In-situ monitoring of the Atomic Force Microscopy (AFM) tip by analysing the cantilever's higher harmonic vibrations

Enrique Rull, Urs Staufer
Delft University of Technology

Jordi Fraxedas, Francesc Pérez Murano
ICN2-CNM-CSIC

MNC

8/12/2015

aim4np

TU Delft

Outline

- Automated in-line Metrology for Nanoscale Production (aim4np)
- Overview and fundamentals
- Tip monitoring in Amplitude Modulation AFM
- Conclusions

Outline

- **Automated in-line Metrology for Nanoscale Production (aim4np)**
- Overview and fundamentals
- Tip monitoring in Amplitude Modulation AFM
- Conclusions

TU Delft

A challenge in industry

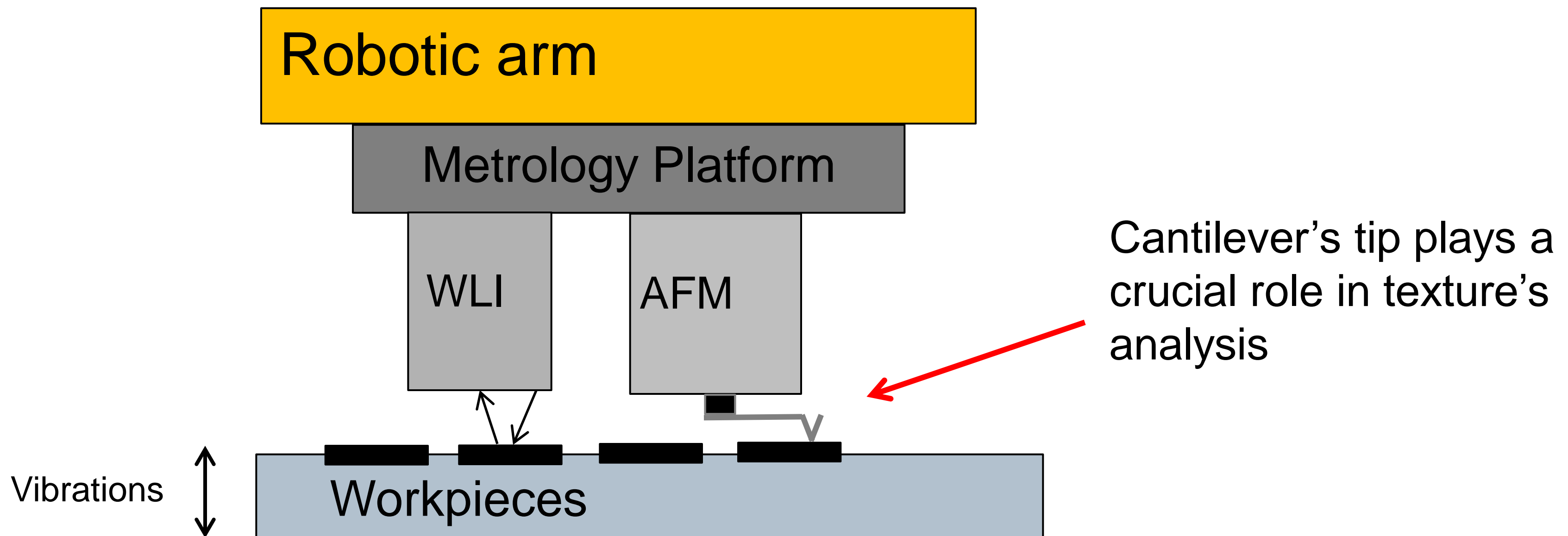
- Surfaces characterization in nanoscale

- Texture analysis

TUDelft

New metrological processes in industry

- Aim4np: (Automated in-line Metrology for Nanoscale Production)



