ENGINEERING
TEXAS A&M UNIVERSITY

Surface Engineering and Quality Assurance

Instructor: Prof. Satish T.S. Bukkapatnam
Teaching Assistant: Zimo Wang

Schedule

- **Day 1**
  - Lecture 1: Learning profilometery on contact and non-contact profilometer
  - Lecture2: Estimation of surface finish, bearing area curve
- **Day 2**
  - Lab session: Measuring surface morphology using profilometer
  - Lecture 3: Mechanical property of finished surface (with hands-on experience on mechanical property tests)
- **Day 3**
  - Advanced analytic approaches for surface characterization

Project Goals

- **Goals**
  - Understand surface finish for manufacturing processes
  - Gain hands-on experiences with non-contact surface roughness measurement
  - Expose to advanced imaging and analysis techniques

- **Lab safety and security**
  - No drinks or food in the lab
  - Be very cautious while using the ZeGage profilometer
  - Use computer only to operate ZeGage profilometer
  - Remember to log out after use
  - Keep the door closed

Contact information

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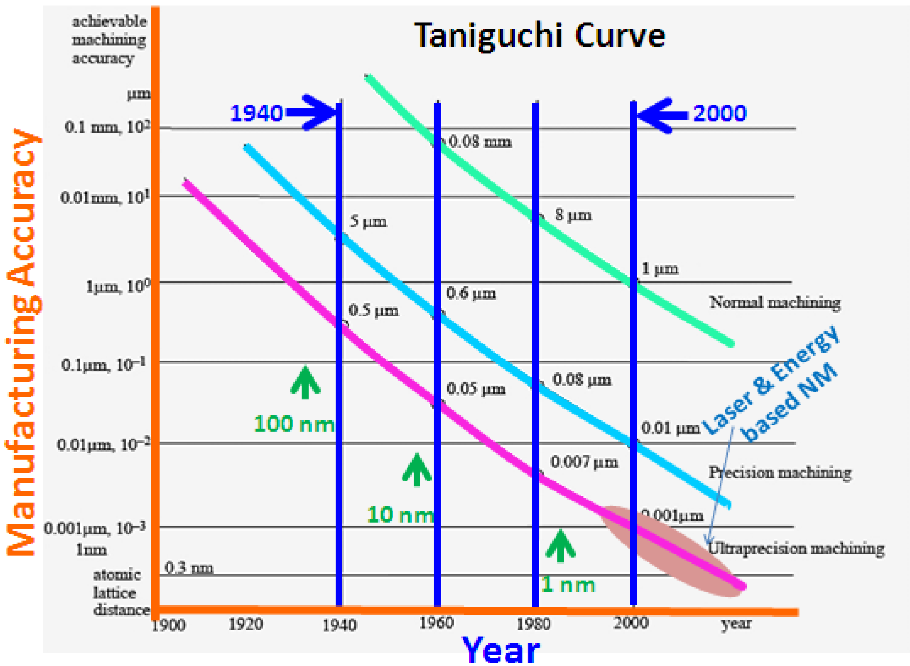
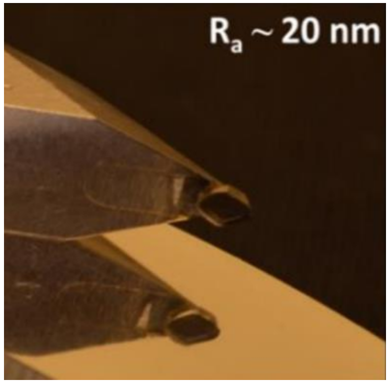
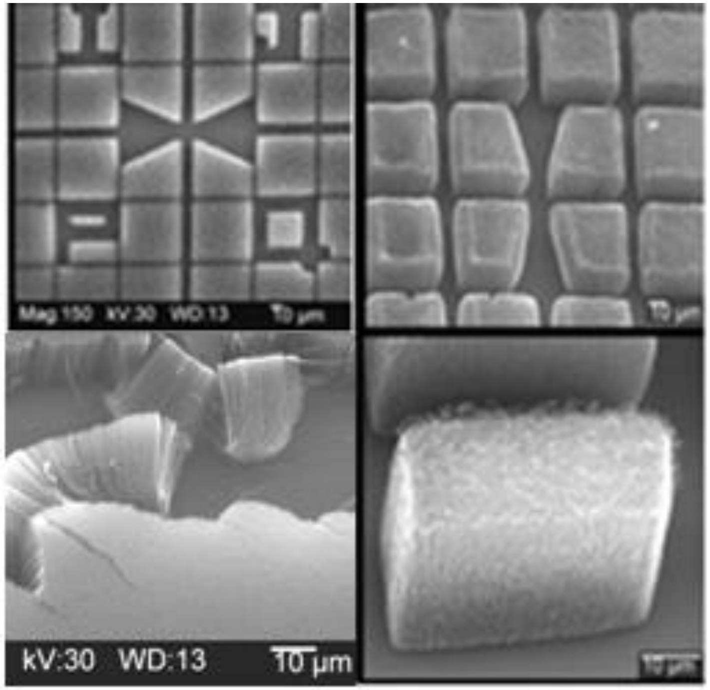
- Office: ETB 4050, ETB 3018

- **Surface finish of advanced manufacturing processes**



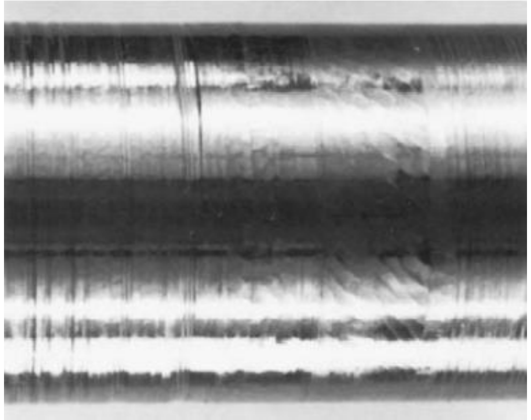
Ikawa, Donaldson, Komanduri *et al. 1991*



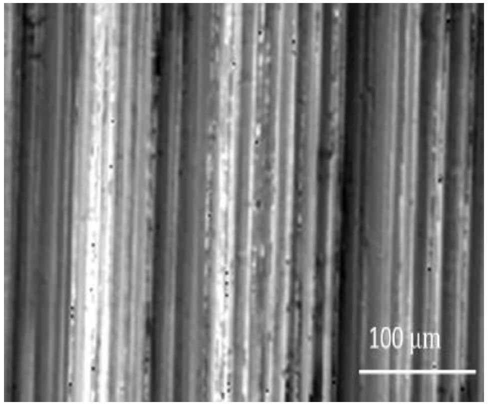


Issue on surface finish during manufacturing processes

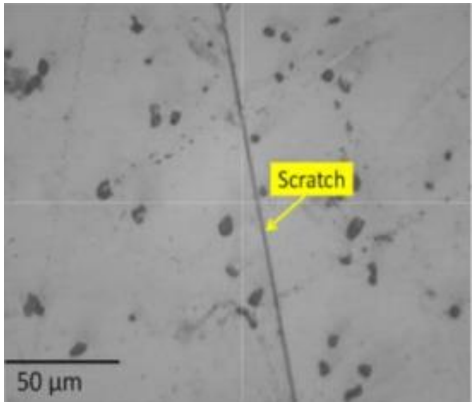
- **Stability of process dynamics and vibrations** are crucial to surface quality (Altintas 2008)
- Several surface defects are due to instability and uncertainty issues
- Chip thickness, vibrations, grain size are of similar magnitude
  - **Low amplitude instability** modes need to be investigated
  - Significant **uncertainties** exist in specifying stability boundaries



