DEPARTMENT OF
CHEMICAL ENGINEERING
University of California, Berkeley

VUV Photons and Synergistic Roughening Mechanisms of 193 nm Photoresist in Inductively Coupled Plasmas

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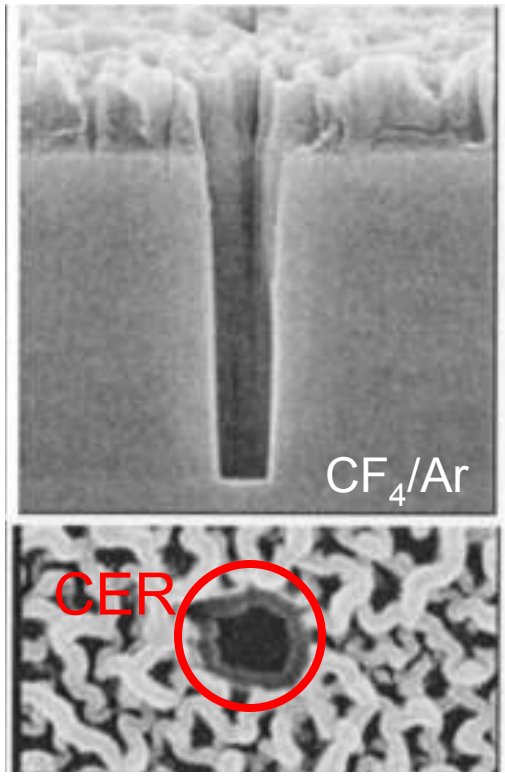
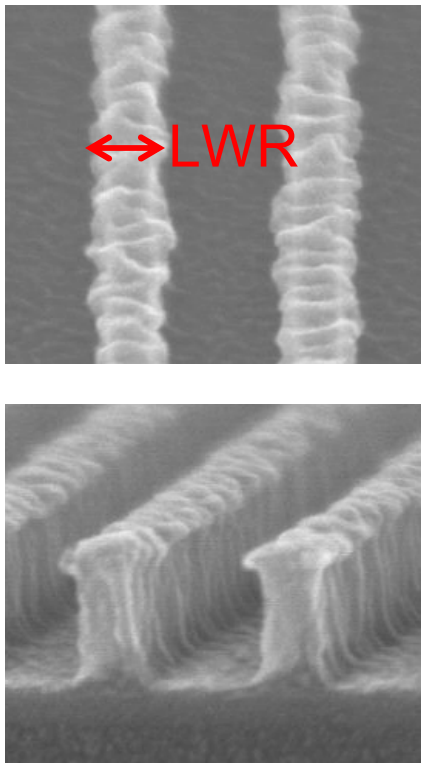
Changes in Technology & Materials Introduce New Problems in Pattern Transfer: Degradation of 193 nm Photoresists

Key Changes in Photolithography:
Wavelength
Polymer Chemistry (193 nm PR)

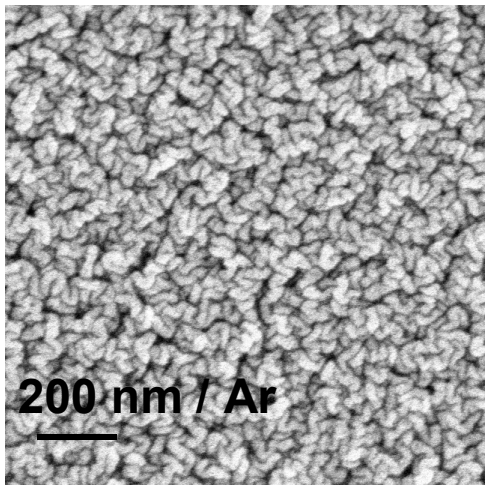
Key Changes in Pattern Transfer:
Plasma (Dry) Etching



Negeshi, N. et al. J. Vac. Sci. and Technol. 23(1). 2005.

