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Accelerating Yield

Surface Scattering technique for Micro-roughness characterization

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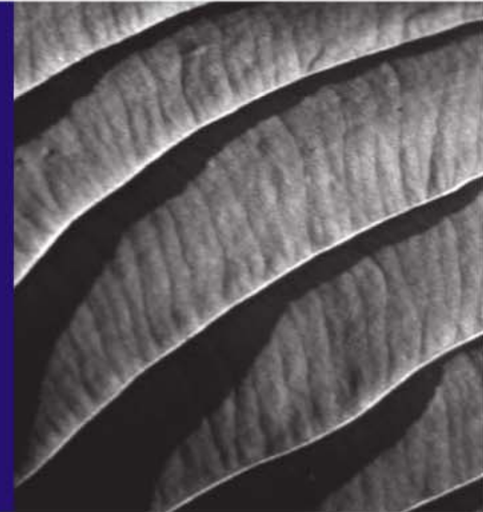

Outline

- Background & Motivation
- Theory
- Methodology
- Results
- Conclusions and Future Work

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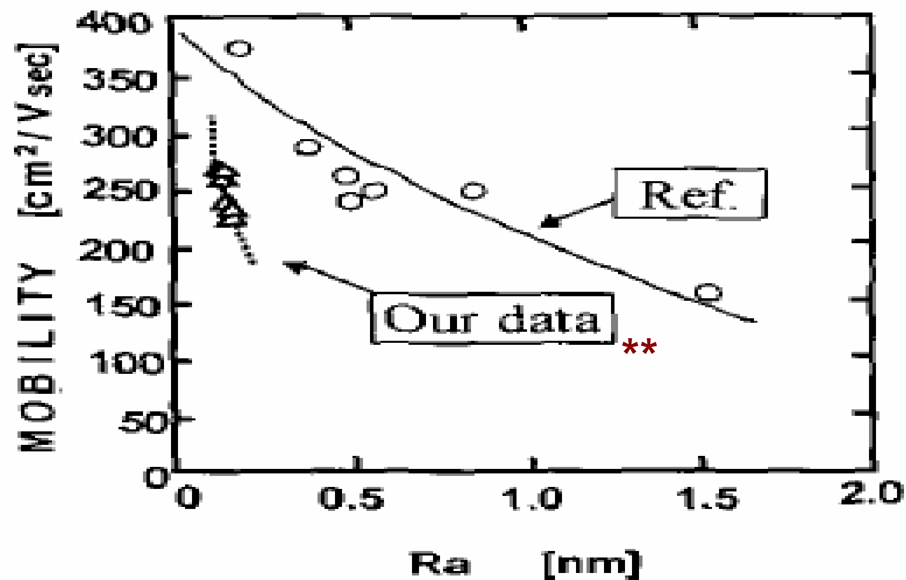
Surface – The Next Frontier

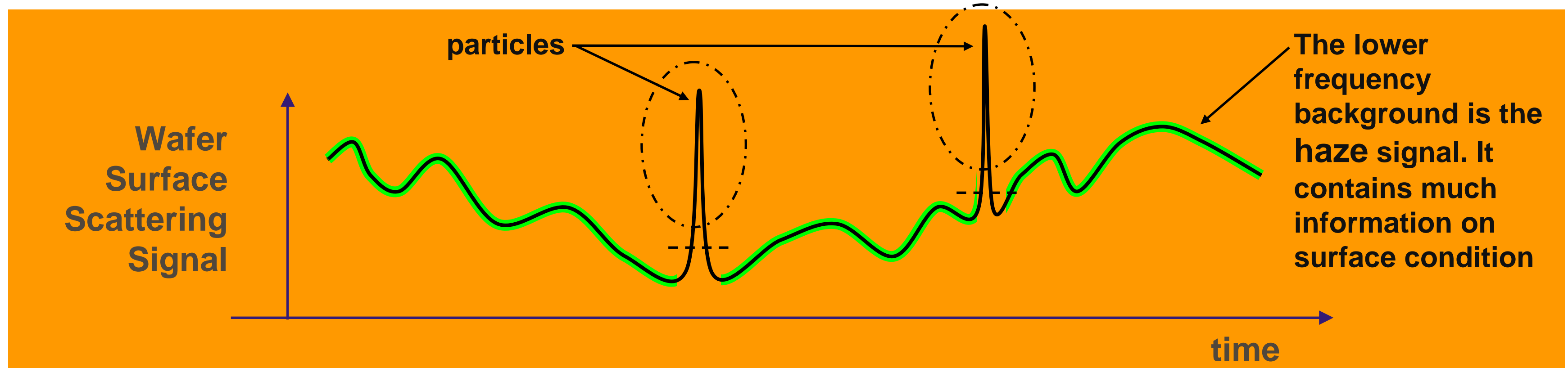
- Surface condition is now becoming the next challenge and limiter for yield and device performance