AFM…Atomic Force Microscope

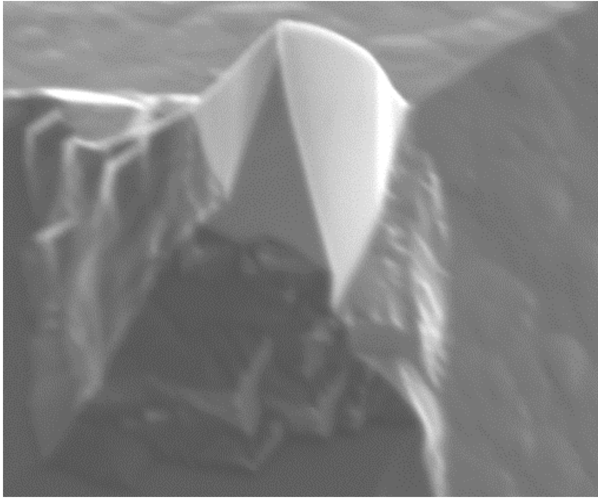
WLI…White Light Interferometer

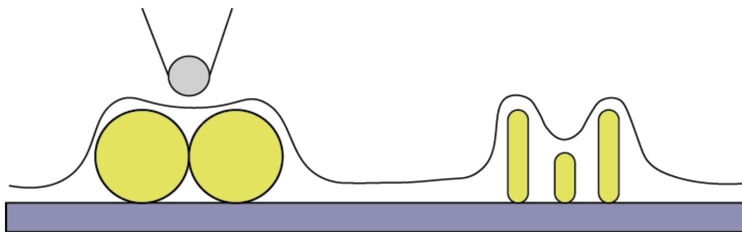
TU Delft

Outline

- Aim4np Project: New metrological processes in industry
- **Overview and Fundamentals**
- Tip monitoring in Amplitude Modulation AFM
- Summary and conclusions

Tip shape and wear studies



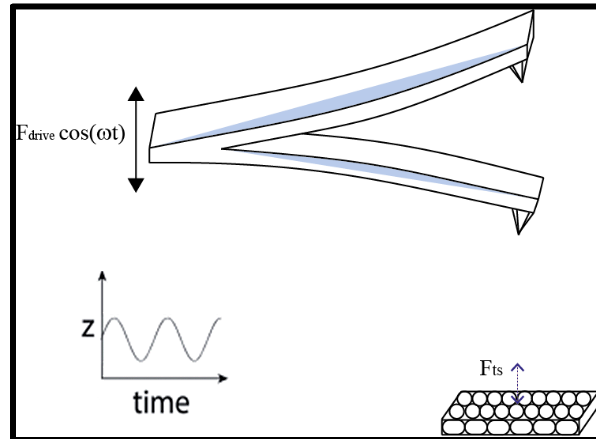


- Tip shape during scanning
  - Hard samples: tip wear
  - Soft samples: tip contamination
- Techniques
  - Choosing right parameters
  - Tip characterization

Information from Tip-sample interaction

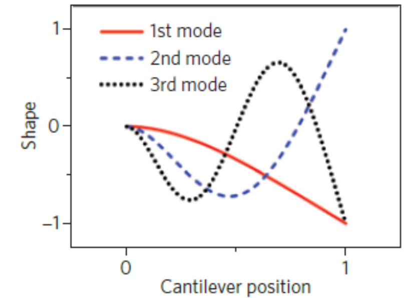
Tip-surface interaction OFF:

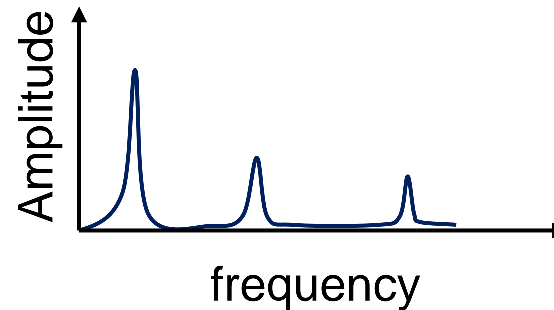
Free oscillating cantilever: flexural eigenmodes



