HTEC Haas Technical Education Center

LINCOLN COLLEGE OF TECHNOLOGY

TEXAS A&M UNIVERSITY

Advanced Measurement of Machined Surfaces

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Grand Prairie, Texas
March 29, 2014

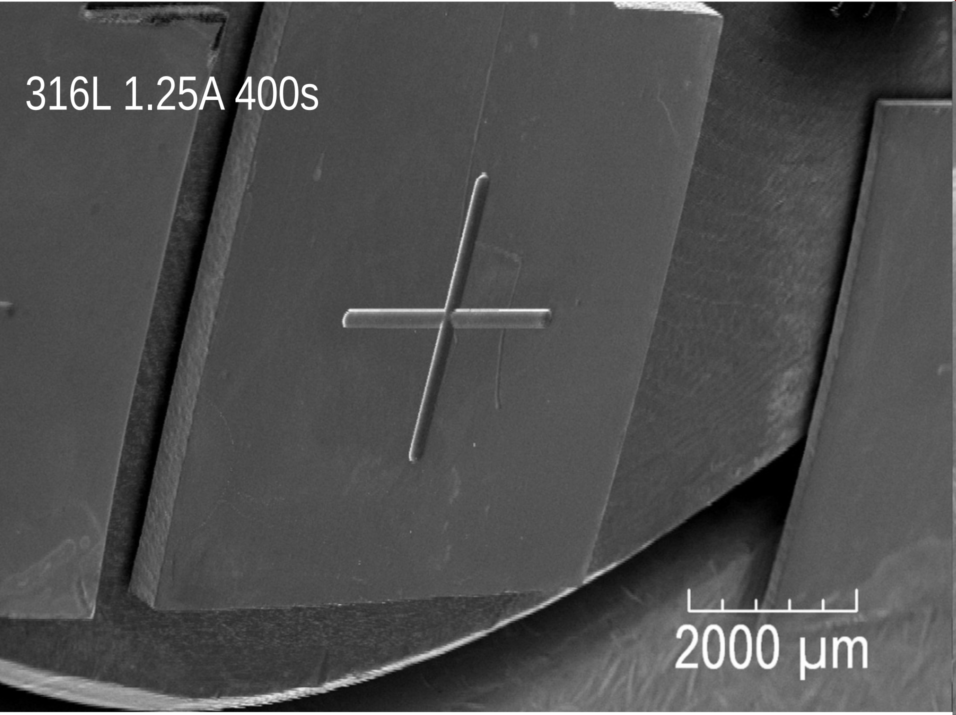
AGENDA

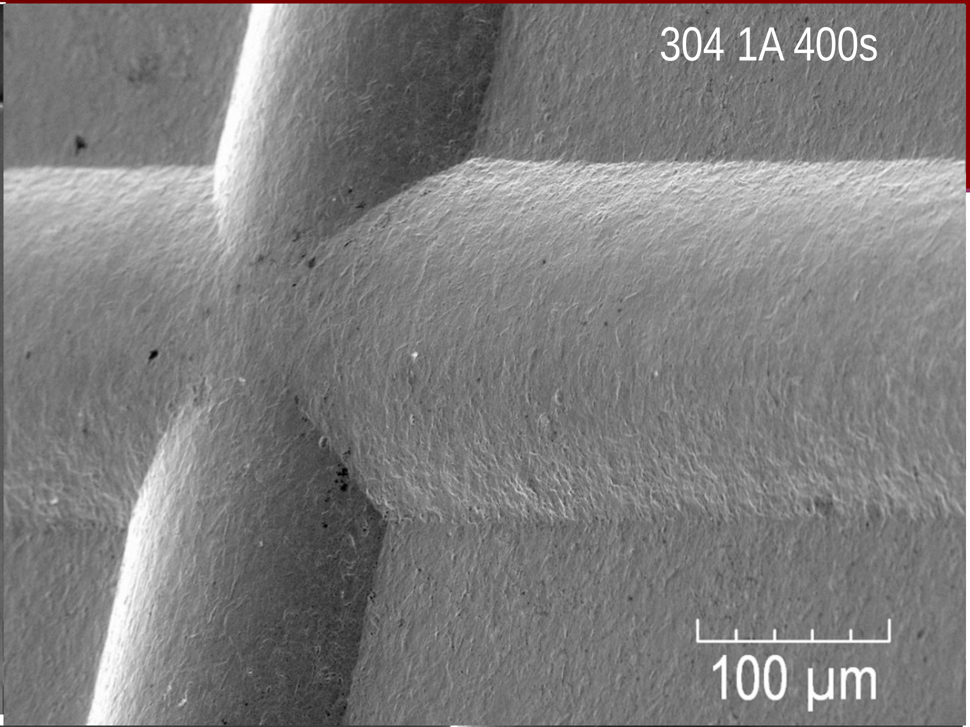
1) Introduction
2) Surface measurement
    - Theory
    - Comparison
    - Profilometry
    - Interferometry
    - Scanning probe microscopy
3) Machined surface models
4) Summary

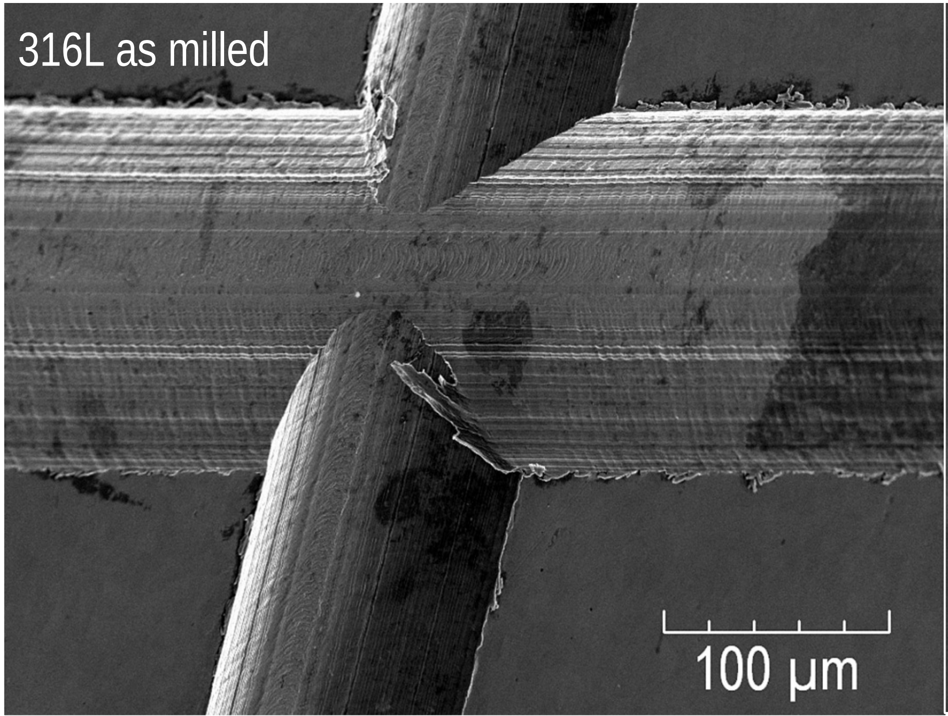
Surface finish: introduction

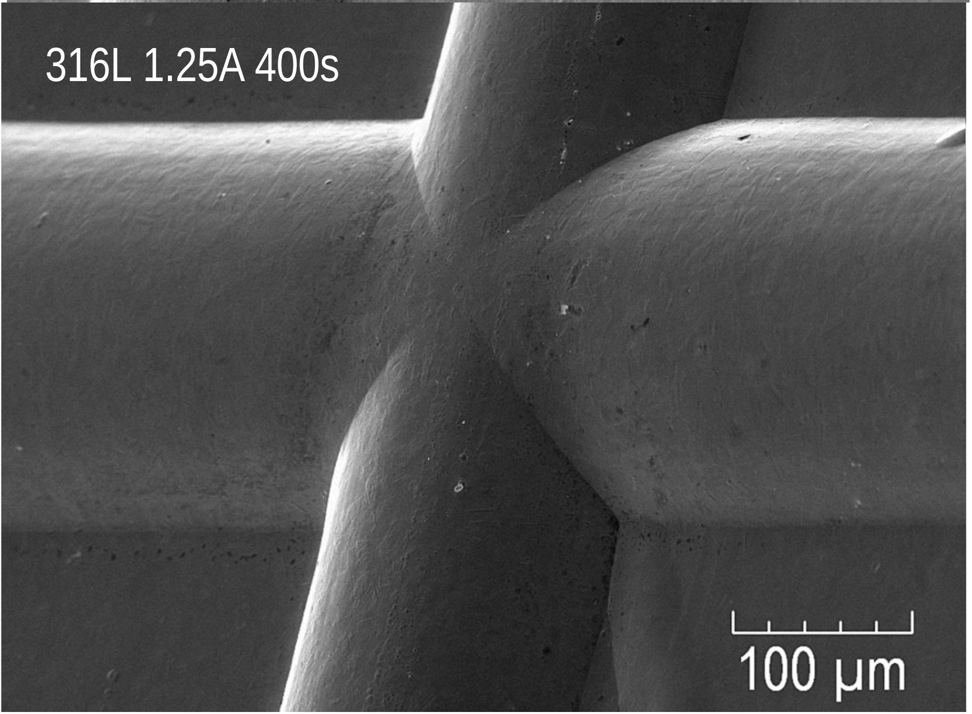

www.nih.gov


www.cssfirm.com


316L 1.25A 400s
2000 µm


304 1A 400s
100 µm


316L as milled
100 µm


316L 1.25A 400s
100 µm

Surface finish: Theory

Maximum valley depth R_v $$R_v = \min y_i$$

Maximum peak height R_p $$R_p = \max y_i$$

Average roughness R_a $$R_a = \frac{1}{n}\sum_{i=1}^{n} |y_i|$$

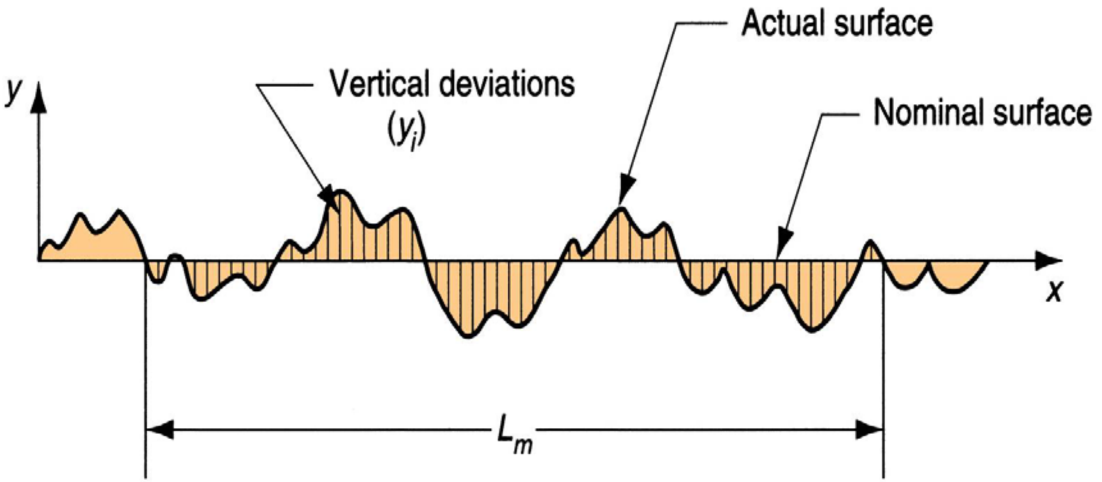
Root mean squared roughness R_{RMS} or R_q $$R_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (y_i)^2}$$

Total roughness R_t from the highest peak to the lowest valley points. It is also referred to as R_{tm} or R_{max}.

$$R_t = R_p - R_v$$

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

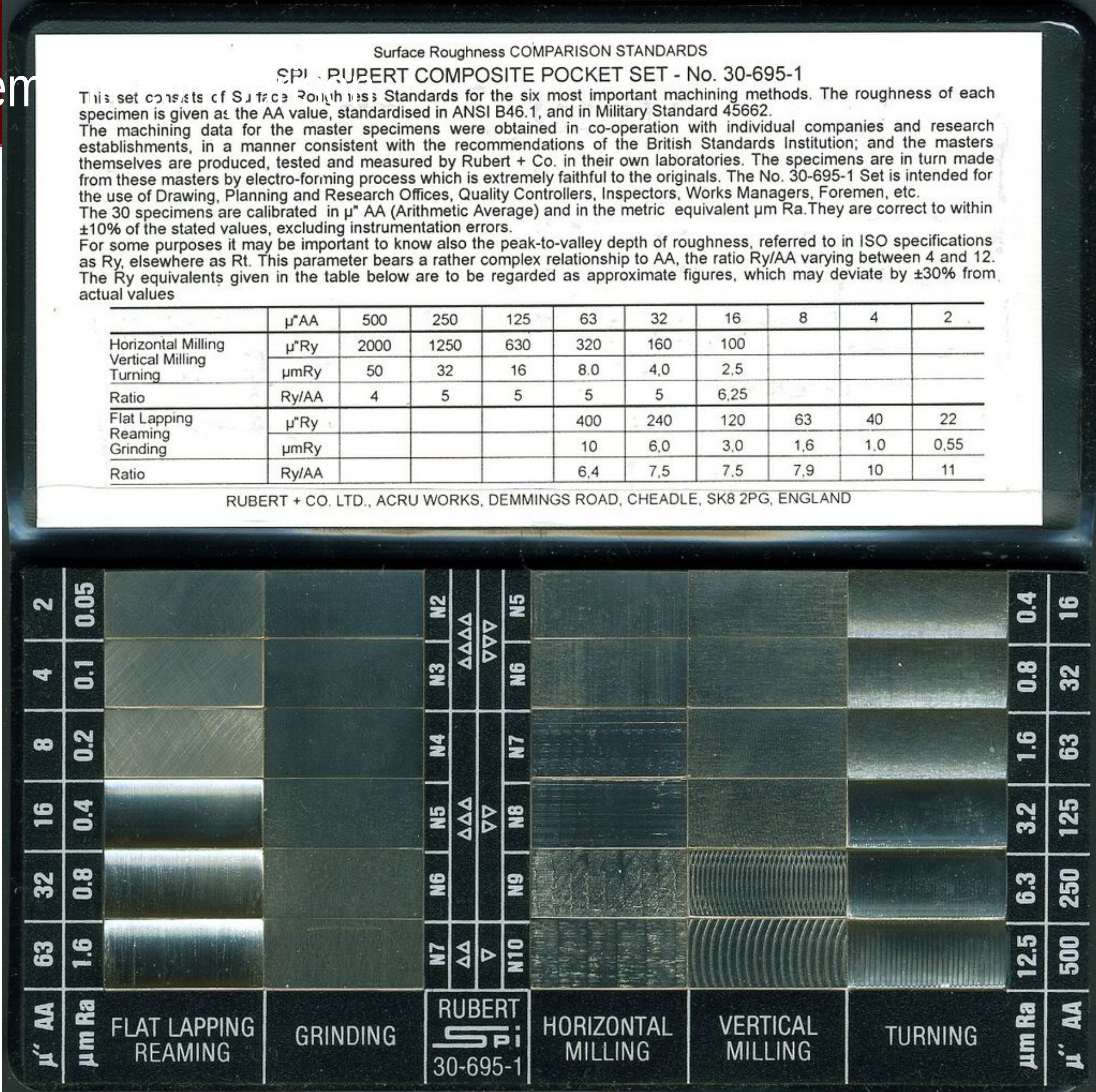
$$R_z = \frac{1}{5}\left[\sum_{i=1}^{5} (R_{pi} - R_{vi})\right]$$



