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# AFM-BASED METROLOGY FOR ADVANCED PATTERNING

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# INTRODUCTION
## ADVANCED PATTERNING AND METROLOGY

Scatterometry

Optical Microscopy

- Advanced patterning research is metrology dependent.
  - If you're changing something in the process recipe

  you need to be sensitive to changes and as accurate as possible (if something has changed…).

Scanning Electron Microscopy

Ellipsometry

High Resolution Profilometry

Reflectivity

# ATOMIC FORCE MICROSCOPY

- How?
  AFM works...
  - By scanning a probe over the surface
    - →AFM is slow
  - Piezo material allows AFM to be very accurate even on small scan
    - →AFM is local

- Limitation?
  - Probe shape and dimensions
  - Signal

- **Solution?**
  - Signal analysis, locally on images (software needed)
  - Tilted scanner head open dark corner, but close other...

# AFM SYSTEM

# IN LINE AFM

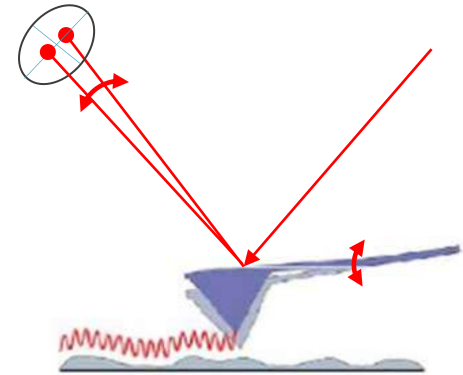
## OVERVIEW AND PRINCIPLE

- Probe oscillation at resonance frequency
- Feedback: Amplitude (+ Phase)

**Park**
**NX-3DM**

**Automated (recipes)**

- Mode: True non contact
- XY scanner: 100x100 $\mu m^2$
- Z scan travel: 15 $\mu m$
- 300mm wafer
- Automation:
  - wafer loading and alignment
  - probe exchange and alignment
  - pattern recognition
  - positioning pre-scan
  - Analysis

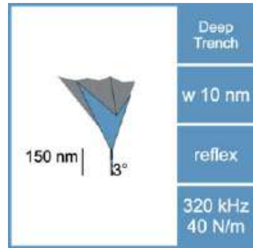


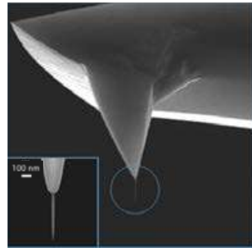
The probe is following the topography by oscillating **above** it.

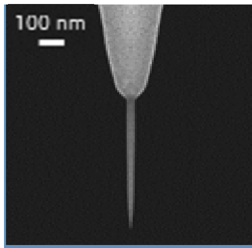
No contact
=
No Damage

# IN LINE AFM

## PROBE AND ITS LIMITATIONS

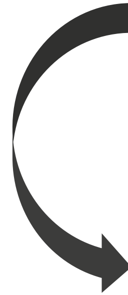




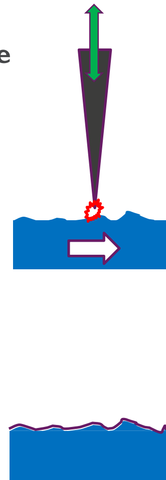

CNT100
High Aspect ratio
Cylindrical
Width~15nm

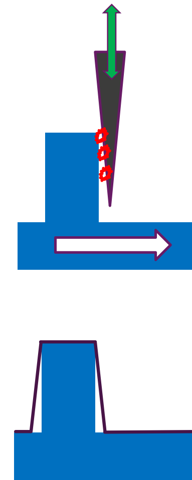
**Probe/sample interaction**

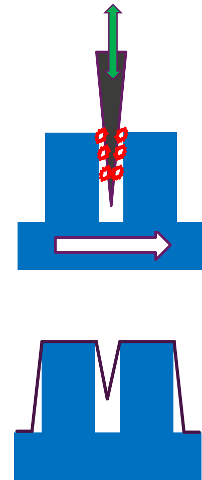


Due to probe shape and probe/sidewall interactions, a line will always be measured wider and a trench narrower.

This effect is stronger at the bottom







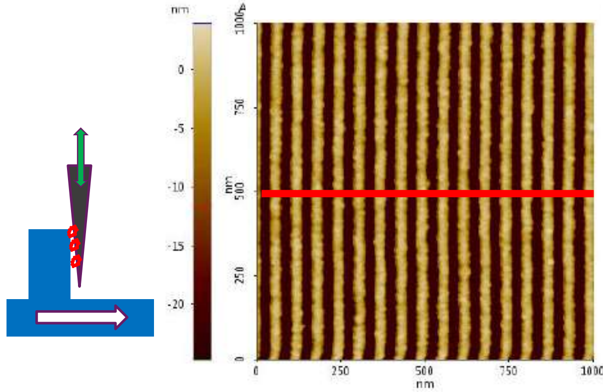
In addition, even for a trench slightly wider than the probe, these interactions will impede the probe from reaching the bottom

# EUV PATTERNING

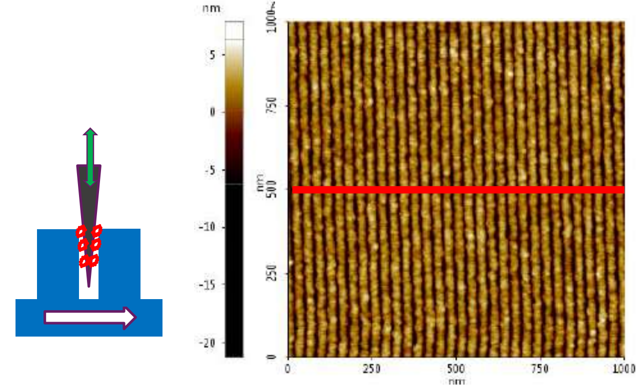
# EUV PATTERN

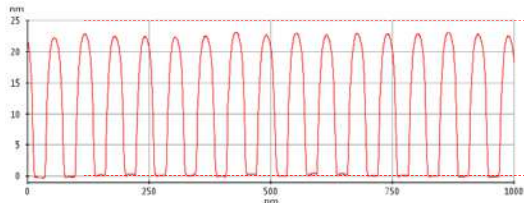
## WHEN THE PROBE AND THE SPACE ARE OF THE SAME ORDER