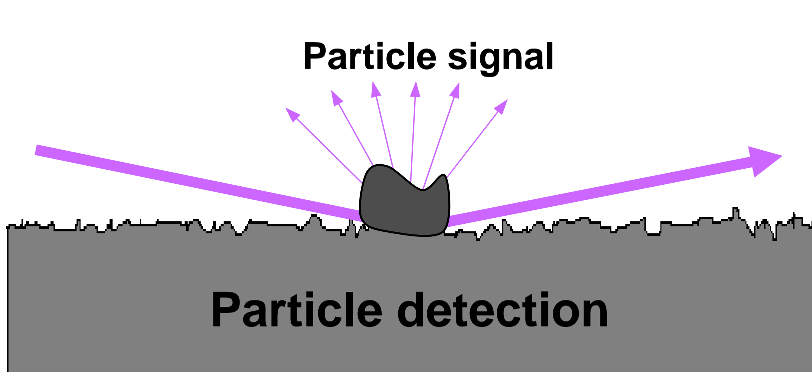


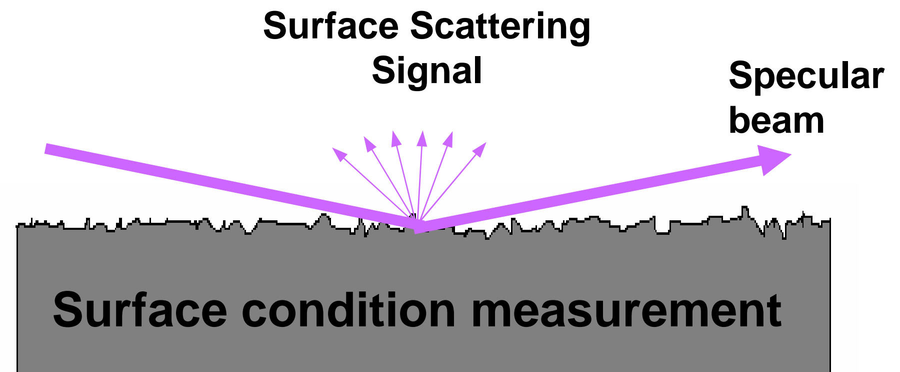
- Full-wafer surface characterization tools are needed

** Nemoto et al., IEEE ISSM 2003

Laser scattering can measure both particles and surface morphology







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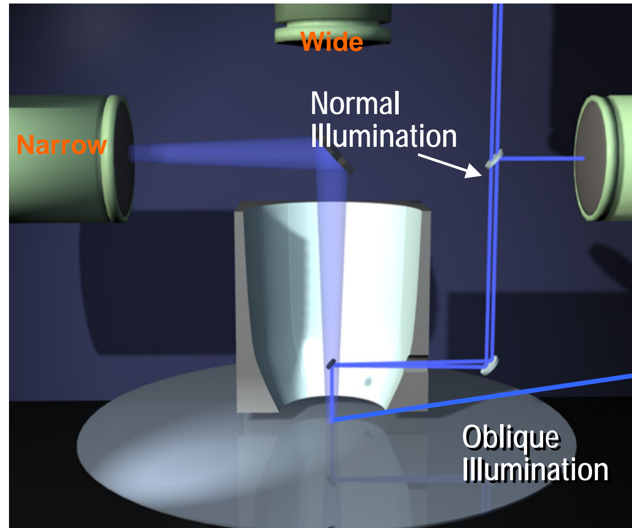
Schematic of SP2 Surface Scanning System