Chatter marks

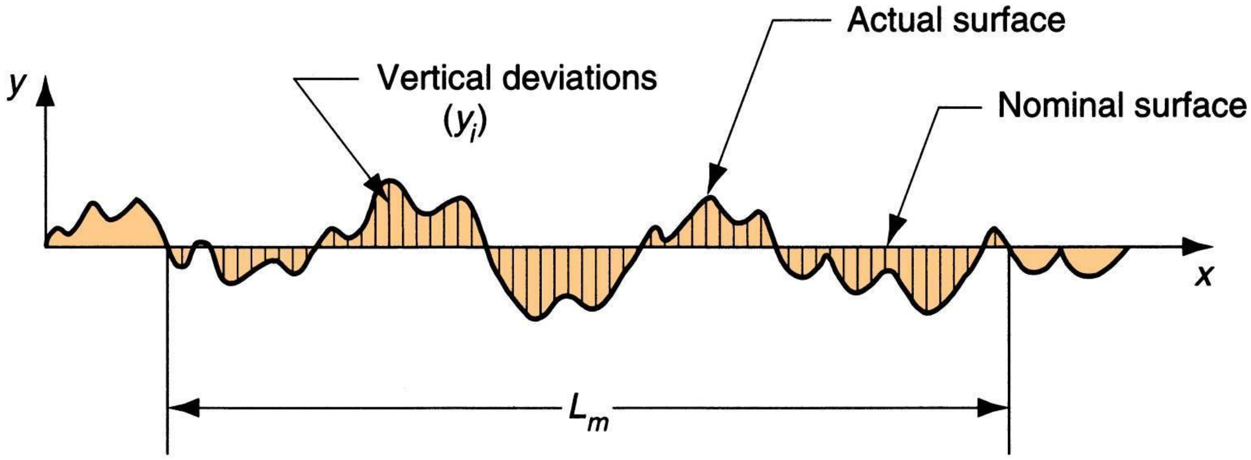


Texture Variation



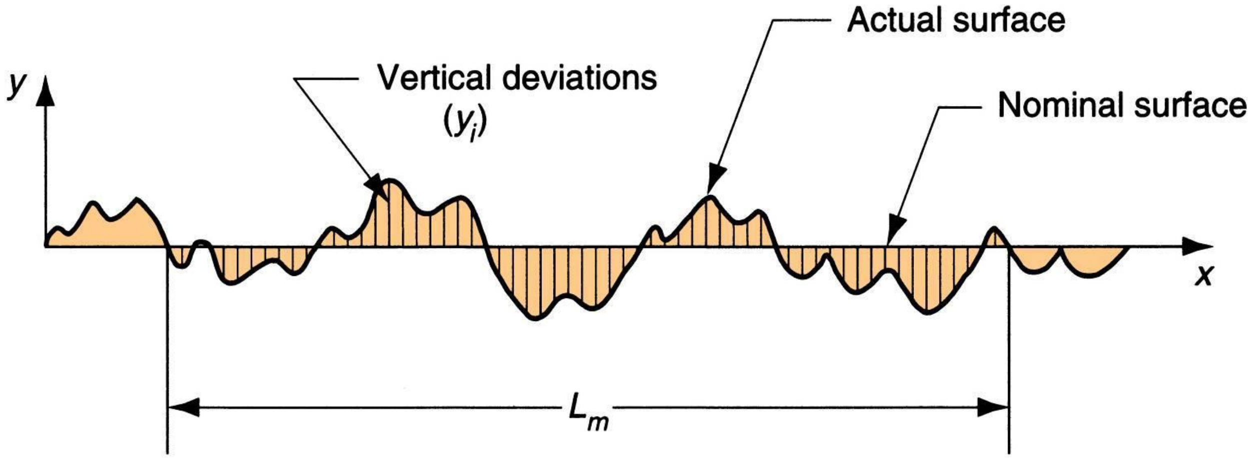
Scratch

- **Surface Roughness**
  - Sometimes also called "surface finish" or just "surface". Acceptable surface roughness depends on the applications
  - A laser mirror requires a very smooth surface whereas an orthopedic titanium implant requires a rough surface. Surface roughness is calculated from the asperities (high and low points) of a surface



Surface profile along a scanned line

- **Surface Roughness**
  - After collecting the amplitude y_i's all points i's along an axis, the common surface roughness values are defined as:
    - Maximum Valley depth: $R_v = \min(y_i)$
    - Maximum Peak depth: $R_p = \max(y_i)$
    - Average roughness: $R_a = \frac{1}{n}\sum_i^n |y_i|$
    - Root mean squared $R_q = \sqrt{\frac{1}{n}\sum_i^n y_i^2}$



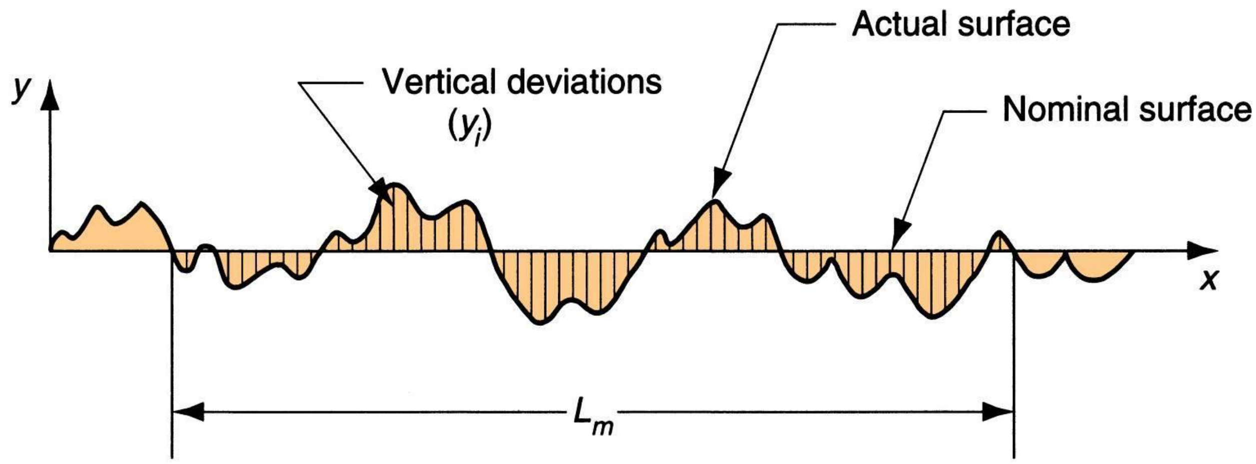
Surface profile along a scanned line

- **Surface Roughness**
  - Total roughness R_t from the highest peak to t he lowest valley points. It is also referred to as R_t or R_{max}:

$$R_{max} \equiv R_t = R_p - R_v$$

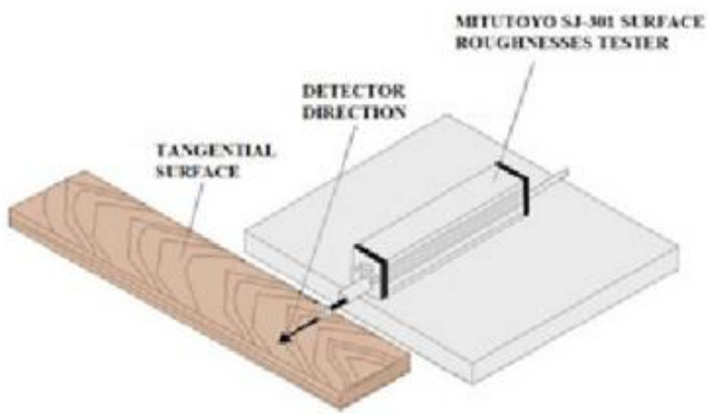
  - Average consecutive peak-valley roughness R_z. This is the average of 5 largest consecutive peak-valley distances

$$R_Z = \frac{1}{5}\left[\sum_{i}^{5}(R_{pi} - R_{vi})\right]^2$$

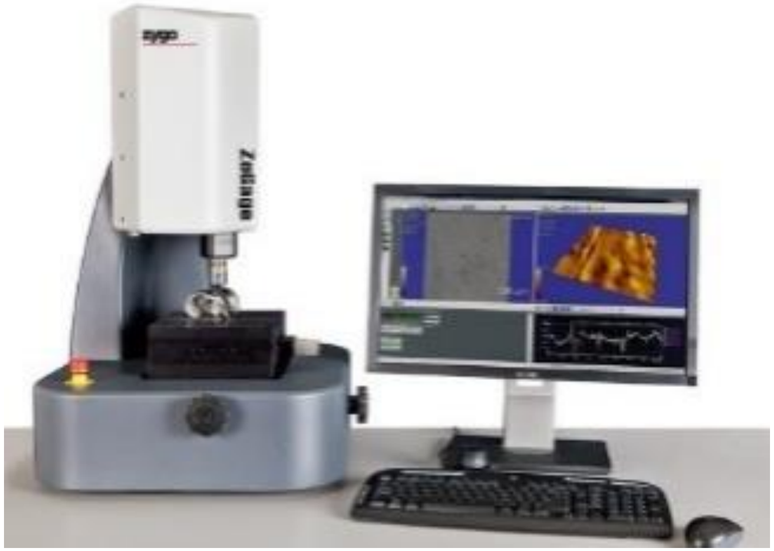


Surface profile along a scanned line

- **Surface roughness**



Surface finish measurement with a (contact type) profilometer

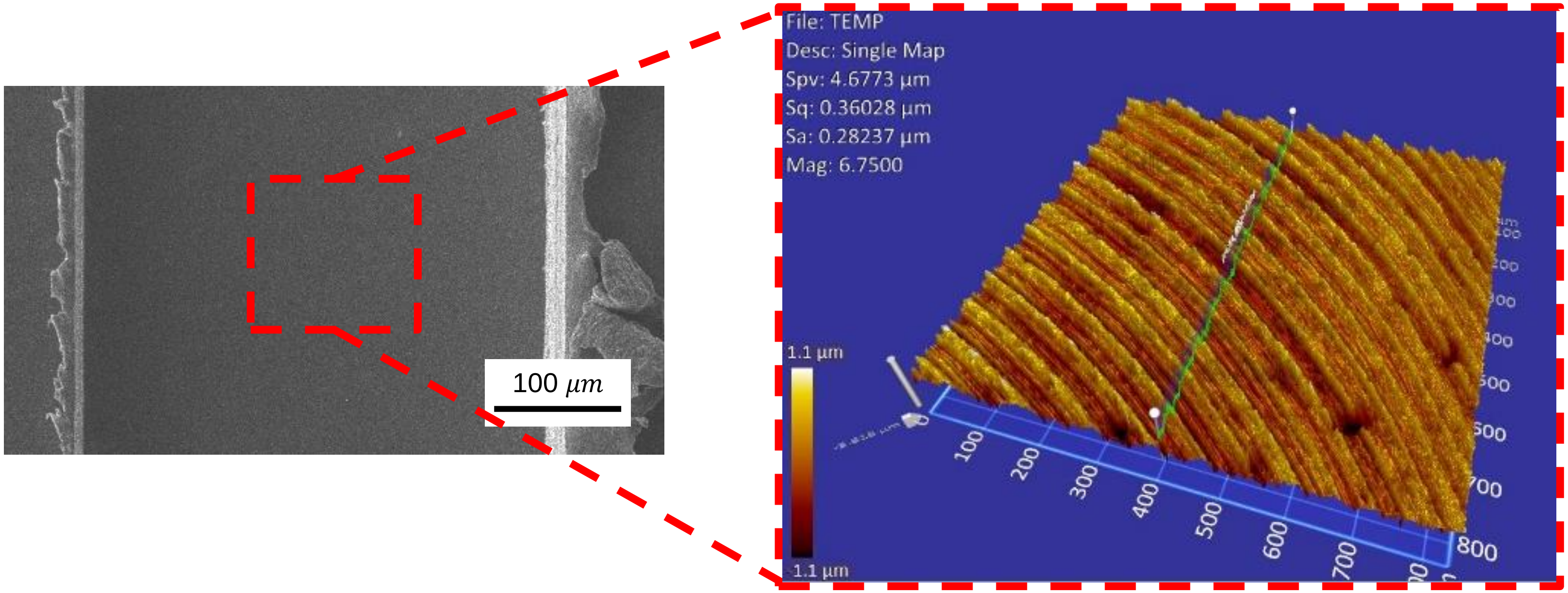


Surface finish measurement with a noncontact optical interferometer [www.zygo.com]

  - Surface texture means integrity of surface which includes finish and defects at or below surface.
  - For a 2D surface, similar calculations are performed but the results are labeled with a letter 'S" as in S_a, S_q, S_z… rather than R_a, R_q, R_z… for line roughness measurement

Profilometry

- **Profilometry**
  - A method to extract topographical data from a surface
  - Instrument used for this purpose is known as Profilometer