L/S, Pitch: 62

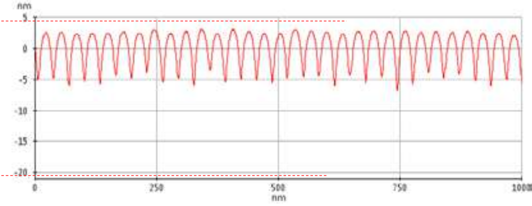


L/S, Pitch: 32





25nm



Bottom cannot be reached
**Top is trustable**

# EUV **TOP LINE** ANALYSIS

## ROUGHNESS

L/S, Pitch: 32

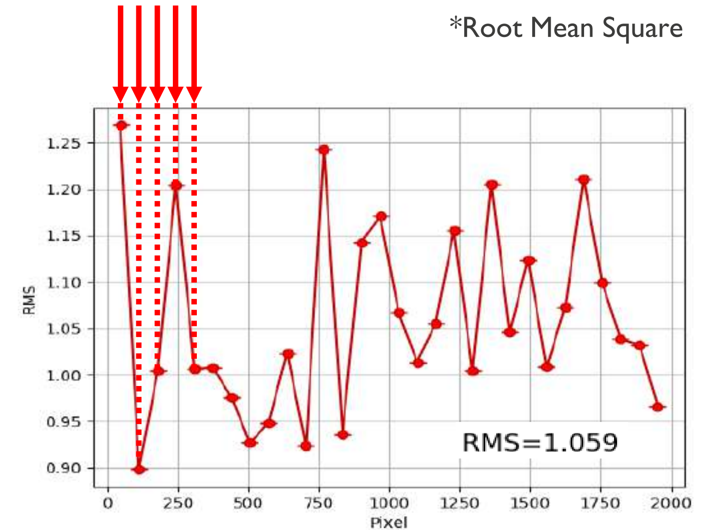
pitch=32.23 nm

Scan lines

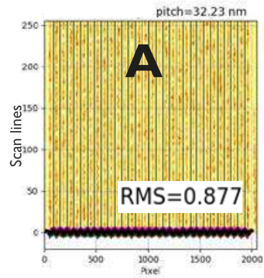
Pixel

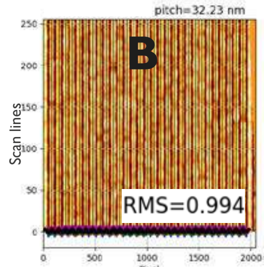
RMS* is calculated **on top** of **each** line and average per image

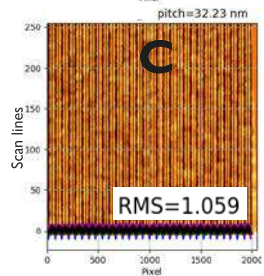
*Root Mean Square



# EUV TOP LINE ANALYSIS L/S, Pitch: 32

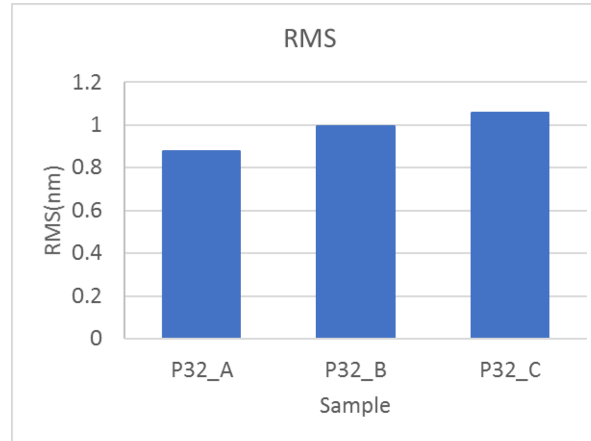


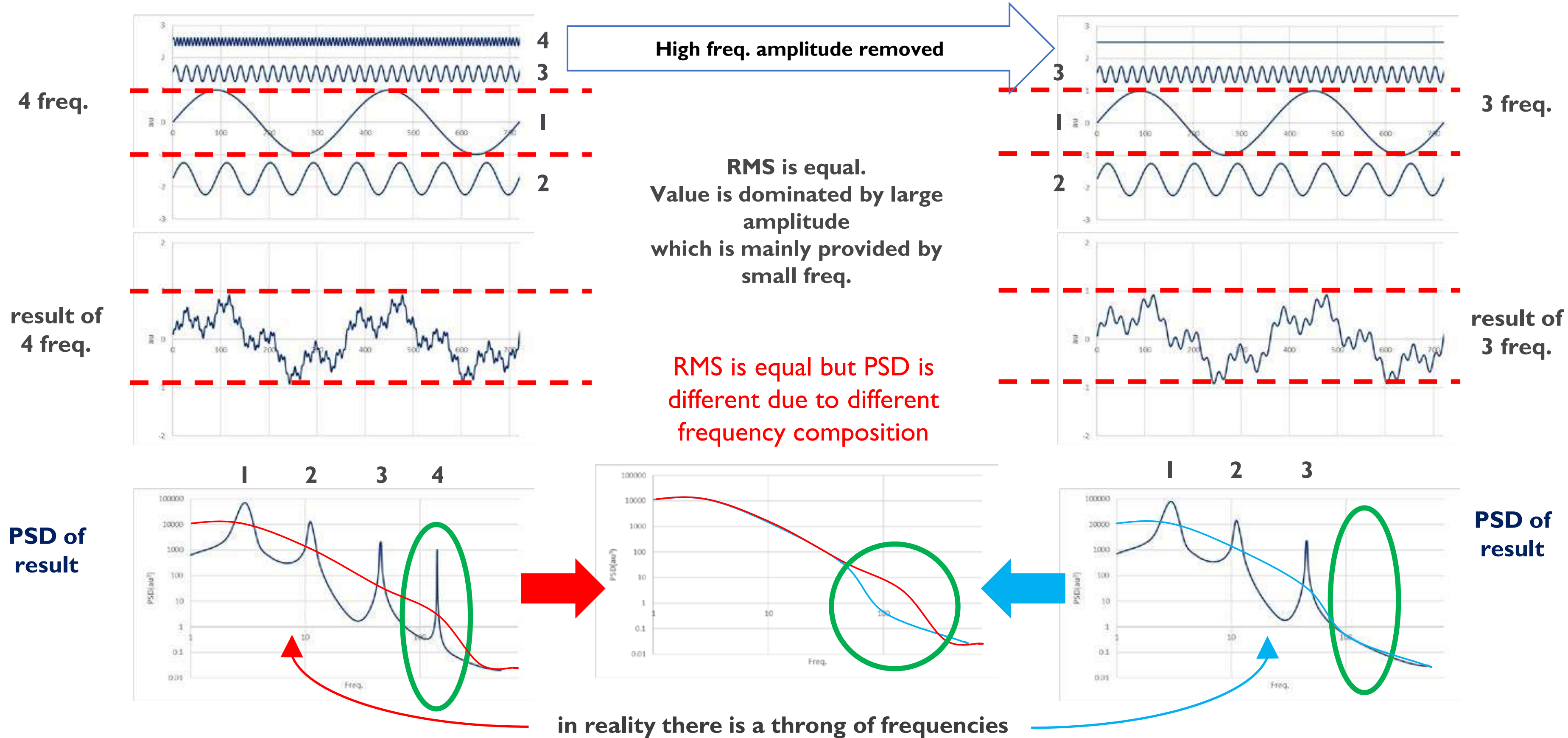

**1x1um images**

The contrast difference in the image is due to the colored Z-scale.
The line height is different for each sample.
Samples A, B, C are obtained with different process conditions.