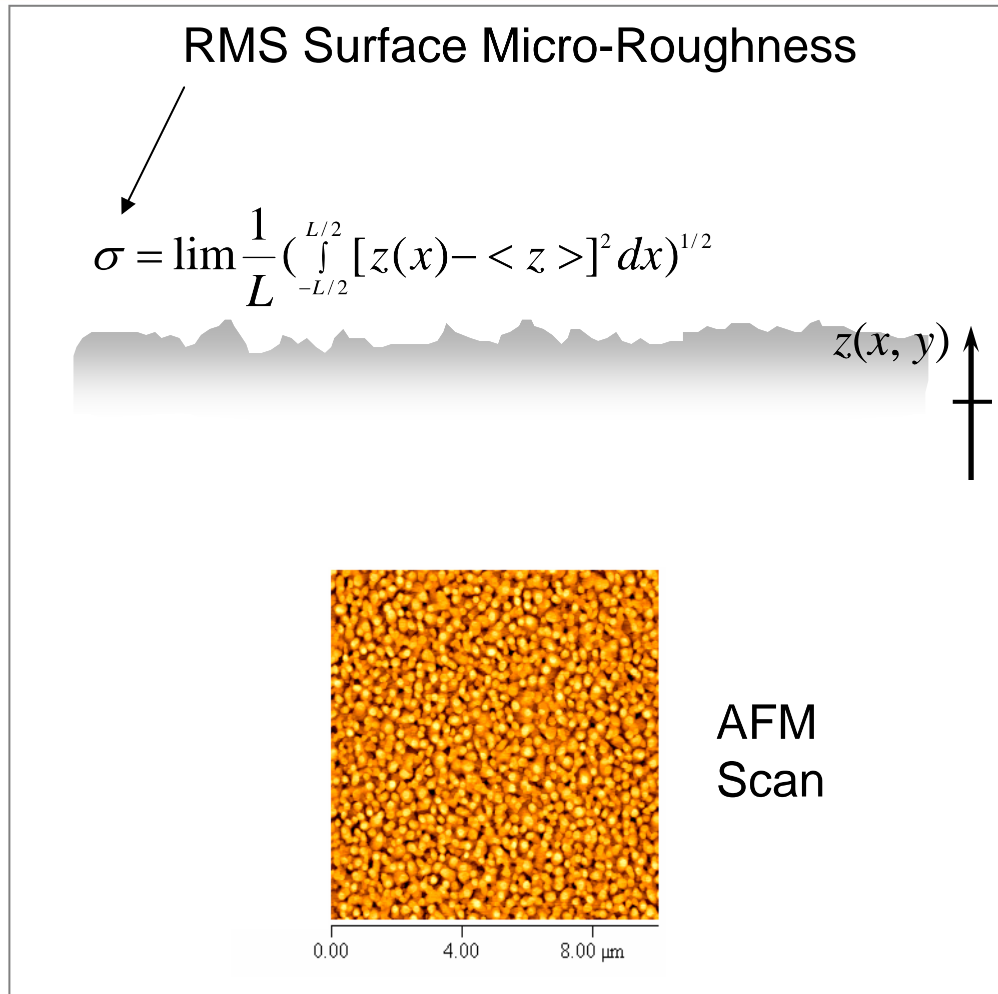
2 incidence modes: Normal and Oblique

2 channels of data collection: Wide and Narrow

Light source: UV laser

Scan time: 45s - 3 minutes per wafer

What is RMS Roughness?



Roughness contains information about grain size, film morphology, crystallinity

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For comparing across measurement systems, a more general treatment is needed

Any surface can be described by a spectrum of Spatial frequencies PSD(f)

$$\sigma = \left(\int_{f\,min}^{f\,max} PSD(f)\,df \right)^{1/2}$$

f_{min} and f_{max} are the limits of the instrument

For a light scattering inspection system

$$f = \frac{\sin(\theta_s) - \sin(\theta_i)}{\lambda}$$

θ_i and θ_s are the angles of incident and scattered light

λ is the wavelength of the light

For a surface profiler or AFM

$$f_{\min} = \frac{1}{L}$$

L is the scan length

$$f_{\max} = \frac{1}{2d}$$

d is the sampling distance or the min. system resolution, whichever is larger. (In this study, rel. large AFM scans were taken, so d is the sampling distance)