f_0, 6.27 f_0, 17.55 f_0, …

k, 39.31k, 308k, …



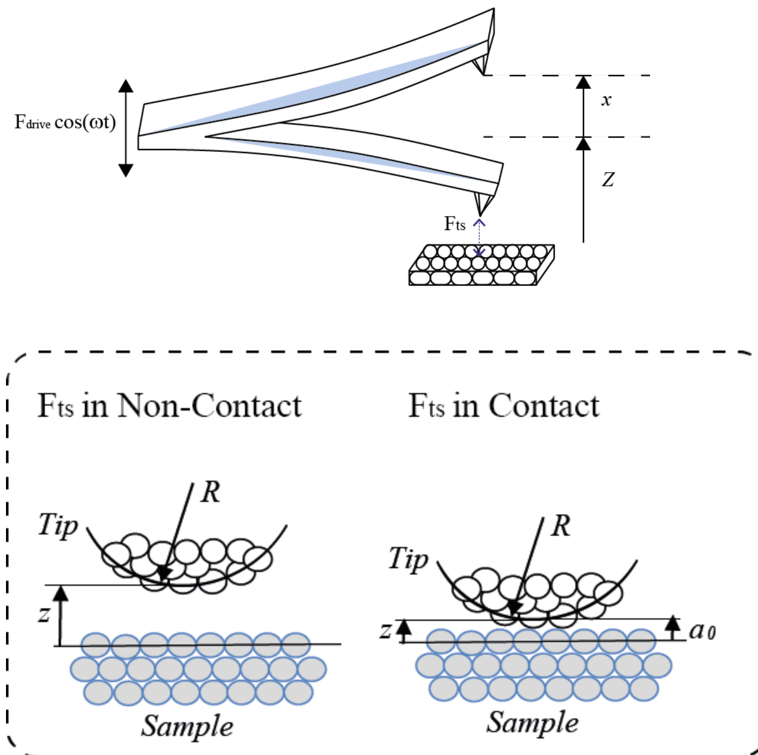


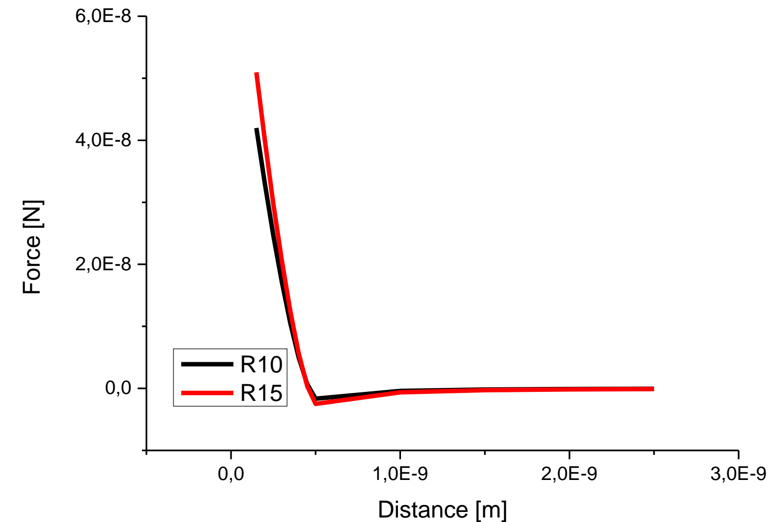
Amplitude-Modulation AFM (Tapping Mode)

Frequency constant (close to 1st resonance)
Amplitude modulated

Information from Tip-sample interaction

- The tip-sample interaction introduces nonlinearity into the system
- Dependence: Tip radius





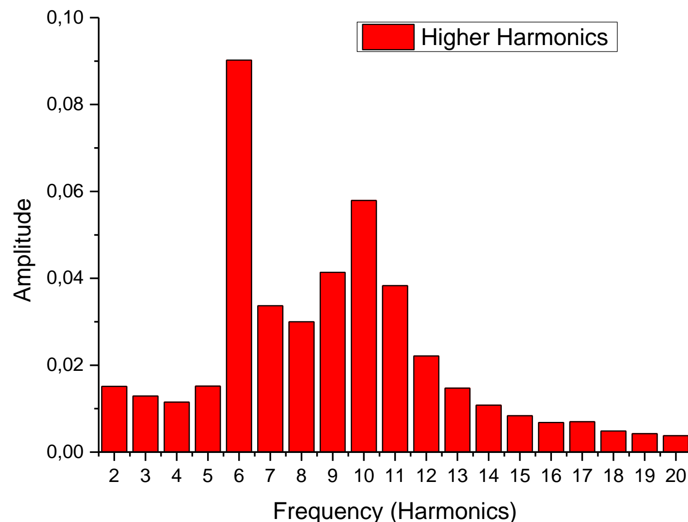
$$F_{ts}(d) = \begin{cases} -\dfrac{HR}{6d^2}, & d > 0 \\ -\dfrac{HR}{6a_0^2} + \dfrac{4}{3}E^*\sqrt{R}(a_0 - d)^{3/2}, & d \le 0 \end{cases}$$