Measurem

Estimate surface finish by comparing with standards

- Inexpensive
- Portable
- Subjective
- Qualitative



Surface Roughness COMPARISON STANDARDS

SPI - RUBERT COMPOSITE POCKET SET - No. 30-695-1

This set consists of Surface Roughness Standards for the six most important machining methods. The roughness of each specimen is given as the AA value, standardised in ANSI B46.1, and in Military Standard 45662.
The machining data for the master specimens were obtained in co-operation with individual companies and research establishments, in a manner consistent with the recommendations of the British Standards Institution; and the masters themselves are produced, tested and measured by Rubert + Co. in their own laboratories. The specimens are in turn made from these masters by electro-forming process which is extremely faithful to the originals. The No. 30-695-1 Set is intended for the use of Drawing, Planning and Research Offices, Quality Controllers, Inspectors, Works Managers, Foremen, etc.
The 30 specimens are calibrated in µ" AA (Arithmetic Average) and in the metric equivalent µm Ra.They are correct to within ±10% of the stated values, excluding instrumentation errors.
For some purposes it may be important to know also the peak-to-valley depth of roughness, referred to in ISO specifications as Ry, elsewhere as Rt. This parameter bears a rather complex relationship to AA, the ratio Ry/AA varying between 4 and 12. The Ry equivalents given in the table below are to be regarded as approximate figures, which may deviate by ±30% from actual values

	µ"AA	500	250	125	63	32	16	8	4	2
Horizontal Milling Vertical Milling Turning	µ"Ry	2000	1250	630	320	160	100			
	µmRy	50	32	16	8.0	4,0	2,5			
Ratio	Ry/AA	4	5	5	5	5	6,25			
Flat Lapping Reaming Grinding	µ"Ry				400	240	120	63	40	22
	µmRy				10	6,0	3,0	1,6	1,0	0,55
Ratio	Ry/AA				6,4	7,5	7.5	7,9	10	11

RUBERT + CO. LTD., ACRU WORKS, DEMMINGS ROAD, CHEADLE, SK8 2PG, ENGLAND

bbs.homeshopmachinist.net

Measurement: Profilometry

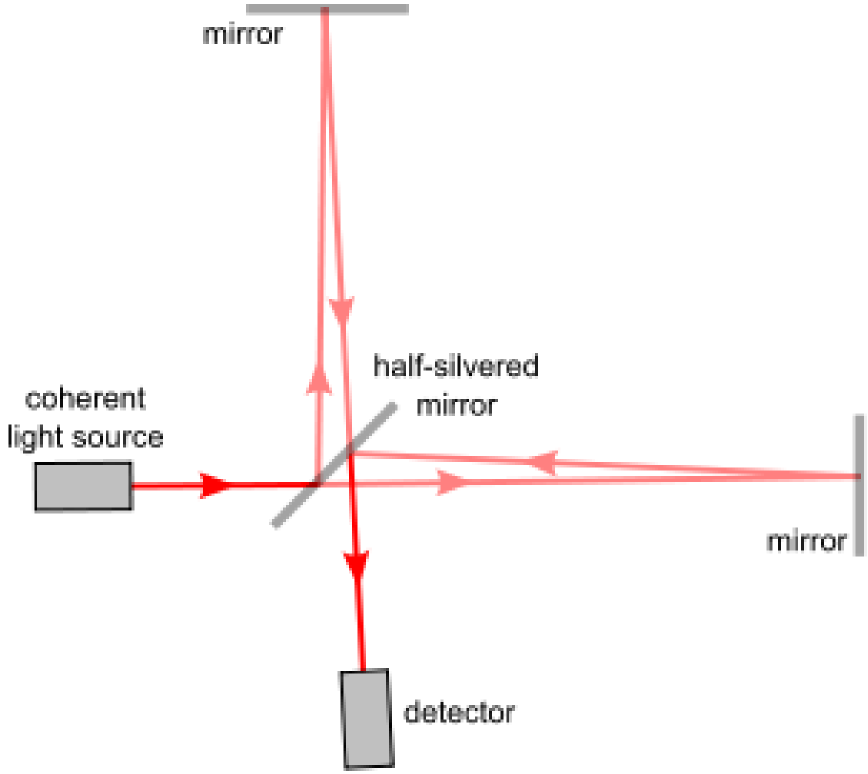
www.worldoftest.com

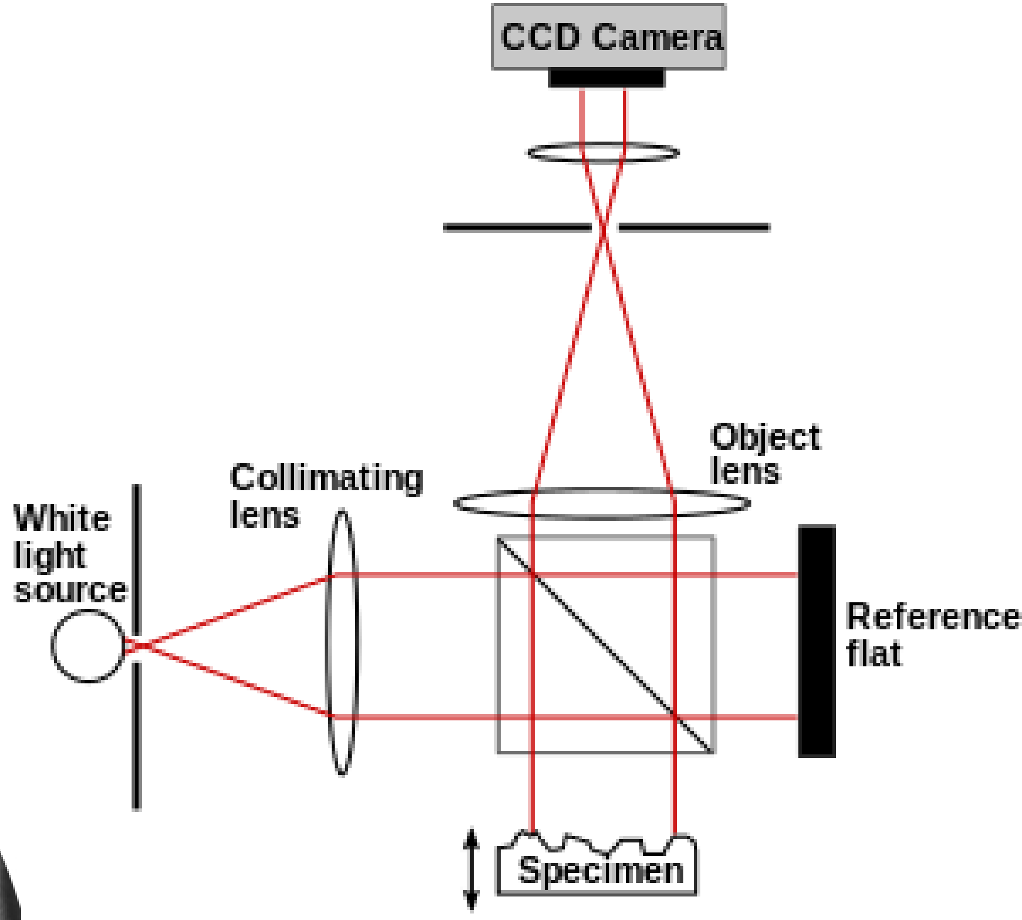
store.gaging.com

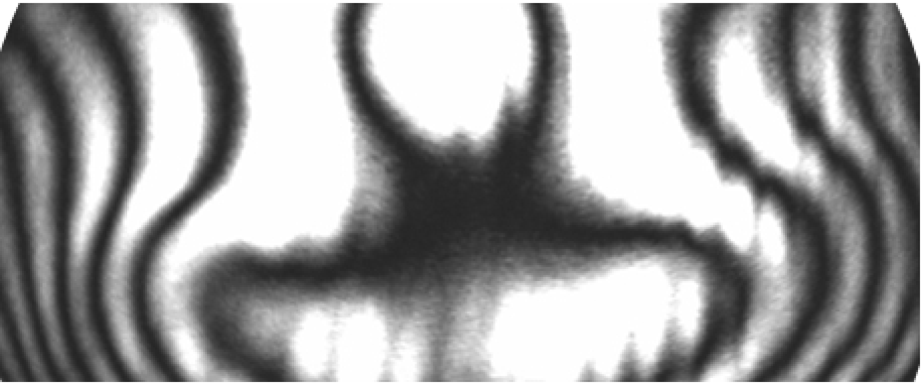
Contact stylus with different head/force

- Inexpensive
- Portable
- Not accurate due to stylus size
- Scratch soft surface

Measurement: Interferometry







www.activeopticalsystems.com

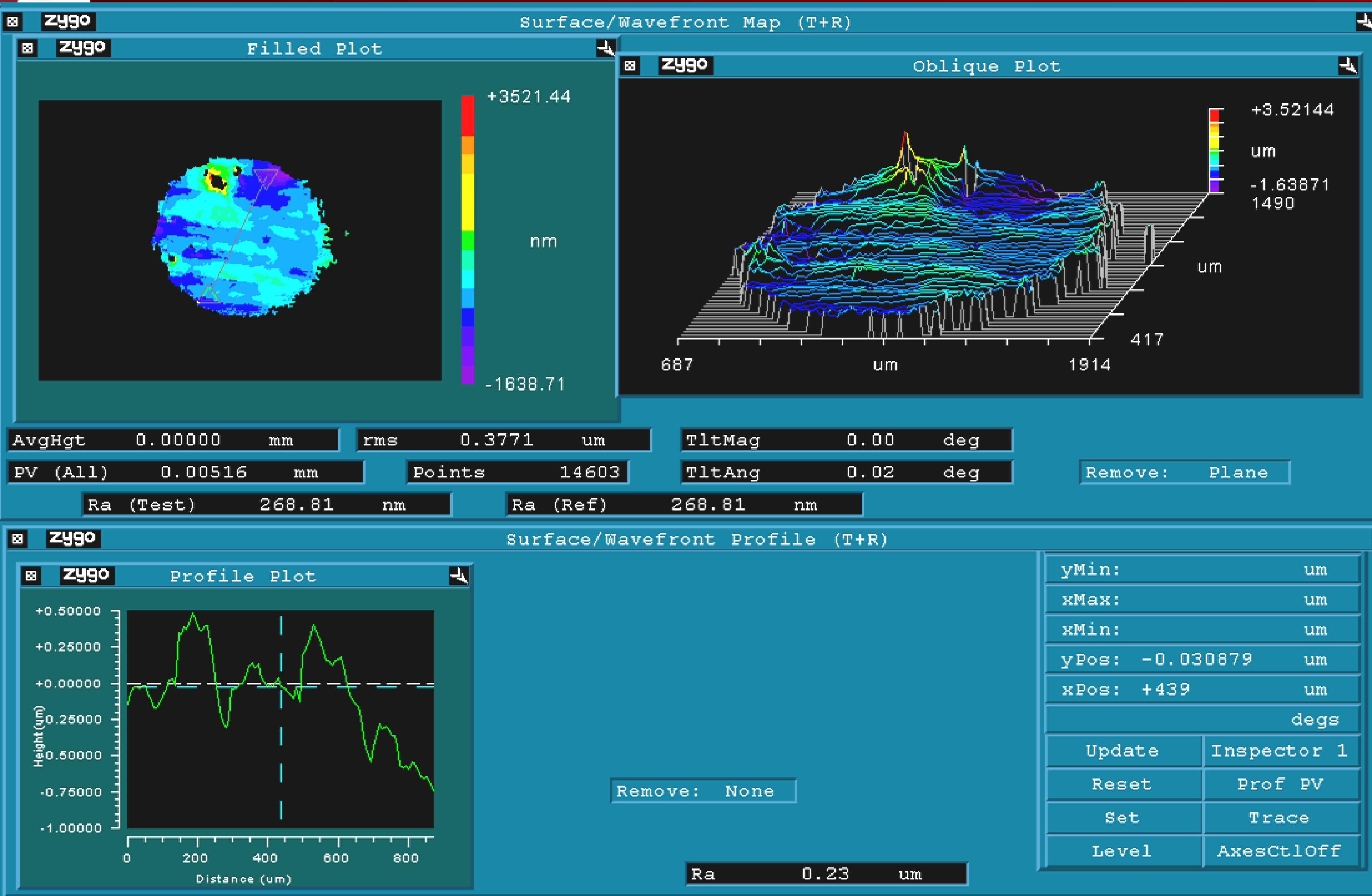
http://en.wikipedia.org/wiki/Interferometry