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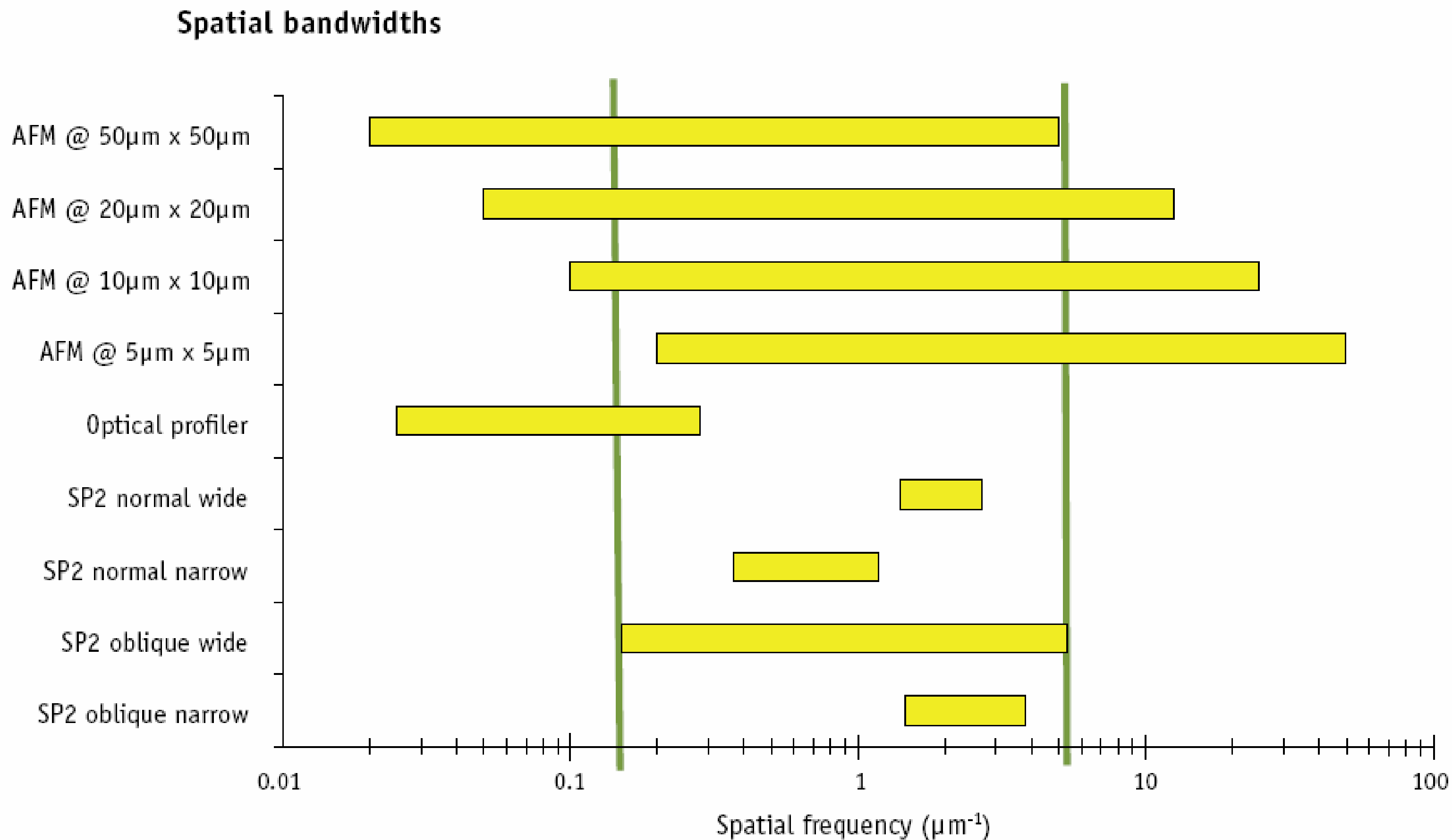
Comparison of AFM and SP2 spatial frequencies



Significant overlap between AFM* and SP2, especially for the "Oblique-Wide" channel

* Park Scientific Instruments M5™

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Relationship between Haze and Surface Roughness

$$Haze = \left(\frac{4\pi \cos(\theta_i)}{\lambda} \right)^2 \bullet R_0 \sigma^2$$