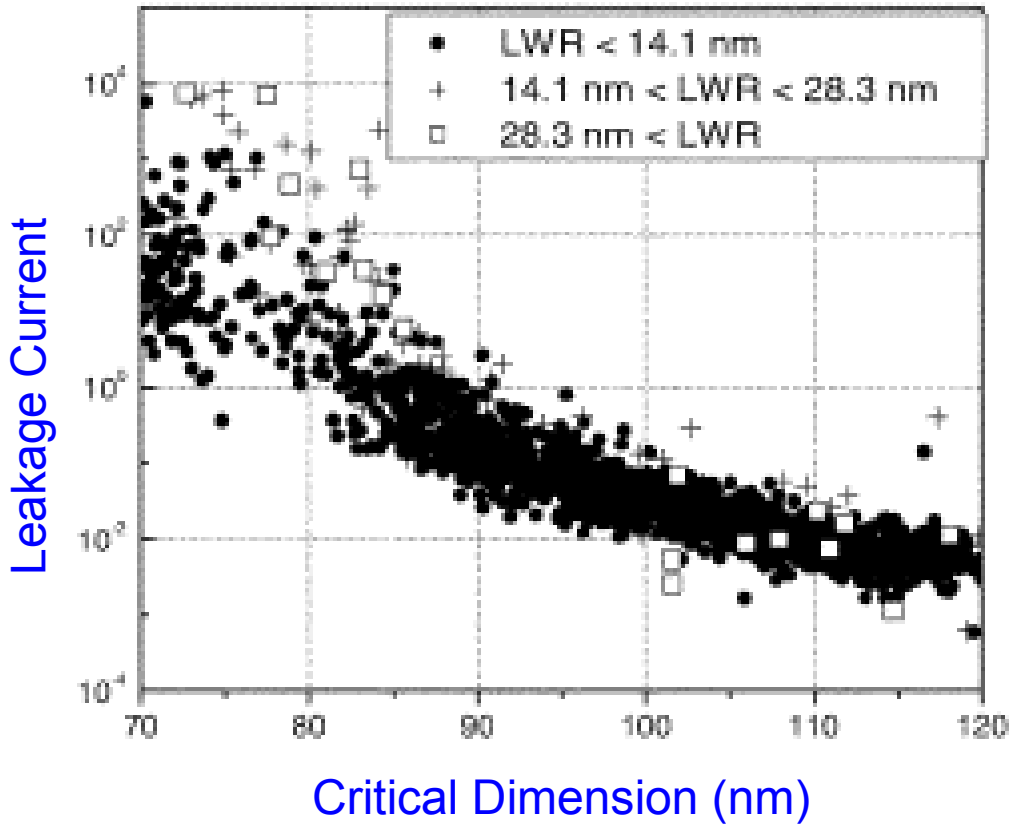


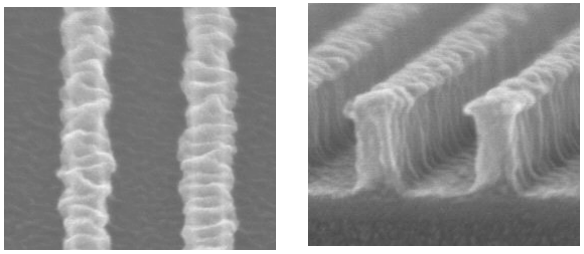
Morimoto, M. Hitachi



Nest, D. Experimental Beam System Studies of Plasma-Polymer Interactions. UC Berkeley. 2009.

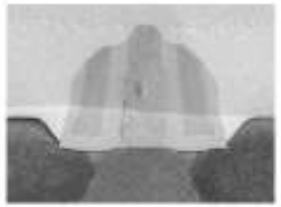
Transistor Leakage Current Increases as PR Line Roughening Increases and Device Dimensions Shrink