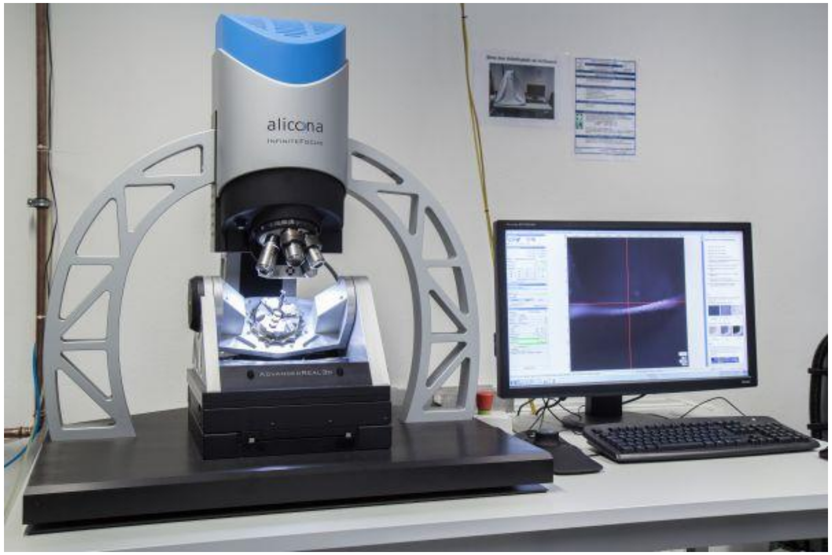


Profilometry

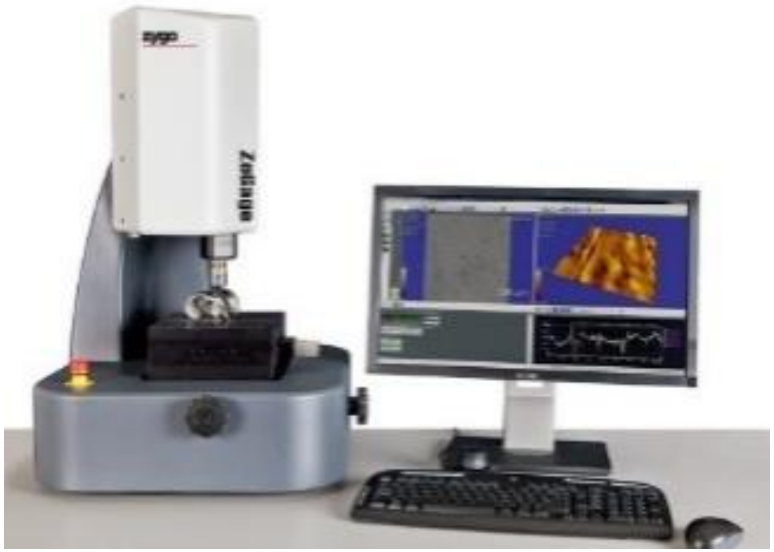
- **Purpose of using profilometer**
  - How rough is surface?
  - What is the density of defects?
  - What is the area of voids?
  - What is the height of the features

- **Functionality of profilometer**
  - Measure surface profile/morphology and defects/voids
  - Generate quantifiers (surface roughness) for surface characteristics
  - Questions: what are the approaches for getting the profile?
    - It can be a single point, a line scan or even a full three-dimensional scan

- **Contact/Non-contact profilometers**
  - Digital holographic microscopy
  - White light interferometry
  - Phase shifting interferometry
  - Advantages:
    - Prevent surfaces from scratches
    - High lateral resolution
    - High speed when requirement is of small steps

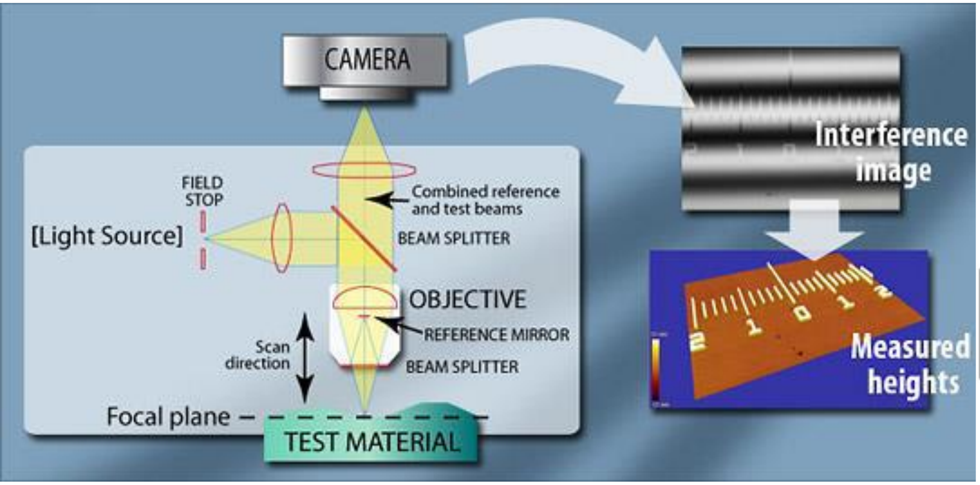


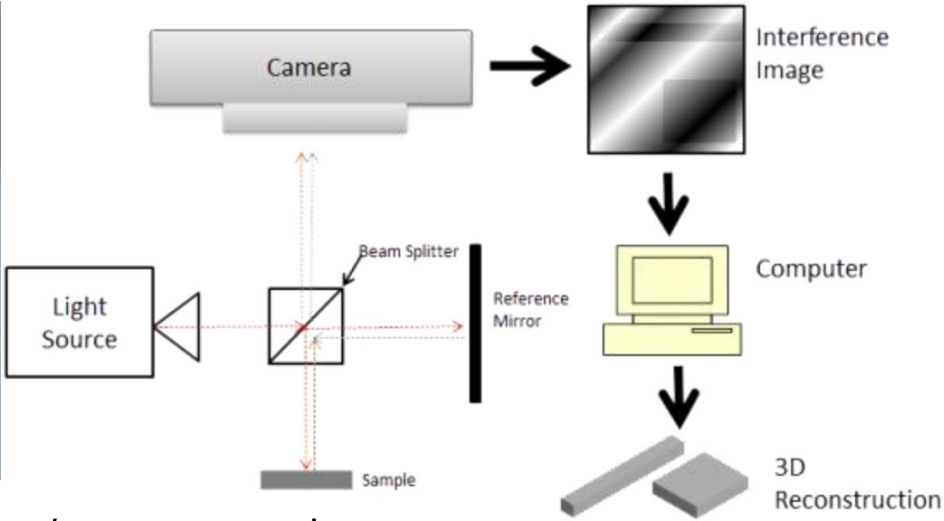
http://www.isf.de/en/institut/ausstattung/alicona.html



Surface finish measurement with a noncontact optical interferometer [www.zygo.com]

Principles of Optical Profilometry



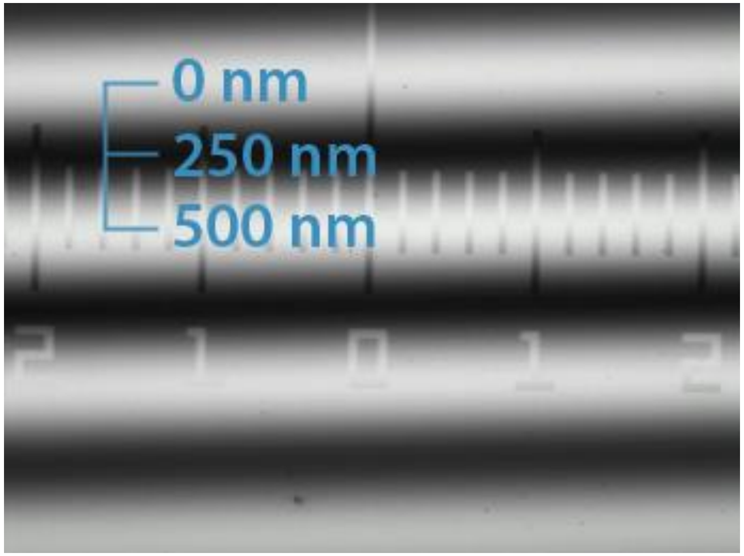


Courtesy of www.zygo.com/www. nanoscience.com

– Light beam is splits, and then reflection from reference and test material occurs, resulting in the interference
– Formation of inference fringes(light and dark bands) can be seen
– Constructive inferences areas are the lighter ones and destructive inference areas are darker ones

