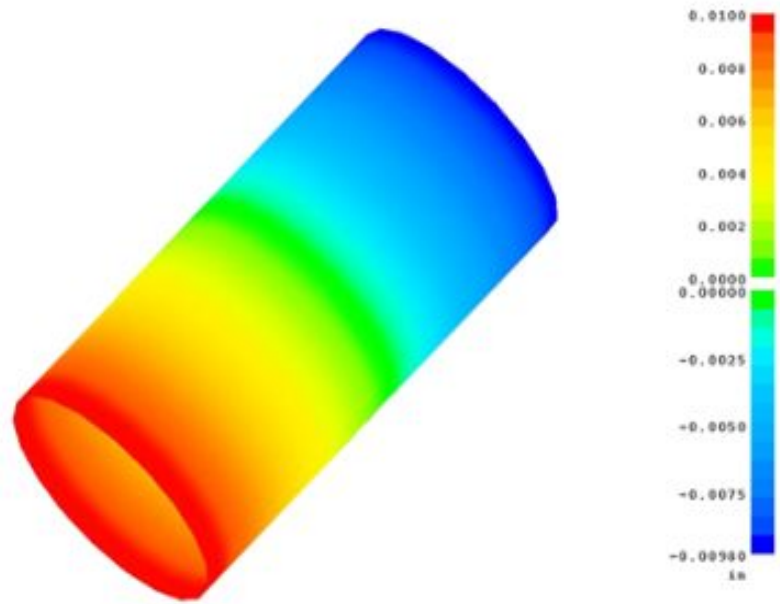
(ABOVE SIZES ARBITRARILY SELECTED FOR ILLUSTRATION)

CROSS SECTION THE POINT CLOUD AND BEST FIT A CIRCLE TO THE CROSS SECTION. THEN COLOR MAP THE POINT CLOUD TO THE CIRCLE FOR A CIRCULARITY REPORT.

Cylindricity ⌭

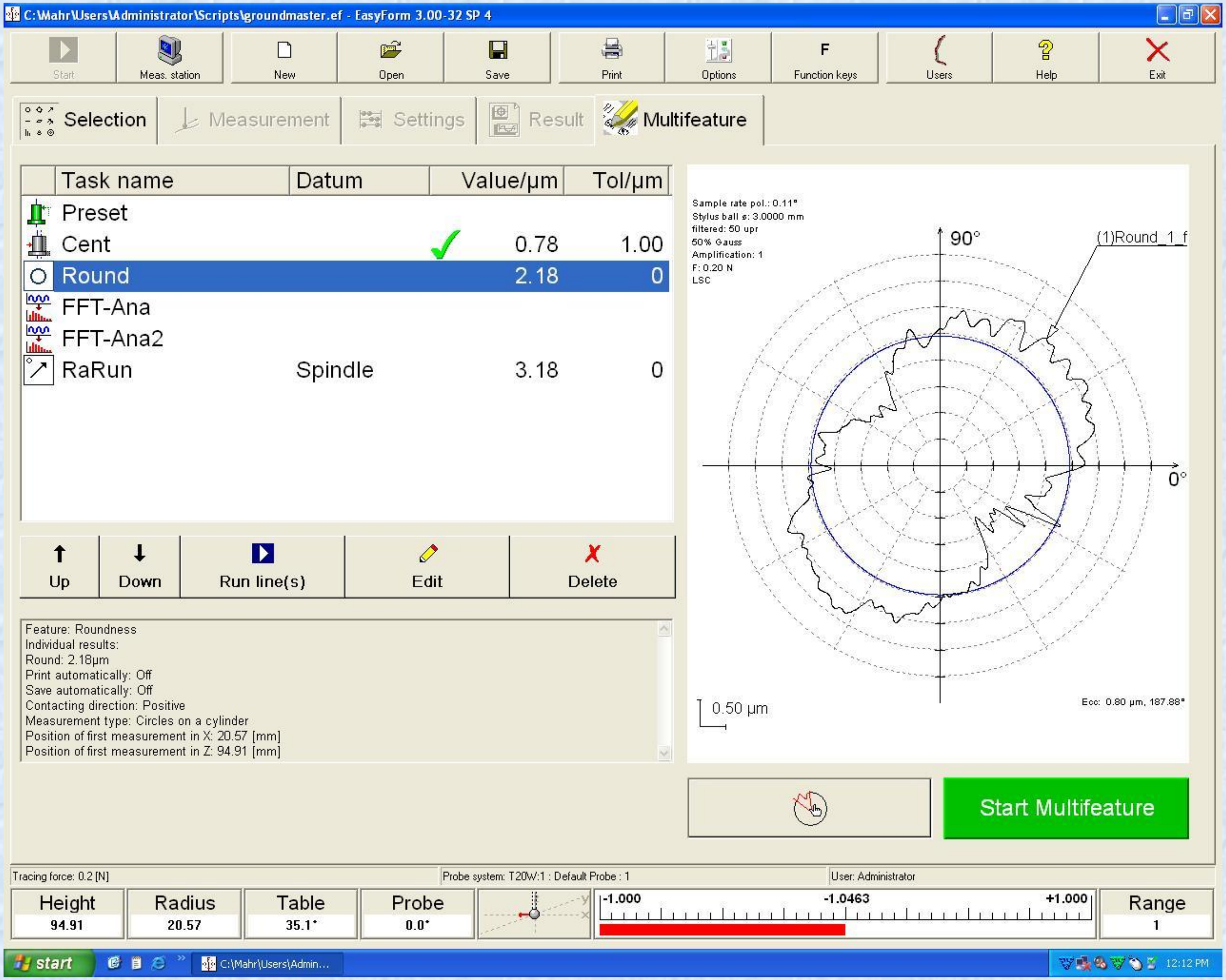






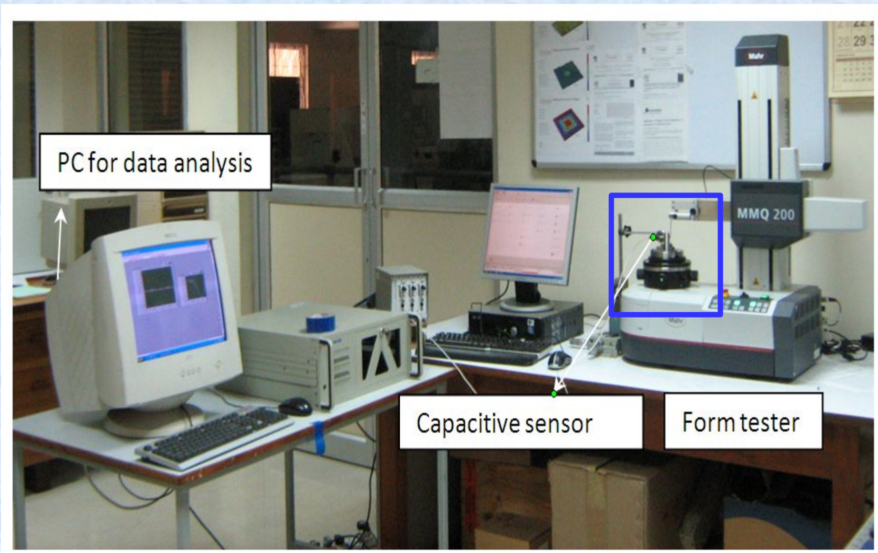
BEST FIT A CYLINDER TO THE POINT CLOUD AND COLOR MAP THE RESULTFOR CYLINDRICITY REPORT

Roundness and Cylindricity


C:\Mahr\Users\Administrator\Scripts\groundmaster.ef - EasyForm 3.00-32 SP 4
Start
Meas. station
New
Open
Save
Print
Options
Function keys
Users
Help
Exit
Selection
Measurement
Settings
Result
Multifeature
Task name
Datum
Value/µm
Tol/µm
Preset
Cent 0.78 1.00
Round 2.18 0
FFT-Ana
FFT-Ana2
RaRun Spindle 3.18 0
Up
Down
Run line(s)
Edit
Delete
Feature: Roundness
Individual results:
Round: 2.18µm
Print automatically: Off
Save automatically: Off
Contacting direction: Positive
Measurement type: Circles on a cylinder
Position of first measurement in X: 20.57 [mm]
Position of first measurement in Z: 94.91 [mm]
Sample rate pol.: 0.11°
Stylus ball ⌀: 3.0000 mm
filtered: 50 upr
50% Gauss
Amplification: 1
F: 0.20 N
LSC
90°
(1)Round_1_f
0°
0.50 µm
Ecc: 0.80 µm, 187.88°
Start Multifeature
Tracing force: 0.2 [N]
Probe system: T20W:1 : Default Probe : 1
User: Administrator
Height
94.91
Radius
20.57
Table
35.1°
Probe
0.0°
-1.000
-1.0463
+1.000
Range
1
start
C:\Mahr\Users\Admin...
12:12 PM

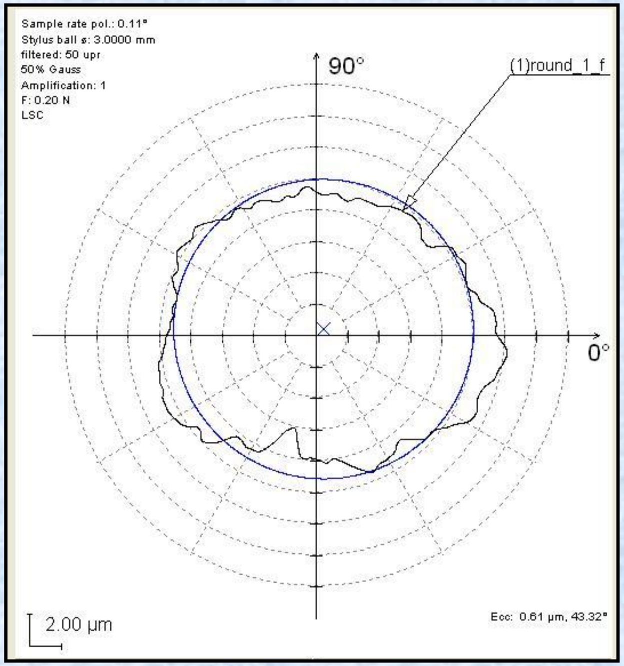
Measurement of Roundness Error

Separation method based on Harmonics in the form profile

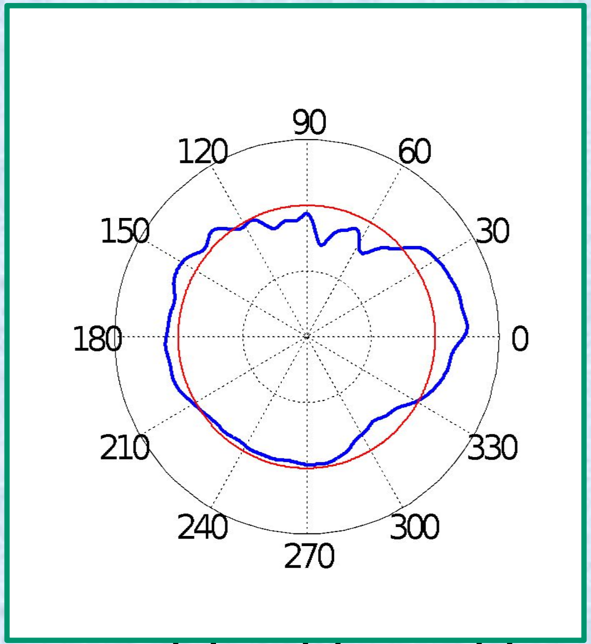


Experimental arrangement for measurement of form error using capacitance sensor and roundness tester