RMS barely changes from sample A to C
RMS is not sufficient to describe roughness variations
Frequency analysis is required ⇨ PSD analysis (Power Spectral Density)

# NEW METRIC: PSD ANALYSIS



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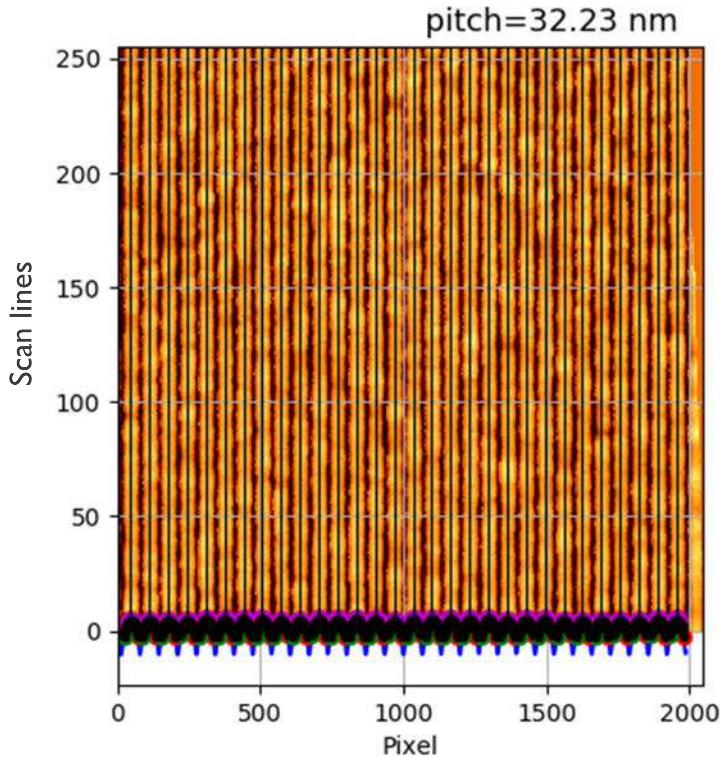
PUBLIC

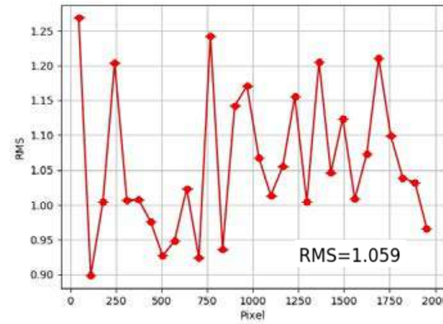
1x1um images

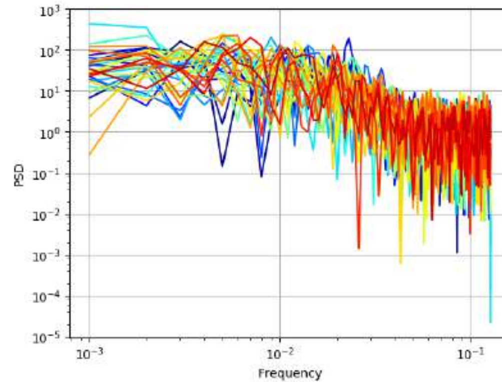
# EUV TOP LINE ANALYSIS

L/S, Pitch: 32

## ROUGHNESS + PSD ANALYSIS



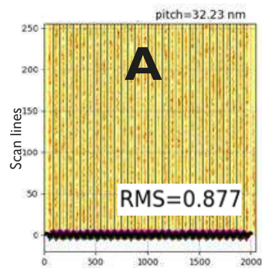

Pixel=46
Pixel=112
Pixel=179
Pixel=243
Pixel=310
Pixel=375
Pixel=441
Pixel=506
Pixel=571
Pixel=638
Pixel=705
Pixel=768
Pixel=835
Pixel=901
Pixel=968
Pixel=1034
Pixel=1099
Pixel=1165
Pixel=1230
Pixel=1296
Pixel=1363
Pixel=1428
Pixel=1493
Pixel=1559
Pixel=1625
Pixel=1690
Pixel=1756
Pixel=1822
Pixel=1889
Pixel=1953

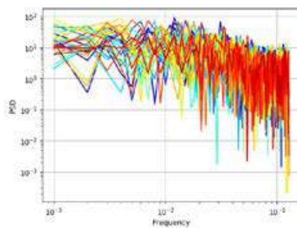
Number of lines studied per image (pitch dependent)