R_0 is the specular reflectance of the surface

Haze is proportional to σ^2

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Methodology

- Sample: Clean CU ECD wafer with large x-wafer grain size variation
- Data Collection:
  - AFM: tapping mode, Park Scientific Instruments M5™
  - Surface Scanner: KLA-Tencor SP2, Oblique and Normal Incidence
- Analysis:
  - "Frequency-matched" roughness was calculated (to match SP2 spatial bandwidths)

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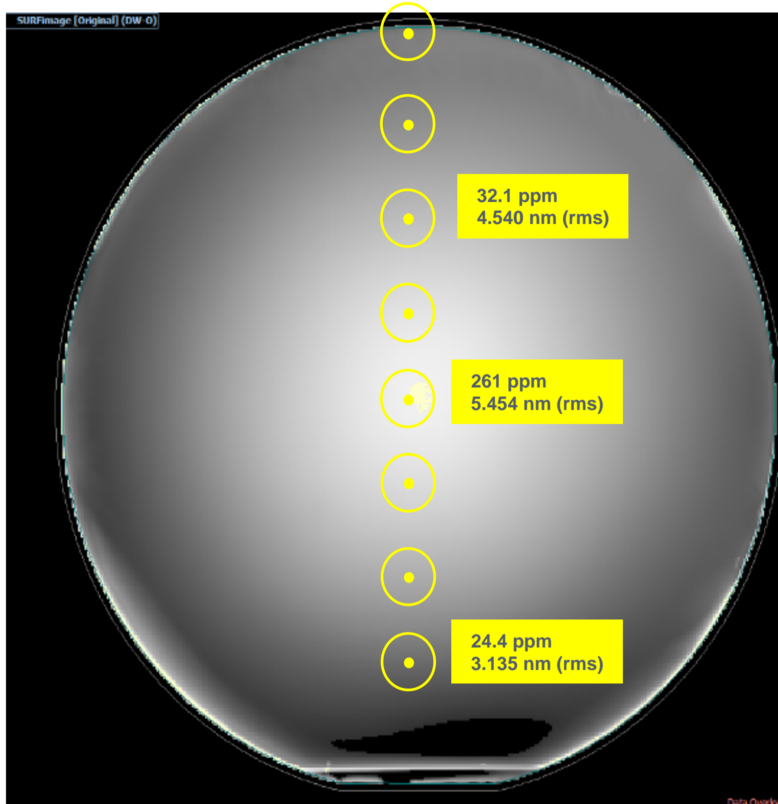
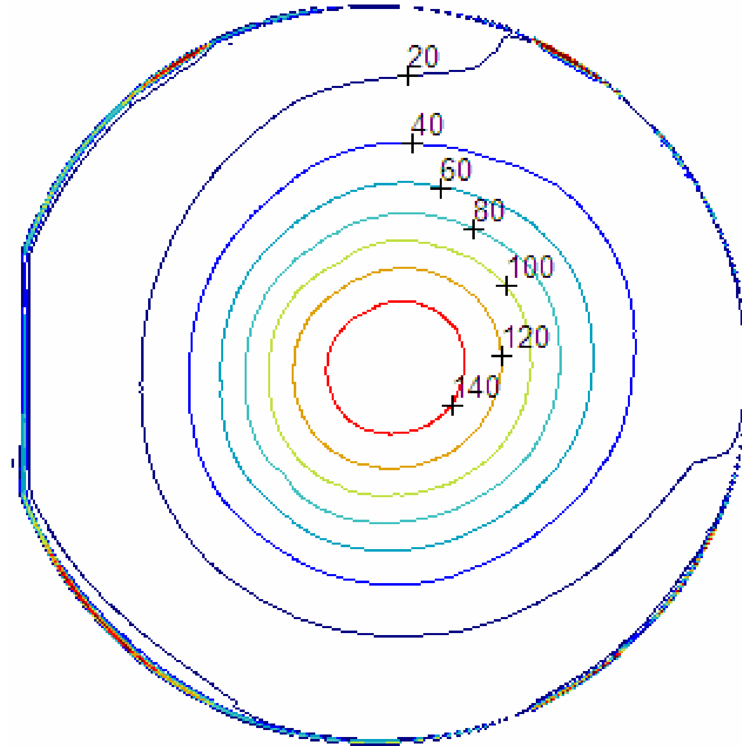
Full Wafer Haze Map showing AFM scan locations