Profile of the artifact measured using roundness/form tester and capacitance sensor

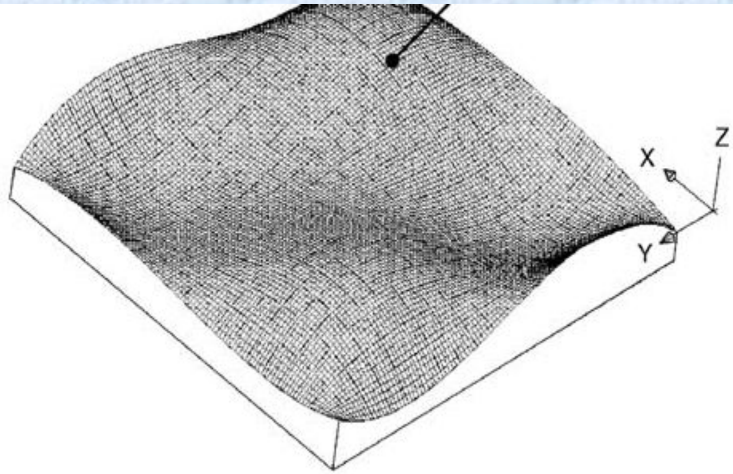


Form profile obtained using roundness tester

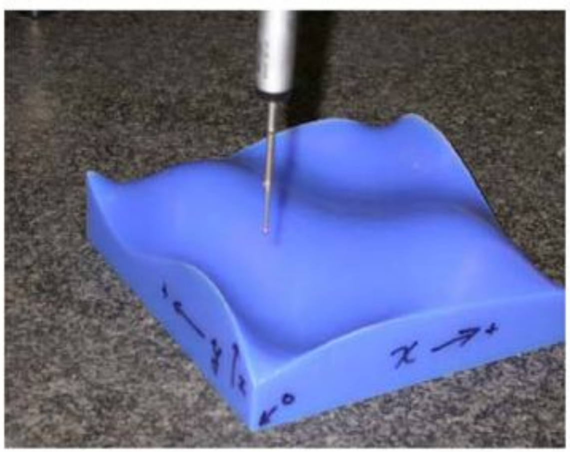


Form profile obtained by capacitive sensor at10KHz sampling frequency (Base circle radius : 10μm)

Inspection of Freeform Surfaces



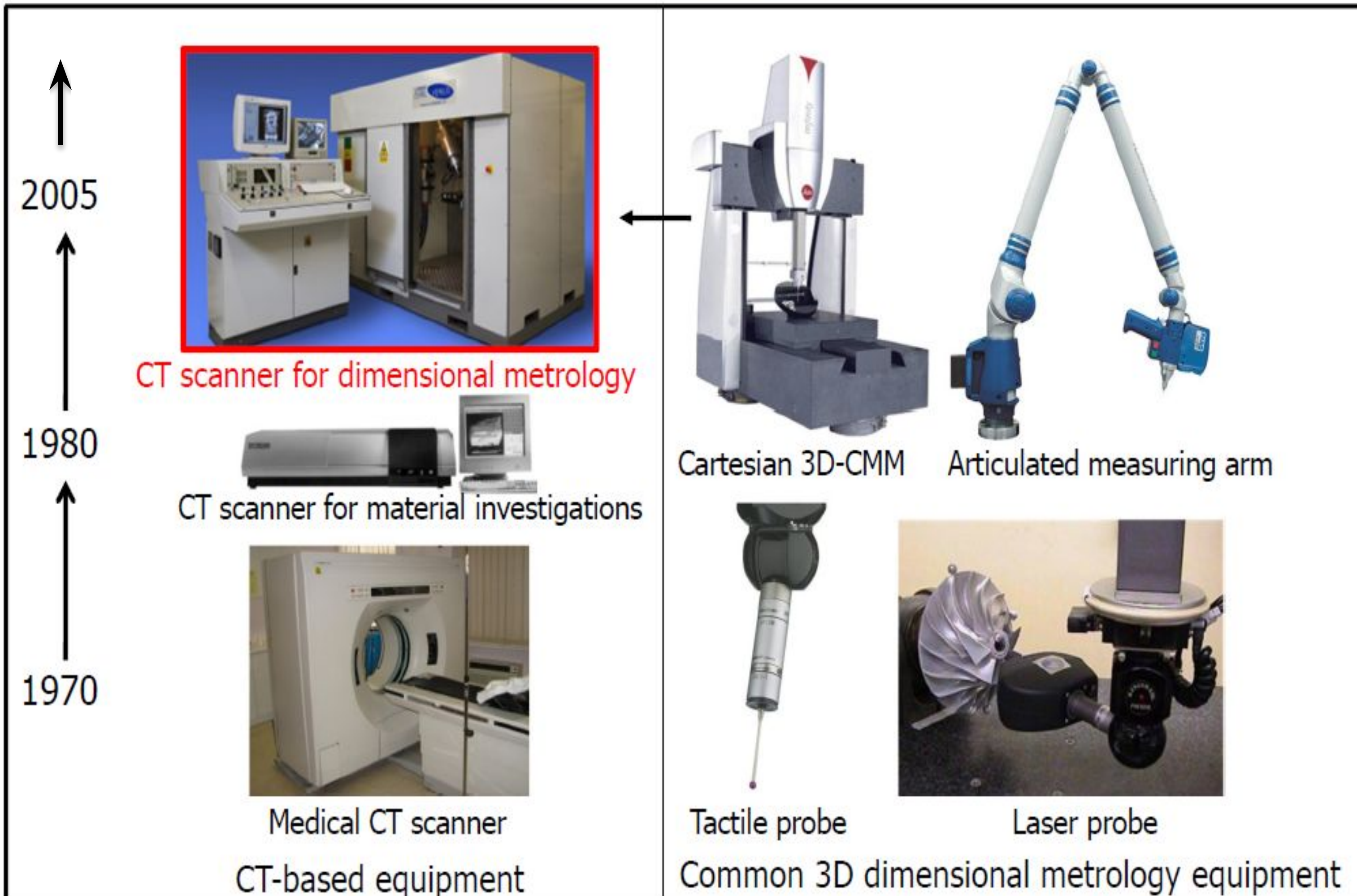
(a) Design model



Click for more images

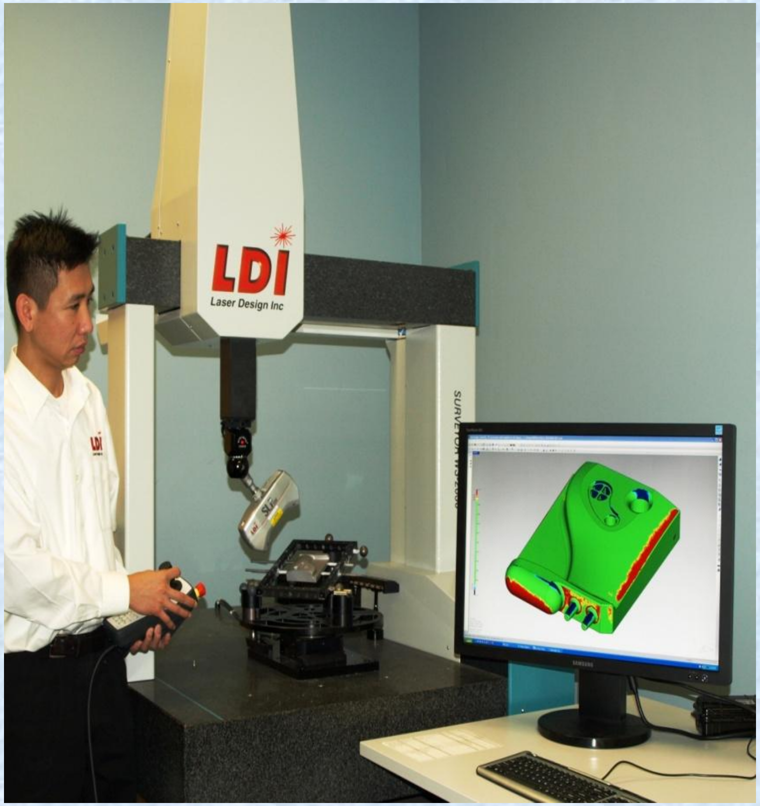
Dimensional Measurement

Evolution in 3D measuring devices



3D Laser Scanner

- 3D Laser Scanner CMM determines laser cloud point data samples from the object surface capturing work piece physical shape.
- A digital CAD model is made.
- A Laser Scanner is like spray painting of an object.
- Painting goes with laser scanner. hence difficult when sprayed deep.