Morimoto, M. Hitachi

PR Roughness does NOT scale with feature size



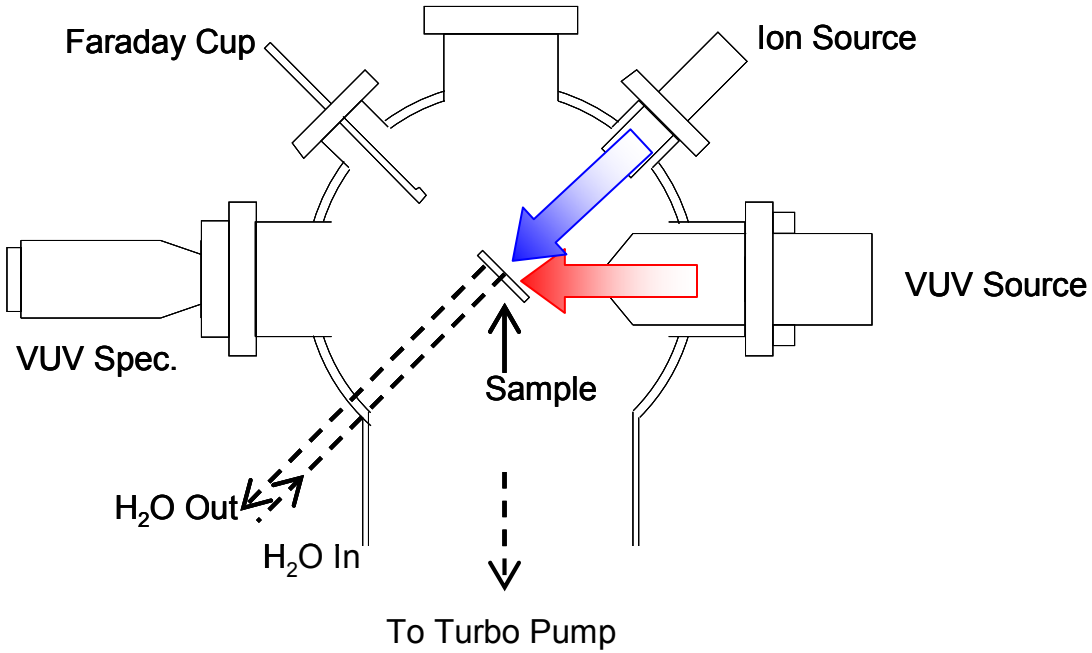
Kelin Kunn / IWCE / Beijing / 2009

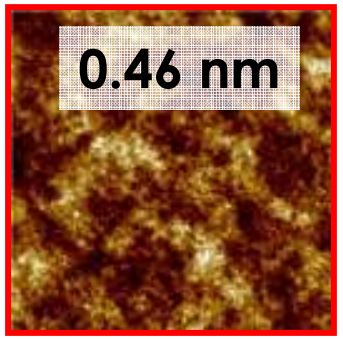
22 nm node: 1.4 nm LWR

Kim, H-W., et al. IEEE Transactions on Electron Devices. 51 (12) 2004.

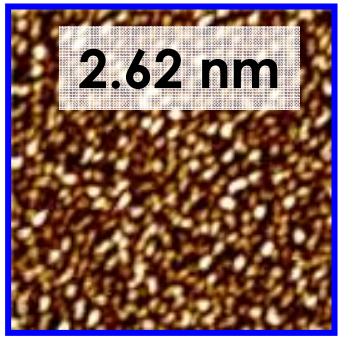
193 nm PR Degradation Depends on Synergy between Vacuum Ultraviolet Photons and High Energy Ions

Ultra-High Vacuum Beam System

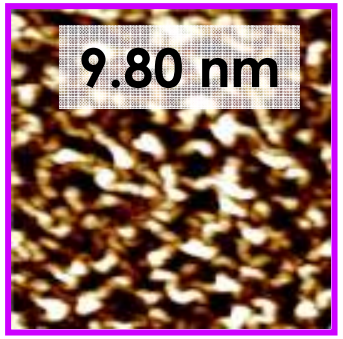




VUV-Only
100°C



150 eV Ions-Only
100°C

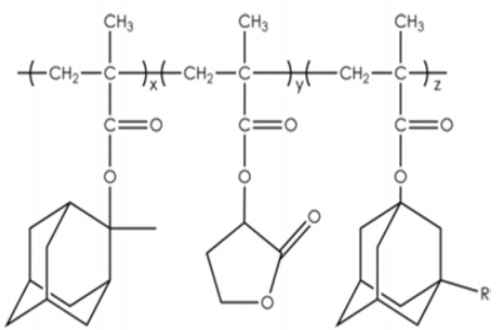


150 eV Ions + VUV
100°C

D. Nest et al., Plasma Processes and Polymers **6**, 8 (2009).

What Plasma Process Control Parameters affect the Degradation of 193 nm PR caused by VUV Photon & Ion Bombarding Synergy?

