Reducing Roughness in EUV Lithography

FRACTILIA

Chris A. Mack

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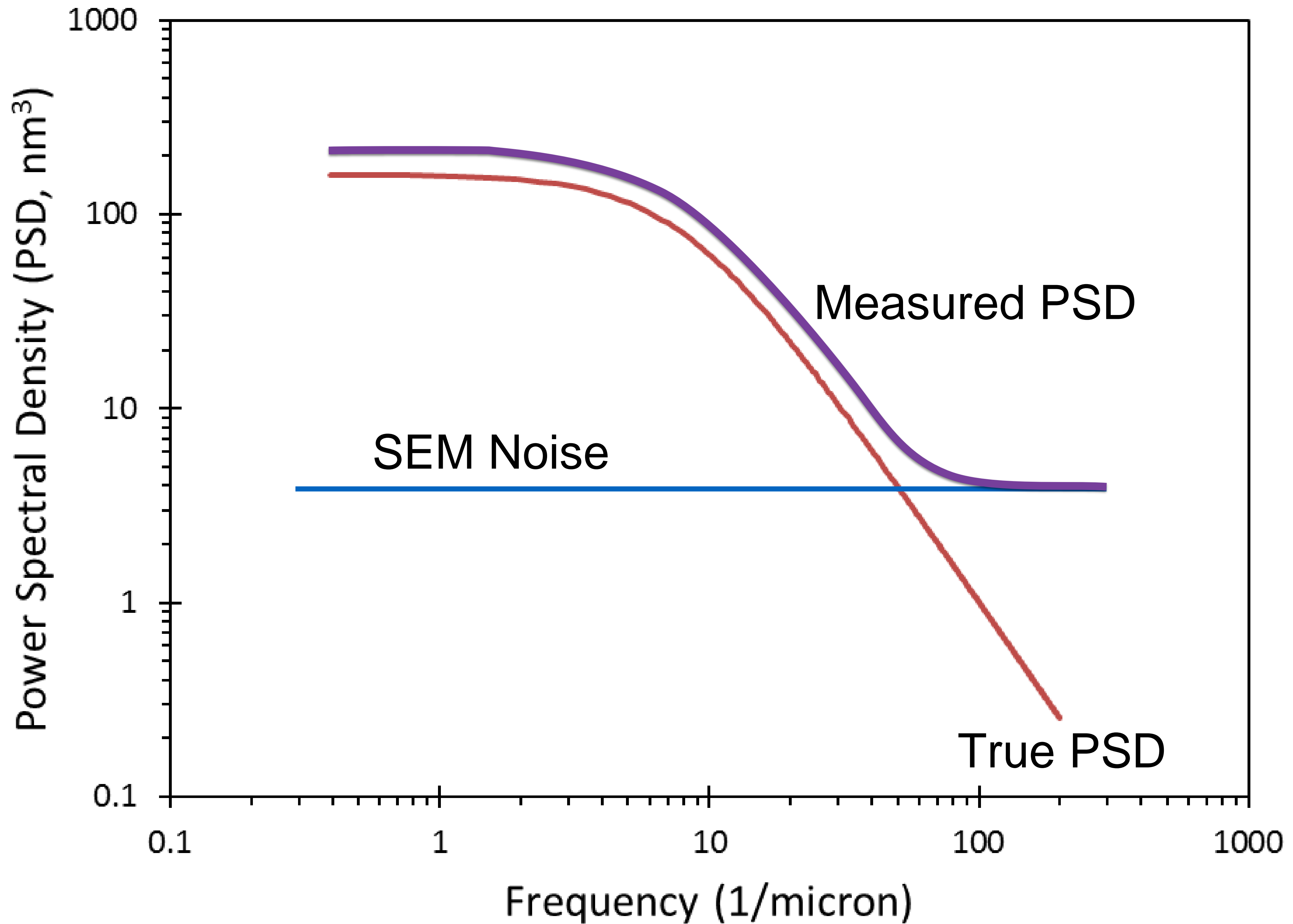
Conclusions

- SEM noise produces biased roughness that is significantly different from the true value
  - Almost everything affects SEM image noise
  - Using biased measurements can lead to bad decisions
- We need more than just 3σ to understand roughness
  - We need the unbiased power spectral density (PSD) to understand roughness
- New strategy: litho should minimize unbiased PSD(0) and correlation length (not 3σ roughness), then let etch grow the correlation length to minimize 3σ roughness, while not increasing PSD(0)