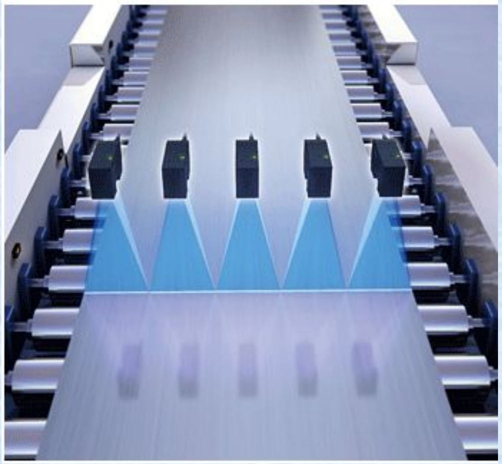
3D Laser Scanning integrated with CMM System

- **Advantages:**

- ❑ Throughout fast
- ❑ Accurate
- ❑ Covers all the parts.
- ❑ It is repeatable
- ❑ It is a non contact
- ❑ User friendly based Windows System

3D inspection of powdered metal components

Bearing seal inspection

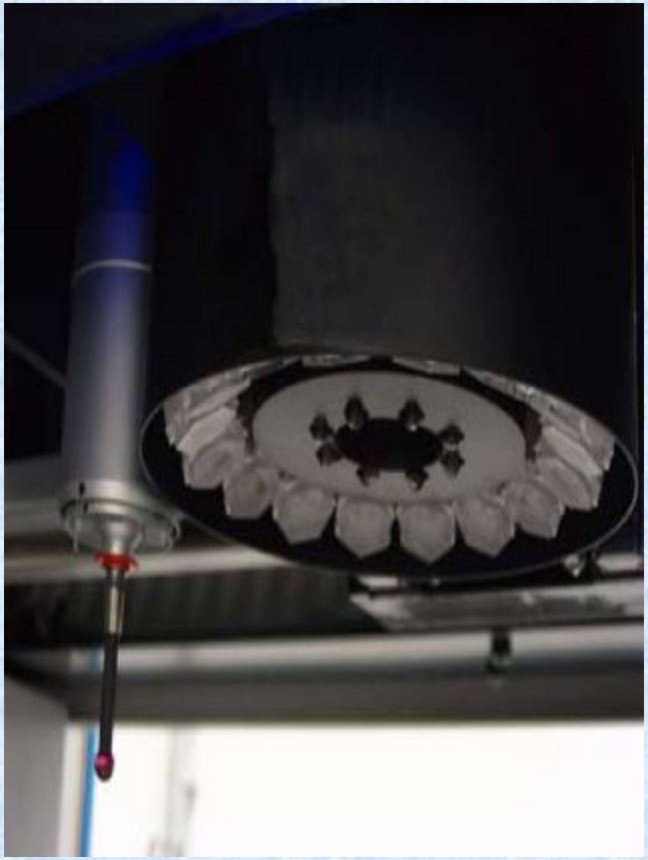


Rolled steel defect inspection

Pre-weld assembly and weld bead inspection

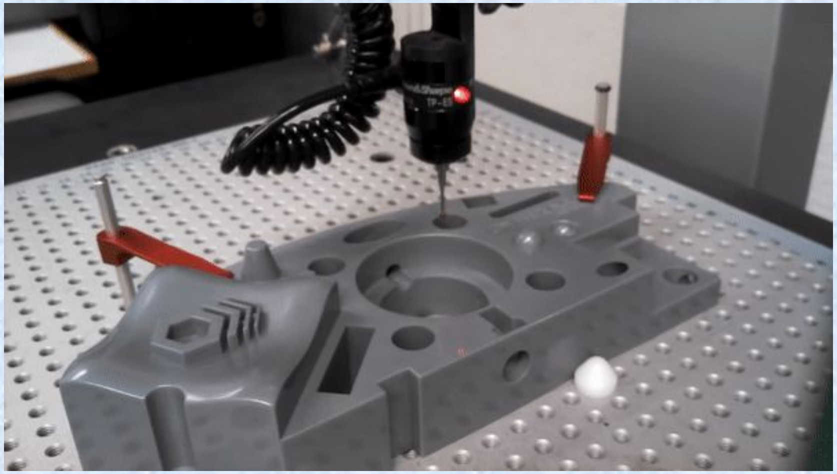
Multi-sensor CMM

Probes – Contact and Non-contact

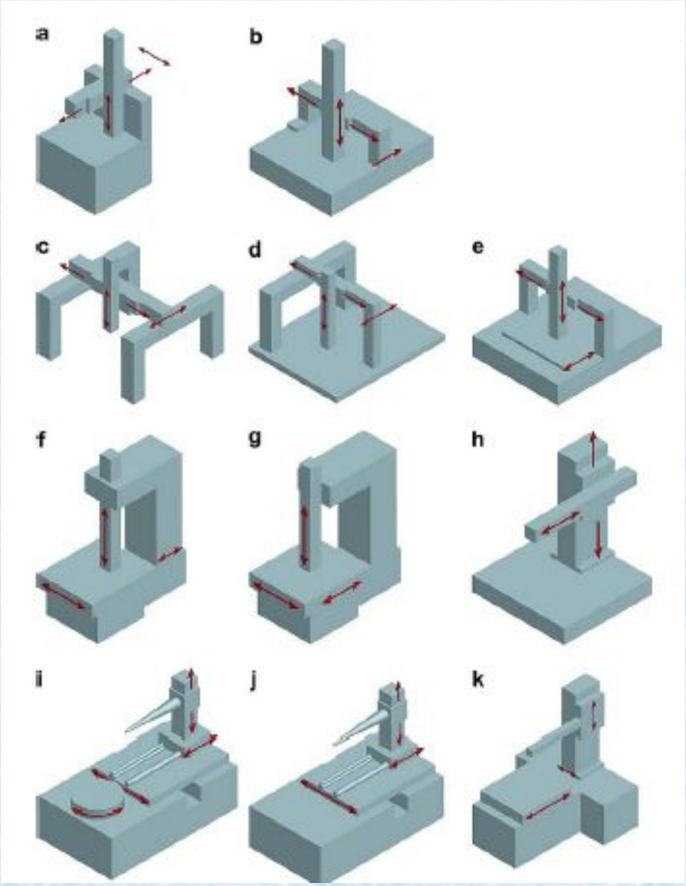


Coordinate Measuring Machine (CMM)

- A CMM consists of a constant probe that can be positioned in 3D space relative to the surface of a work part, and the x, y, and z coordinates of the probe can be accurately and precisely recorded to obtain dimensional data concerning the part geometry



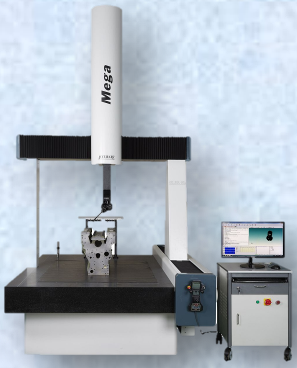
Classification of CMM - structures



a. Fixed Table Cantilever
b. Moving Bridge
c. Gantry
d. L Shaped Bridge
e. Fixed Bridge
f. Moving Table Cantilever
g. Column
h. Moving Ram Horizontal arm
i. Fixed Table Horizontal arm
j. Fixed Table Horizontal arm
k. Moving Table Horizontal arm

Classification of CMM - structures

1) Cantilever

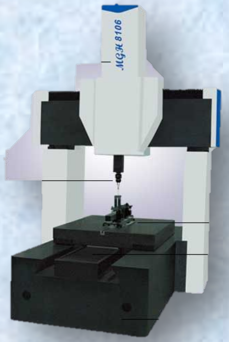


2) Bridge

3) Gantry

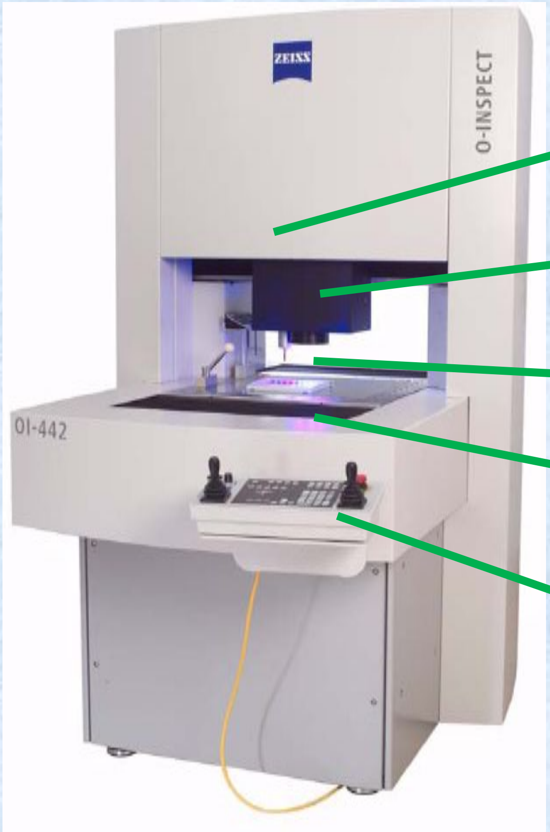
4) Column type

5) Horizontal arm type



6) Moving Bridge Type

Multi sensor CMM (IITM)



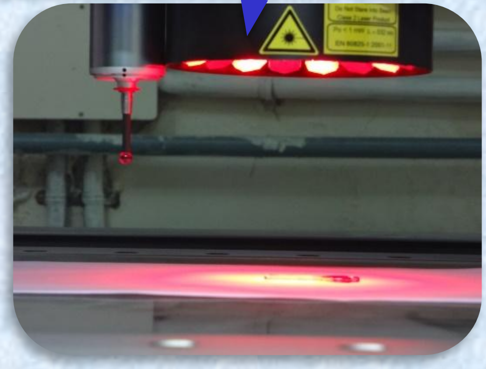
Bridge

Probe head (moves in X and Z direction)

Probes

Movable table (Moves in Y direction)