Principles of Optical Profilometry

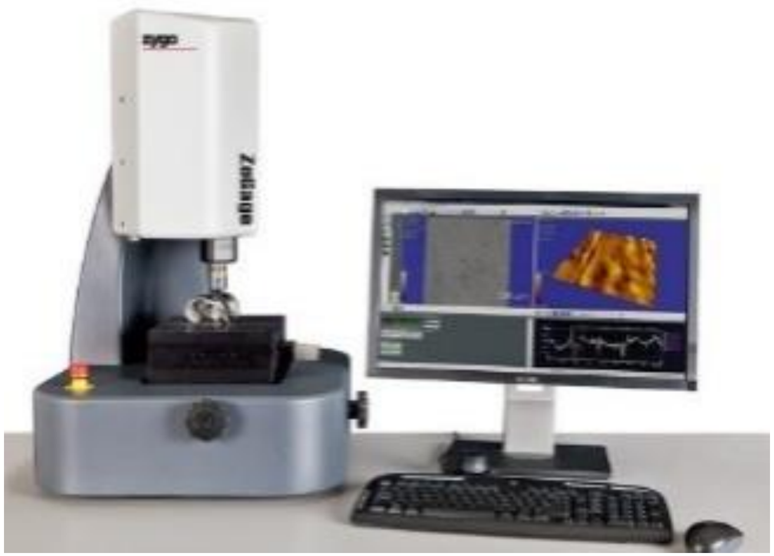
- Wavelength of difference between reference and test path is equal to distance between consecutive fringes of same color
- Height variance on the test surface causes optical path differences
- Out of focus area means less inference
- Higher the contrast means better the focus



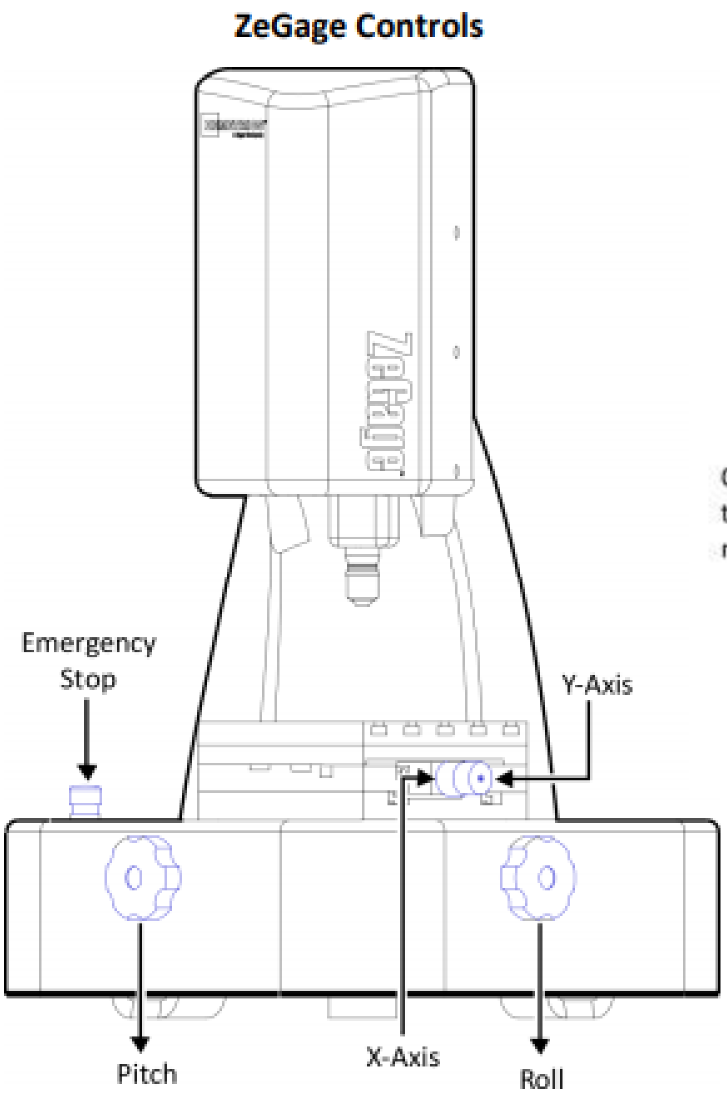
www.zygo.com

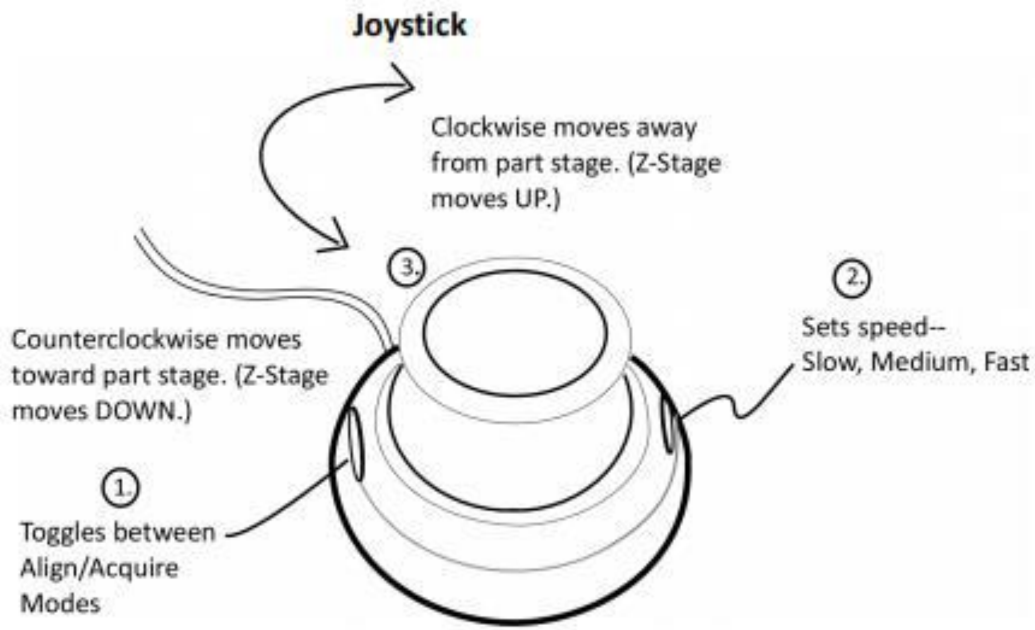
Profiolometer

- **ZeMaps Software**
  - It has a visually rich interface enabling you to see what is happening at virtually every step in the process
  - Each 3D measurement provides one million data points, making it possible to evaluate the effects of surface processing
  - ISO roughness parameters are standard with the software as are a variety of profiling, plotting, filtering and other interactive data analysis tools



ZeGage Profilometer





How to Log in ZeMaps ?

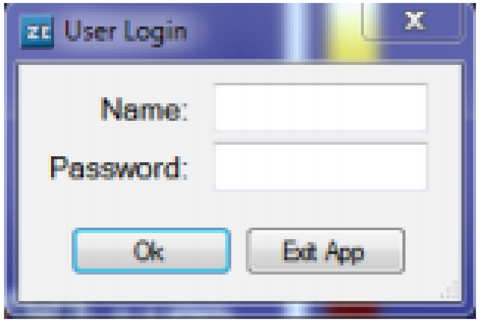
Open ZeMaps

1. Open the ZeMaps software by double-clicking on the ZE icon on the desktop. Wait for the initialization routine to be completed.
2. If log in is required for your system, there are two locations from which you can access the login dialog.
   - In the menu bar at the top of the screen, select:

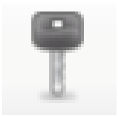
     File→Logout

     OR,
   - Click on the Login/Logout icon in the Stage Control Window.
3. Enter Name and Password and click Ok.