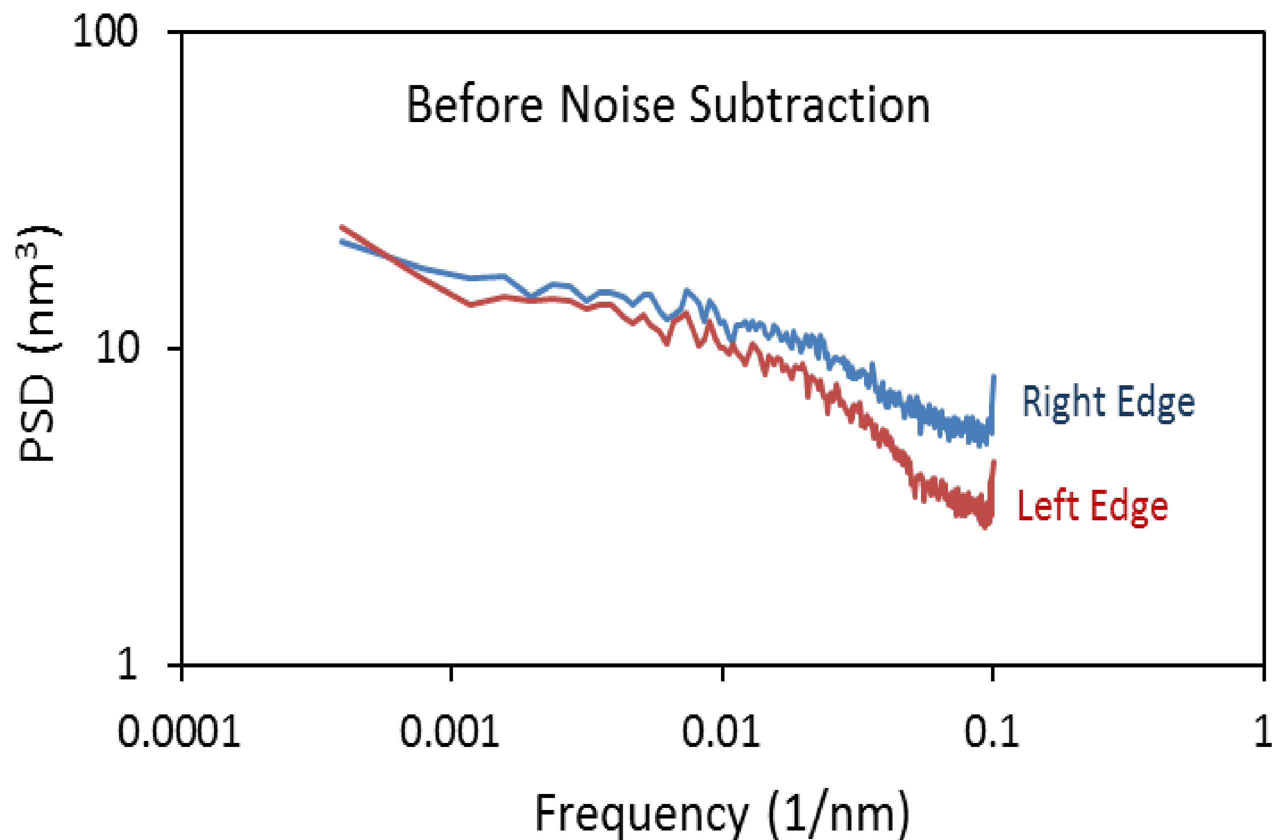
Measuring Roughness is Hard

- SEM images contain both random and systematic errors that bias our results
  - Random noise in the image produces white noise
  - Systematic field variations (intensity, distortion) increase the apparent low-frequency roughness
  - Standard measurements today are *biased*
- We need to measure these SEM errors in order to subtract them out and obtain the *unbiased* roughness
  - Using biased roughness can lead to bad decisions whenever SEM errors (especially noise) vary