CMM Controller



Types of CMM Control

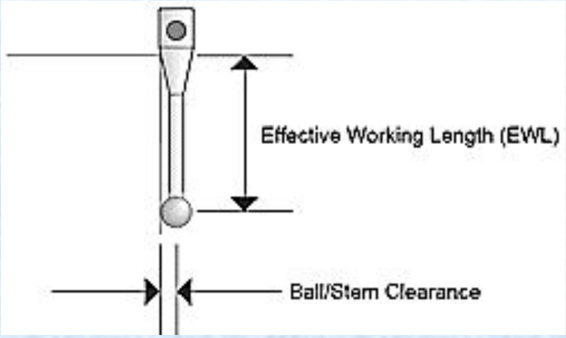
Manual Control

Manual drive with computer-assisted data processing

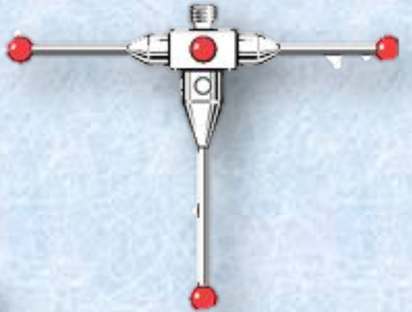
Motor drive with computer-assisted data processing

About the Probe Tips

- CMMs generally gather their data by touching the workpiece with a probe (either a solid probe or an electronic touch-trigger probe) attached the machine's measuring axis



Various Types of Styli



a) 5 way   b) disc   c) star   d) Cylindrical   f) hollow ball   e) pointer

TYPES OF PROBES

Two general categories

1. Contact (see figure)

    Touch-trigger probe

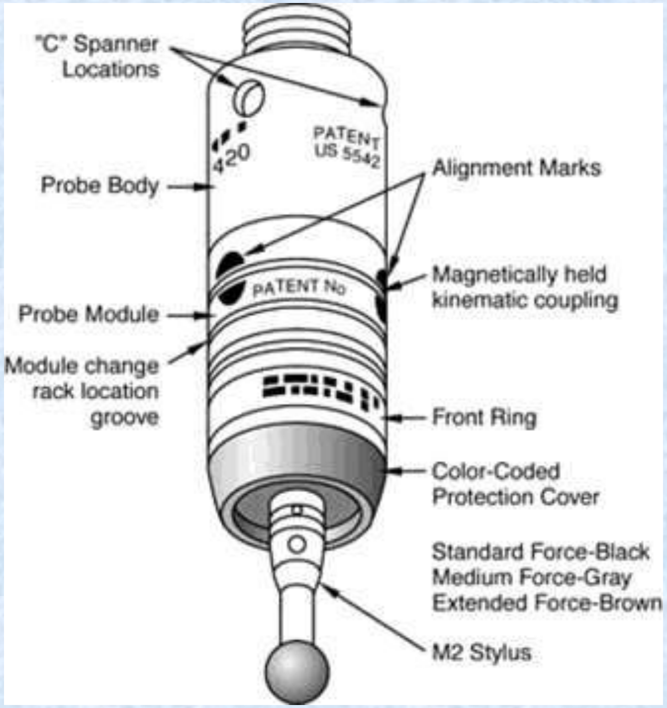
    Analog scanning probe

2. Noncontact

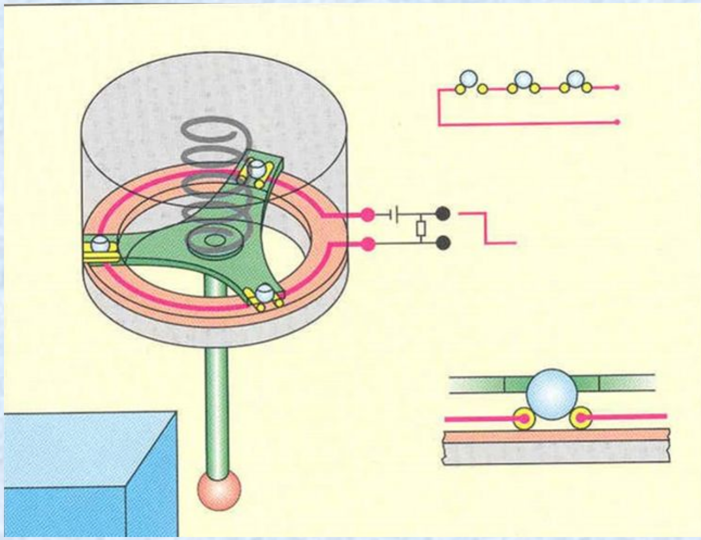
For inspection of printed circuit board, measuring a clay of wax model, when the object being measured would be deformed by the for of stylus

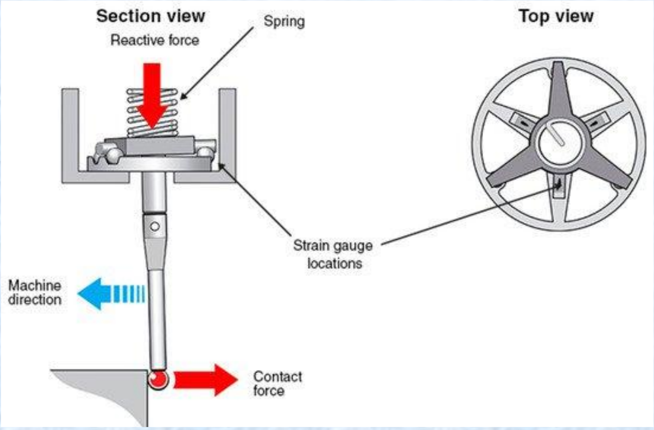
• laser probes

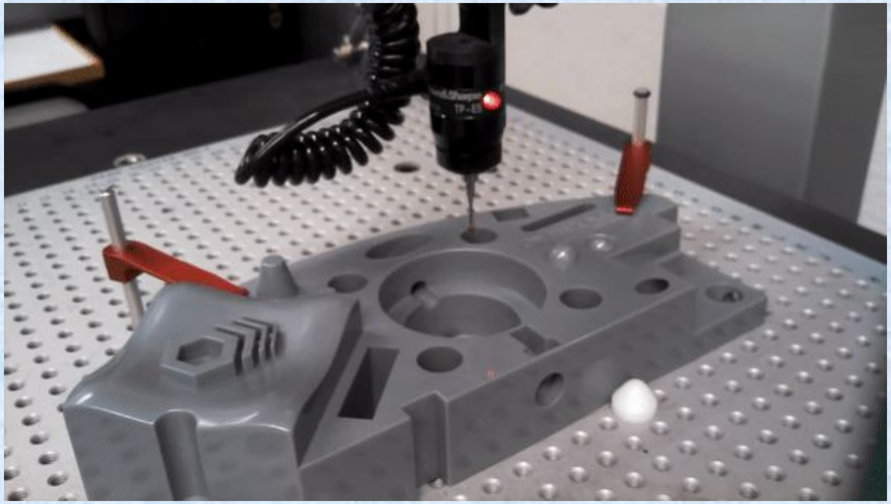
• video probes



Principle of Touch Trigger Probe







Advantages and Disadvantages of CMM

Advantages

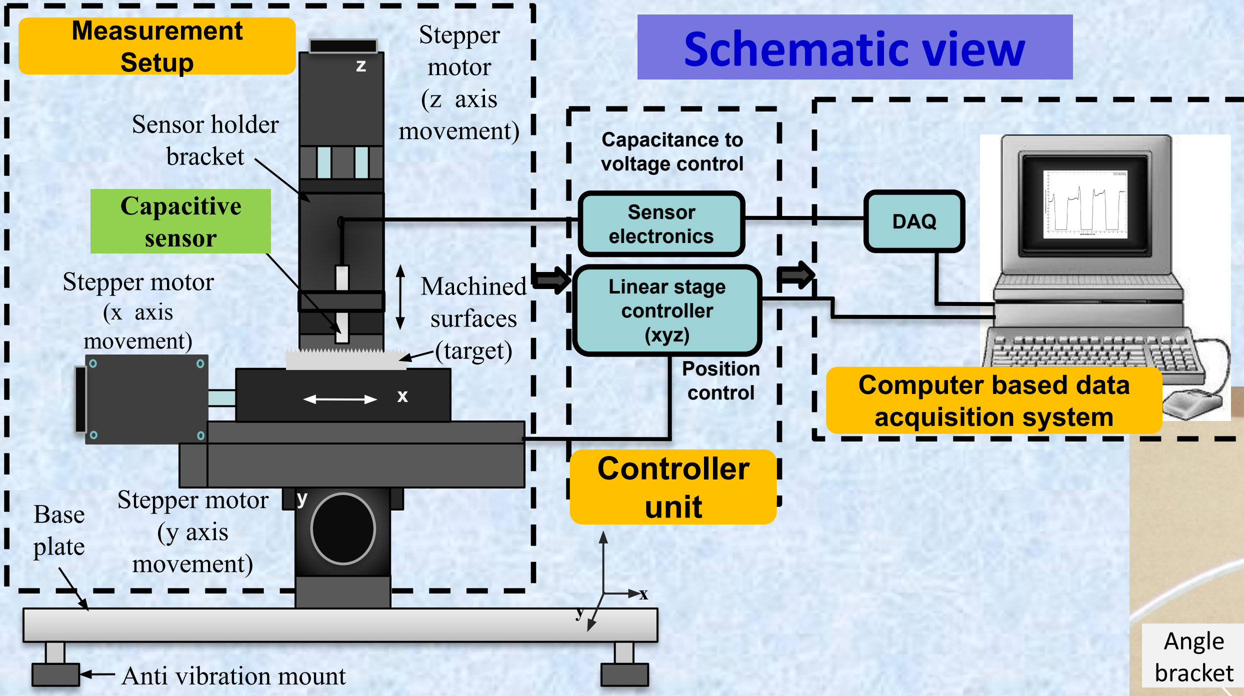
- The inspection rate is increased.
- Accuracy is more.
- Operators error can be minimized.
- Skill requirements of the operator is reduced.
- Reduced inspection fix Turing and maintenance cost.
- Reduction in calculating and recording time.
- Reduction in set up time.
- No need of separate go / no go gauges for each feature.
- Reduction of scrap and good part rejection.
- Reduction in off line analysis time.

Disadvantages

- The table and probe may not be in perfect alignment.
- The probe may have run out.
- The probe moving in Z-axis may have some perpendicular errors.
- Probe while moving in X and Y direction may not be square to each other.
- There may be errors in digital system.