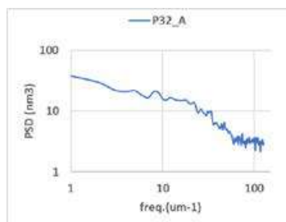
# EUV TOP LINE ANALYSIS

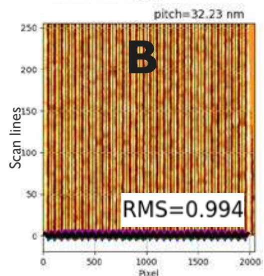
L/S, Pitch: 32

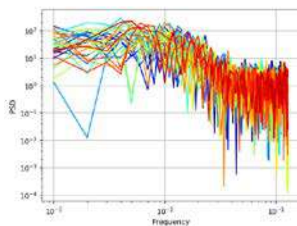
## ROUGHNESS + PSD ANALYSIS

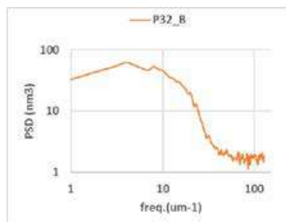


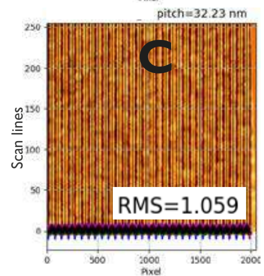



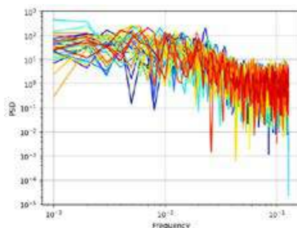


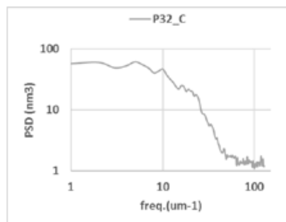



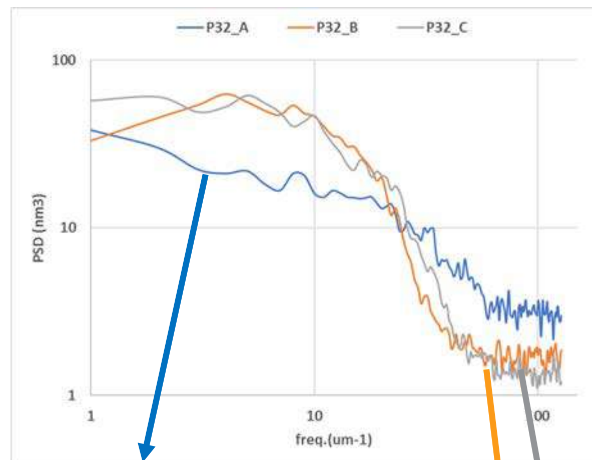


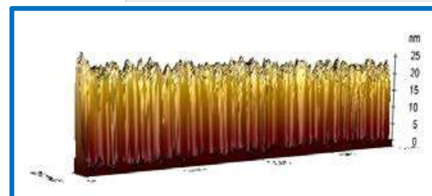






1x1um images



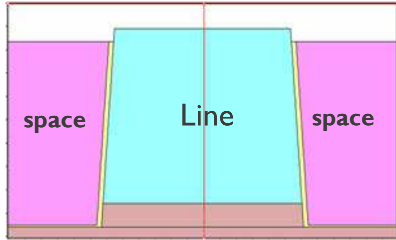
PSD curve is significantly different from sample A to B and C

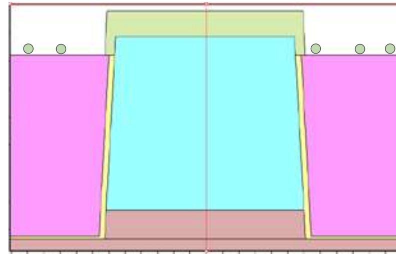
# AREA SELECTIVE DEPOSITION

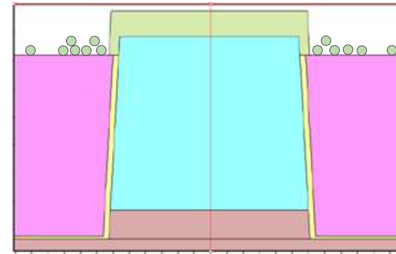
# SELECTIVE DEPOSITION

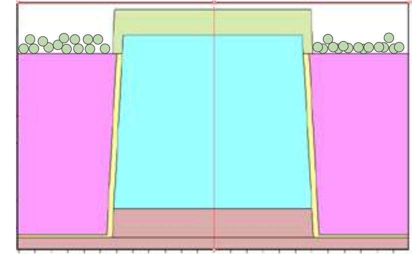
## WHAT IS THE METROLOGY CHALLENGE? HOW SELECTIVE IS IT?

If the bottom of the trench is flat, It should be "easy" to distinguish the deposition on it

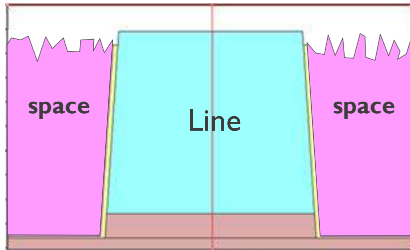


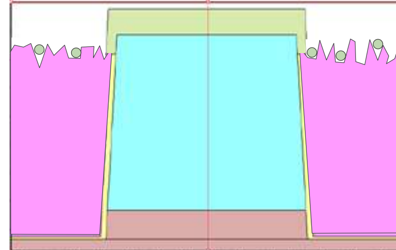




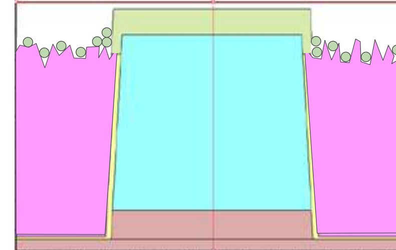
But, If the bottom of the space is rough?



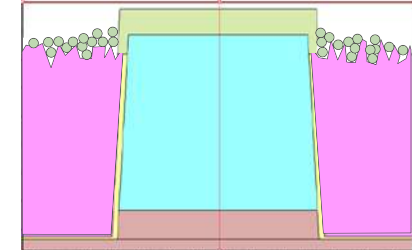

Reference
No deposition



Deposition "1"



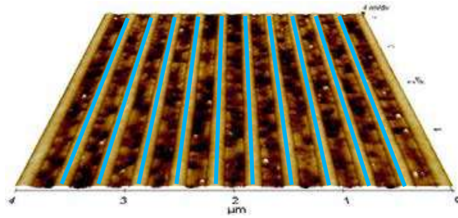
Deposition "2"



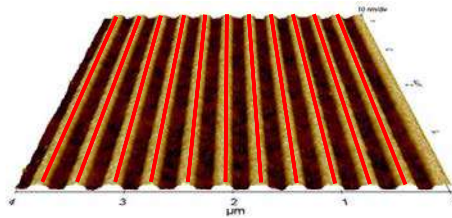
Deposition "3"

# SELECTIVE DEPOSITION

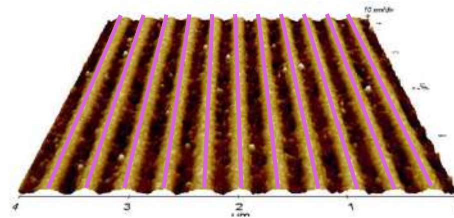
## WHEN SUBSTRATE IS FLAT: ON TOP OF FLAT LINE



Reference
No deposition



Deposition “1”



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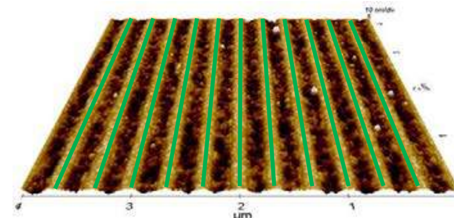
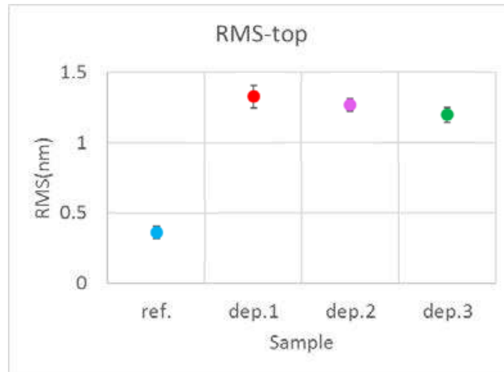
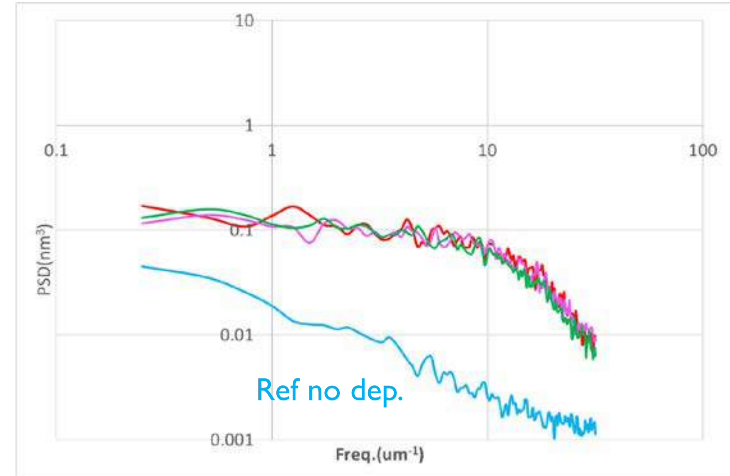