Measurement: Interferometry

www.zygo.com

- Non-contact
- Measure line and area surface finish
- Non-portable
- Expensive

ECM+ ECP, sample A12



AvgHgt 0.00000 mm

rms 0.3771 um

TltMag 0.00 deg

PV (All) 0.00516 mm

Points 14603

TltAng 0.02 deg

Remove: Plane

Ra (Test) 268.81 nm

Ra (Ref) 268.81 nm

yMin: um

xMax: um

xMin: um

yPos: -0.030879 um

xPos: +439 um

degs

Remove: None

Ra 0.23 um

Measurement: Tunneling microscopy

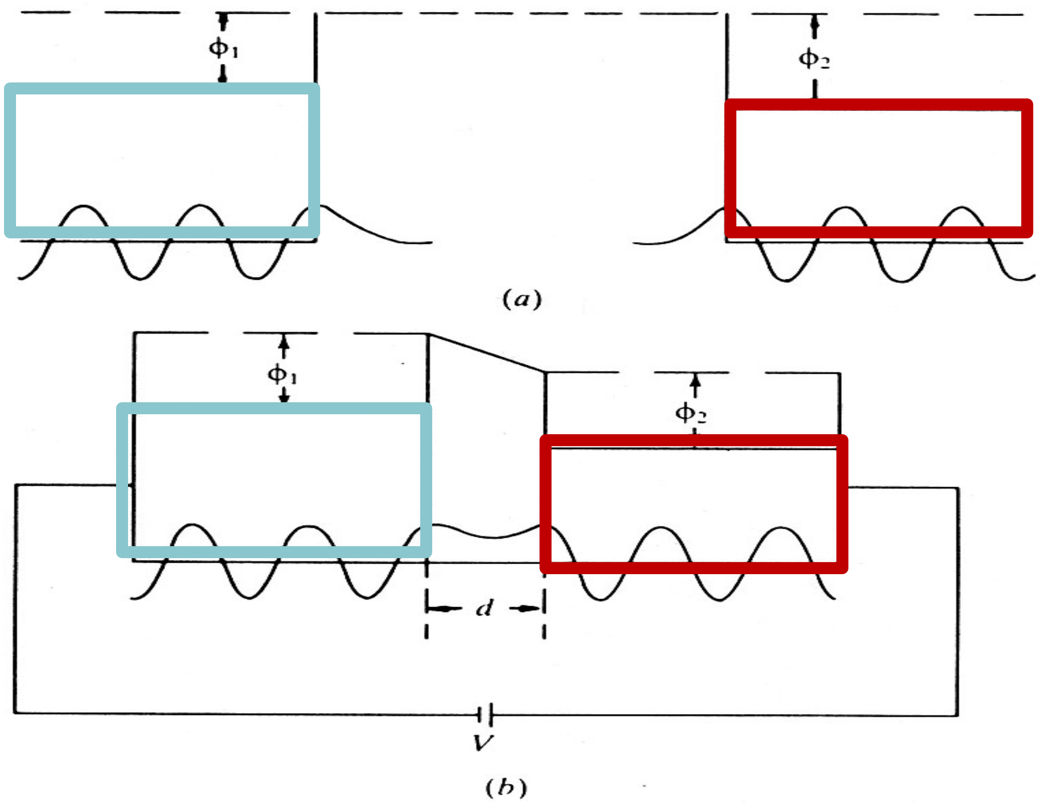
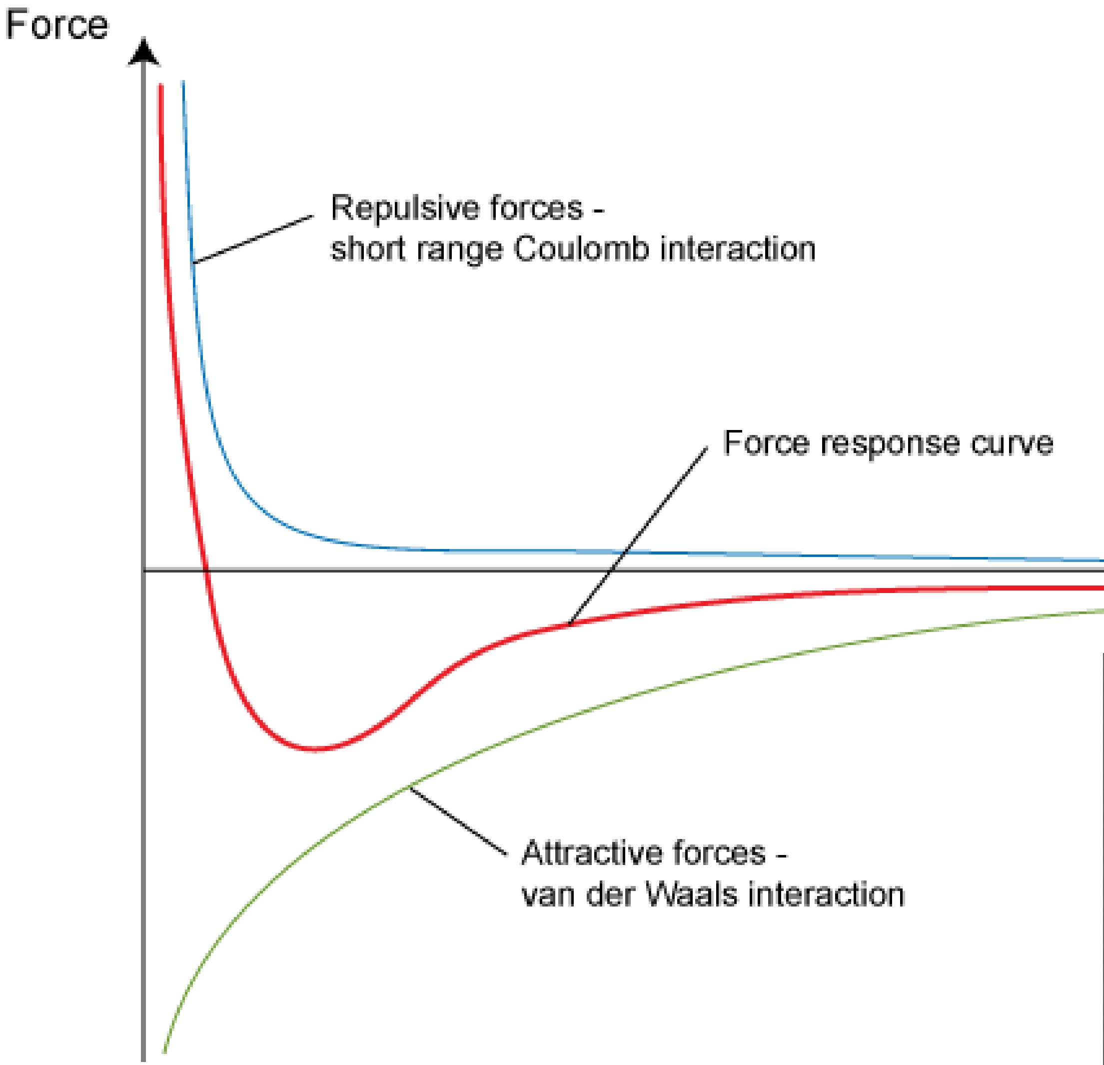


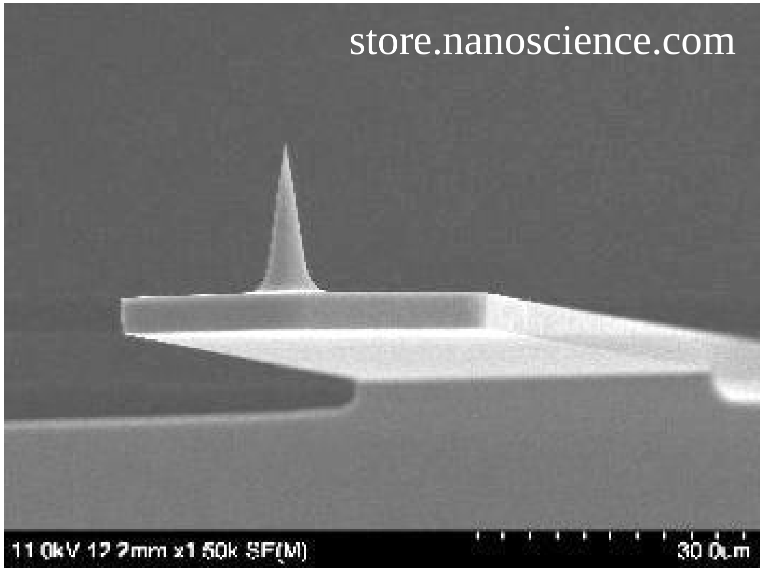
Fig. (a) Electron wavefunctions for two separate metals 1 and 2 with work functions ϕ_1 and ϕ_2. (b) Electron wavefunction for the same two metals connected and separated by a small distance d; V is the bias potential. Tunnelling through the barrier may now proceed since the wavefunctions overlap.

Tunneling current between 2 parts:

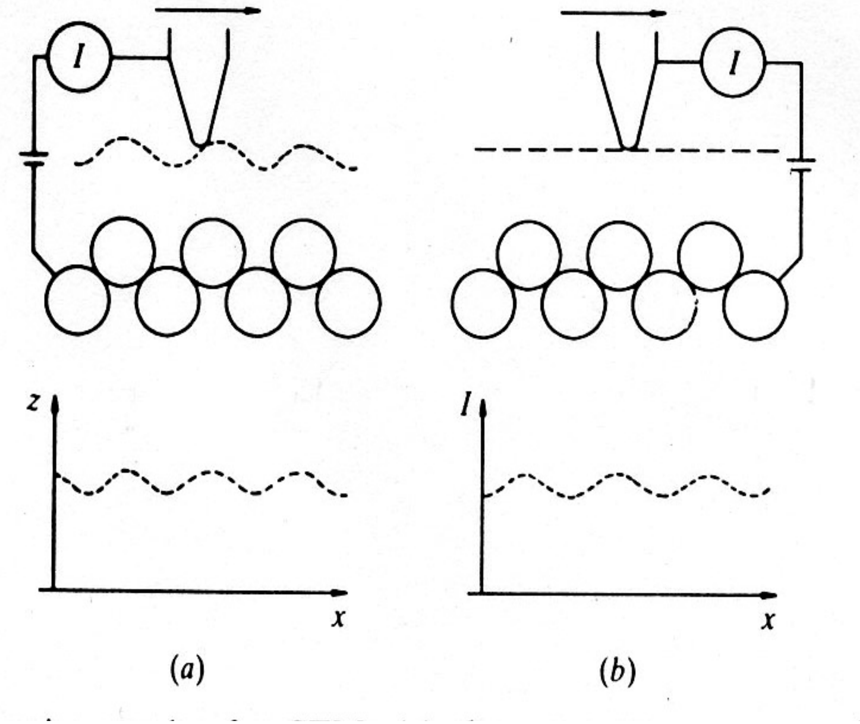
$$I \sim e^{-2Kd}$$

Measurement: Atomic force microscopy

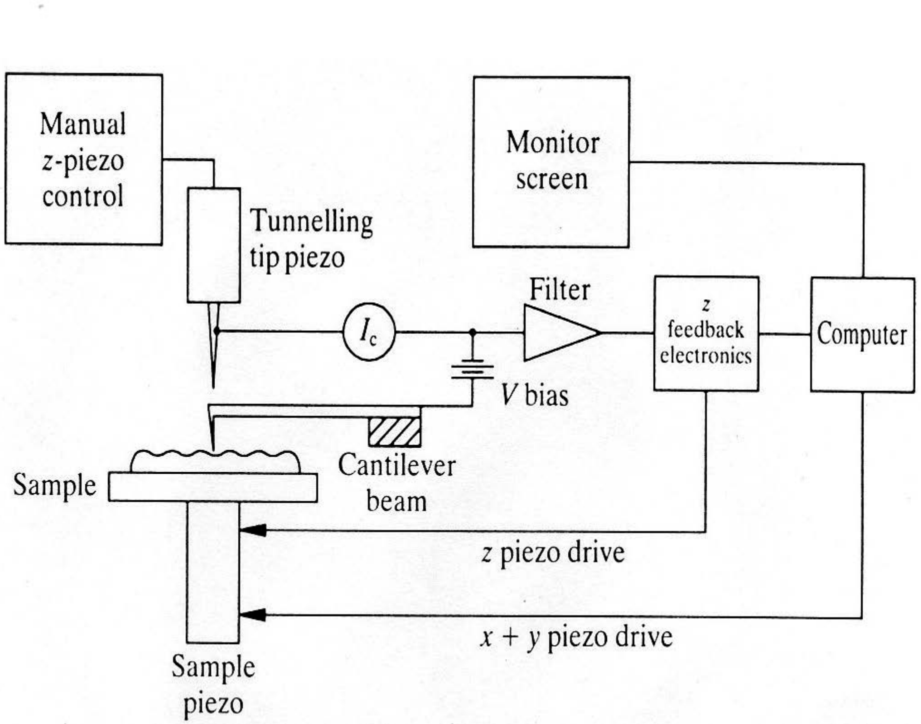



store.nanoscience.com

Measurement: scanning probe microscopy



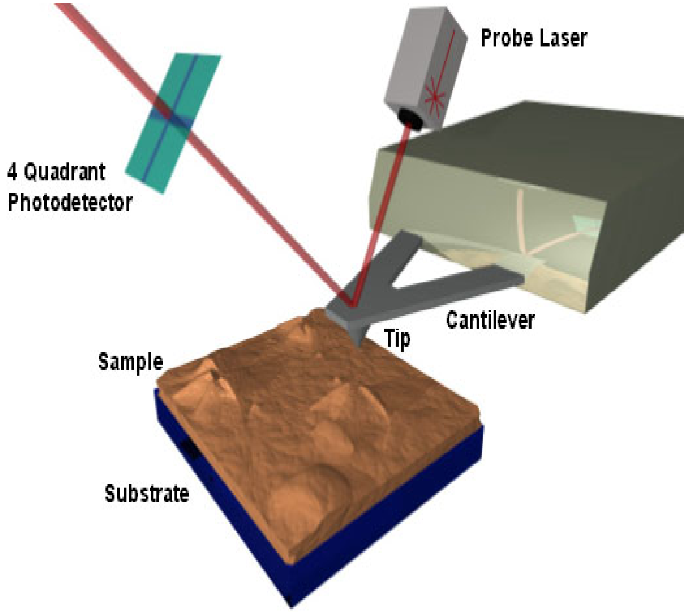
(b) the



STM/AFM imaging modes

STM/AFM system

STM/AFM system

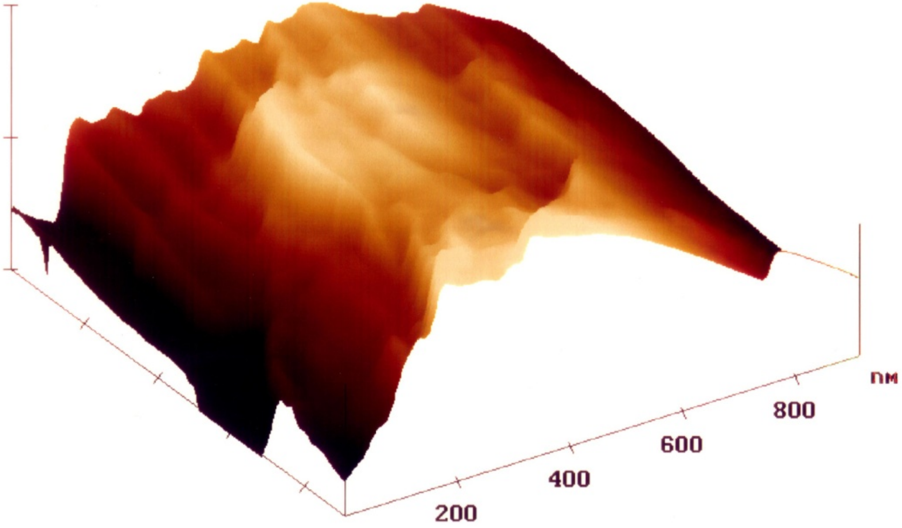


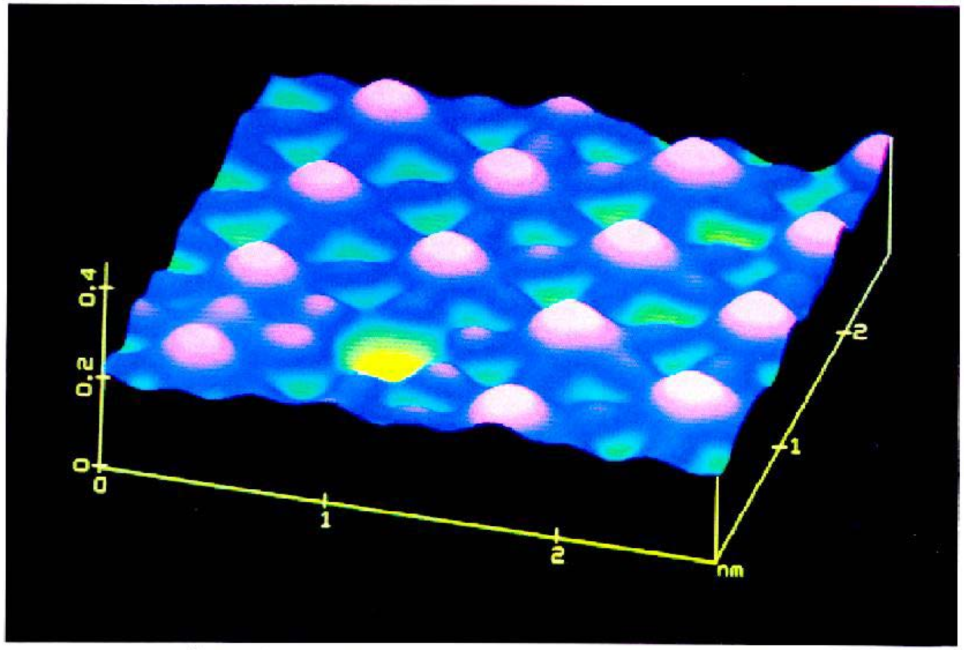
education.mrsec.wisc.edu

- Tapping/scanning modes
- Atomic resolution
- Expensive
- Very slow
- Non-portable

http://mcf.tamu.edu/instruments/new-afm

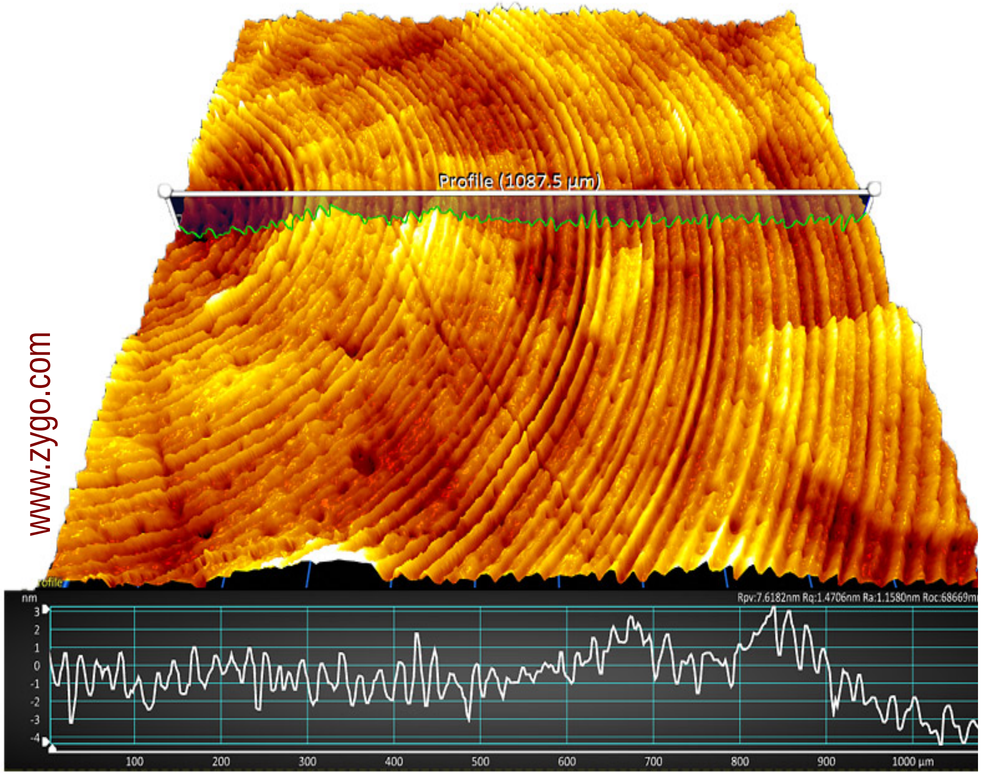
AFM



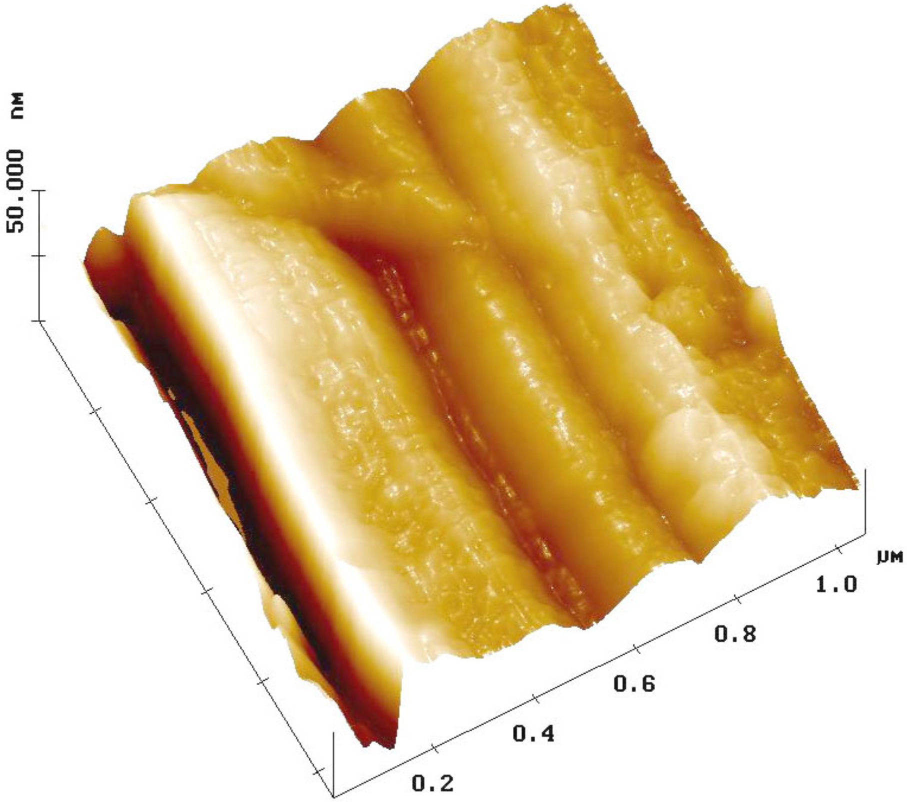


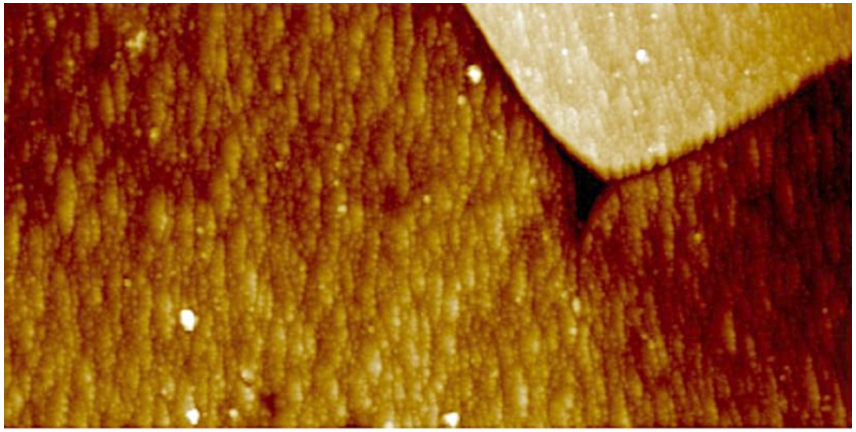
Iodine atoms in a 3x3 array adsorbed on platinum. Data from Dr. Bruce Schardt, Purdue University.

Machined surface measurement



www.zygo.com



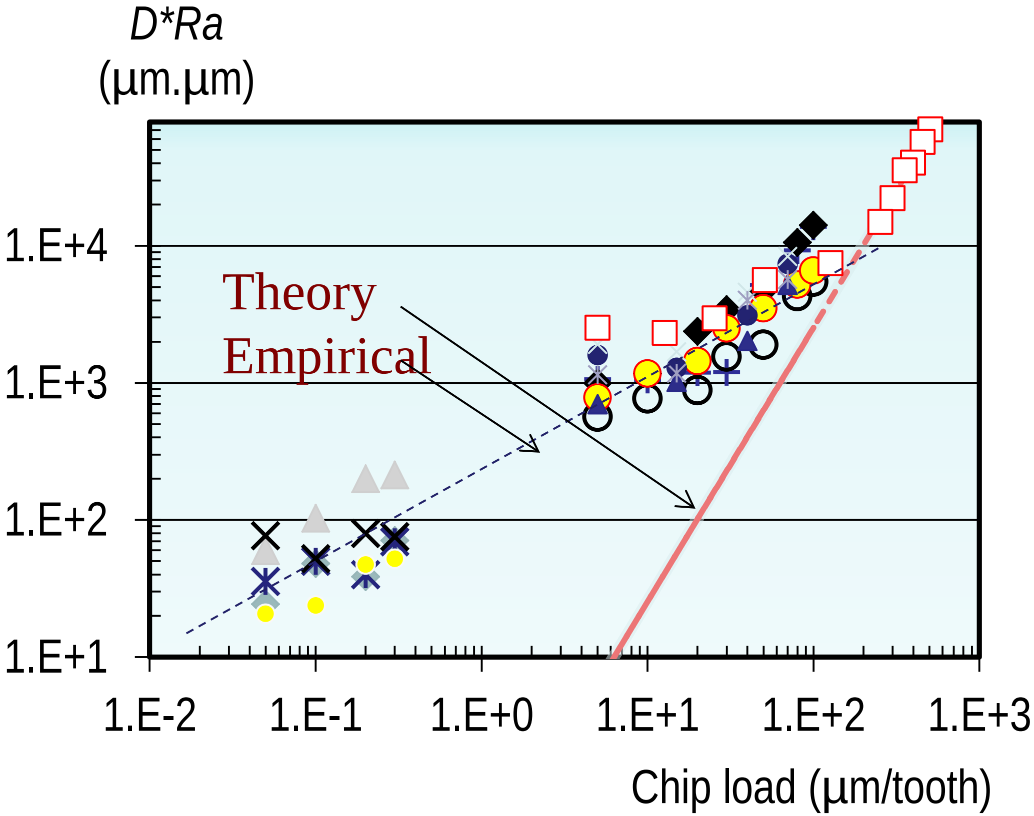


Ball-end milling: model

Effect of tool geometry and chip load

$$R_t = D - \sqrt{D^2 - {f_t}^2}$$

$$R_a = 0.2423 \frac{(f_t)^2}{D}$$



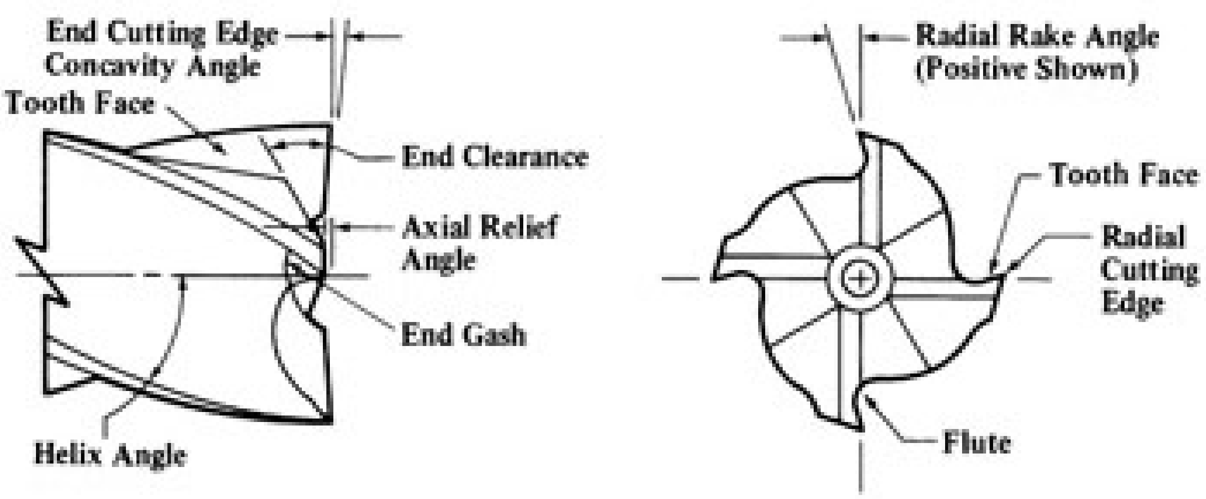
R_a = theoretical average surface finish (in, mm)
R_t = theoretical peak-valley surface finish (in, mm)
f_t = chip load (in/tooth, mm/tooth)