Software Icon

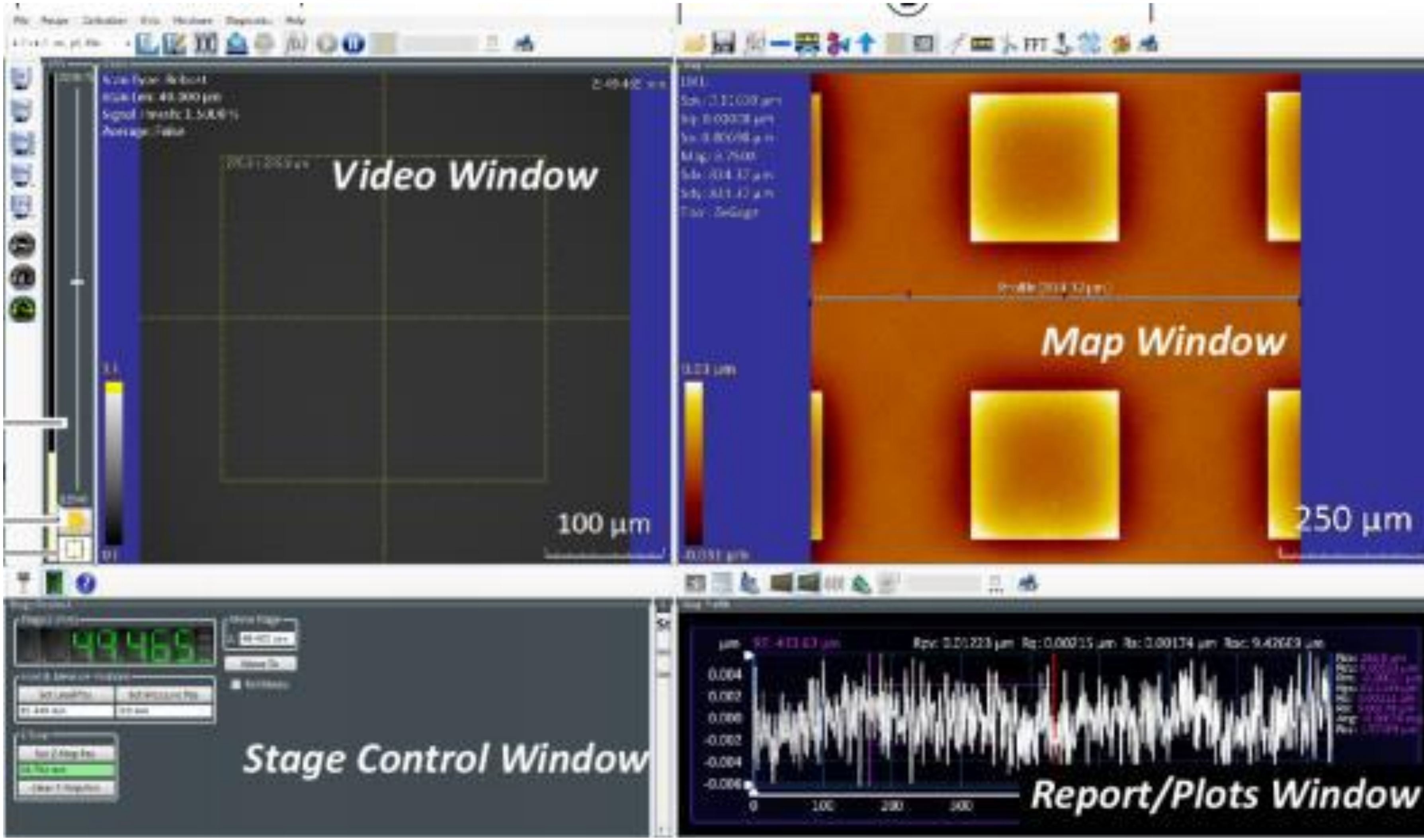


Login Dialog



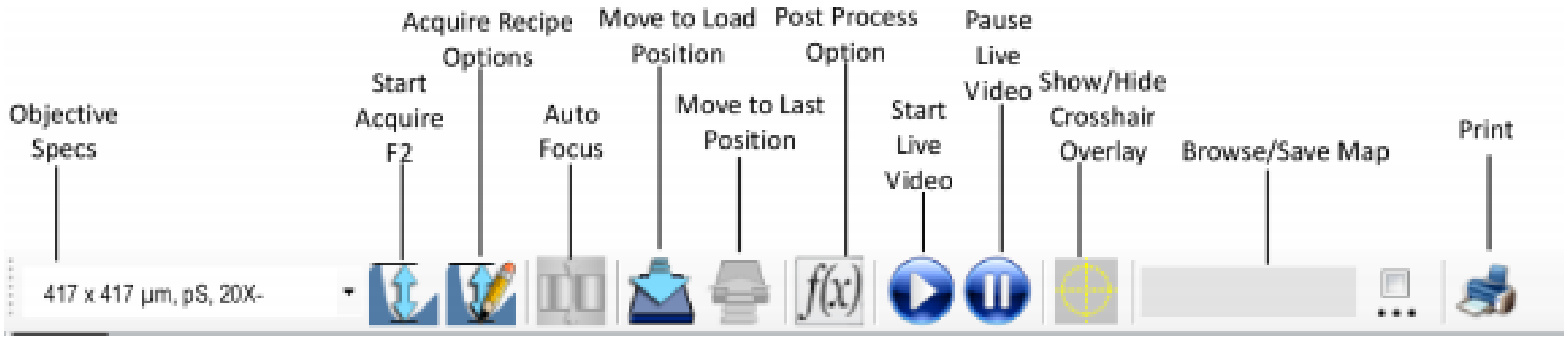
Log In/Logout Icon

Understanding ZeMaps



Understanding ZeMaps

- **Video Window-** This window provides access to controls for focus and alignment, data acquisition, viewing, locating areas of interest on a test part, and saving files.

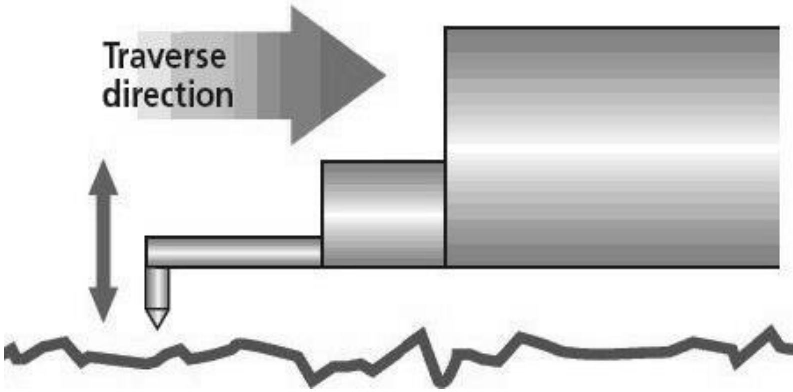


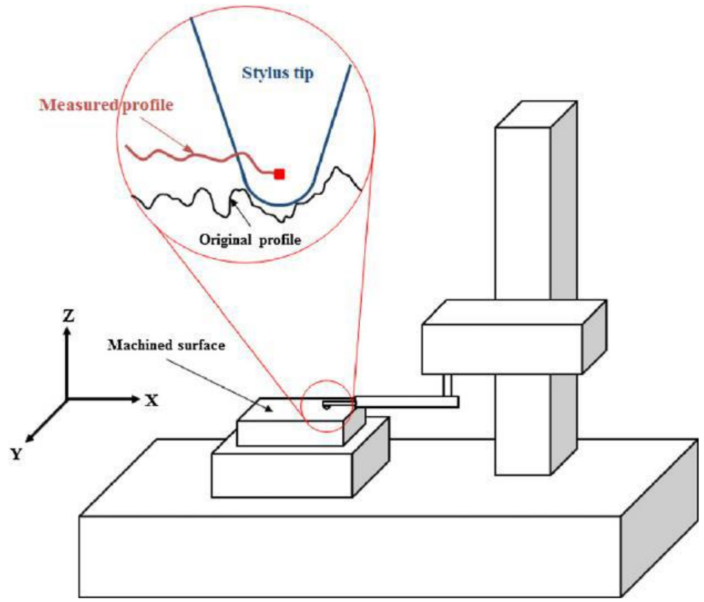
- **Map Window -**This window displays 2D and 3D maps of surface data. There are options for saving and loading maps, processing data, changing plot types, and printing.