Deposition “3”



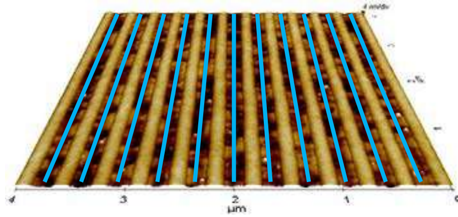

Calculating the **PSD** on section of each top line from one image and averaging them

PSD can be use to quantify the deposition **fingerprint**

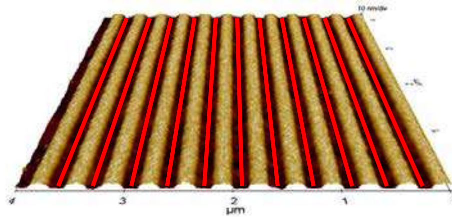


# SELECTIVE DEPOSITION

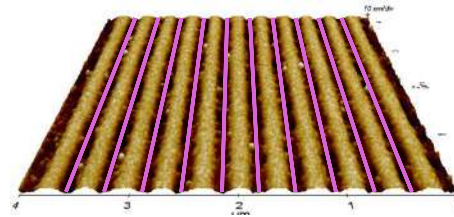
## WHEN SUBSTRATE IS ALREADY ROUGH: ON BOTTOM OF TRENCHES



Reference
No deposition



Deposition “1”



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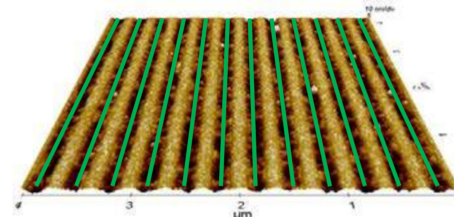
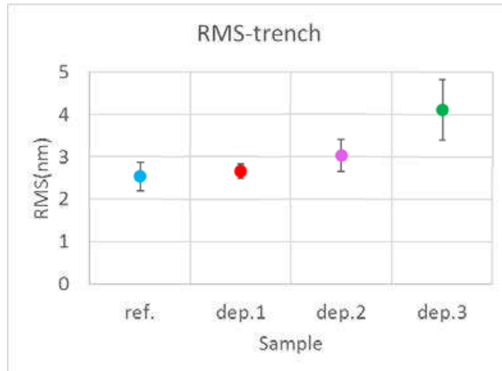
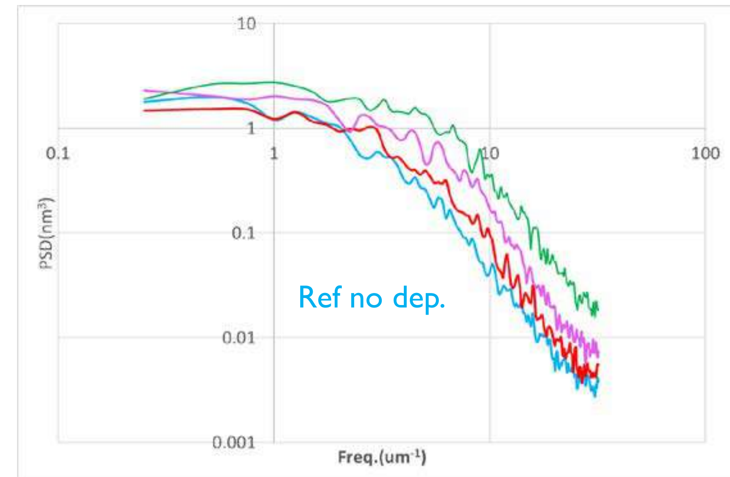


Deposition “3”




Calculating the PSD on section of each bottom trench from one image and averaging them

Samples with deposition DON’T show the same PSD!



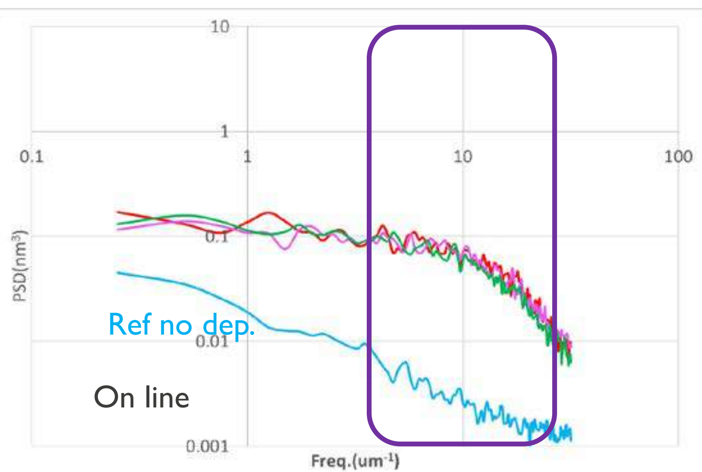
# SELECTIVE DEPOSITION
## SUMMARY

Reference
No deposition

Deposition “1”

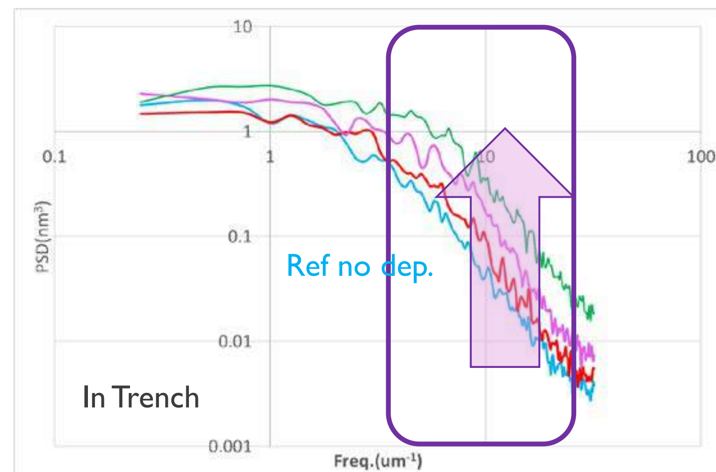
Deposition “2”

Deposition “3”