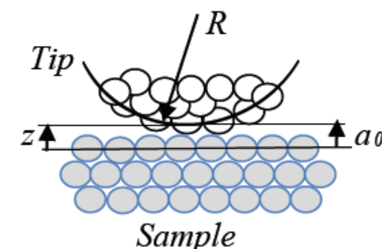
Why Higher Harmonics

Tip-surface interaction ON

- Higher Harmonics
  - The nonlinear interaction between tip and sample induces higher frequency vibrations that are harmonics of the fundamental

f_0, 2 f_0, 3 f_0, 4 f_0, 5 f_0, 6 f_0, 7 f_0, …nf_0

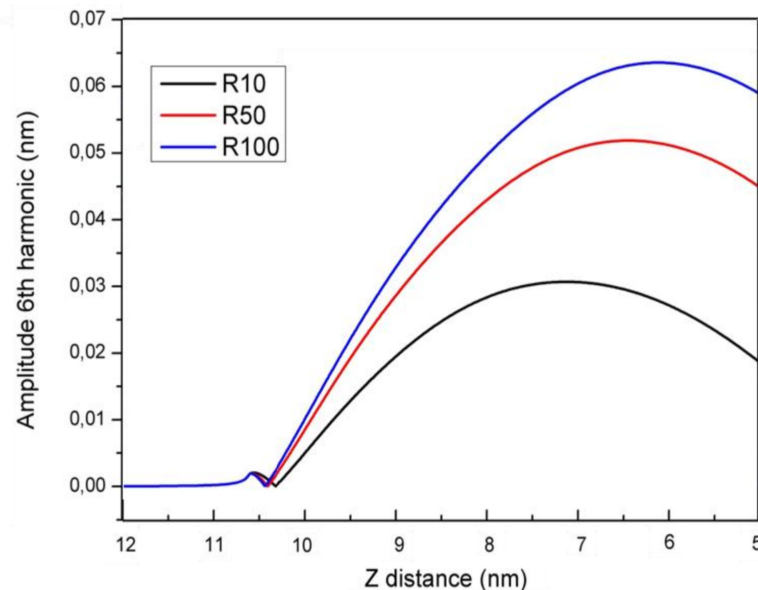




Simulations

- Amplitude increases with the tip radius

Approach Curves: Register the excitation of the harmonic signals during the approach of an oscillating cantilever to a surface.