Experimental setup

Schematic view



XYZ linear stage

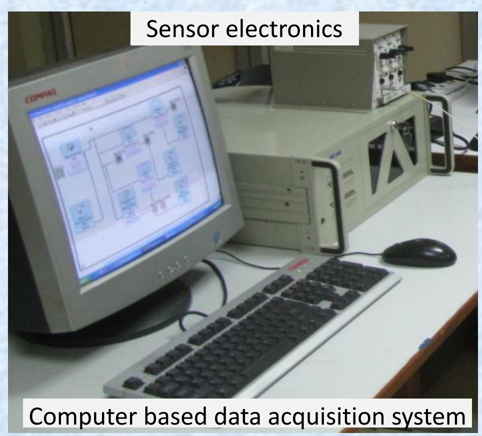
Travel range: 50 mm

Resolution: 0.156 µm (1/8 step)

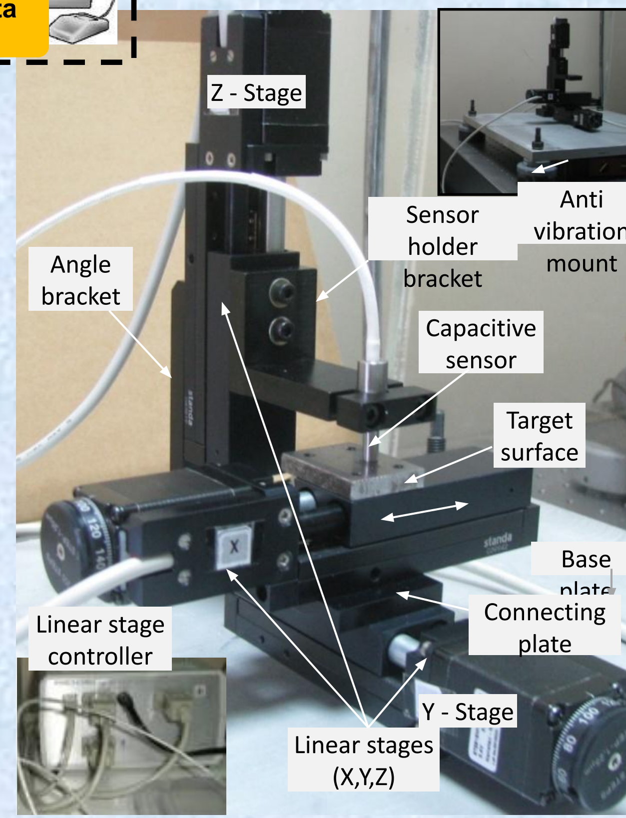
Min. incremental speed:0.1mm/s

Data capturing device

- NI PCI 6250 DAQ system

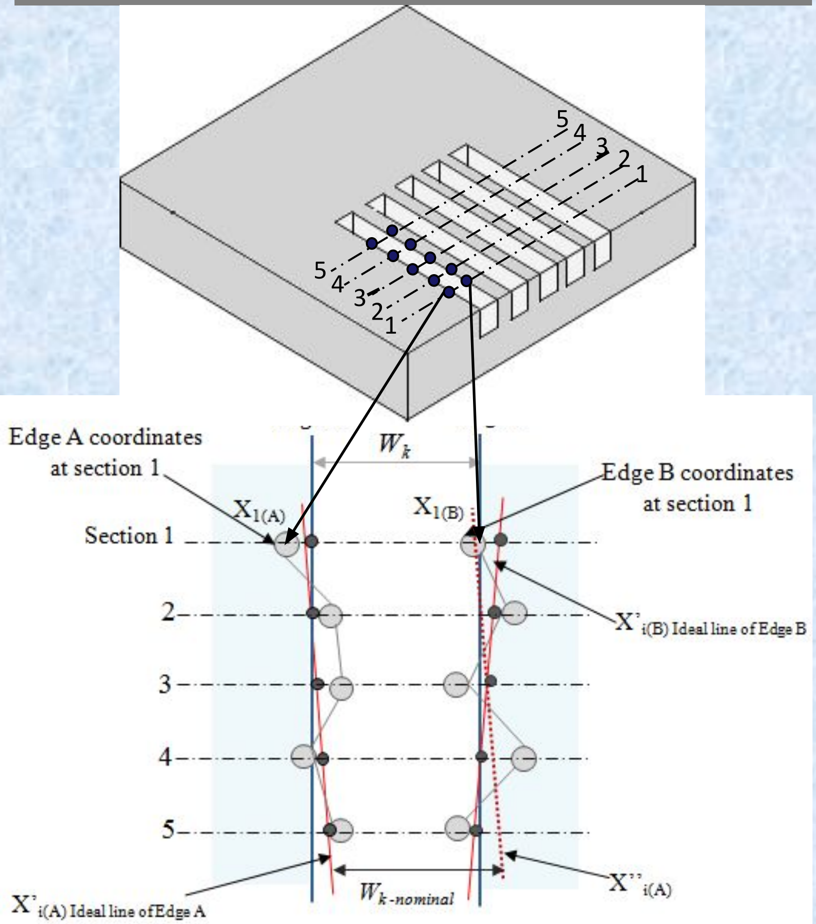


Photographic view



Evaluation of dimensional feature

Evaluation of nominal width of the channel



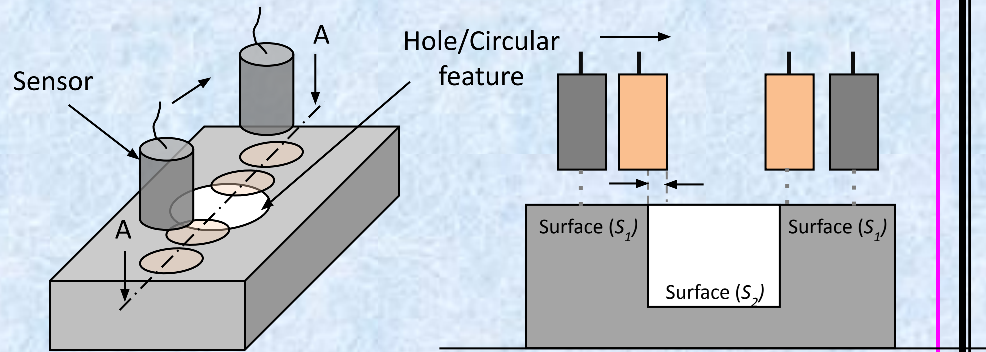
- Least square line (LSL) is fitted for the edge coordinates of A and B **(Shunmugam, 1988)**

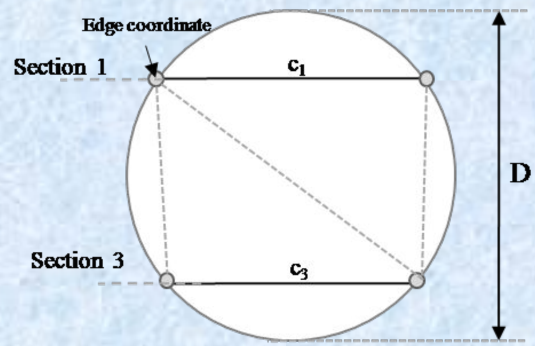
Ideal line reference to edge A

$$X'_{i(A)} = X_{i(A)} + (X_{N(B)} - X_{N(A)})$$

Measured width the channel $$W_{k-measured} = X''_{i(A)} - X'_{i(A)}$$

Evaluation of diameter of circular feature





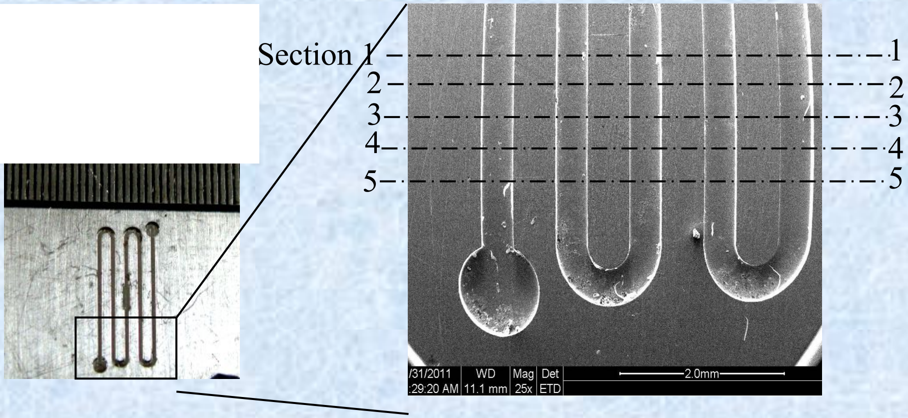
- Based on isosceles trapezoid geometry construction
- c_1,c_3-chord length