Flat-end milling: model

Effect of tool geometry and chip load

$$R_t = f_t tan \propto$$

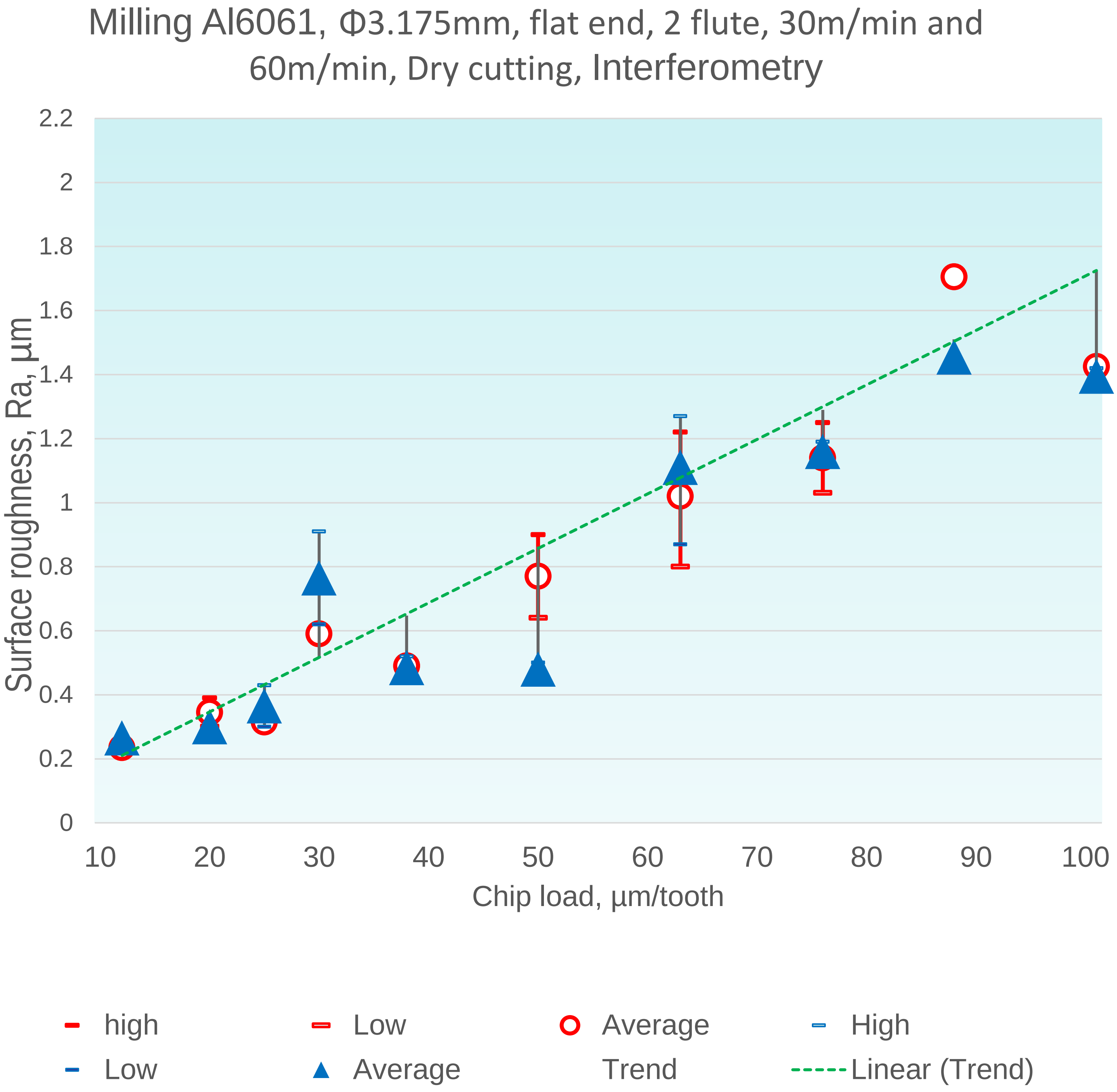
$$R_a = \frac{5}{18} f_t tan \propto$$



Enlarged Section of End Mill

http://www.globalspec.com/reference/68253/203279/milling-cutters

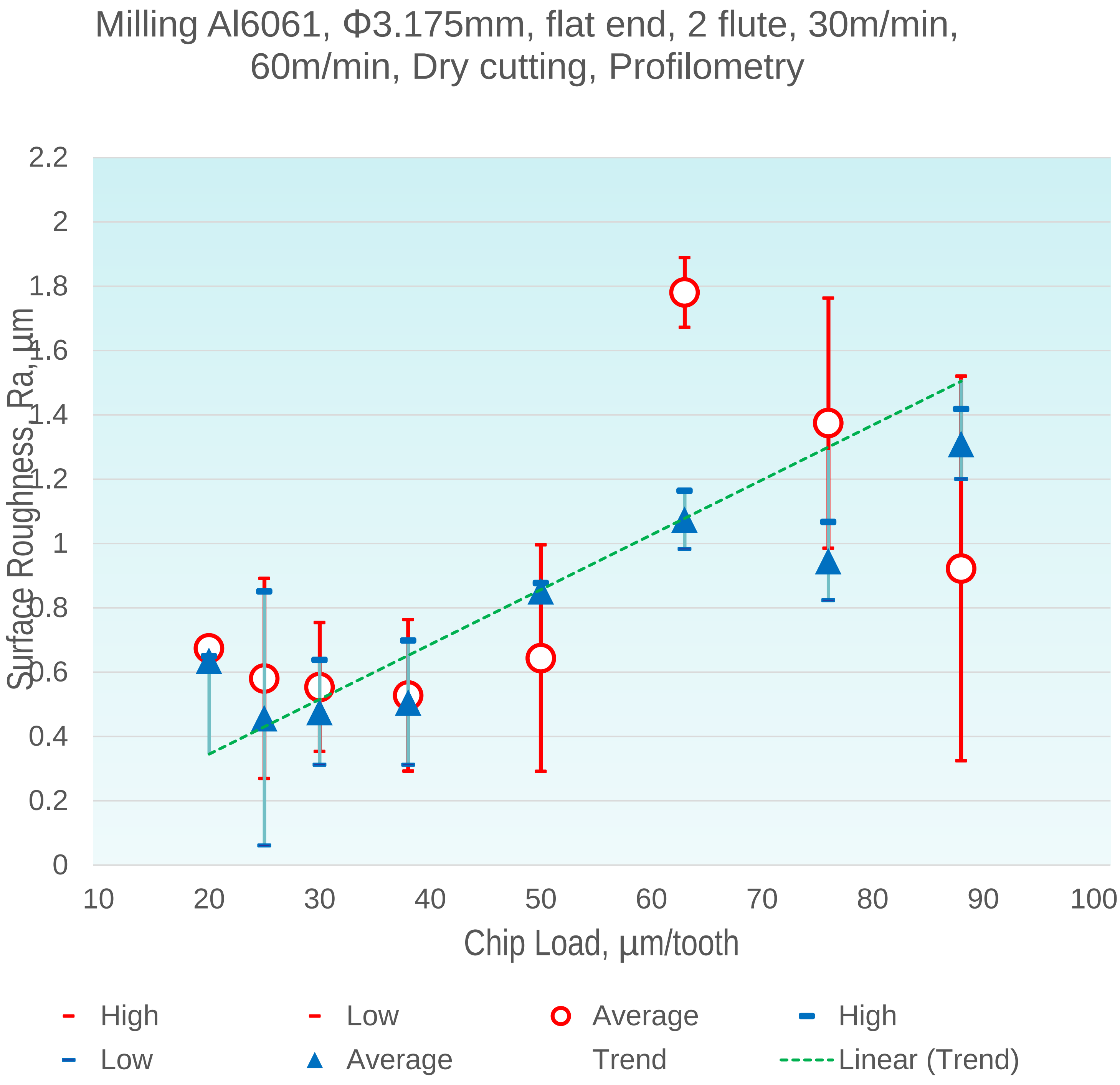
R_a = theoretical average surface finish (in, mm)
R_t = theoretical peak-valley surface finish (in, mm)
f_t = chip load (in/tooth, mm/tooth)



Milling Al6061, Φ3.175mm, flat end, 2 flute, 30m/min and 60m/min, Dry cutting, Interferometry