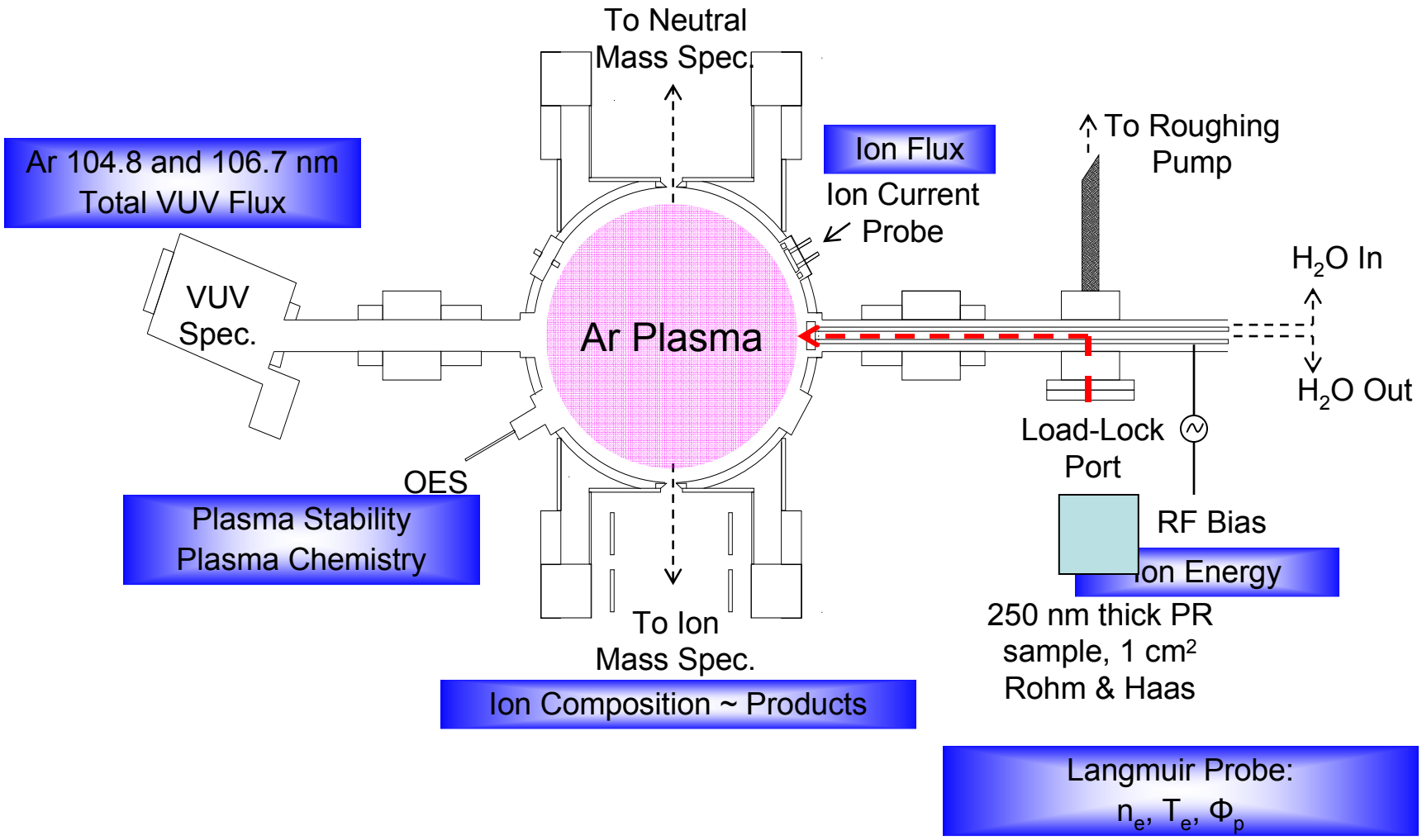
- Process blanket 193 nm PR samples in an inductively coupled plasma (ICP).
  - Exposure Time (Fluence of Species)
  - Substrate Temperature
  - Ion Energy



- Improve understanding of the roughening/degradation mechanism of 193 nm PR.
- Correlate roughening observed in blanket samples to patterned samples.