Removing SEM Noise

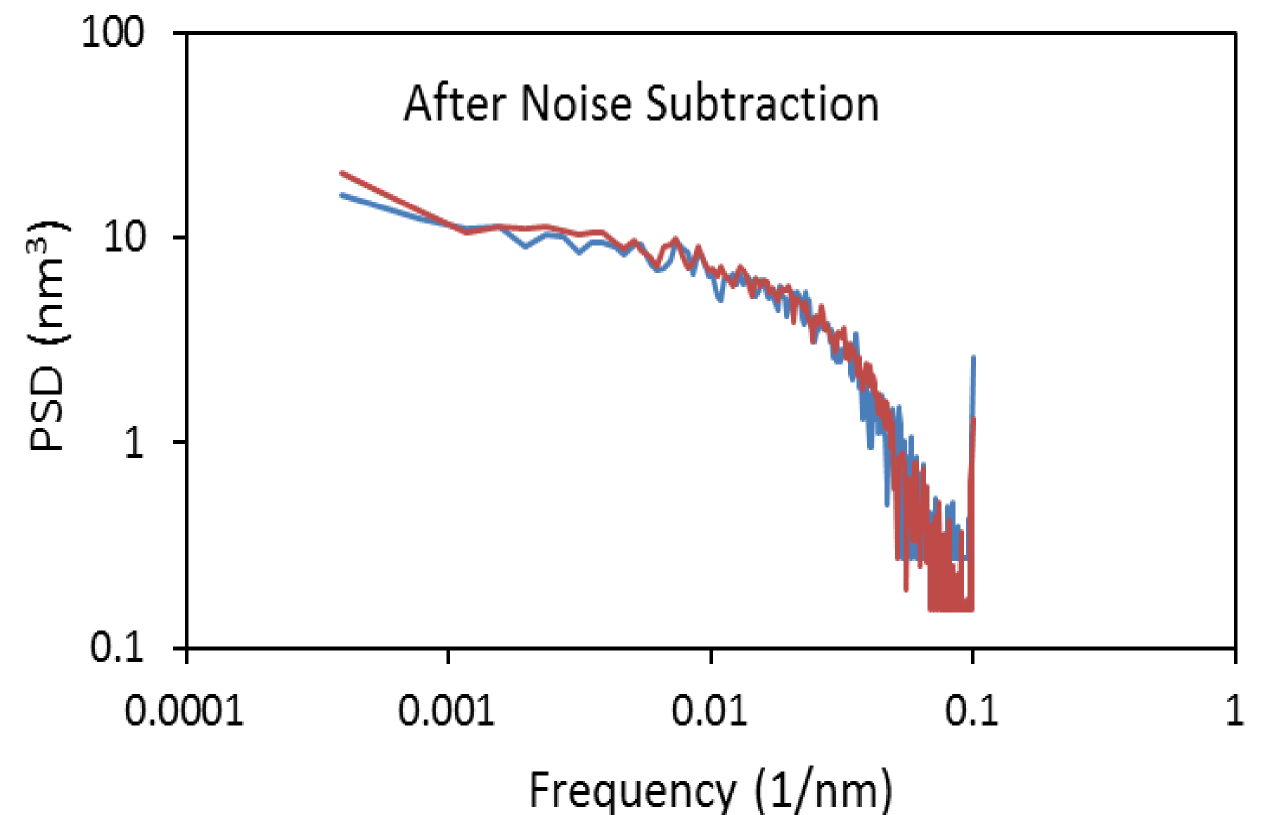


Before and After Noise Subtraction



Left/right differences are an artifact of the SEM, not a property of the wafer feature

Measuring and subtracting SEM noise requires edge detection without image filtering