$$R_a = \frac{5}{18} * f_t * \tan\alpha$$

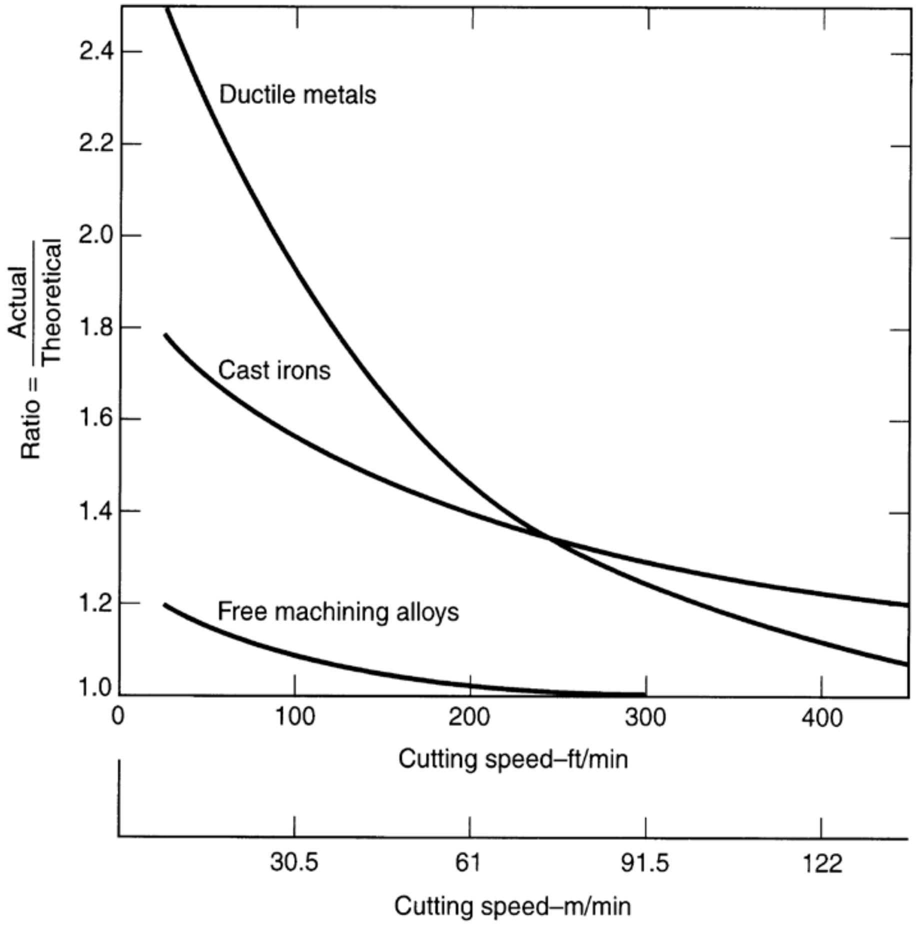
α = end cutting edge angle = 3.49°



$$R_a = \frac{5}{18} * f_t * \tan \alpha$$

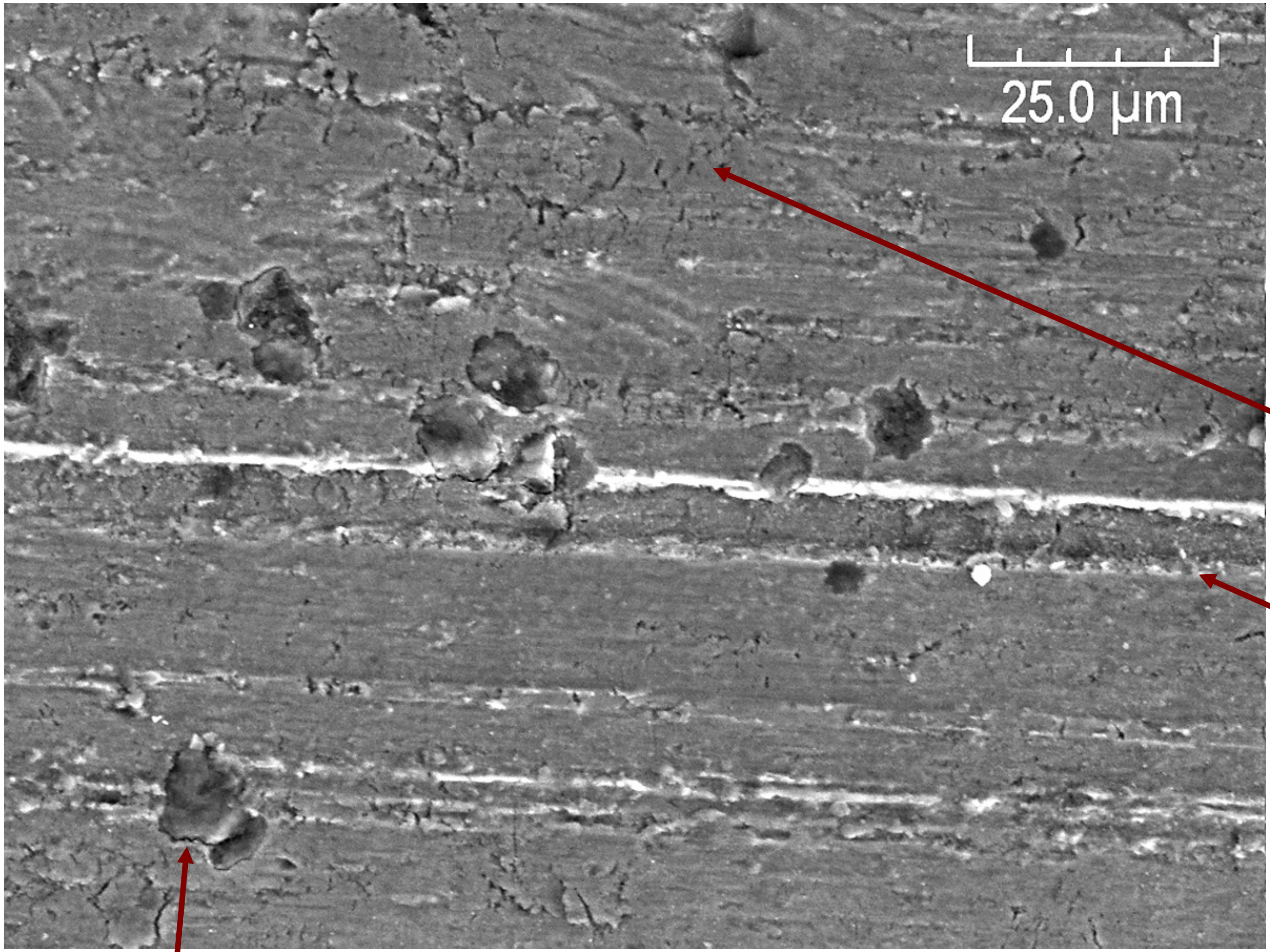
α = end cutting edge angle =3.49°

Modelling issues



- ☐ Effect of workpiece material
  - Built-up edge of ductile material
  - Tearing of surface when machining ductile materials
  - Cracks in surface when machining brittle materials
- ☐ Use correction factor to calculate theoretical surface finish

µECM: Electrode forming on CP Titanium



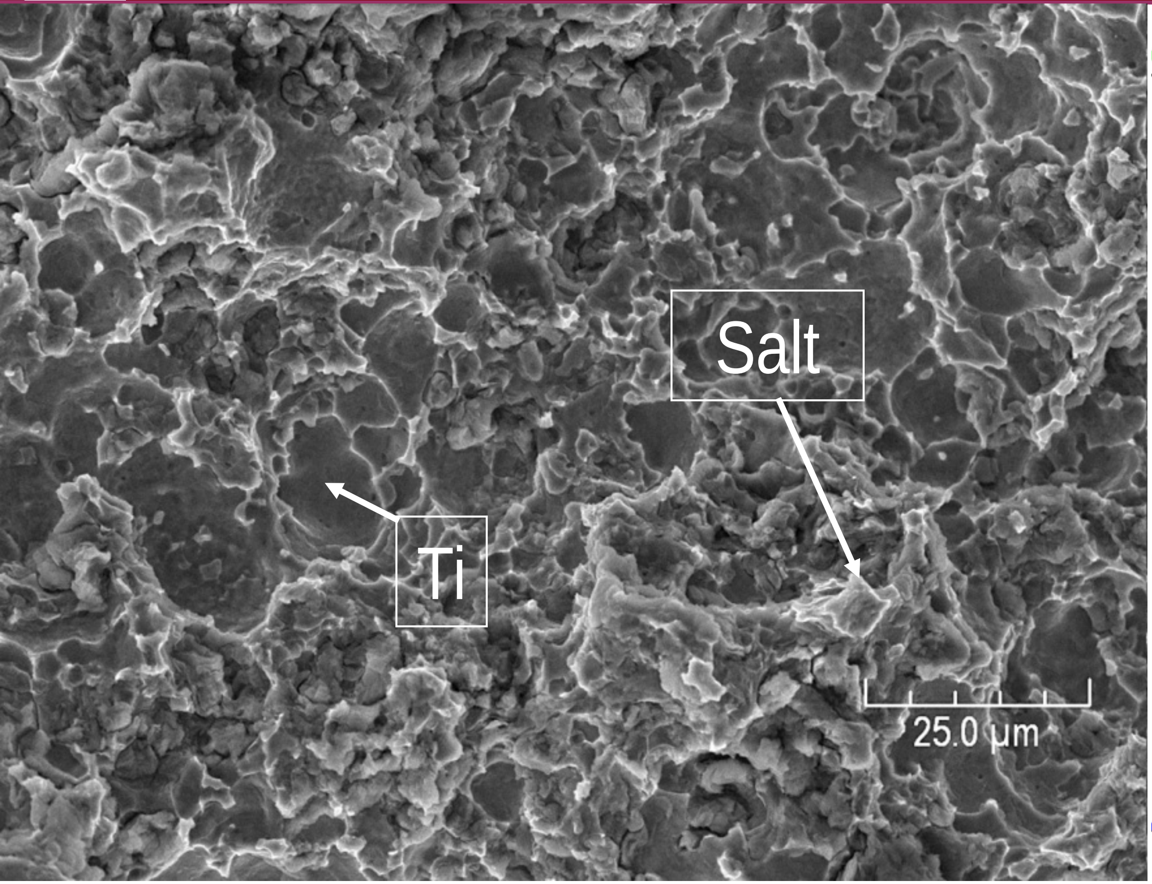
Rolling fracture

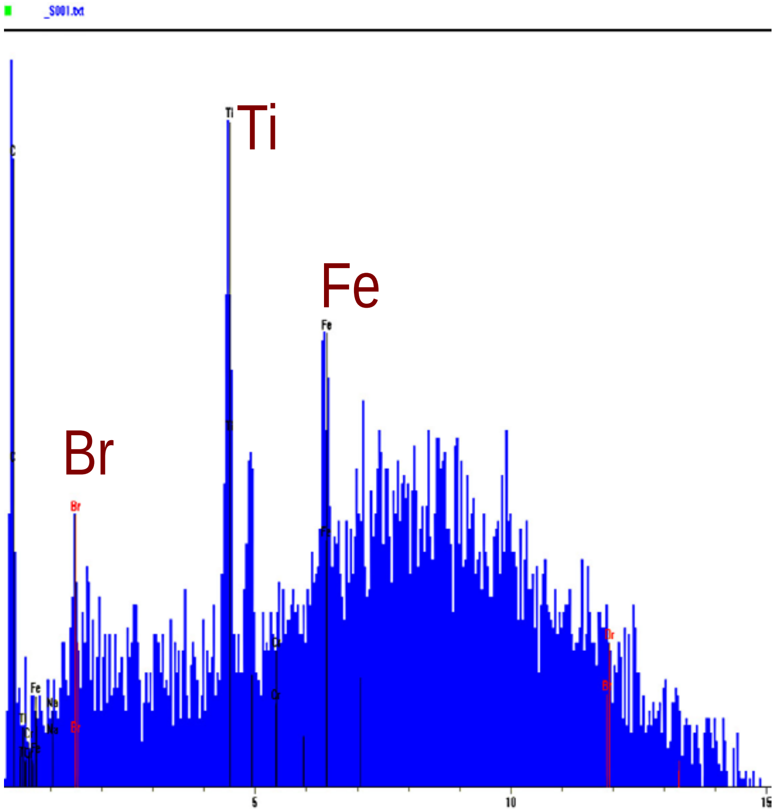
Rolling mark

Embedded inclusion

As received CP titanium sheet

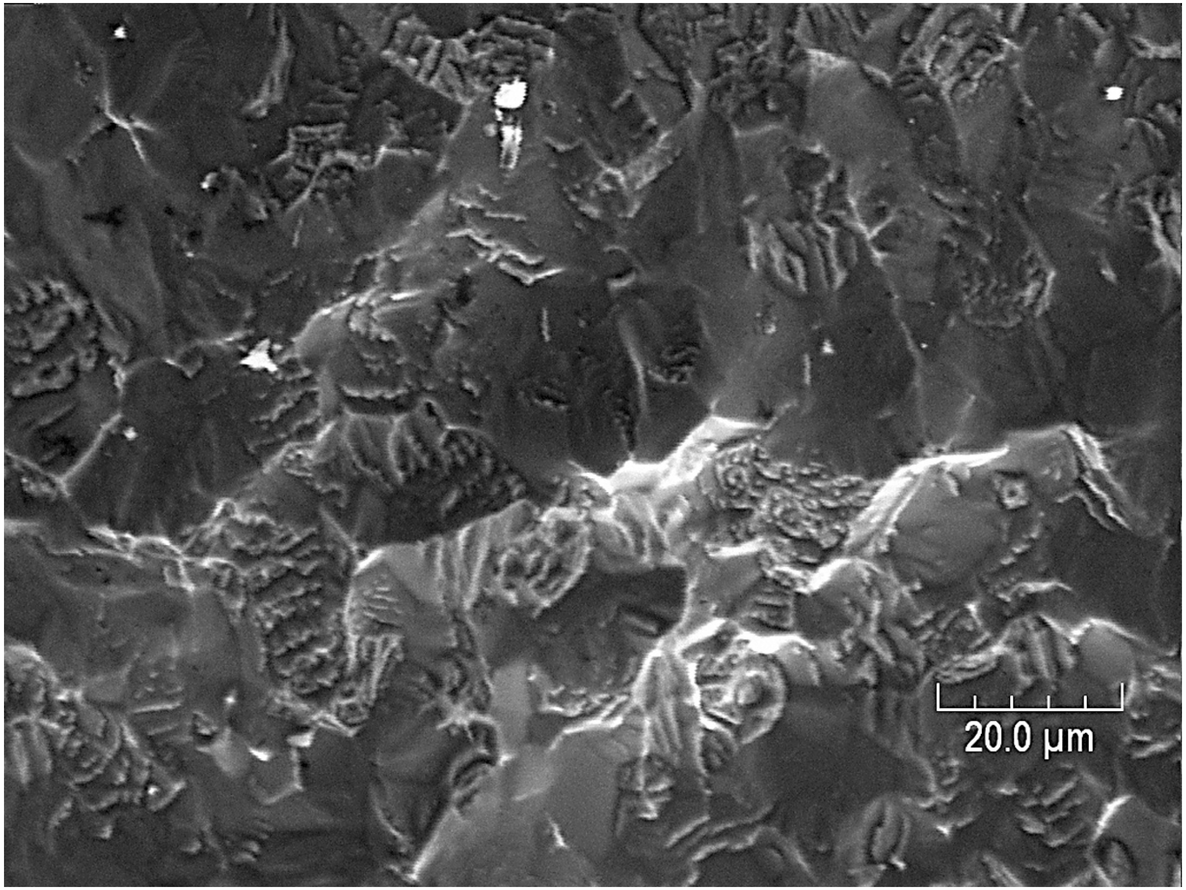
µECM: Electrode forming on CP Titanium





10 kHz, stainless steel electrode, $NaNO_3$ + KBr electrolyte, 3 mm gap, 168 mA/mm^2 current density, 62 µm/s feed.