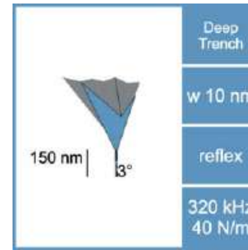

The deposition fingerprint is visible in PSD for top and trench

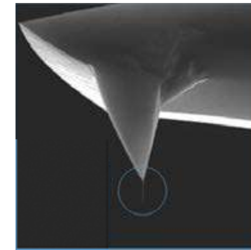
→ Selectivity can be quantified

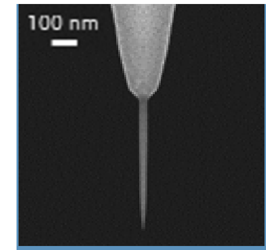


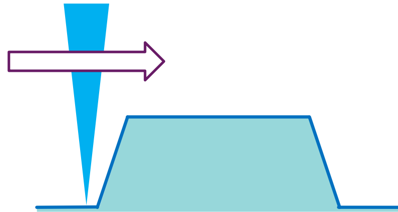
# SIDE WALL MEASUREMENT USING AFM

# SIDE WALL AND REAL PROFILE?

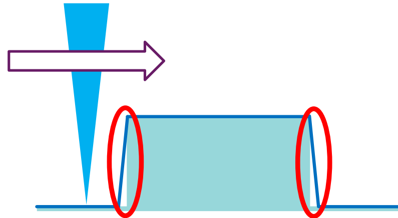


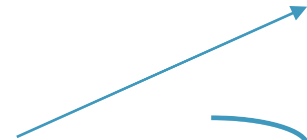


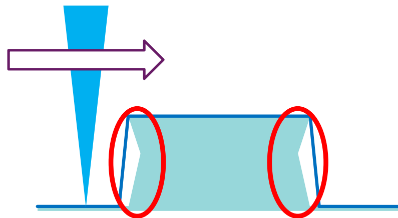
Side wall angle lower than
probe side angle
→ Profile OK



Probe geometry convoluted!
CD at bottom?
Side wall angle?



Side wall angle
smaller than
Probe side angle
Cannot be measured



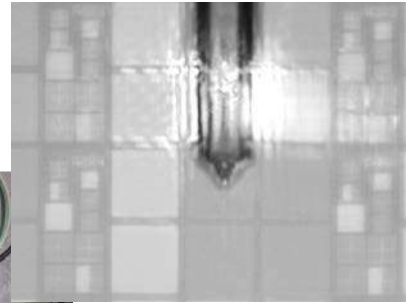
Probe geometry convoluted
Line geometry not revealed
Not real profile!

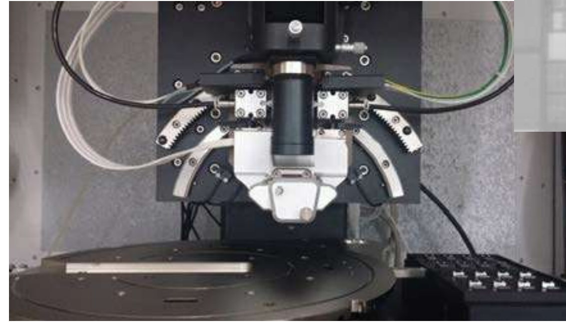
Same profile
(NOK)

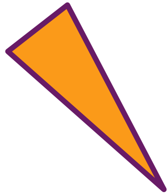
# PROFILE MEASUREMENT

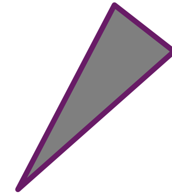
## 3D AFM WITH TILTED Z SCANNER

Center





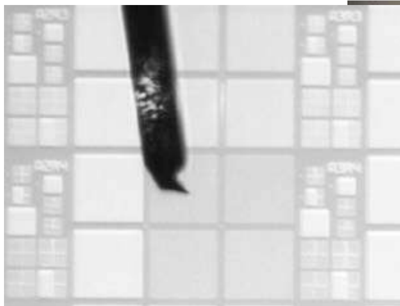


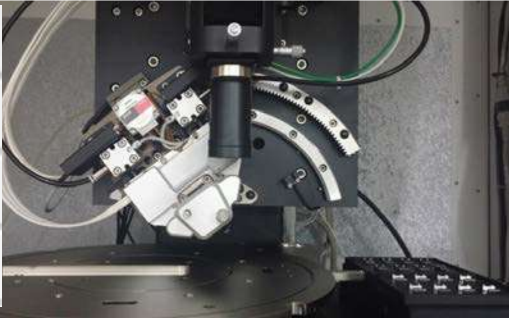


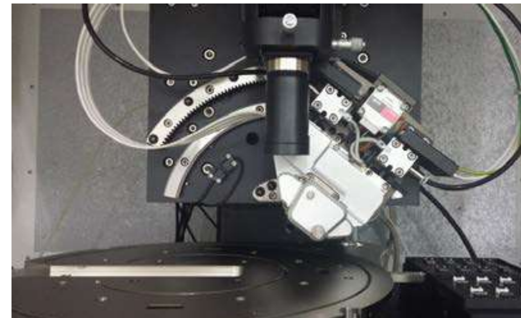
±19° and ± 38°

Left

Right



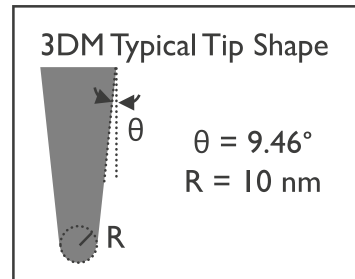




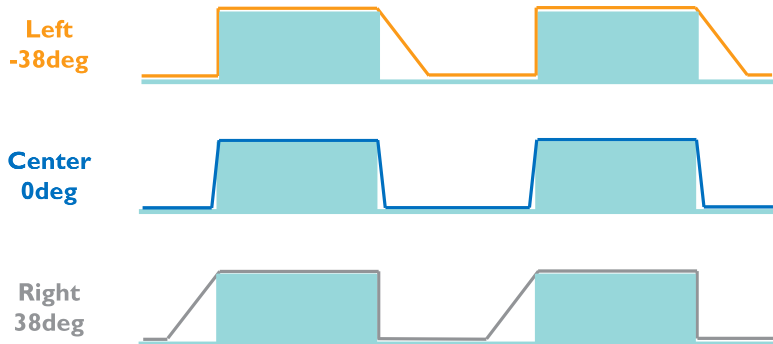
# PROFILE MEASUREMENT

## 3D AFM WITH TILTED Z SCANNER

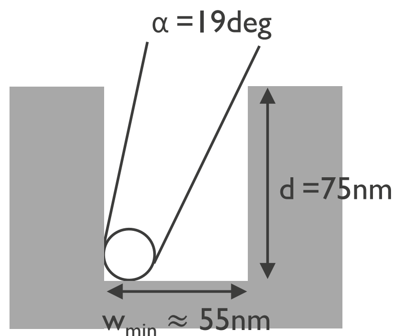
Probe compatible with tilt scanner are still "big"