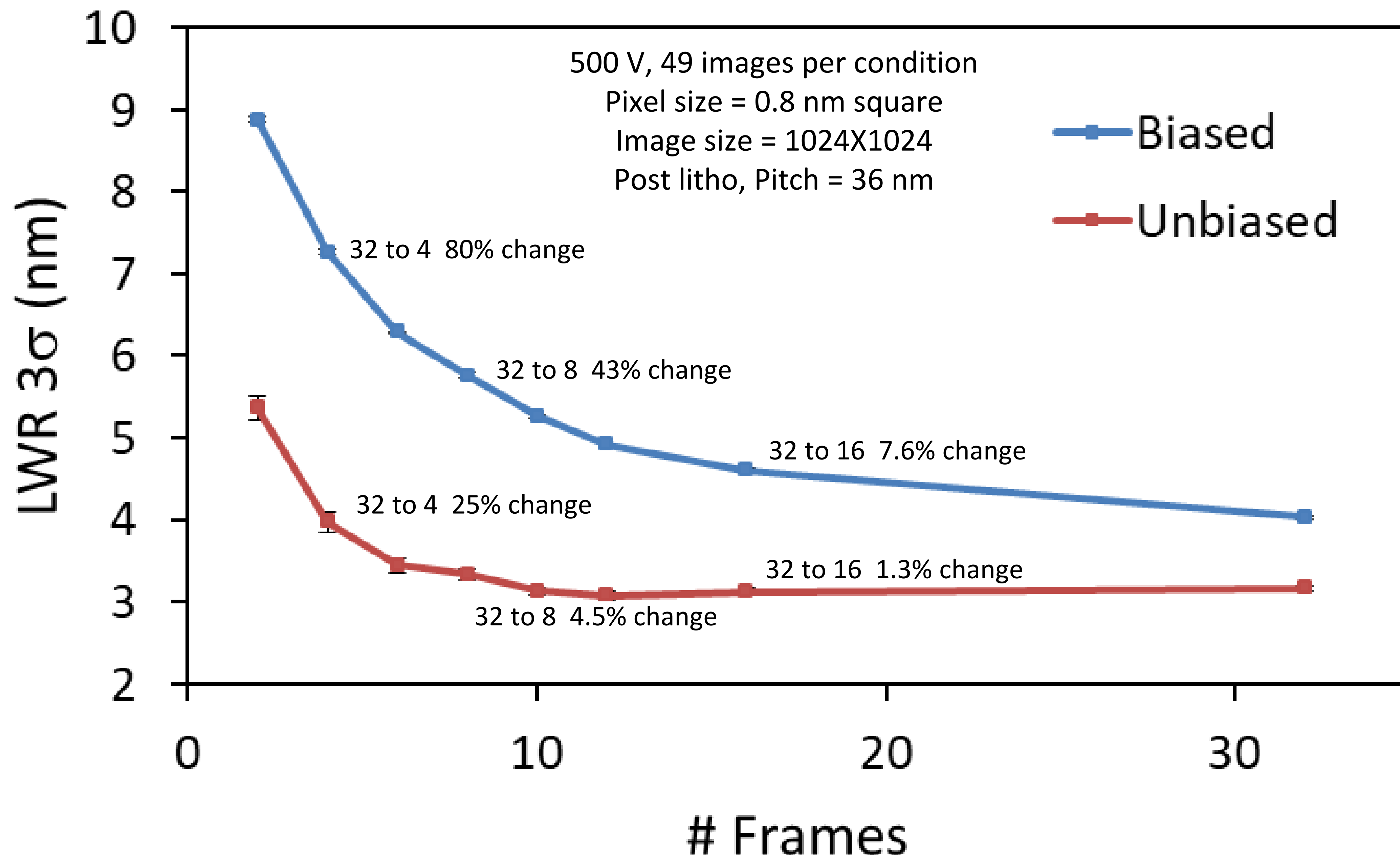
Impact of SEM Pixel Size

	Pixel 0.5 130X	Pixel 0.5 264X	Pixel 0.8 82X	Pixel 0.8 164X	Pixel 0.37 180X
Biased LWR (3-sigma, nm)	4.67	4.61	5.11	4.99	4.47
Unbiased LWR (3-sigma, nm)	3.68	3.64	3.64	3.65	3.63
Unbiased LWR PSD(0) (nm^3)	17.2	16.24	16.0	16.2	16.4
LWR Correlation Length (nm)	5.33	5.14	5.12	5.04	5.38

Biased LWR Range: 0.64 nm (14%)
Unbiased LWR Range: 0.05 nm (<2%)

The unbiased LWR is essentially independent of these SEM settings

Impact of Electron Dose (# Frames)