A. Raman et al. (2013), VEDA: Virtual Environment for Dynamic AFM,
DOI: 10.4231/D3KW57J1T

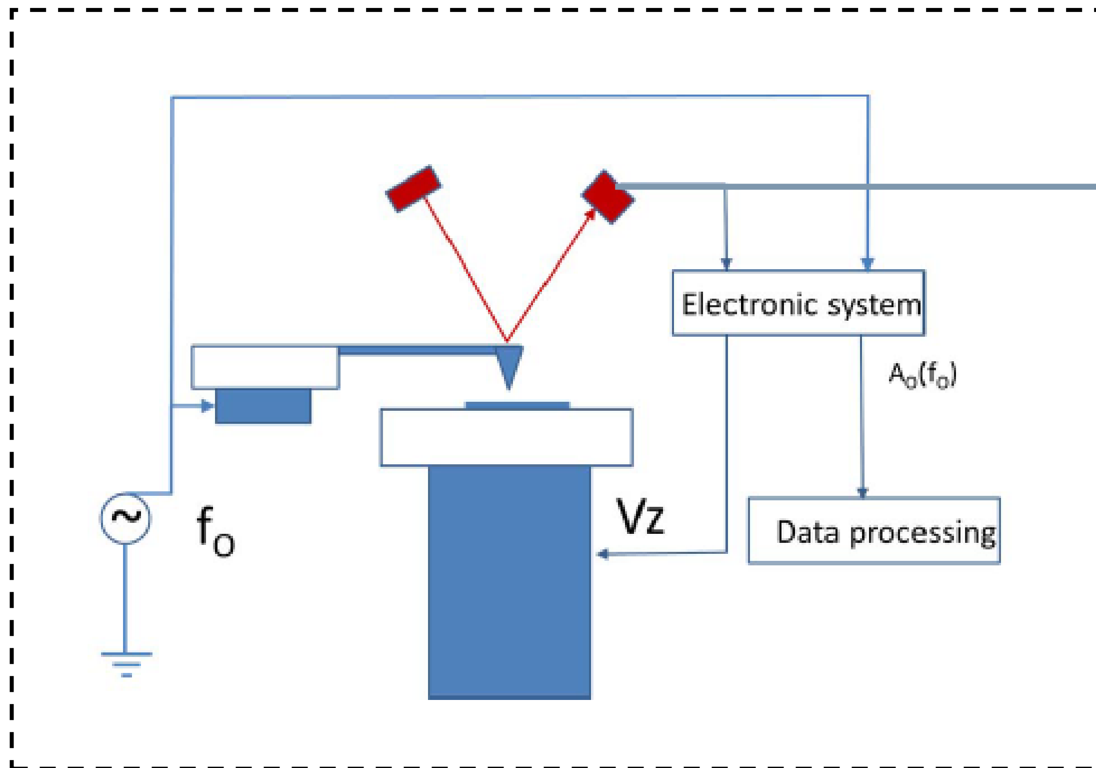
TUDelft

Outline

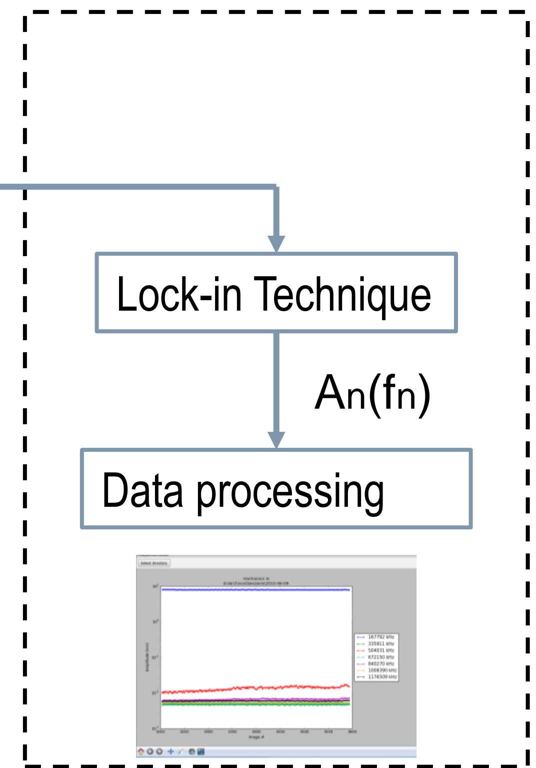
- Automated in-line Metrology for Nanoscale Production (aim4np)
- Overview and fundamentals
- **Tip monitoring in Amplitude Modulation AFM**
- Conclusions

Setup for reading harmonics

AFM Configuration



Higher Harmonics



Monitoring technique

- Continuous analysis

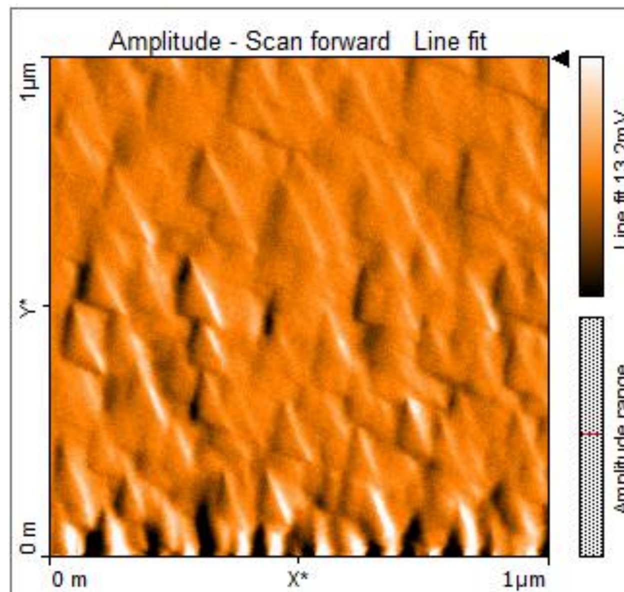
Monitor the amplitude of the harmonics while scanning the topography of samples