Ar Inductively Coupled Plasma Diagnostics & Sample Exposure Method

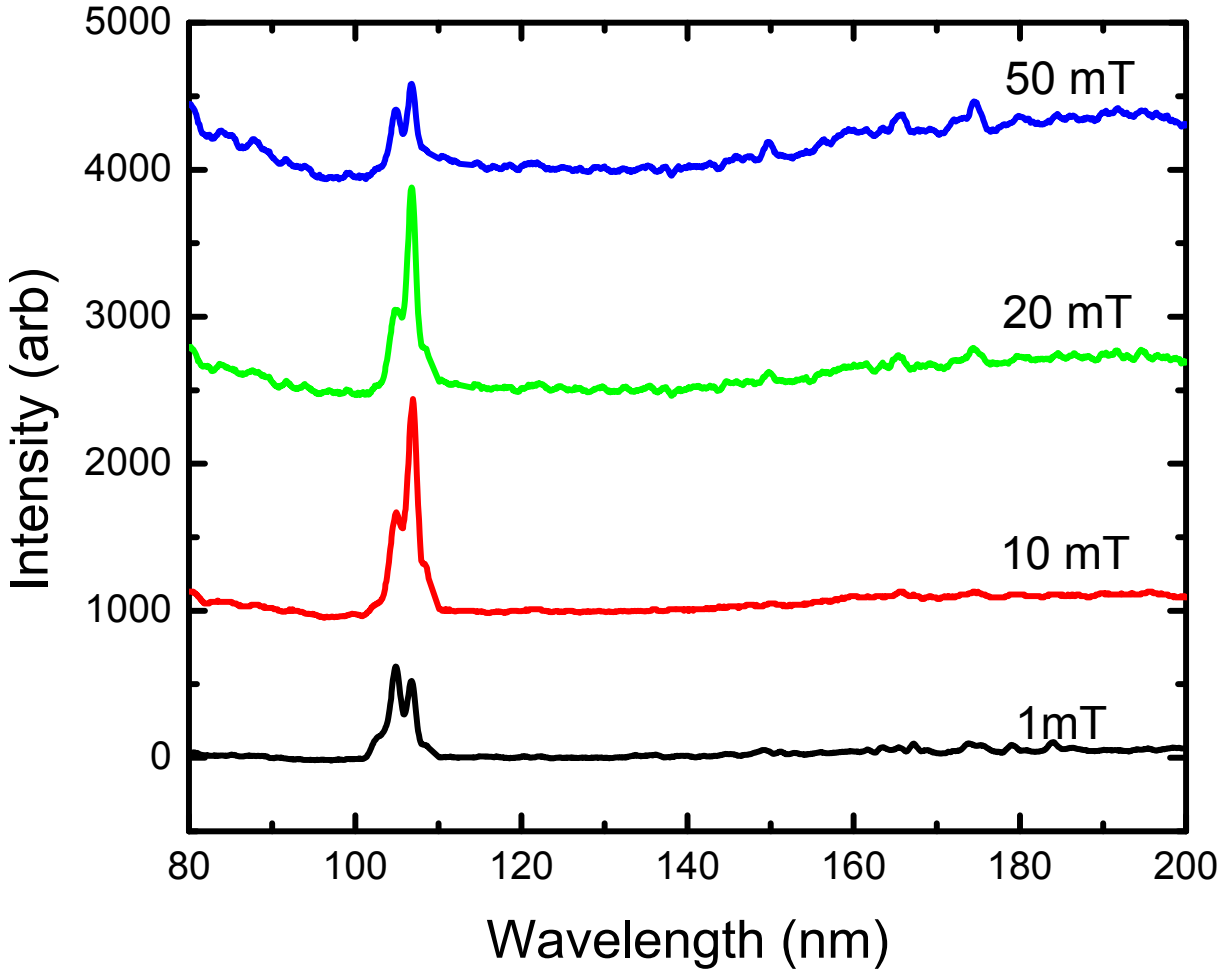
ICP Chamber: Top-Down View



H. Singh, in *Chemical Engineering* (University of California, Berkeley, Berkeley, 2000), p. 262.

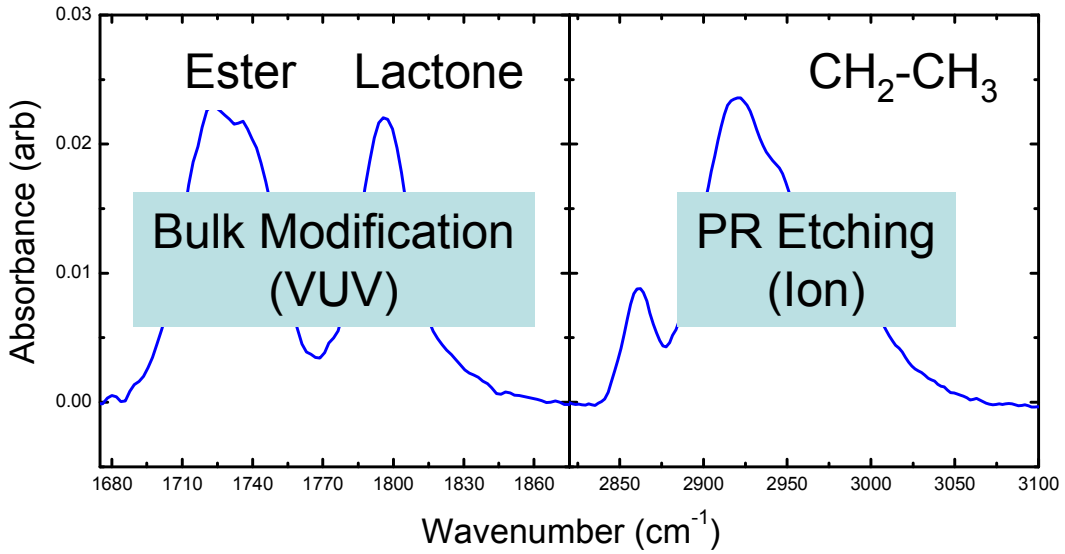