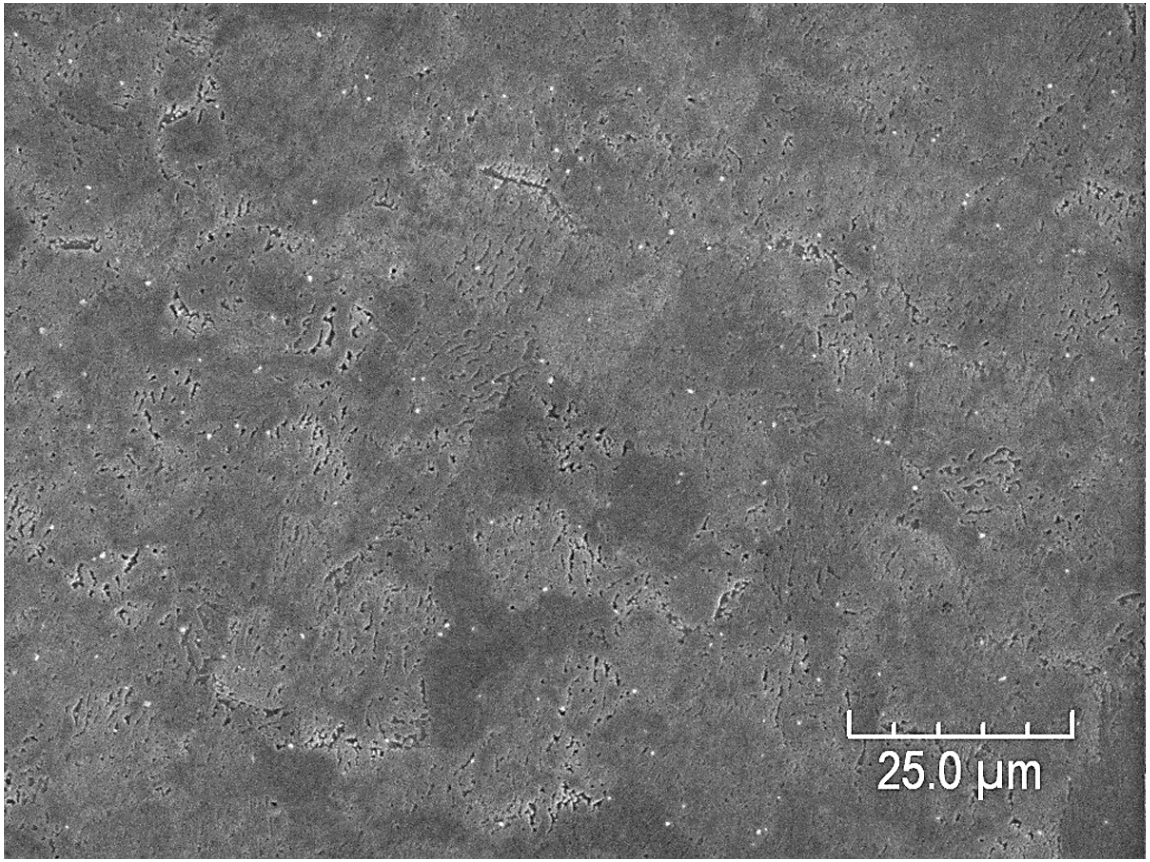
μECM: Electrode forming on CP Titanium

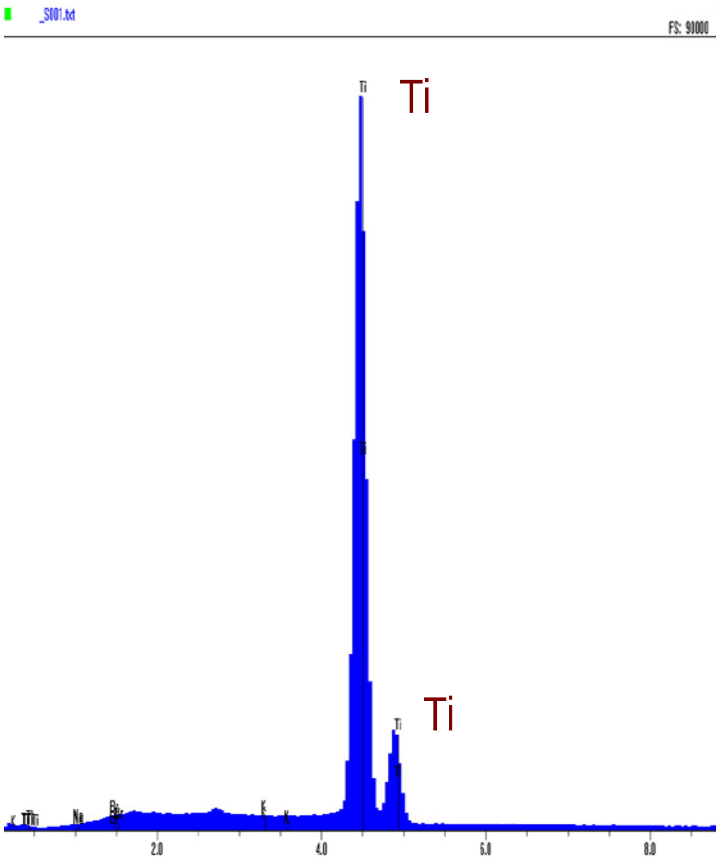


ECM of CP Ti

- ECM: Sample A2,50kHz ,25-0V, 202mA ,485 mA/mm^2, 200um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).

µECM: Electrode forming on CP Titanium

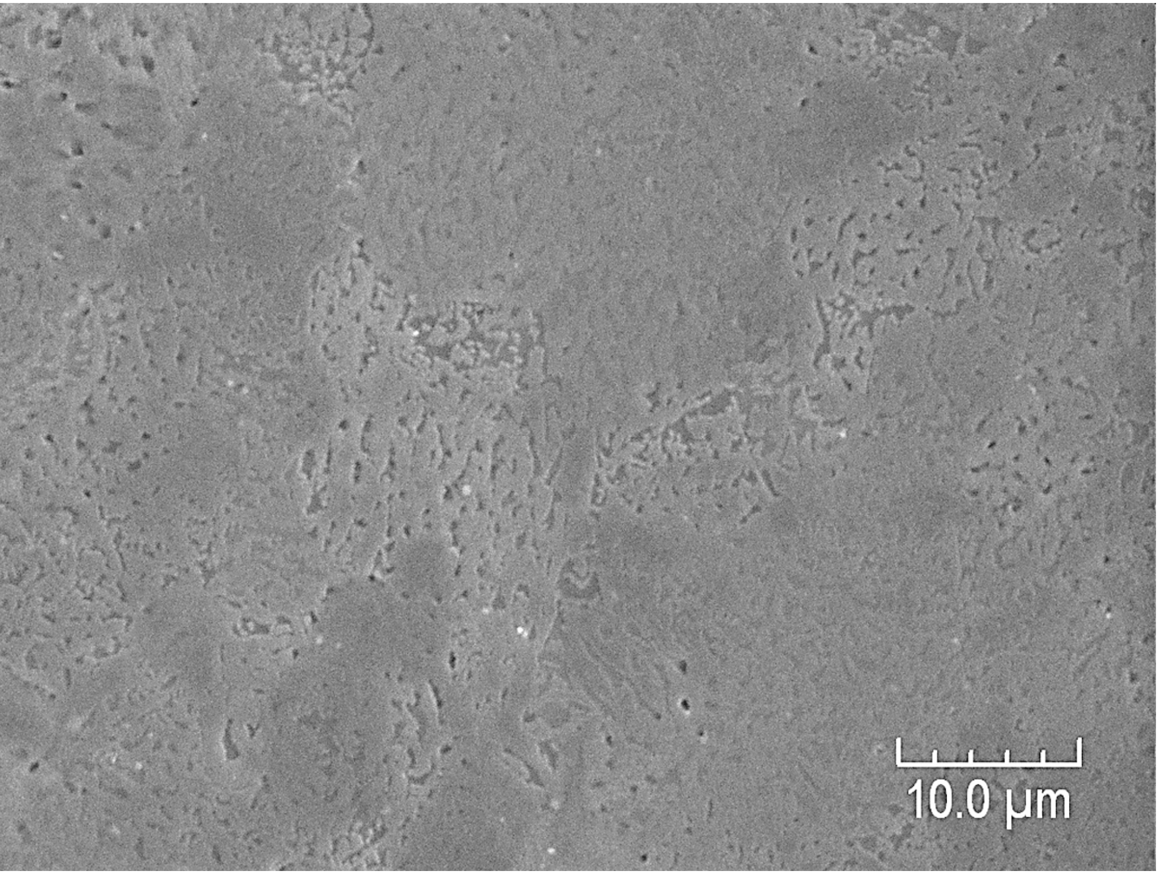




- ECM: Sample A11,100kHz ,25-0V, 205mA ,490 mA/mm^2,100um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).
- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

ECM+ECP of CP Ti

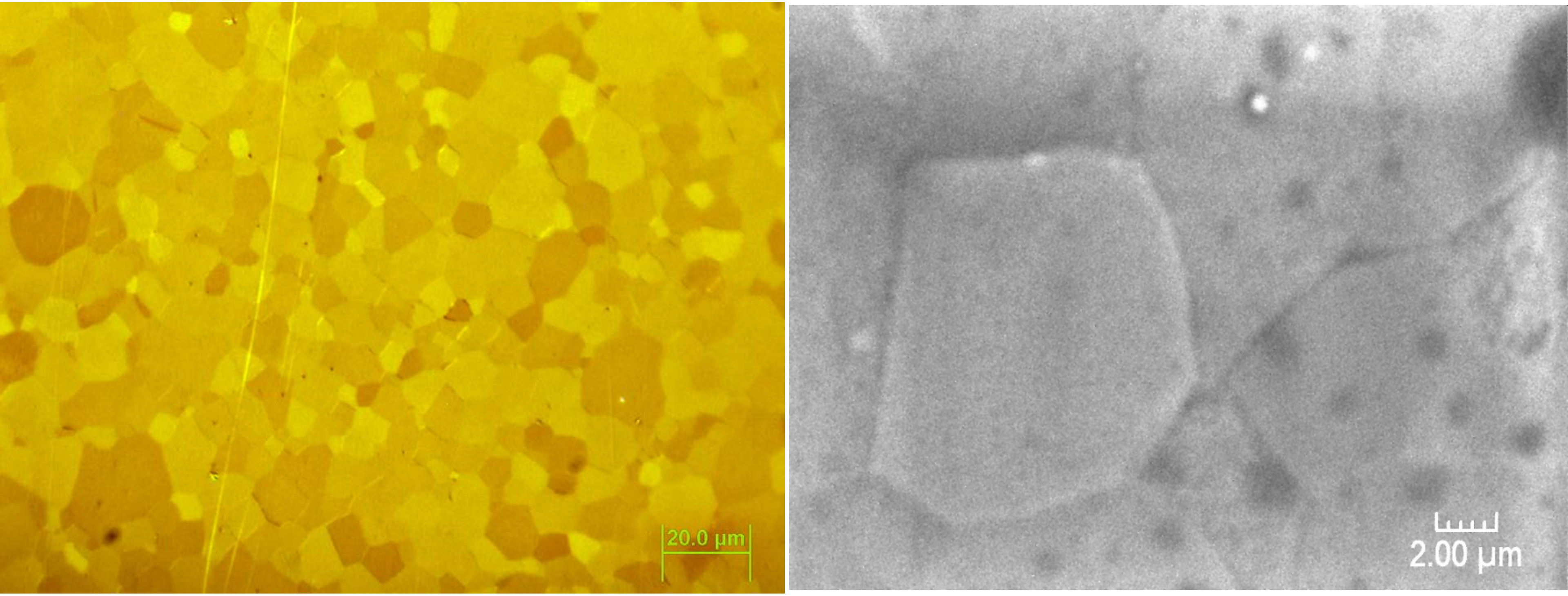
μECM: Electrode forming on CP Titanium



ECM+ECP of CP Ti

- ECM: Sample A12,50kHz ,25-0V, 211mA ,504 mA/mm^2,50um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).
- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