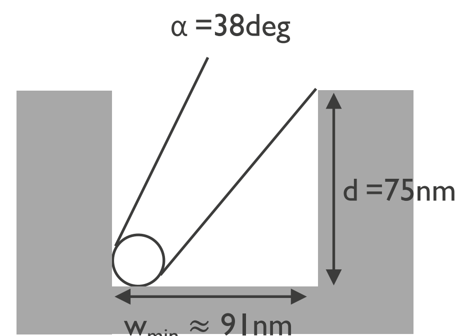



**Tilting the Z scanner allow to measure one side of the line per tilt**




Tilted measurement needs enough open area aside the side wall



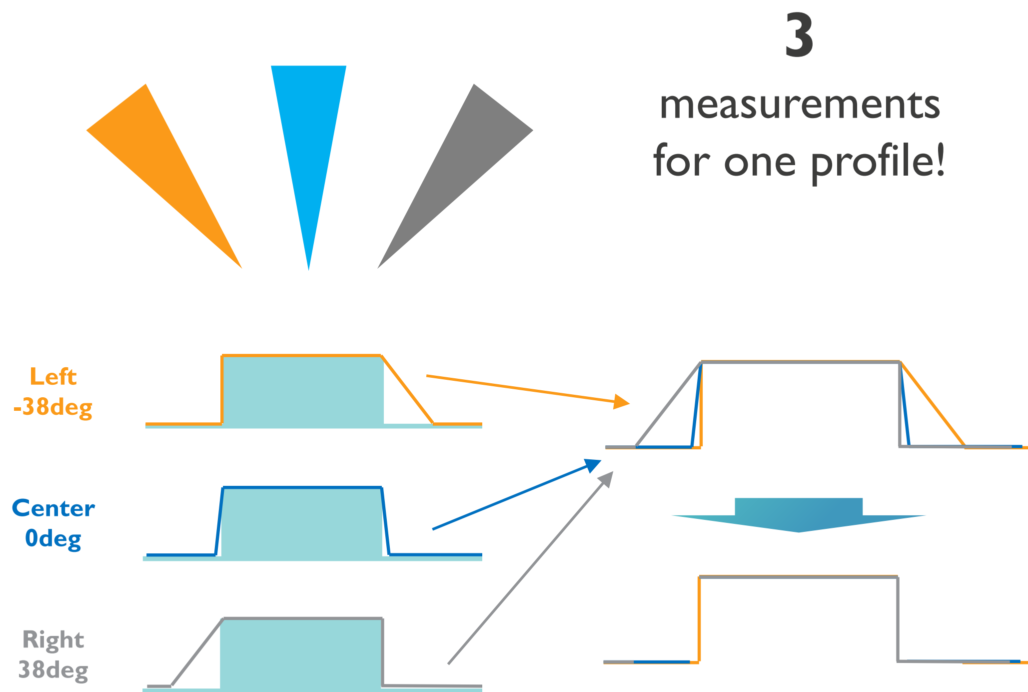



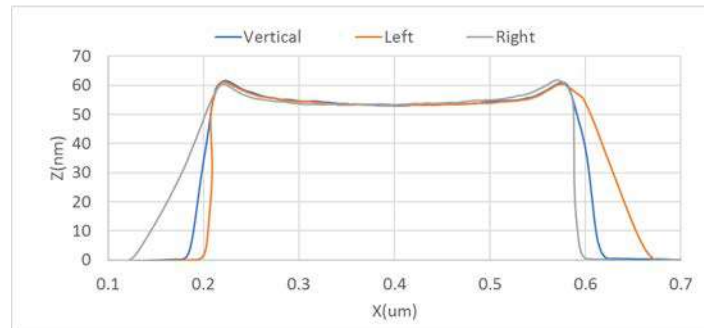
# PROFILE MEASUREMENT

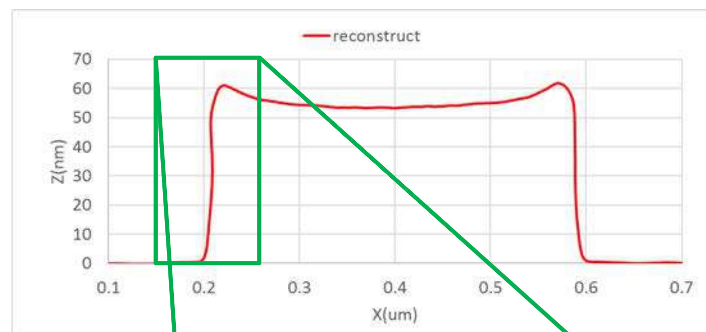
## 3D AFM WITH TILTED Z SCANNER

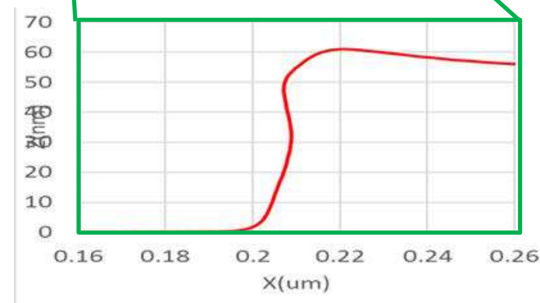
**3**

measurements for one profile!