$$D = \frac{c_1 + c_3}{4}\sqrt{6 + \frac{c_1^2 + c_3^2}{c_1 c_3}}$$

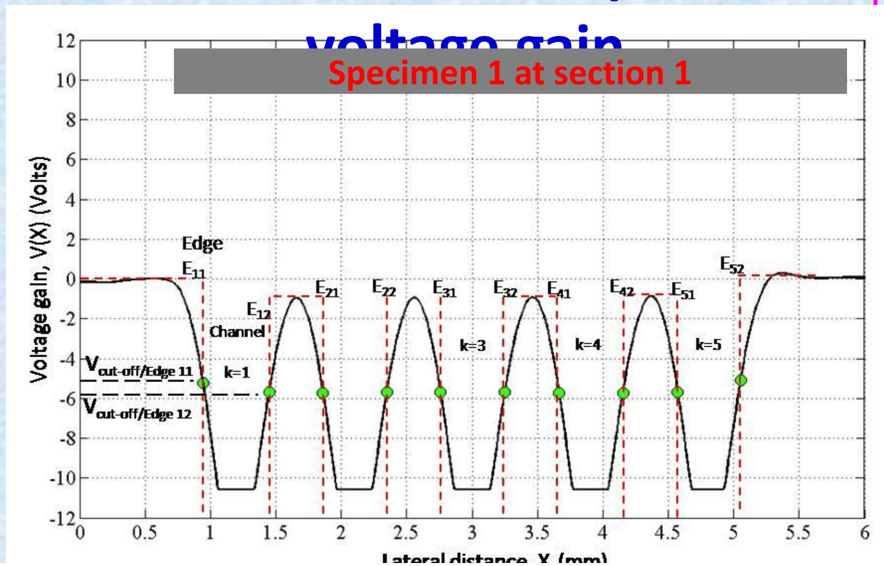
Experimental results

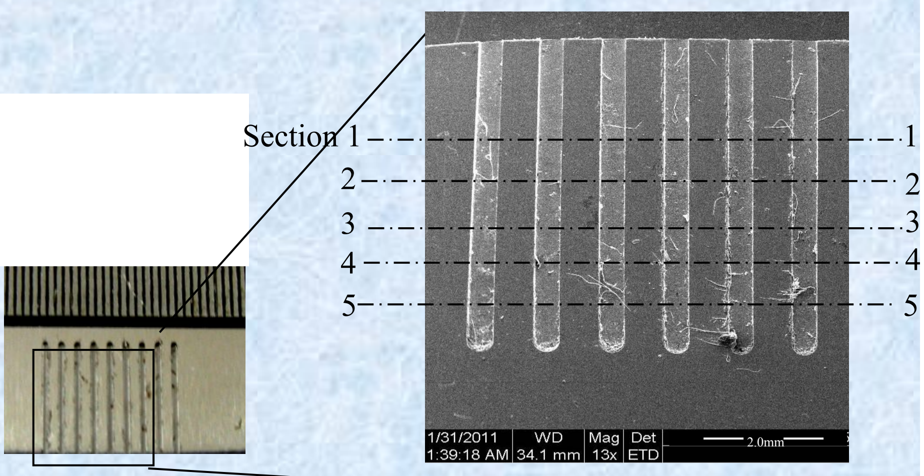
→ Two specimens- Nominal width of channel (500 and 400μm) and diameter of circular feature 1mm

Measured output voltage gain

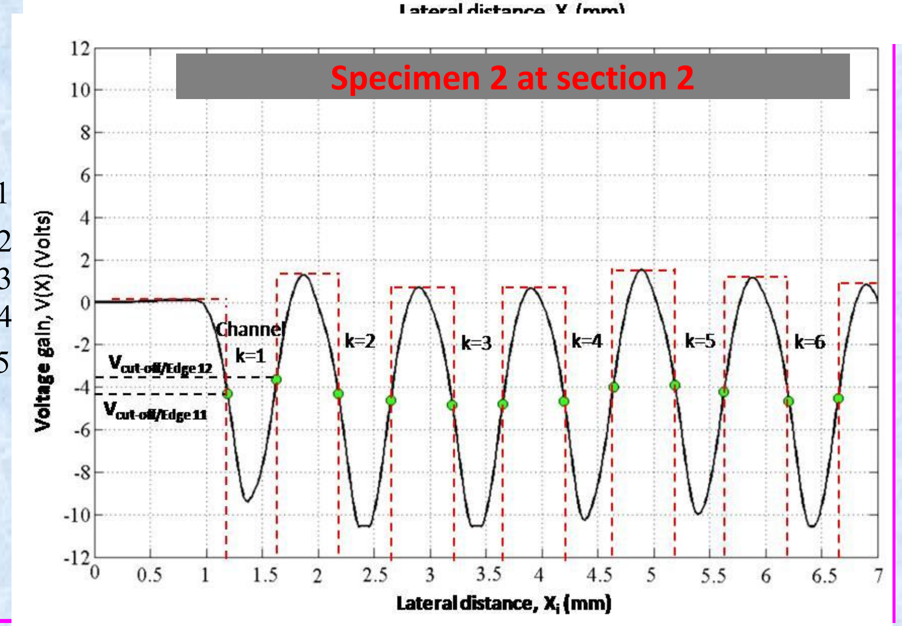


Meso-scale channel feature with nominal width of 500 μm on specimen 1





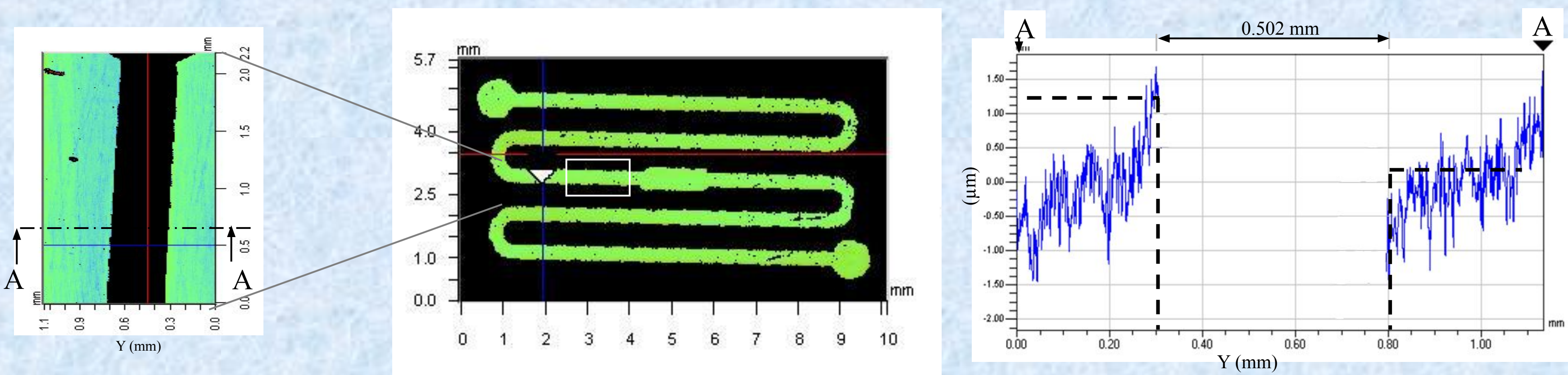
Meso-scale channel feature with nominal width of 400 μm on specimen 2



Experimental results

Evaluation of nominal width of the channel of the specimen 1
(for channel number 1)*

Section (s_i)	Position of Edge A coordinates $x_{i(A)}$ (mm)	Position of Edge B coordinates $x_{i(B)}$ (mm)	Ideal edge features using Least square method		Deviation from the ideal line of the edges		$X'_{i(A)}$ (mm)	Measured width of the channel W_k (mm)
			$X_{i(A)}$ (mm)	$X_{i(B)}$ (mm)	$e_{i(A)}$ (mm)	$e_{i(A)}$ (mm)		
1	1.096	1.599	1.038	1.547	0.058	0.052	1.535	0.497
2	0.955	1.468	1.020	1.526	-0.065	-0.058	1.517	
3	0.948	1.451	1.002	1.505	-0.054	-0.054	1.499	
4	1.058	1.558	0.984	1.484	0.074	0.074	1.481	
5	0.954	1.448	0.966	1.463	-0.012	-0.015	1.463	

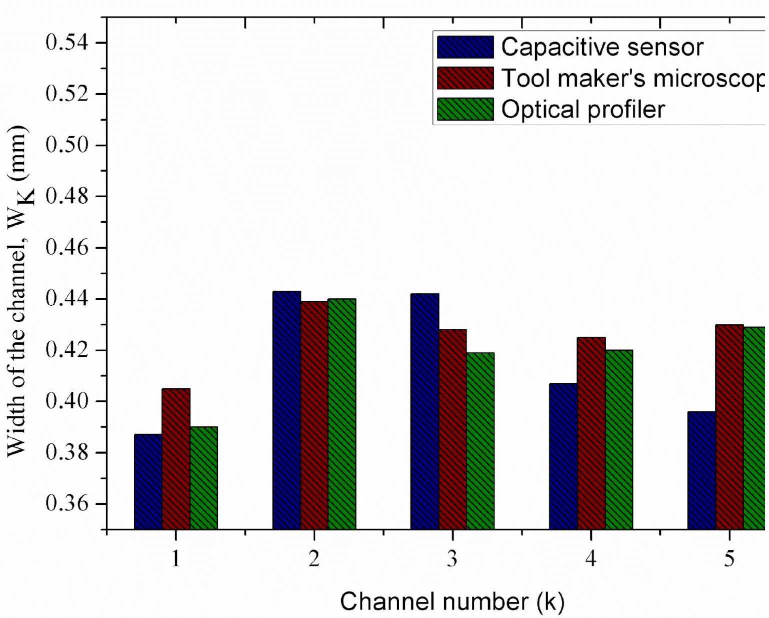


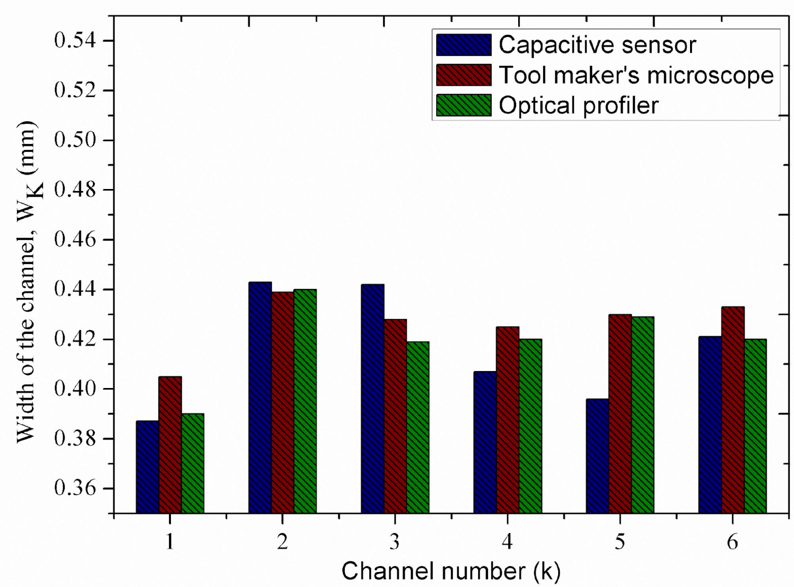
Measurement using optical profiler (Specimen 1 –channel 3)

Comparison of results

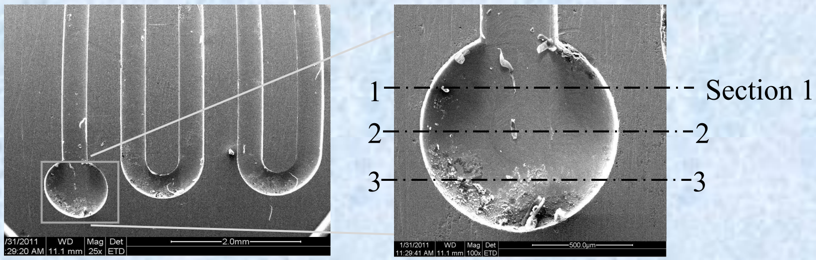
Computed nominal width of the channel and circular features of the specimen 1