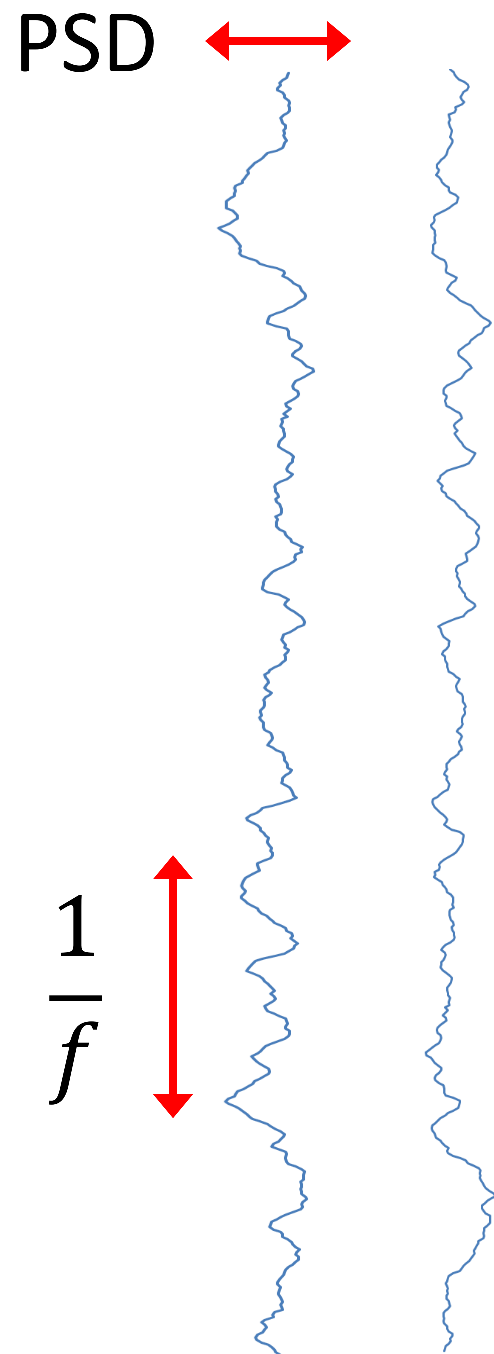


MetroLER's unbiased results are more consistent through SEM dose.