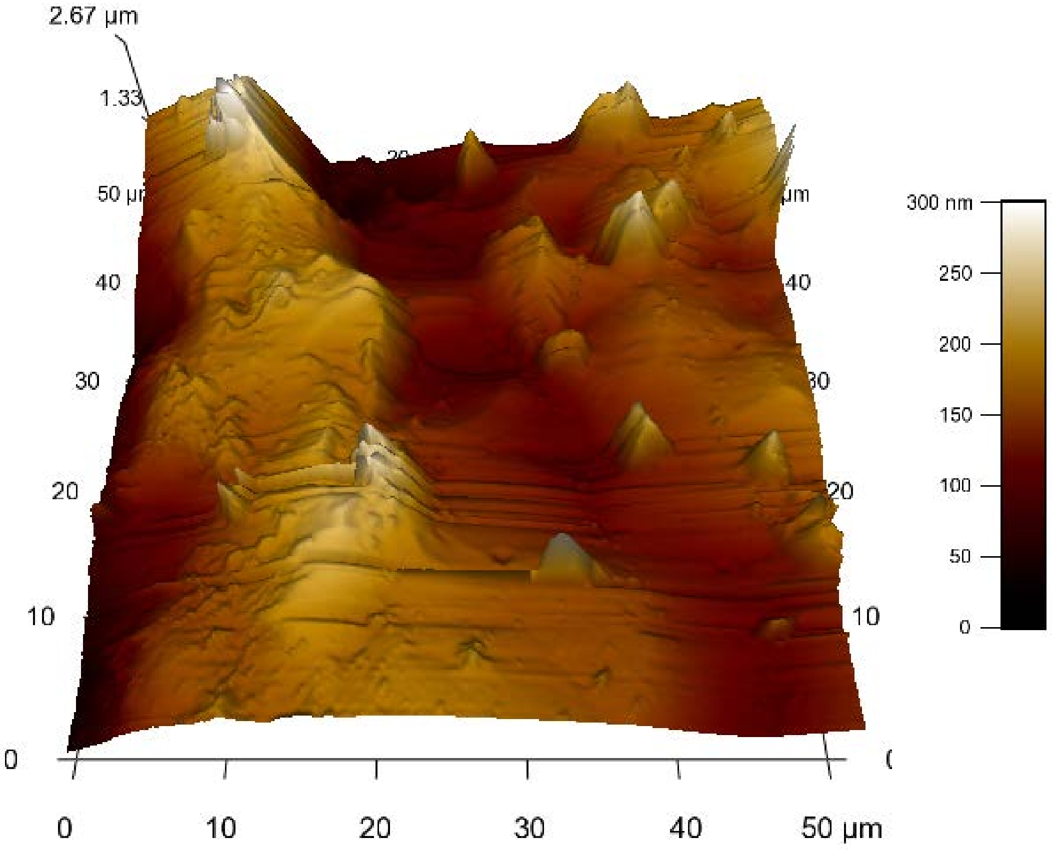
μECM: Polishing of CP Titanium



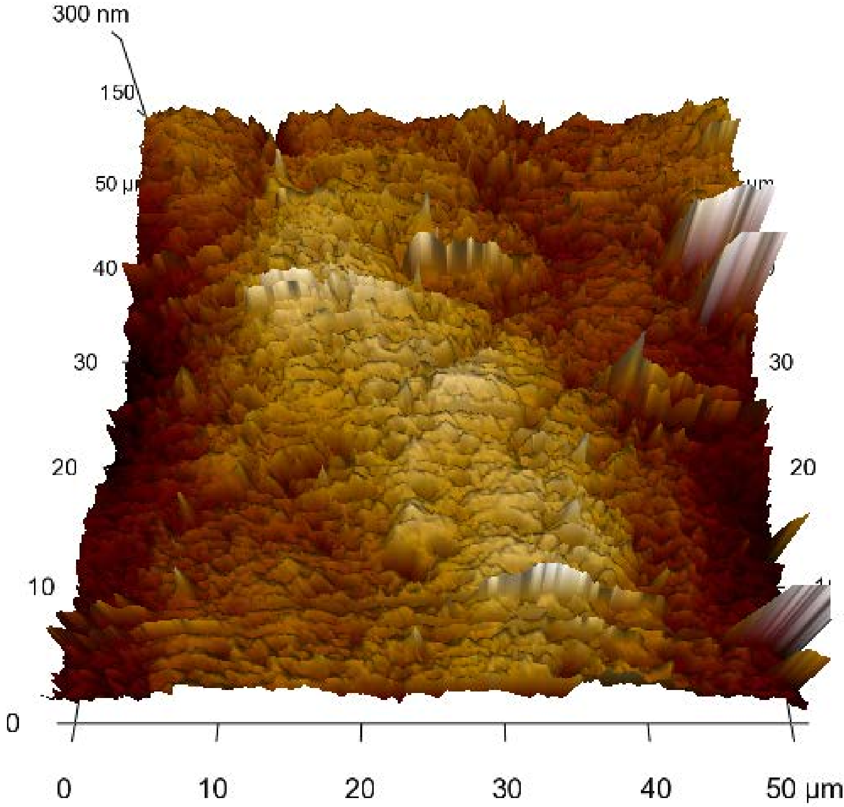
Polishing of as-received CP Ti

- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

μECM: CP Titanium



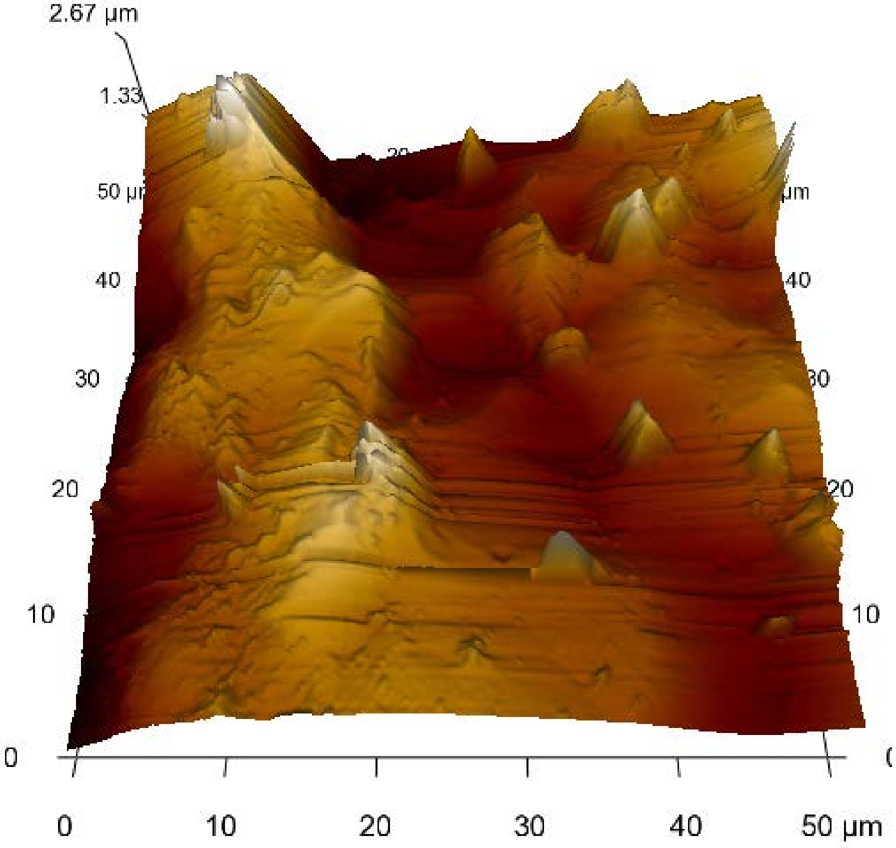
After μECM, Area RMS=340 nm



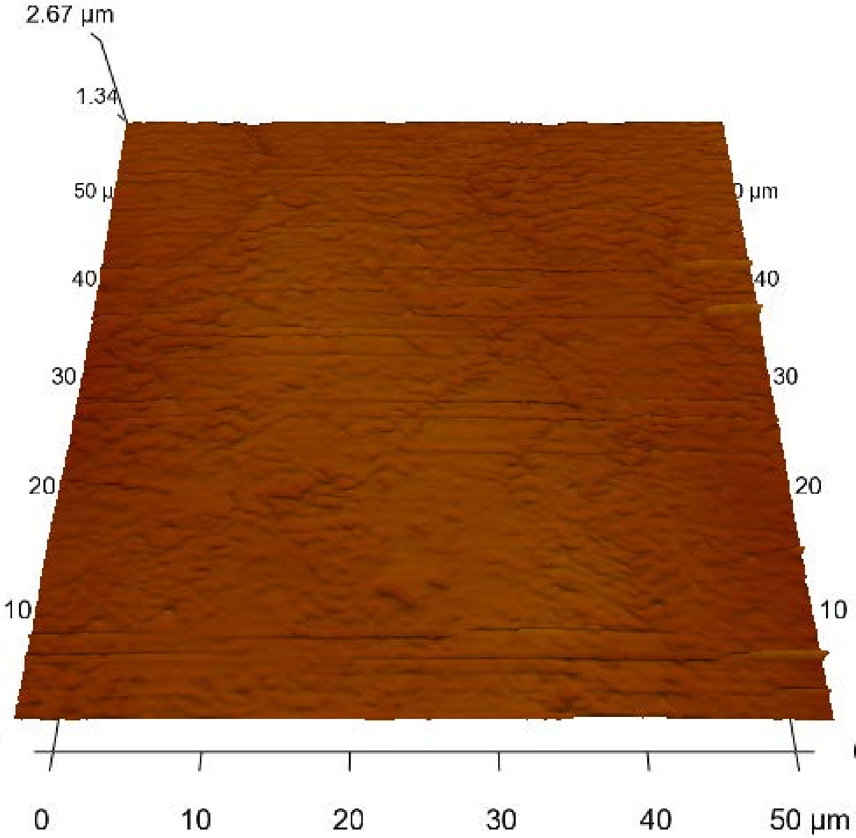
After μECM+ECP Area RMS=42 nm

- ECM: Sample A12,50kHz ,25-0V, 211mA ,504 mA/mm^2,50um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).
- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

µECM+ECP: CP Titanium



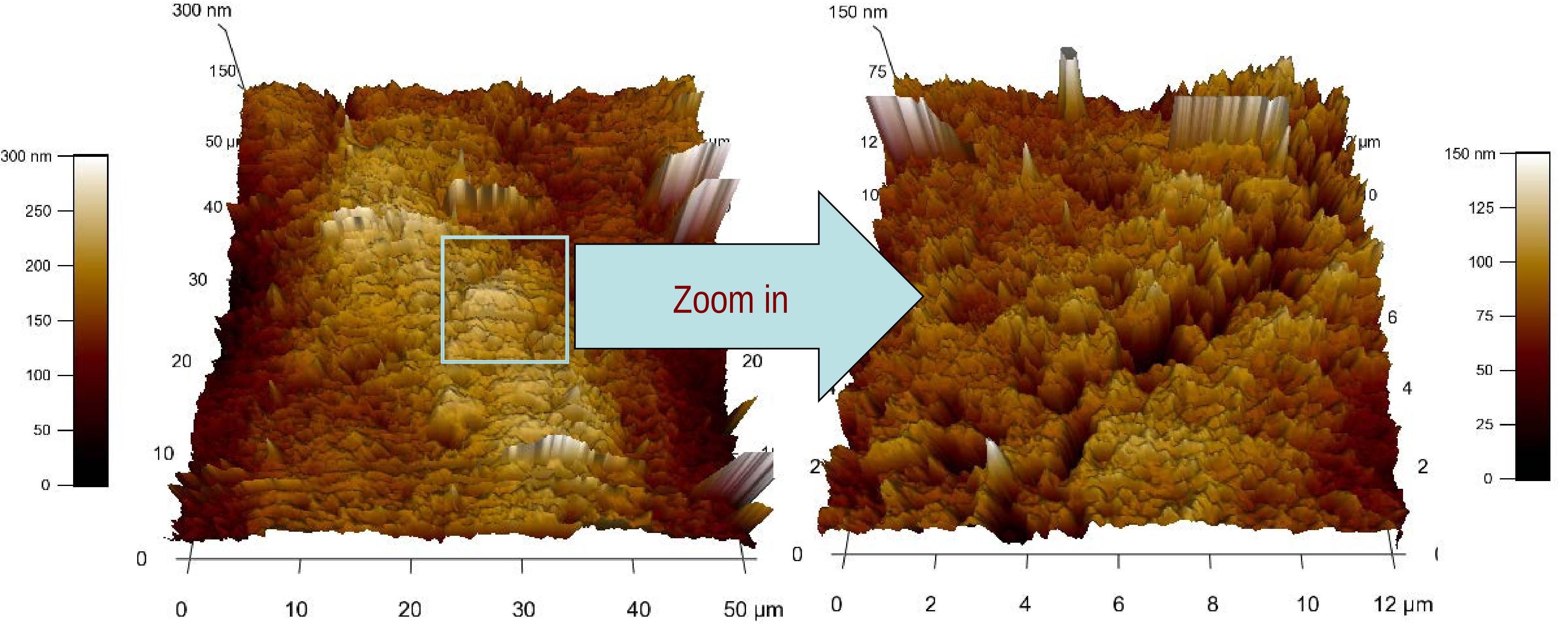
After µECM, Area RMS= 340 nm



After µECM+ECP Area RMS= 42 nm

- ECM: Sample A12,50kHz ,25-0V, 211mA ,504 mA/mm^2,50um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).
- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

µECM+ECP: CP Titanium

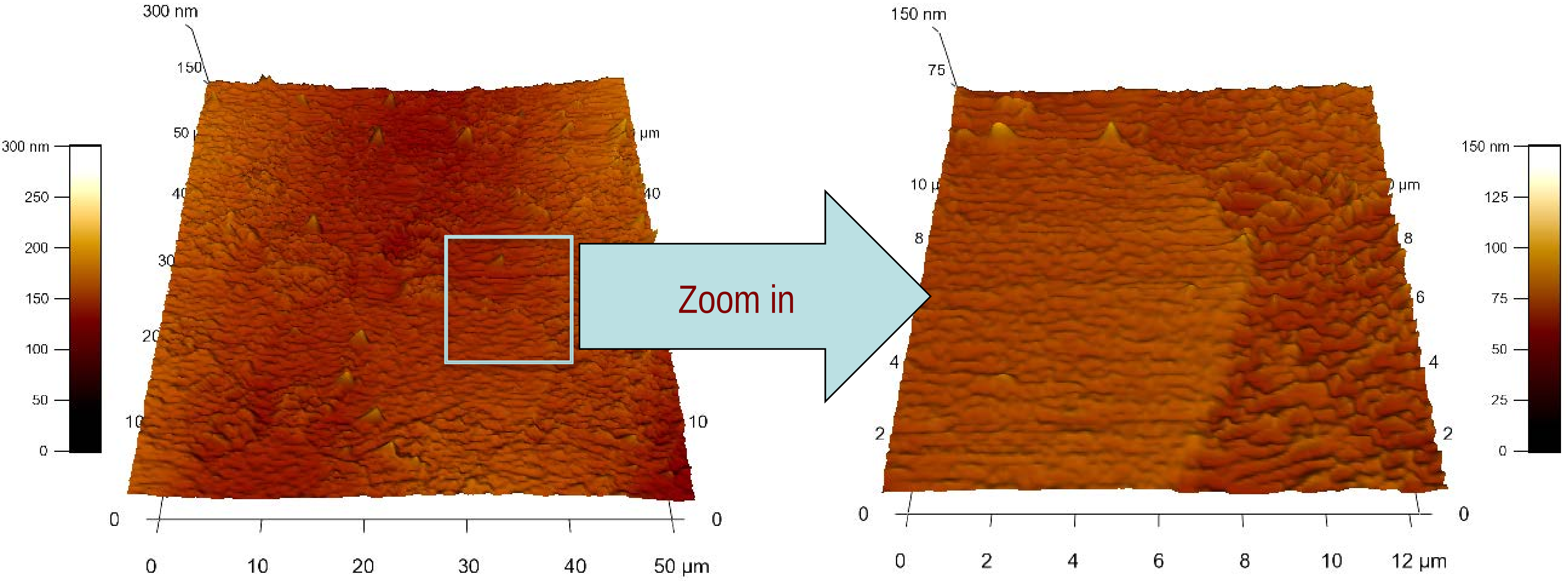


After µECM+ECP, Area RMS= 42 nm

After µECM+ECP Area RMS= 20 nm

- ECM: Sample A12,50kHz ,25-0V, 211mA ,504 mA/mm^2,50um, 90s, (50g KBr+15g $NaNO_3$+500g H_2O).
- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

μECP: CP Titanium



After ECP of as-received material.
Area RMS= 10 nm

After ECP of as-received material.
Zoom-in area RMS= 3.4 nm
Area RMS within a grain = 2 nm

- ECP: (60 g/L, 99%, $AlCl_3$ +280 g/L, 98+%, $ZnCl_2$ + 300 mL/L, C_3H_8O +700 mL/L, USP-200 proof, C_2H_5OH) at 25v DC, 10 mm gap,120 mA/cm^2, 35°C, 20 min, 1mg/cm^2/min MRR.

SUMMARY

1) Measurement of machined surface finish
- Comparison
- Profilometry
- Interferometry
- Scanning probe microscopy (STM and AFM)

2) Modeling of machined surface
- Turning
- Ball-end and flat-end milling
- Macro vs micro machining