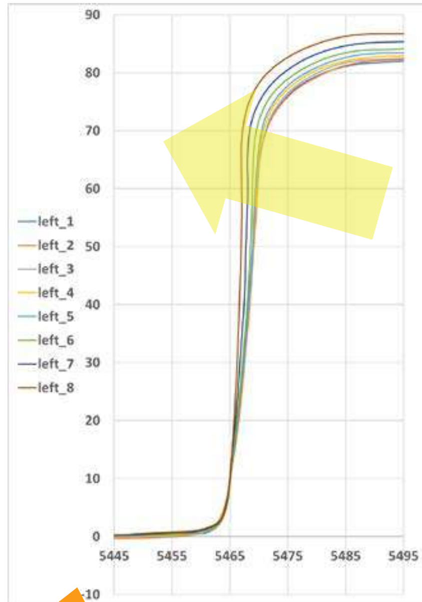



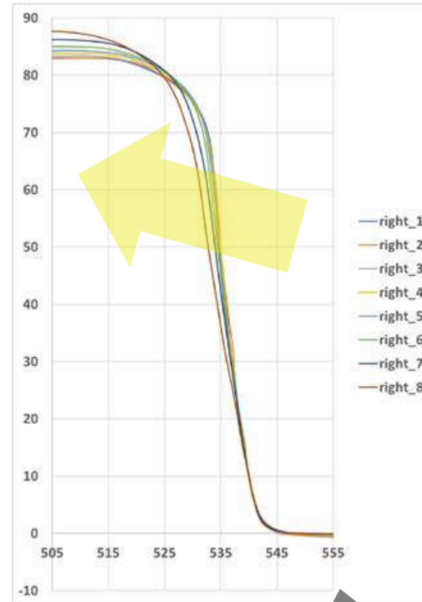



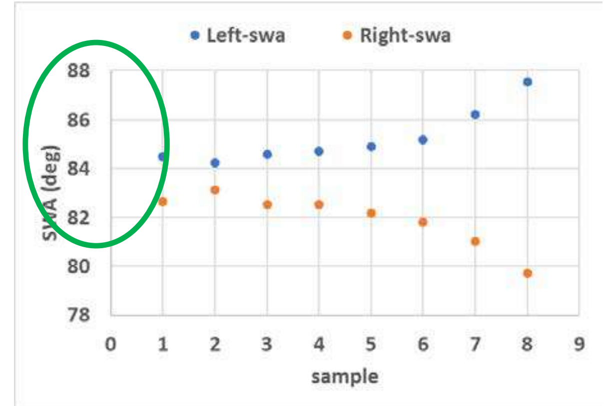



# SIDE WALL ANGLE (SWA)?

## WHEN LINE SWA IS SMALLER THAN PROBE SIDE ANGLE

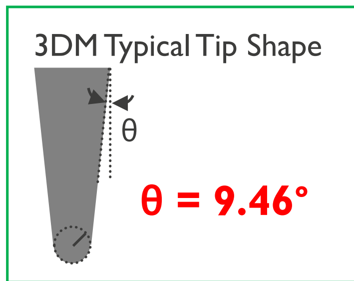


Left
-38deg

Right
38deg




Without tilting the scanner the left side wall couldn't have been measured

# CONCLUSION

# CONCLUSION

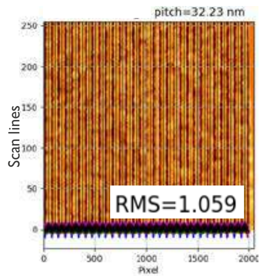
## SIGNAL ANALYSIS: POWER SPECTRA DENSITY

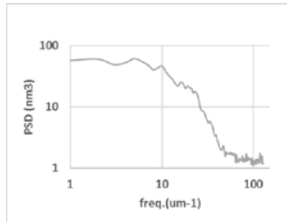
**EUV lines:**

when the probe and the space are of the same order

Discriminate area of interest in the image
Top of the line

RMS analysis
PSD analysis



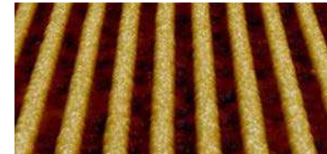



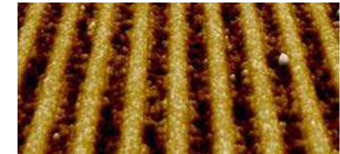

**Selective deposition:**

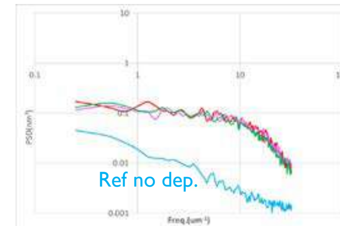
Small structures on rough substrate

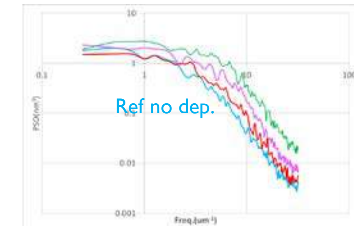
Discriminate area of interest in the image
Top of the line / Bottom of trench

RMS analysis
PSD analysis

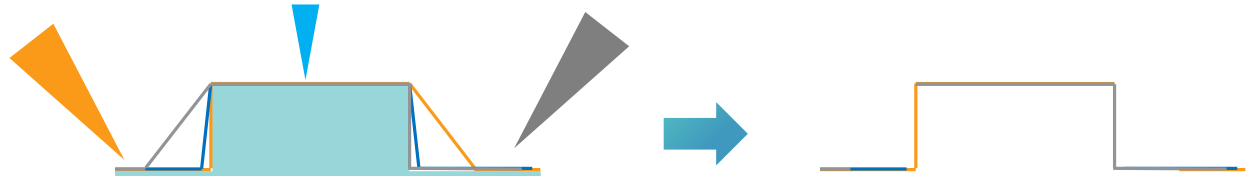




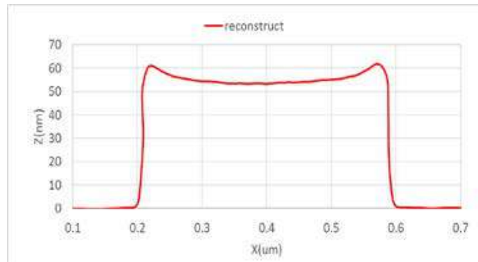


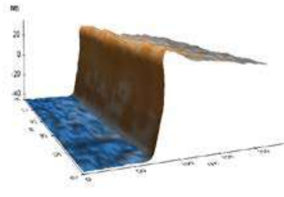



# CONCLUSION
## TILTED SCANNER HEAD



### Profile

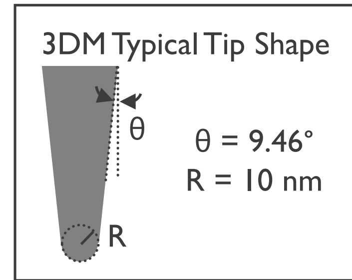


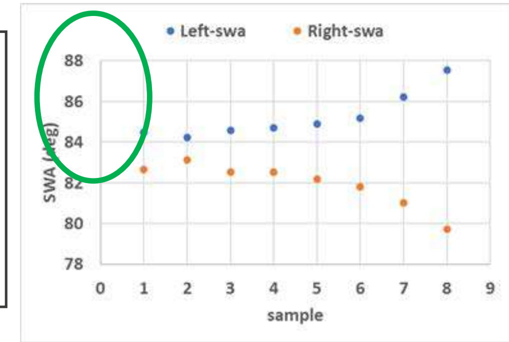



If space aside the line is large enough.
→Aspect ratio

Need 3 measurements
and profile reconstruction
→Time

### Side Wall Angle



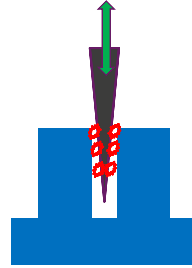



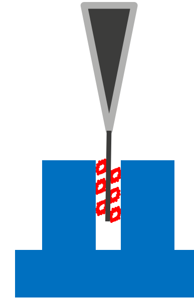

If space aside the line is large enough.
→Aspect ratio

Need 1 measurement per side
(So two per Line, Left/Right)
→Time

# OUTLOOK

- Measurement of 10-16nm trenches
  - Need sharper probe (dwcnt)?
    - But will it work?





- Tilted measurement
  - Need sharper probe

- Acquisition speed
  - Faster acquisition time but with same accuracy...

# THANK YOU
# FOR
# YOUR ATTENTION