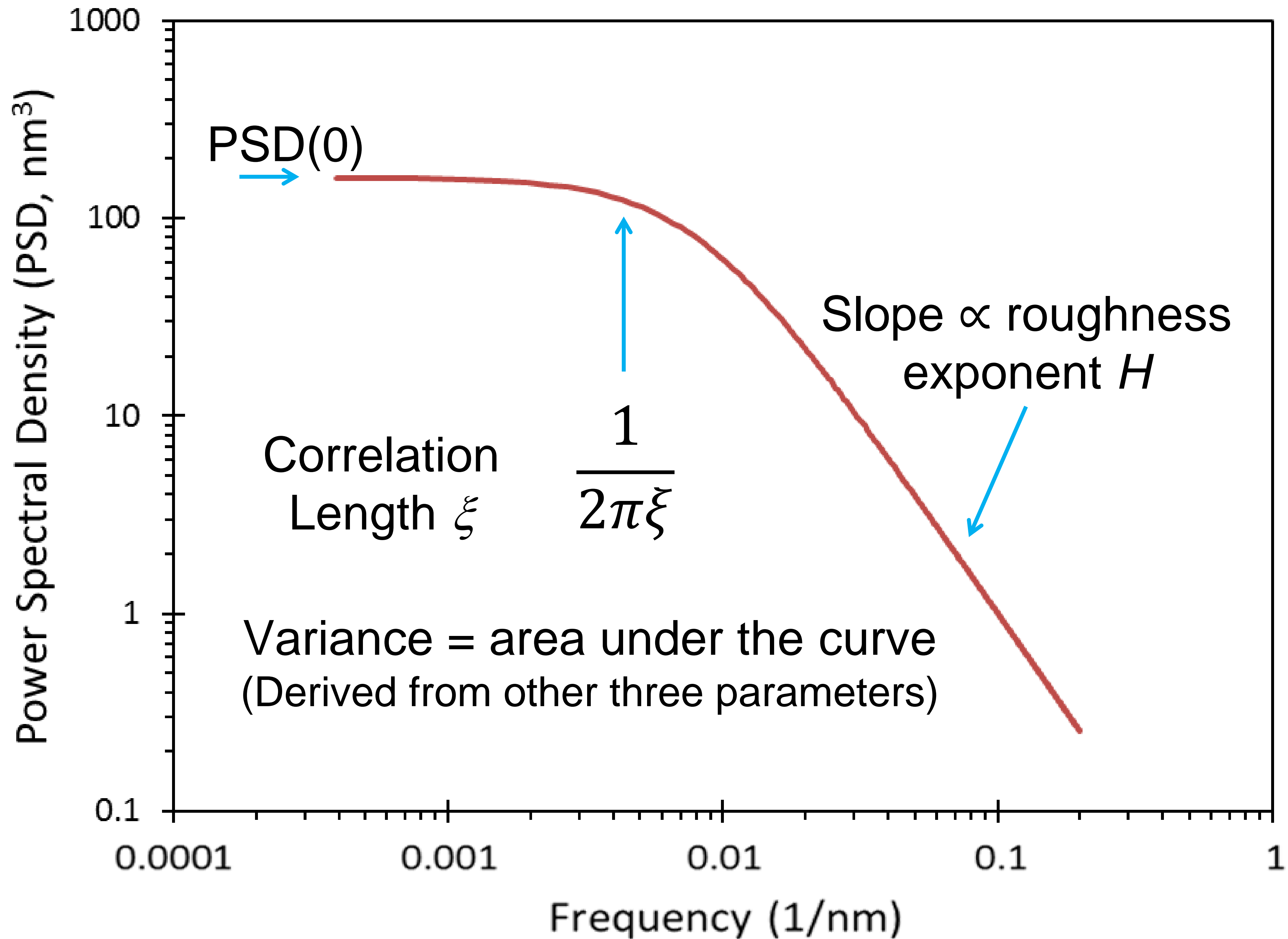
The Importance of Correlations

- **White noise**: uncorrelated, each random event is independent
  - Photon shot noise, absorption, chemical concentration, acid generation
  - Produces a flat power spectral density (PSD)
- **Correlating mechanisms**: random events that are not independent
  - Secondary electron generation, acid generation, reaction-diffusion, development front propagation
  - Lowers (smooths) the PSD on length scales below the correlation length (i.e., high frequency roughness)

The Power Spectral Density

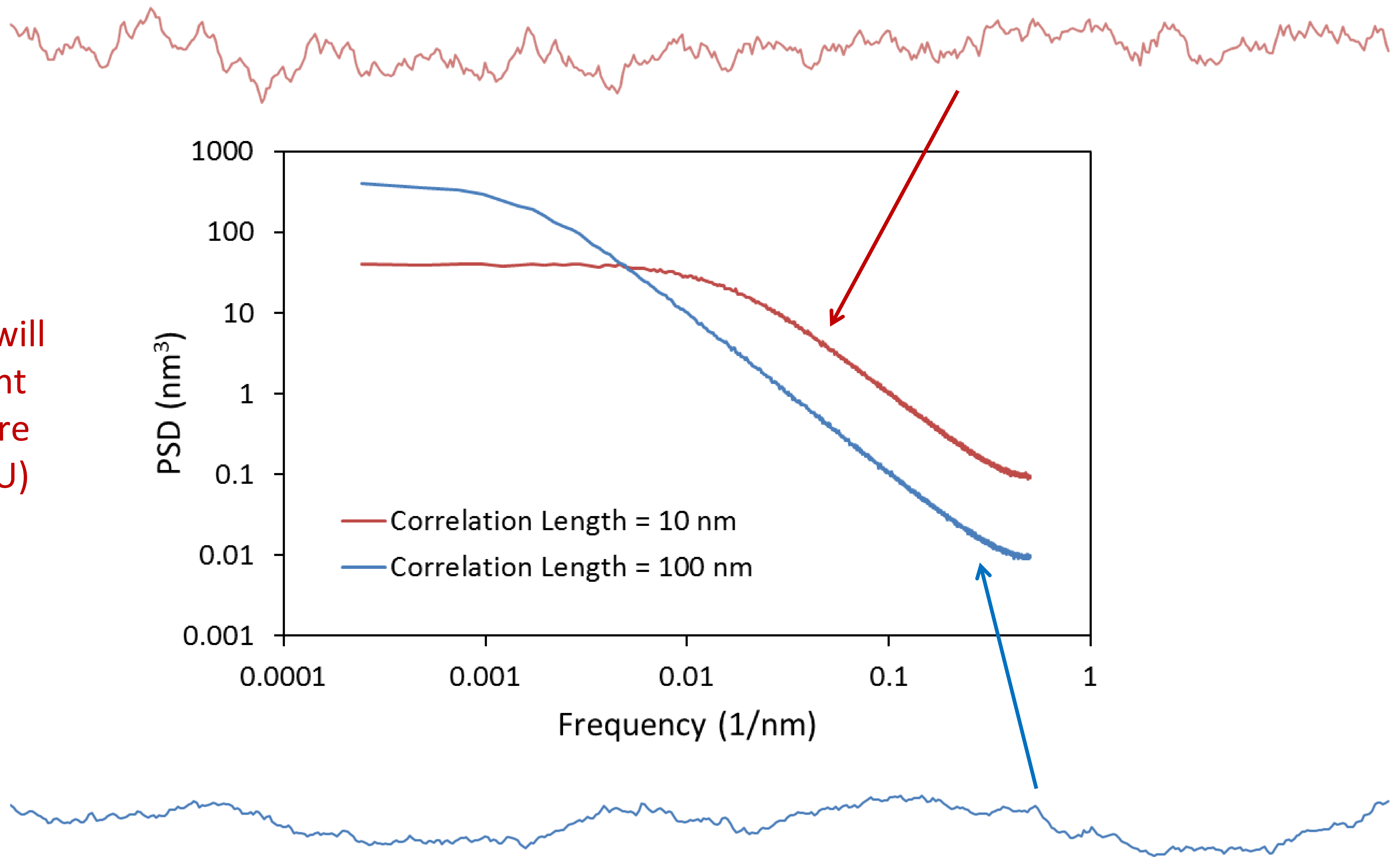


The Power Spectral Density



The Same 3σ, but Different PSDs

These PSDs will have different device feature impact (LCDU)