Haze Map from SP2 scan with AFM locations and Haze/RMS roughness from 3 sites

Haze Contour map (ppm)

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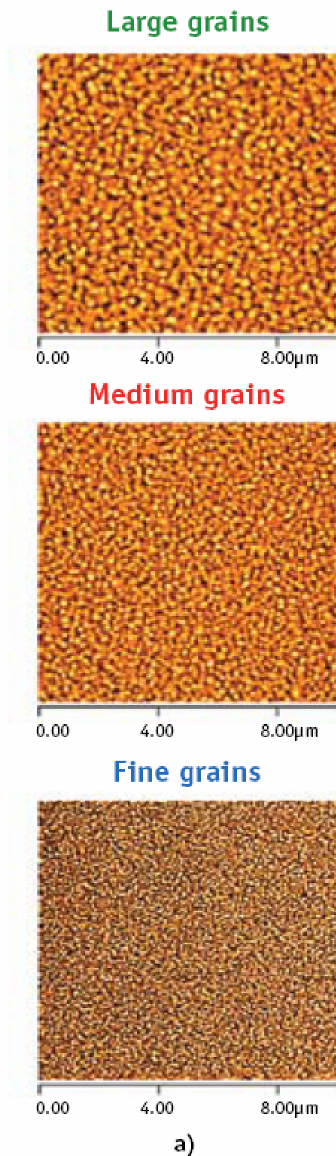
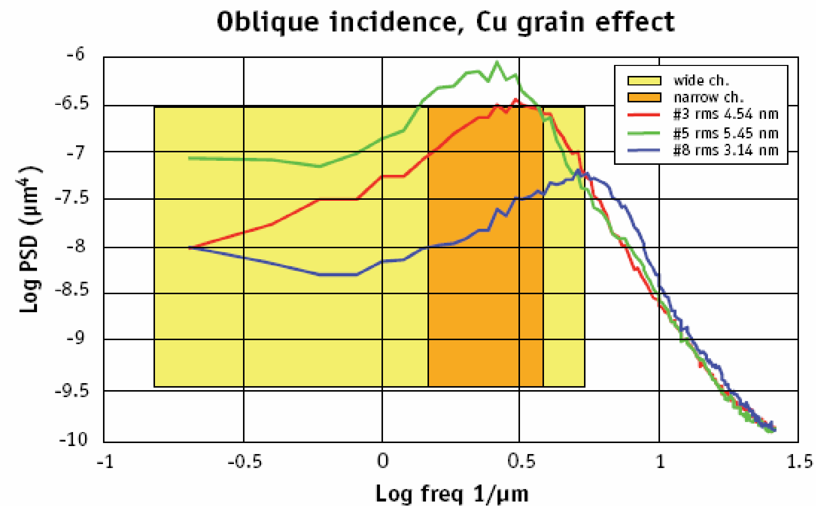
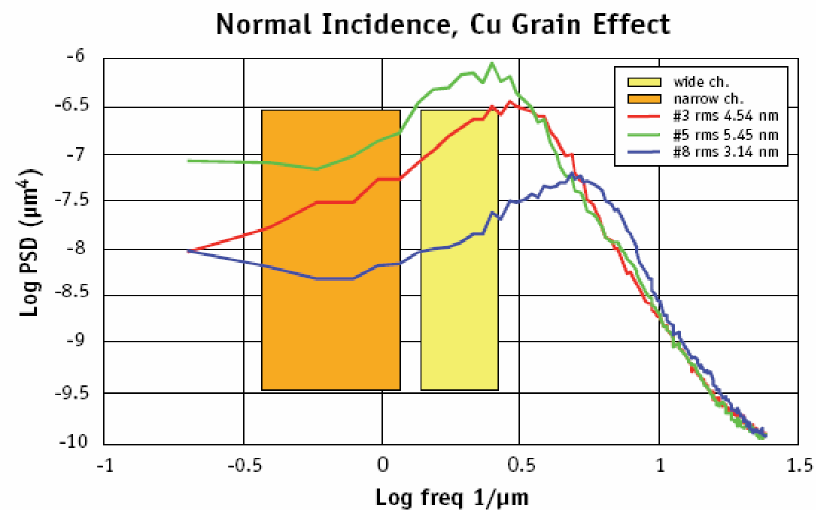
(a) Representative AFM scans of Cu Wafer and (b) PSDs of the scans, overlaid with the SP2 spatial frequency bands



a)





b)