VUV Characterization of Ar ICP determines Processing Conditions

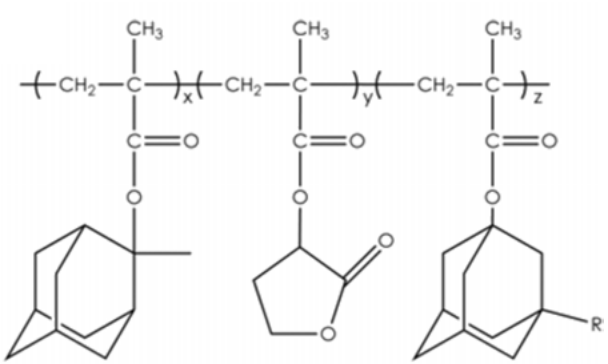
110 W Ar Plasma VUV spectra



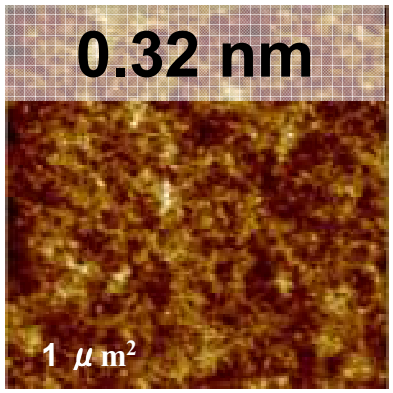
Post Processing Analysis Techniques

Fourier Transform Infrared Spectroscopy (FTIR)