TiN

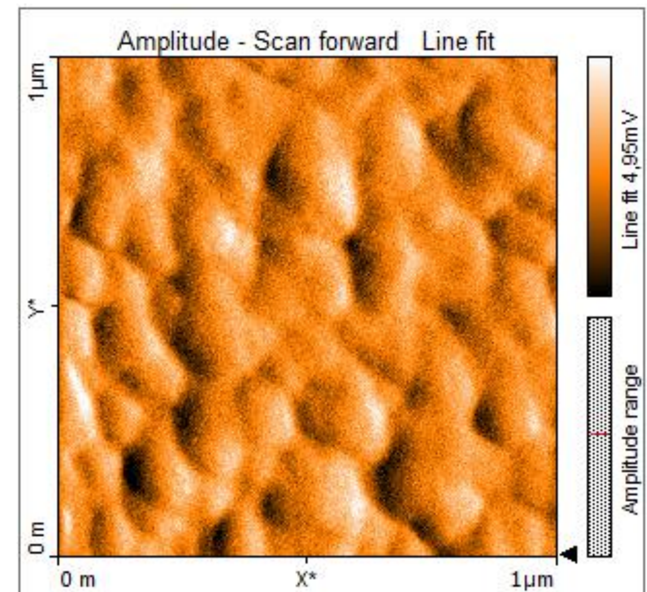
F1=166kHz

A1=16nm

First Image



Last Image



Monitoring technique

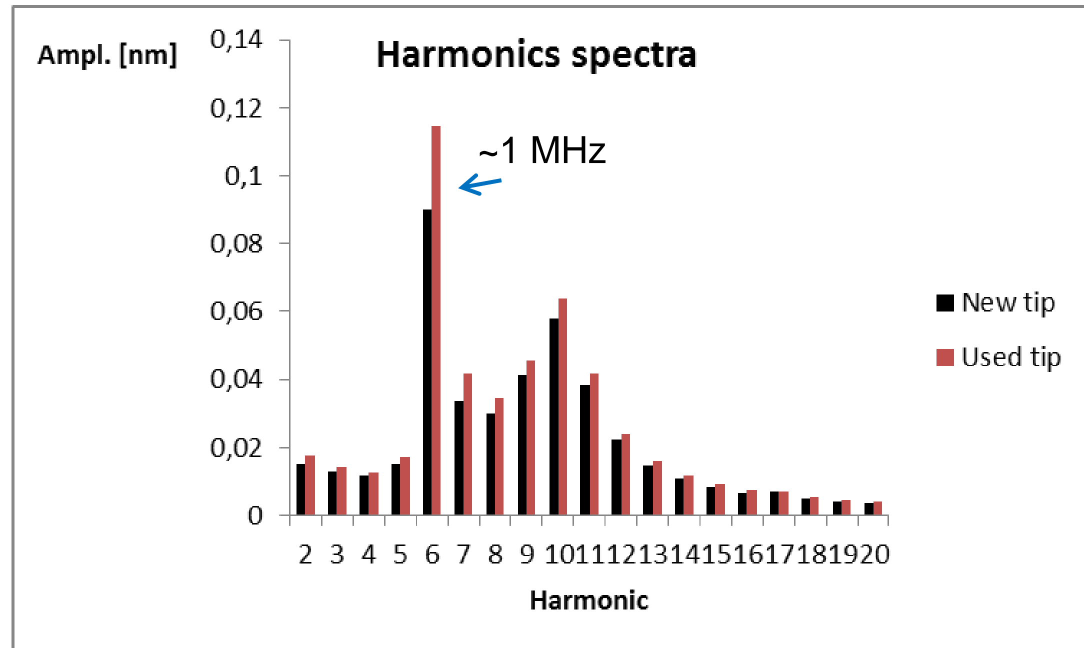
- Continuous analysis

Monitor the amplitude of the harmonics while scanning the topography of samples

TiN

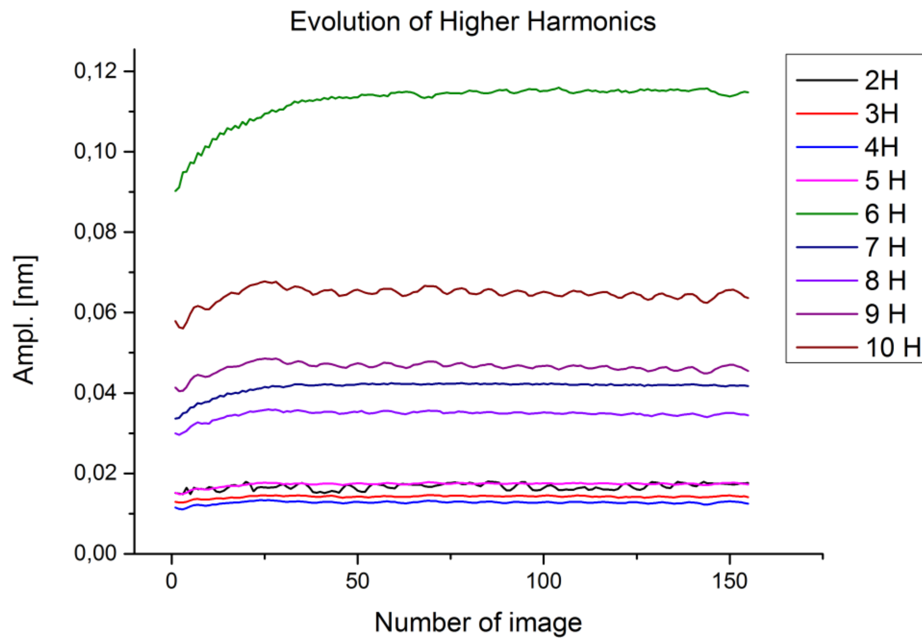
F1=166kHz

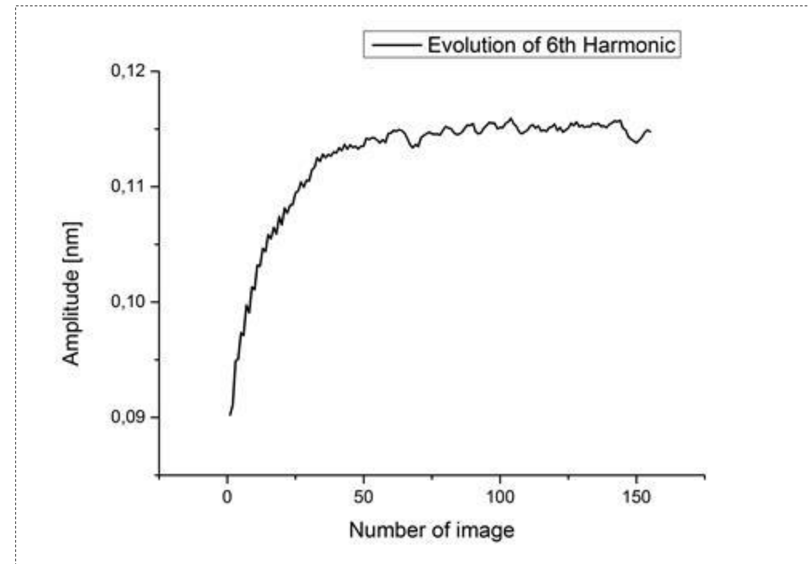
A1=16nm

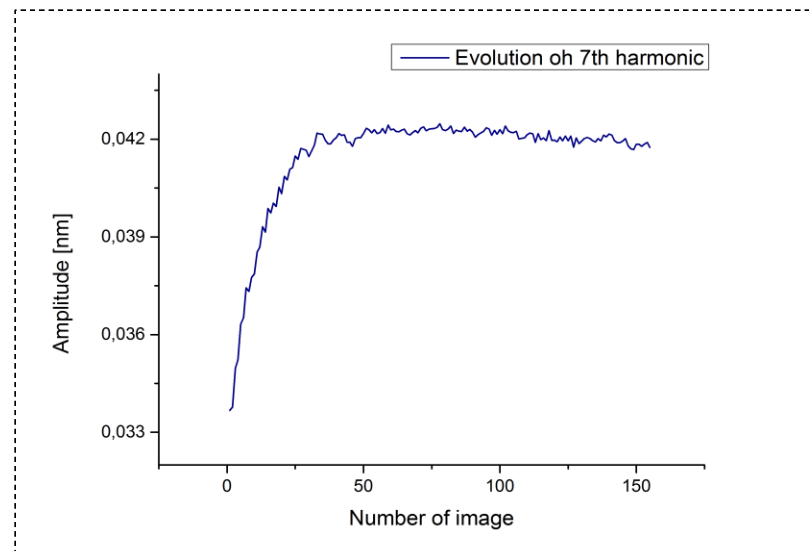