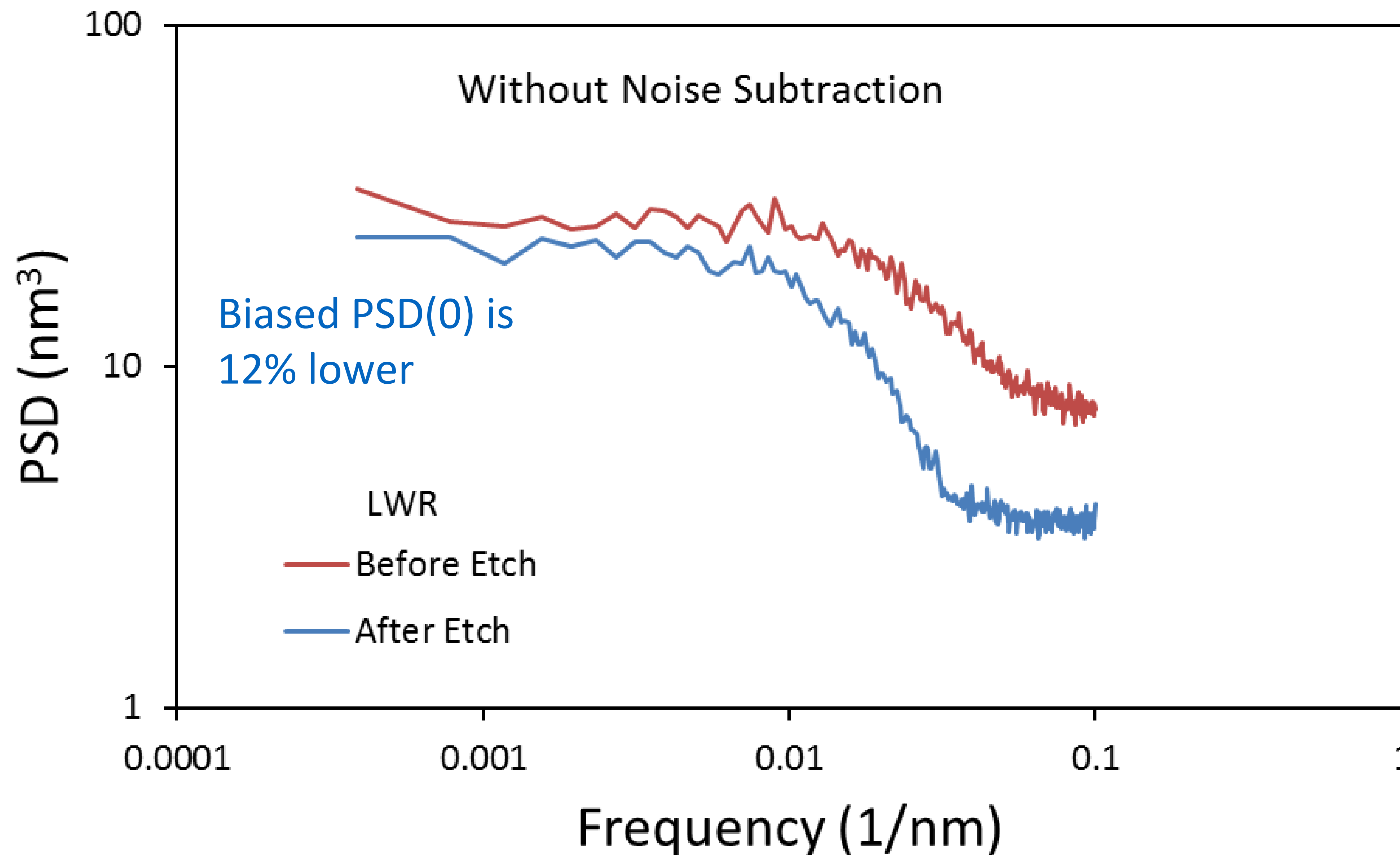
Example: Does etch reduce roughness?