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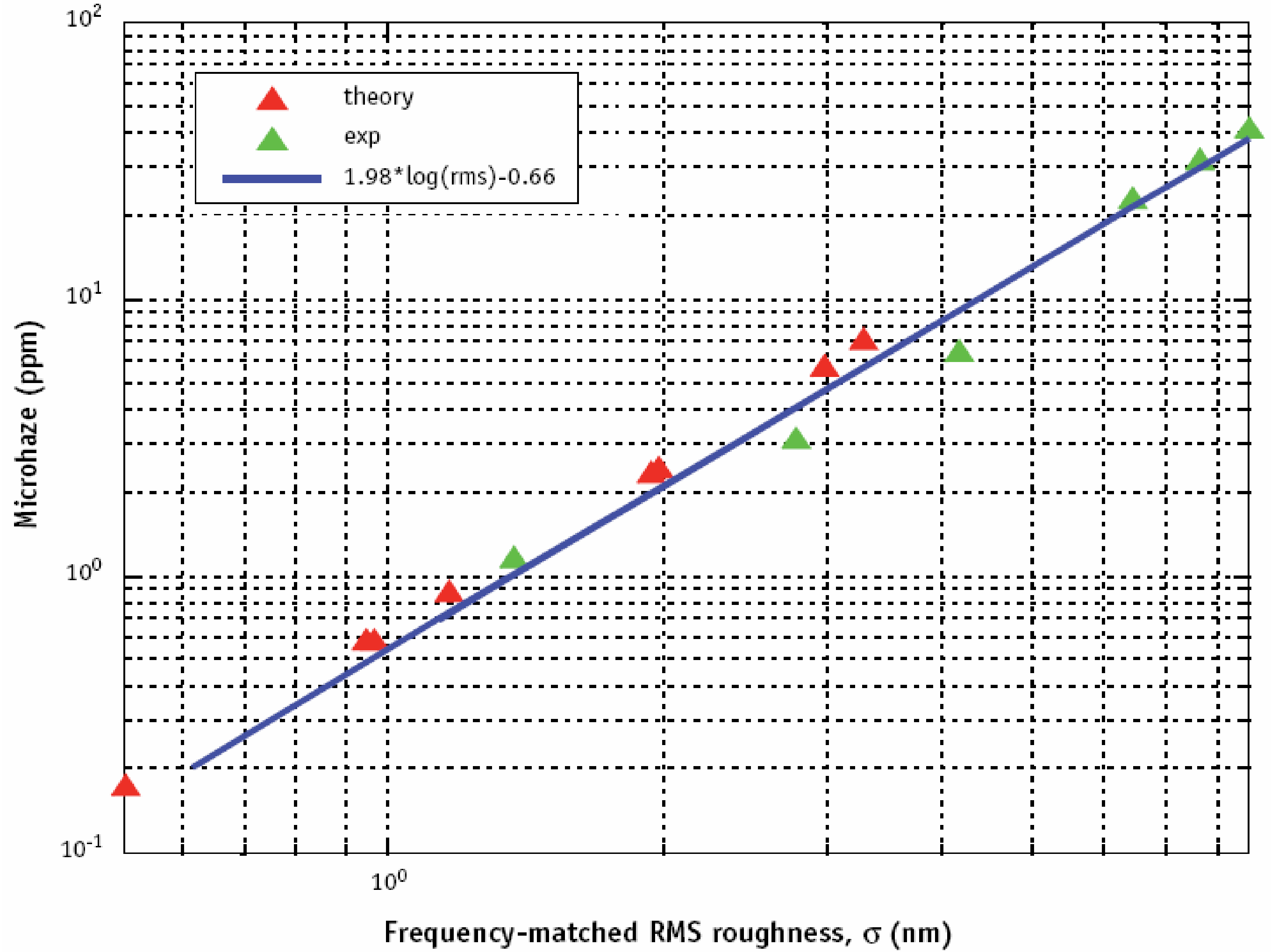
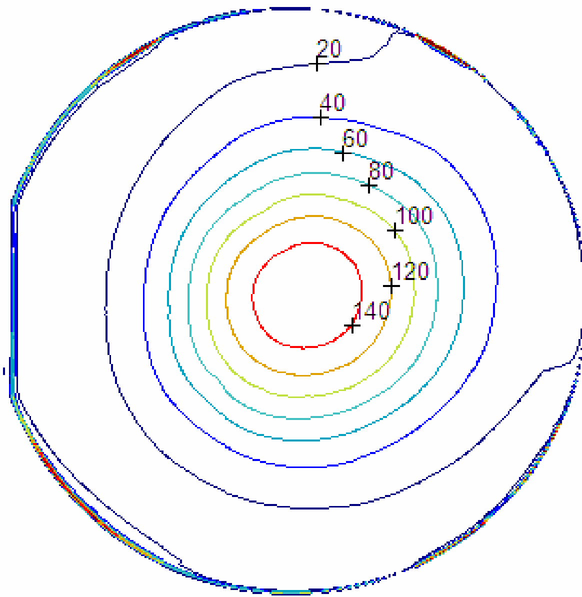
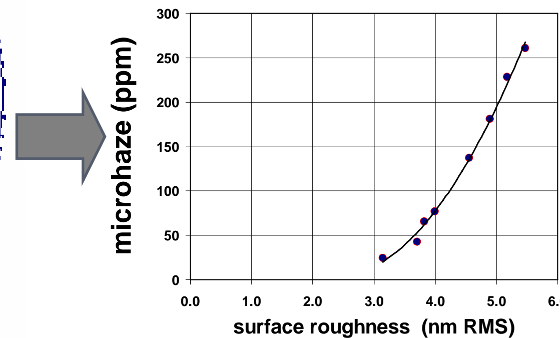
Excellent fit between Experimental results and Theoretical model