Monitoring technique

- Harmonic monitoring graphs







TU Delft

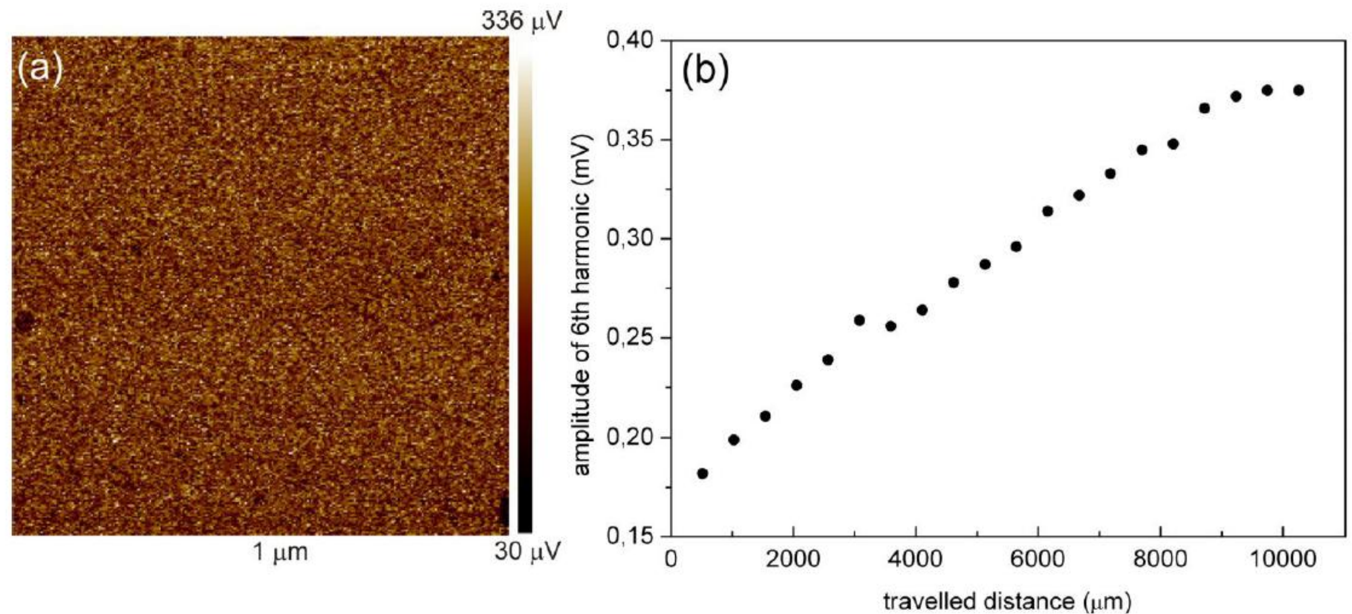
Monitoring technique

- Continuous scanning analysis

Monitor the amplitude of the harmonics while scanning the topography of samples

PS

F0= 300kHz



Outline

- Automated in-line Metrology for Nanoscale Production (aim4np)
- Overview and fundamentals
- Tip monitoring in Amplitude Modulation AFM
- **Conclusions**

Conclusions and Outlook

- Tip monitoring is feasible by tracking the evolution of the amplitude of higher harmonics of the fundamental mode
- Experimentally verified in the 3-45 N/m range and verified by modeling of the tip-sample interaction under dynamic mode operation conditions
- Continue studying the relationship between harmonics and cantilever's properties

Acknowledgements