Channel number (k)	Measured width of the channel/slot features W_k (mm)			% of deviation (compared to tool makers microscope)	% of deviation (compared to optical profiler)
	Capacitive sensor	Optical methods			
		Tool makers microscope	Optical profiler		
Channel feature (from section 1,2,3,4,5)					
1	0.497	0.483	0.493	2.90	0.81
2	0.487	0.497	0.502	2.01	2.99
3	0.491	0.502	0.496	2.19	1.01
4	0.486	0.495	0.494	1.82	1.62
5	0.477	0.482	0.484	1.04	1.45

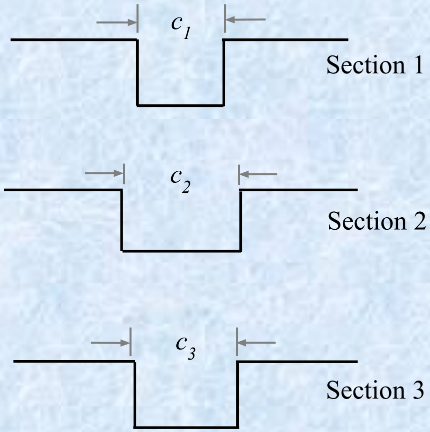




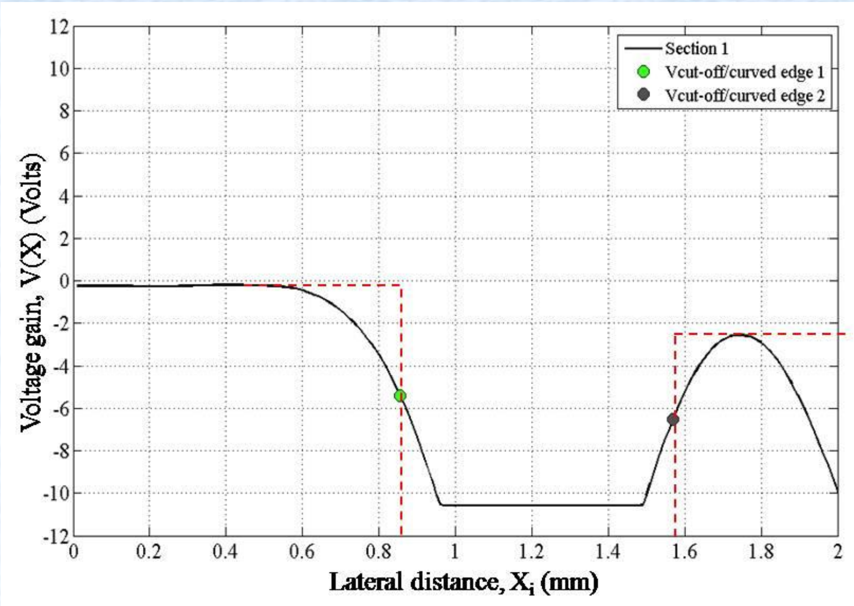
Experimental results-Circular feature

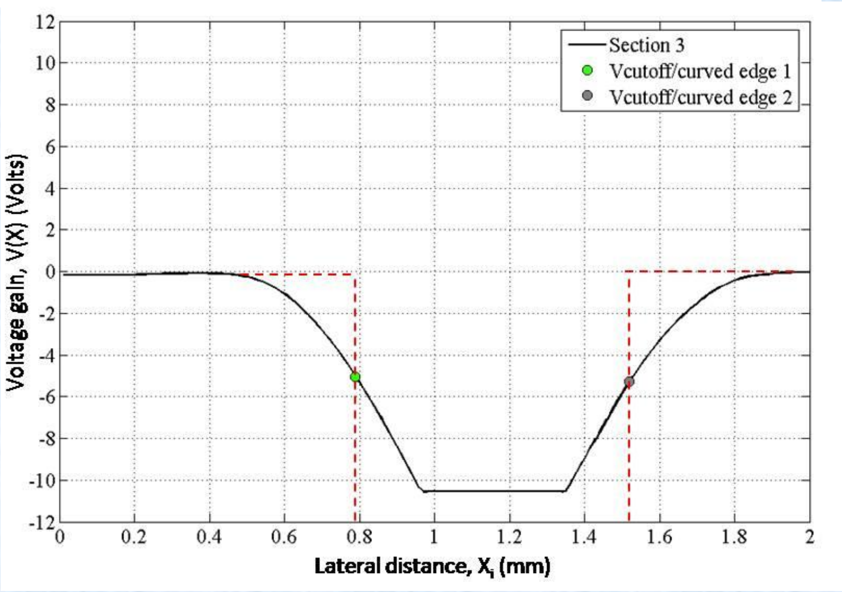


SEM image of circular feature of specimen 1



2-D cross sectional view of the circular feature





C_1=0.714 mm/ C_2=0.719 mm

Diameter of circular feature

Capacitive sensor	Optical instrument	Tool makers microscope
1.013 mm	1.0127 mm	0.970 mm

Measurement of Micro components

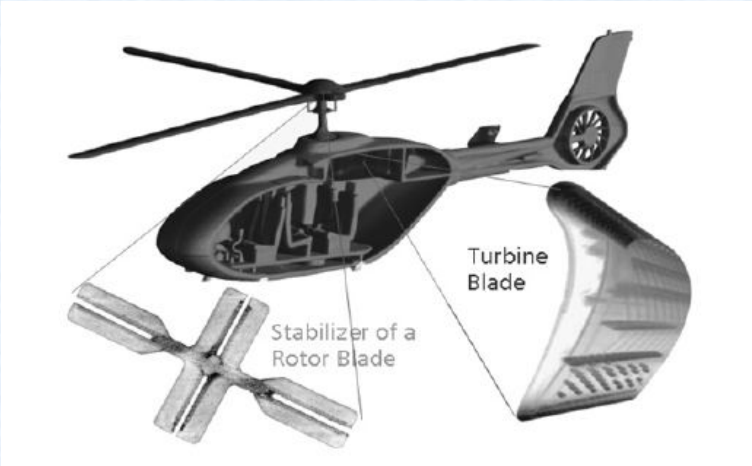
Nano CMM

- Inspection of micro components – Non contact inspection, nano CMM
- Tolerance Specification - ??

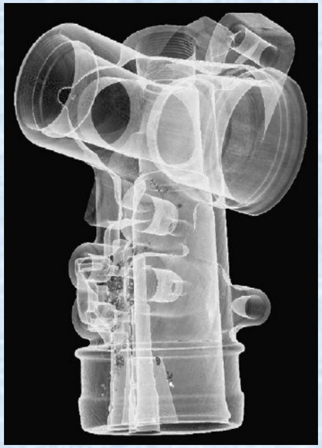
Prototype of Nano-CMM
Measuring range - 10mm x 10mm x 10mm
Resolution - nanometer

Computed Tomography

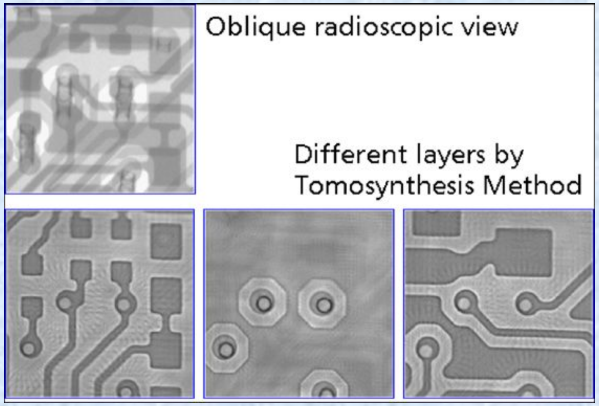
Applications in industrial material inspection



Examples of radioscopy and CT inspection tasks in the aerospace business field.