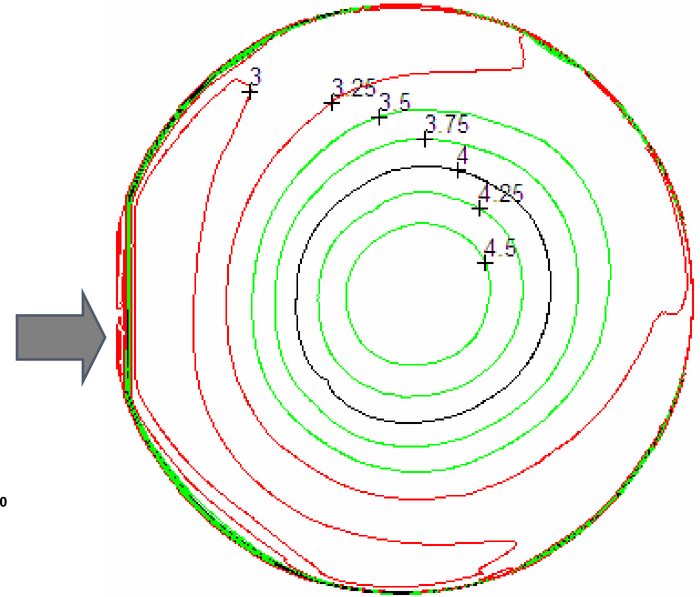


Log-log comparison of frequency-matched micro-roughness (theory) derived from AFM data, with the haze values (experimental) measured by the Normal-Wide channel of the SP2

Contour Maps of SP2 haze and Cu film roughness







Cu microhaze map (ppm)

Cu roughness map (nm RMS)

•Translation from micro-haze to micro-roughness is accomplished by applying the correlation shown in the above figure

•Full-Wafer roughness information obtained in < 1 minute (vs. few hours for 8-10 AFM data points)

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Conclusions and Future Work

- Laser light scattering has been shown to be an effective technique for obtaining substrate morphology information
- Full-wafer haze measurements can be used to obtain quantitative surface roughness information at a throughput of 10s of wafers/hour **(not achievable by any other technique)**
- This technique has the potential to be used for process development, characterization and monitoring
- Future Work:
  - Correlation to bare silicon micro-roughness
  - Other surface characterization applications

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