- Experiment: Measure roughness before and after etch
  - 3σ roughness (for long lines) goes down
  - What happens to the PSD?
- We need to look at unbiased PSDs to understand the impact of etch on roughness
  - Impact on PSD(0)?
  - Impact on correlation length?

Before and After Etch: a biased view

Biased LWR Before Etch: 4.9 nm
Biased LWR After Etch: 3.6 nm

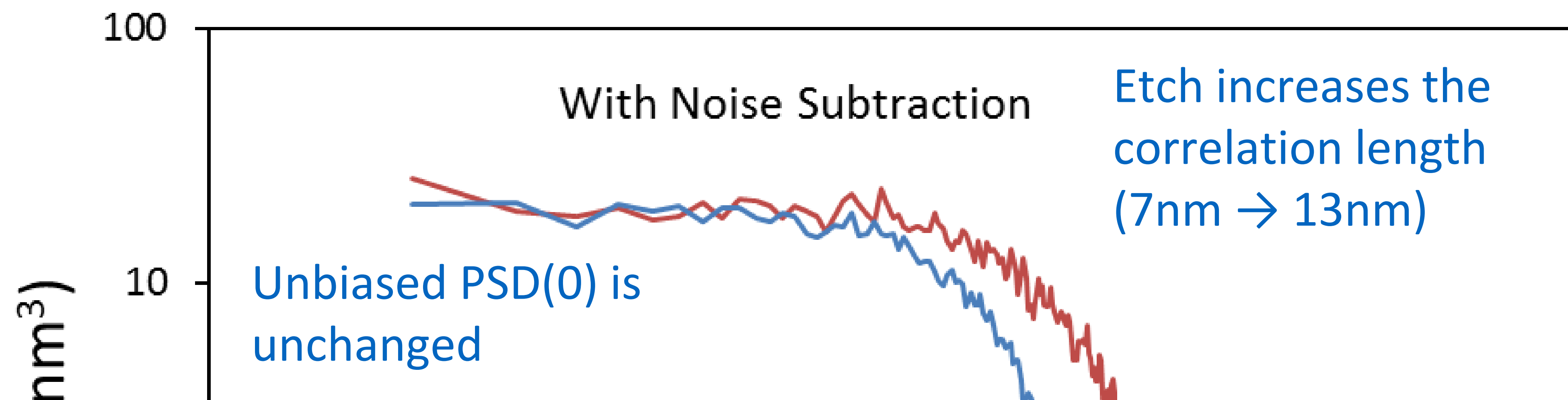
27% reduction



Before and After Etch: an unbiased view

Unbiased LWR Before Etch: 3.5 nm
Unbiased LWR After Etch: 2.6 nm

26% reduction



Lessons:

1. We must use unbiased roughness measurements to know what's really happening
2. Three factors describe and control roughness: 3σ, PSD(0), and correlation length

Are we optimizing the right thing?

- Should we be minimizing the after-litho 3σ LER, or the after-etch 3σ LER?
- A new strategy:
  - For litho, minimize resist blur (correlation length) and PSD(0), not 3σ roughness
  - Use etch to grow the correlation length and reduce final 3σ roughness
  - Make litho responsible for low-frequency roughness, and etch responsible for high-frequency roughness

Chris A. Mack, "Reducing Roughness in Extreme Ultraviolet Lithography", *International Conference on Extreme Ultraviolet Lithography, Proc.*, SPIE Vol. 10450 (2017) p. 10450OP-1.

New Data This Week

- Using biased roughness measurements leads to incorrect etch process optimization
  - Andrew Liang, Lam Research, “Unbiased methodology for improving EUV line roughness” (Tuesday Poster Session)
- Different EUV underlayers have major impact on SEM noise; using biased roughness measurements leads to incorrect choice for best underlayer
  - Vito Rutigliani, imec, “Setting up a proper power spectral density (PSD) and autocorrelation analysis for material and process” (Thursday Metrology session, 10:30am)
- Roughness 3σ after litho does not correlate with after-etch roughness, but after litho PSD(0) does
  - Charlotte Cutler, Dow, “The determination of roughness power spectral density curves as a function of resist parameters”, (Tuesday Optical Lithography session, 11:00 am)

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Thank You

FRACTILIA

Fractilia, LLC
Austin, Texas
512 887-3646
info@fractilia.com
www.fractilia.com