Map Window Toolbar

Contact profilometers

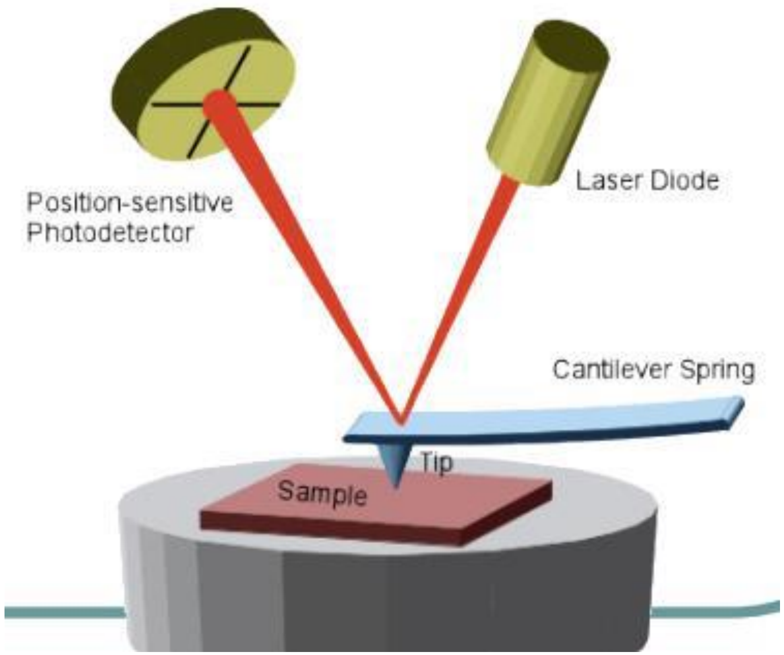
- Exemplary equipment
  - Stylus profilometer
  - Atomic force microscopy
  - Scanning tunneling microscopy
- Advantages
  - Standards of surface finish are mostly written using contact profilometers as benchmark examples
  - Direct technique and modeling is not required
  - “Analog” data- Resolution is very high
  - Independent of the surface and environment contaminants

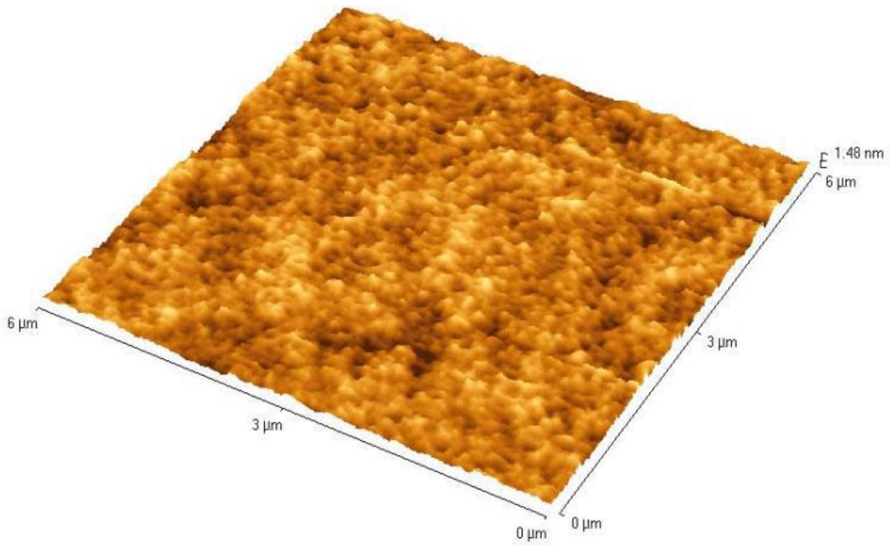




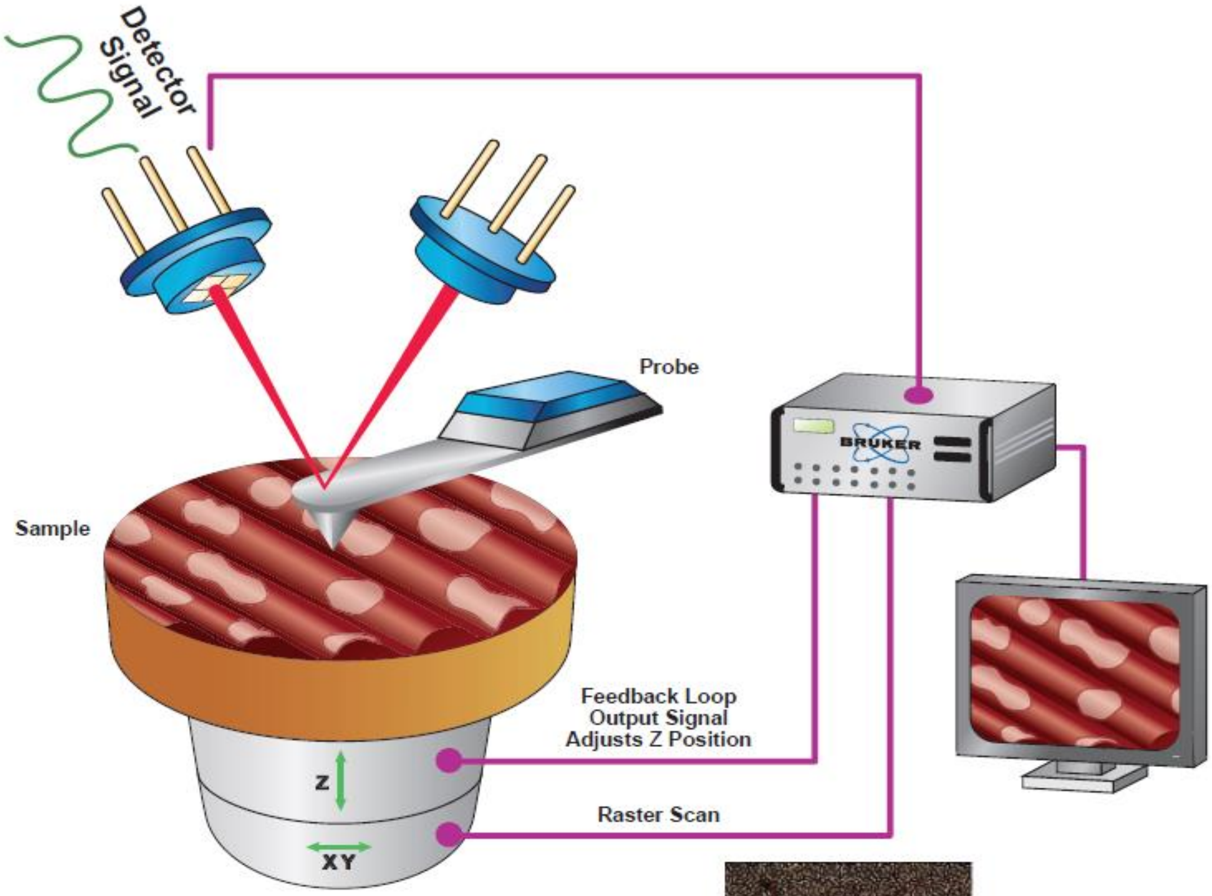
Profile data acquisition by a stylus-type profilometer (Credit: Dong-HyeokLee, MST, 2012, J. Rusnák’ et. al, 2010)

- **AFM**
  - Belongs to the family of Scanning Probe Microscopy
  - AFM senses inter atomic forces that occur between a probe tip & substrate
  - It has very high resolution and can be used in topographical imaging of samples such as DNA molecules, protein adsorption





Working principle of AFM



Protein molecules in liquid before and after force pulling with AFM.