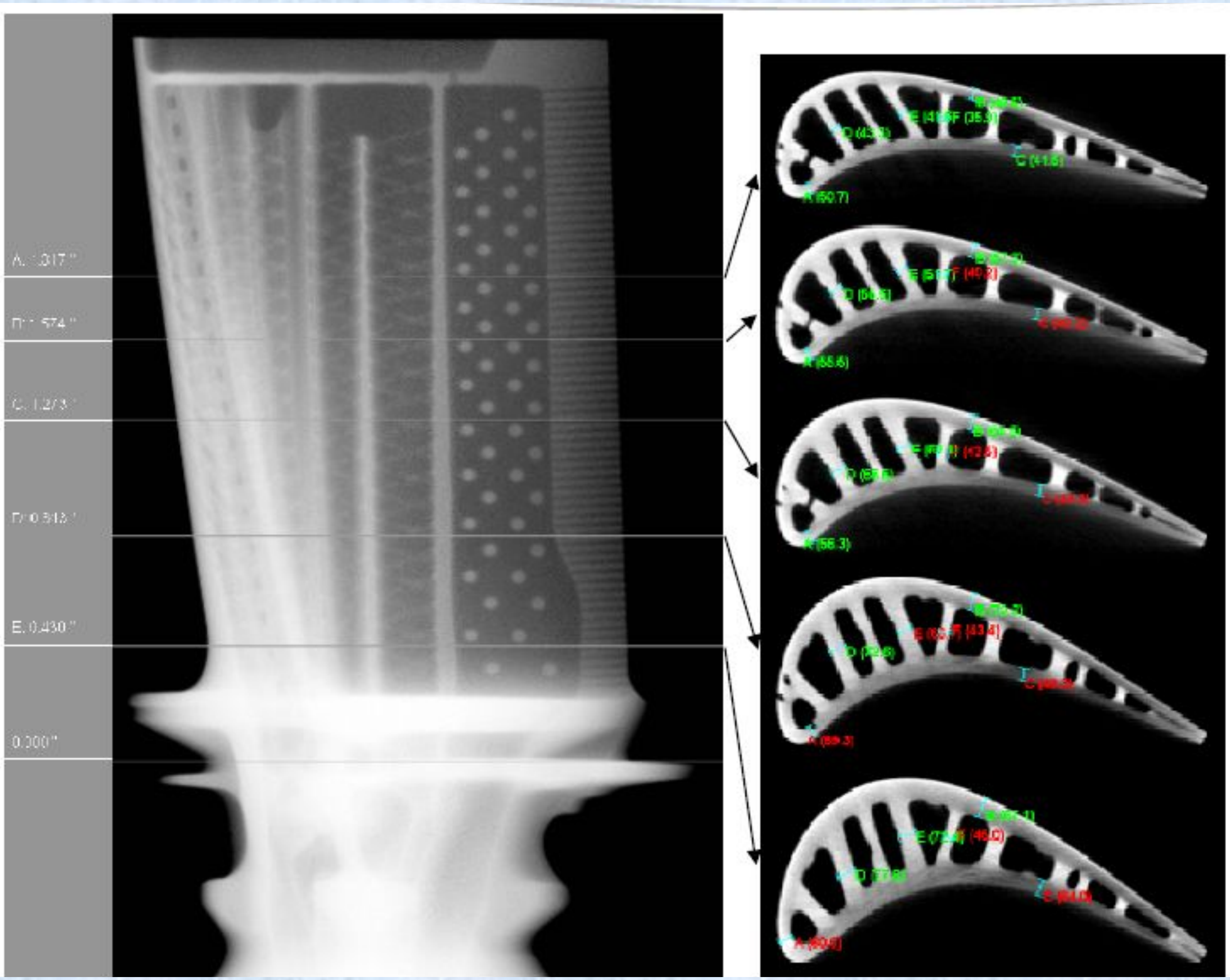


3D visualization of a cone beam CT reconstruction of an aluminum steering gear case; dark spots represent small blowholes.



Digital tomosynthesis applied to a multilayer PCB

Measurement of turbine blades.

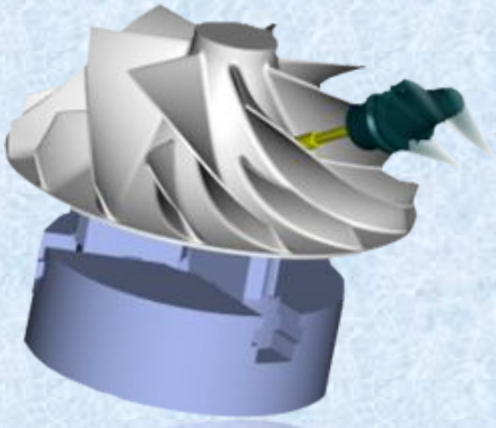


Special blade inspection system with 450kV

RED – outside tolerance

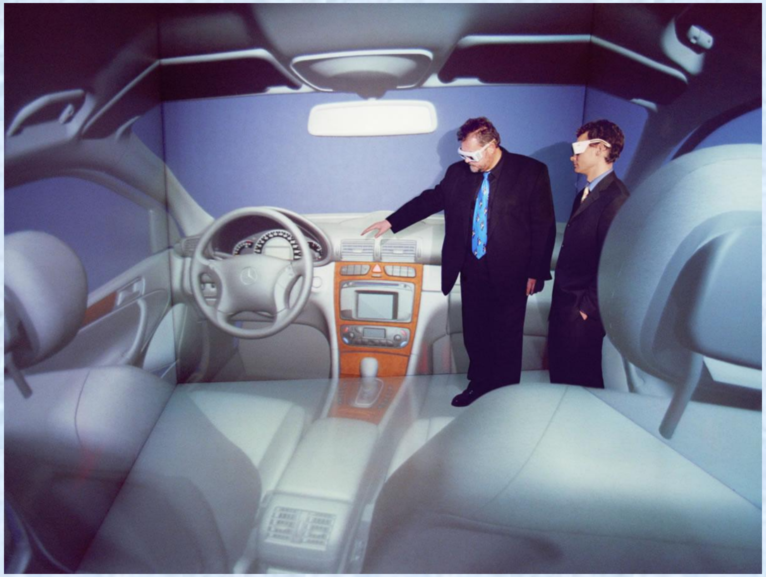
Inspection in Complex assemblies

Digital inspections of machined parts and assemblies for quality assurance purposes and supports both CMM machines and laser scanners.



- Digital quality checking saves time, effort, and money
- Perform simulation in a complete environment including parts, probes, fixtures and machines.
- Gauge quality of machined parts and assemblies, enabling first article inspection

Computer Aided Virtual Environment



Designers are able to experience and judge virtual 3-D interiors in the 'Design Cave' (Computer Aided Virtual Environment)

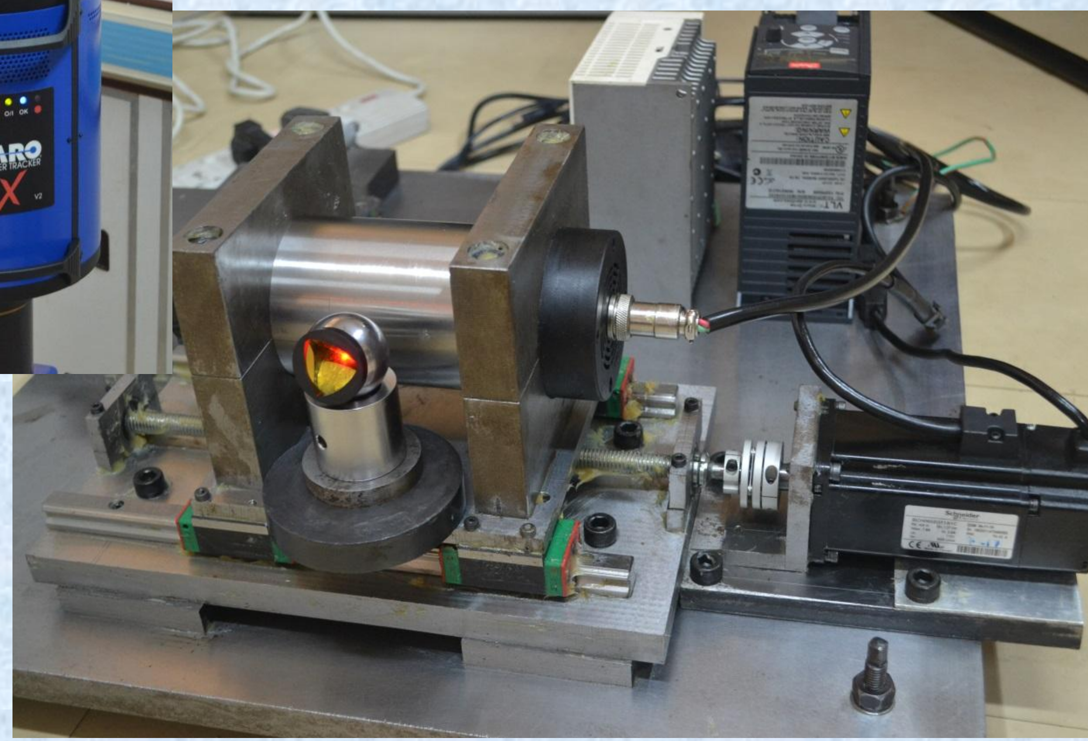
Surface quality inspection in the light chamber

Orientation check before pick and place operation

Extrusion geometry inspection

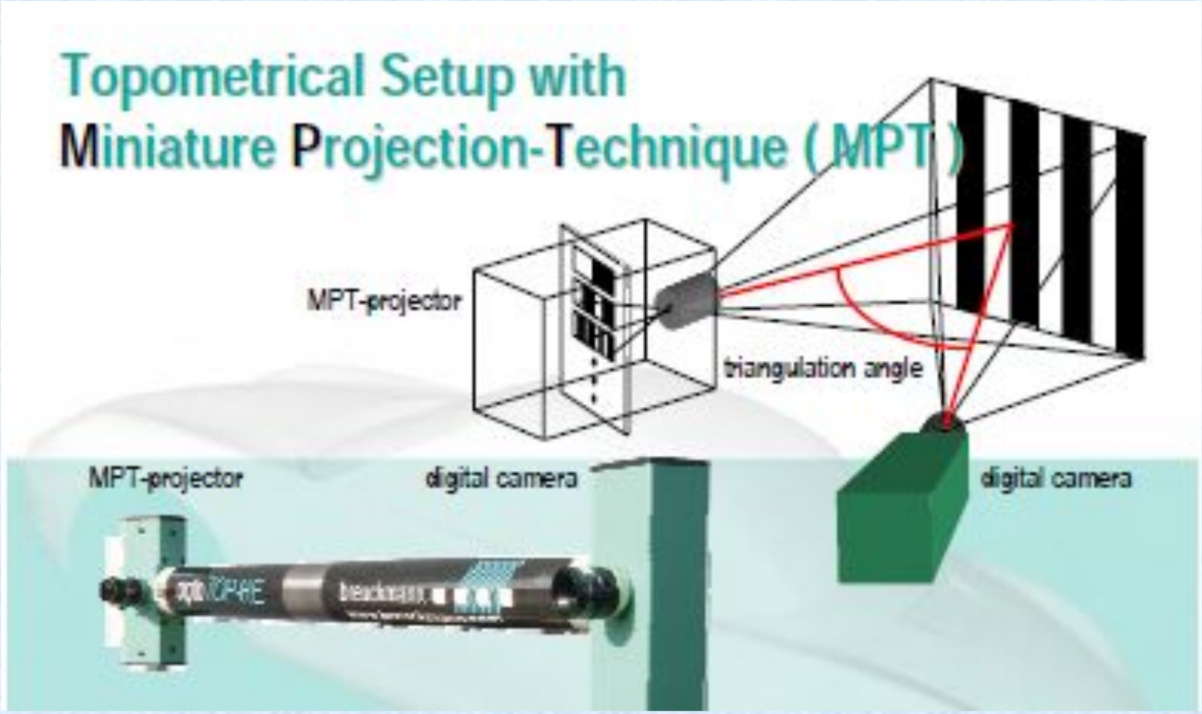
Large Scale Metrology

Laser Trackers



White Light Scanner

- Operating principle. Structured light is projected (a series of
- lines) onto the surface. There is a known angle and distance between the
- projector and the camera(s). This allows triangulation to be used to calculate the
- surface points allowing several million surface points created in a few seconds.



White Light Scanner