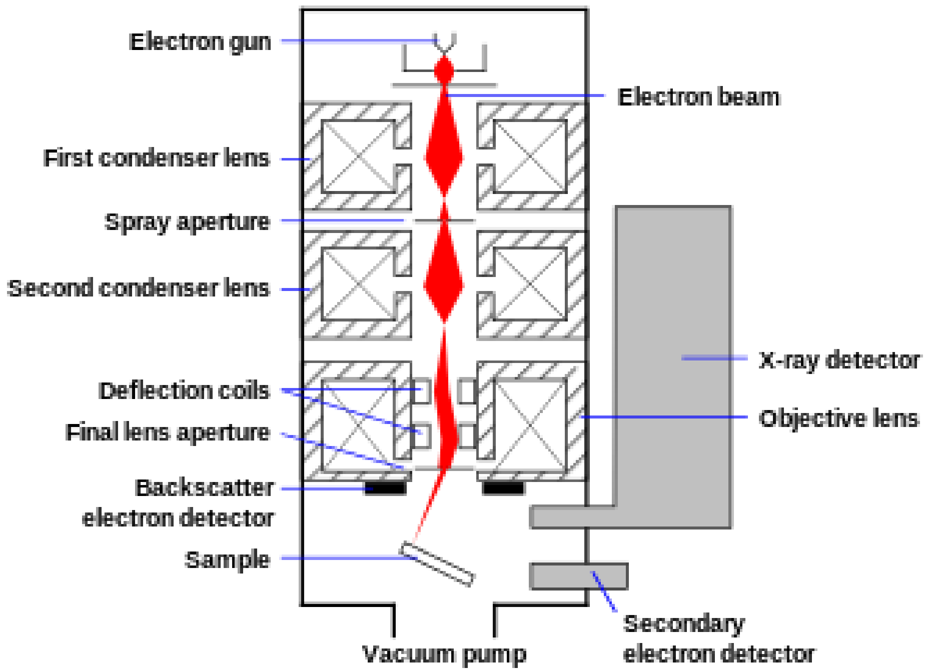
https://www.bruker.com/products/surface-and-dimensional-analysis/atomic-force-microscopes/campaigns/afm-microscopes.html

Scanning Electron Microscopy SEM

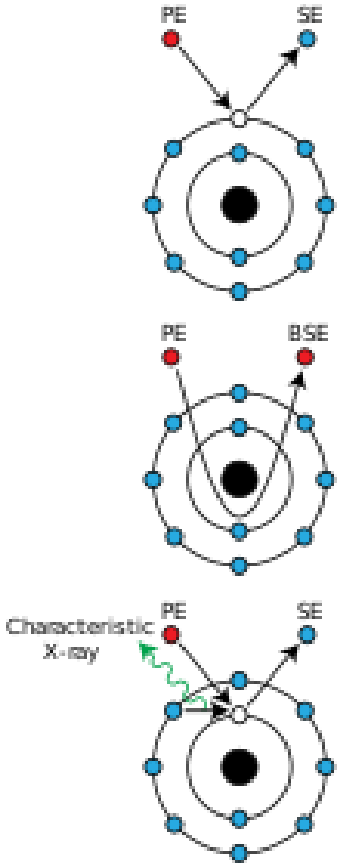
- **Functions of SEM**
  - Tiny electron beam scanned across surface of specimen
  - Magnification range 15x to 200,000x
  - Resolution of 50 Å
  - Wide range on depth of field
  - Specimen should be conducting (or coated with thin conductive layer)
  - Specimen size limited by size of sample chamber

https://www.imaging-git.com/products/electron-and-ion-microscopy/carl-zeiss-reveals-high-definition-fe-sem-sigma-hd

- **Scanning Electron Microscopy (SEM)**
  - Scanning process and image formation



Schematic of an SEM

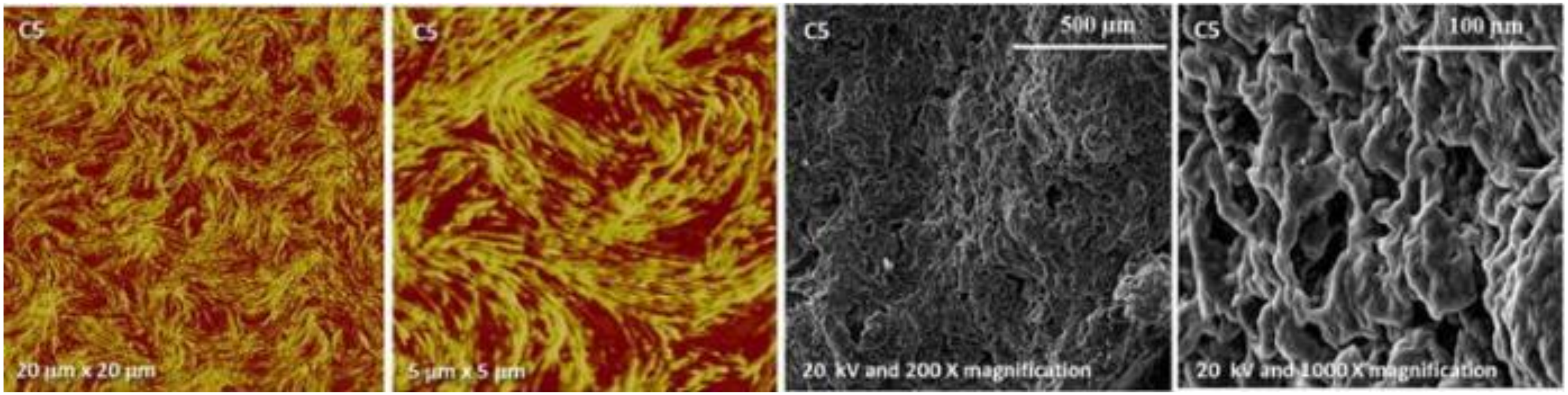


Mechanisms of emission of secondary electrons, backscattered electrons, and characteristic X-rays from atoms of the sample

https://en.wikipedia.org/wiki/Scanning_electron_microscope

SEM vs AFM

	SEM	AFM
Imaging Advantage	High Depth of Field	High Contrast
Dimensions	2-D	3-D
Measurements	Chemical Composition	Physical Properties
Environment	Vacuum	Vacuum, Air, Liquid



AFM (left) and SEM (right) micrograph corresponding to lithium complex (C5) and lithium–calcium complex soap (C6) greases

Credits-Tribology Letters, 2016, Volume 63, Number 2, Page 1

LAB EXERCISE

Lab Exercise

Sample	R_a	S_a	Bearing Area curve (Mr1)	Bearing Area curve (Mr2)