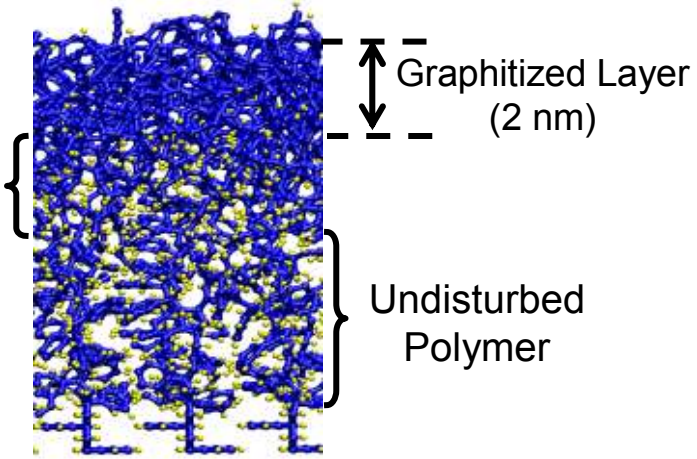




Atomic Force Microscopy (AFM)



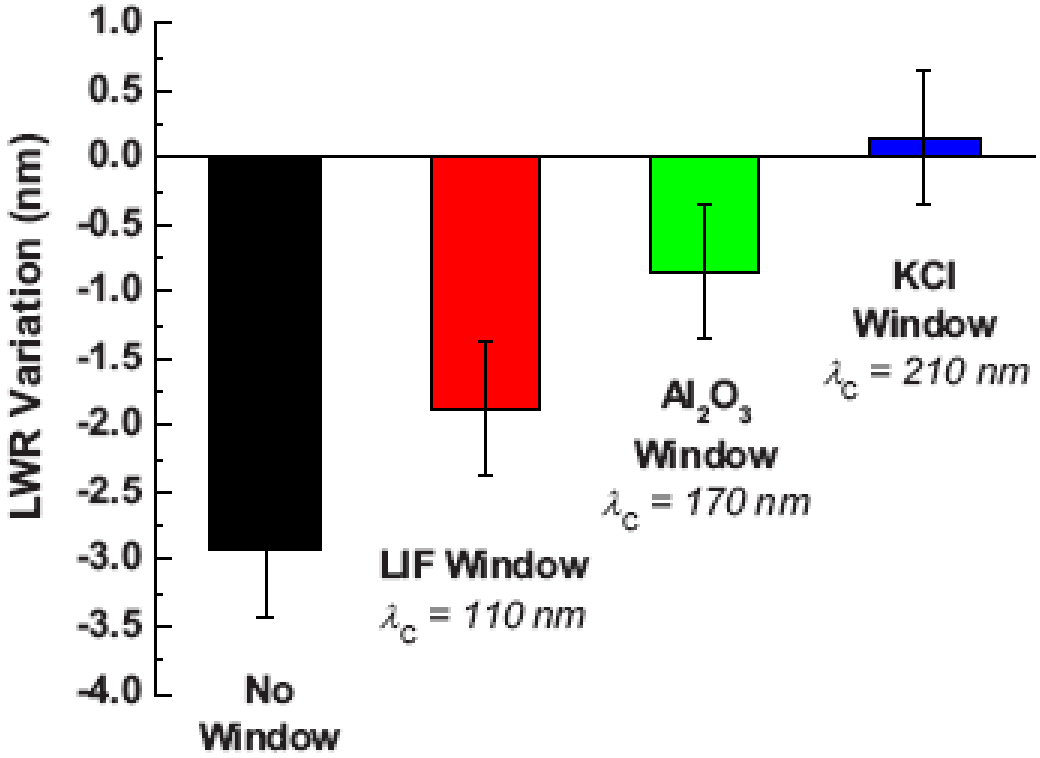
Tetrahydrofuran (THF) dips:



[1]*J.J. Vegh, et al., Appl. Phys. Lett., 91, 233113 (2007).*

Plasma Induced Smoothing of 193 nm PR (Plasma "Cures")

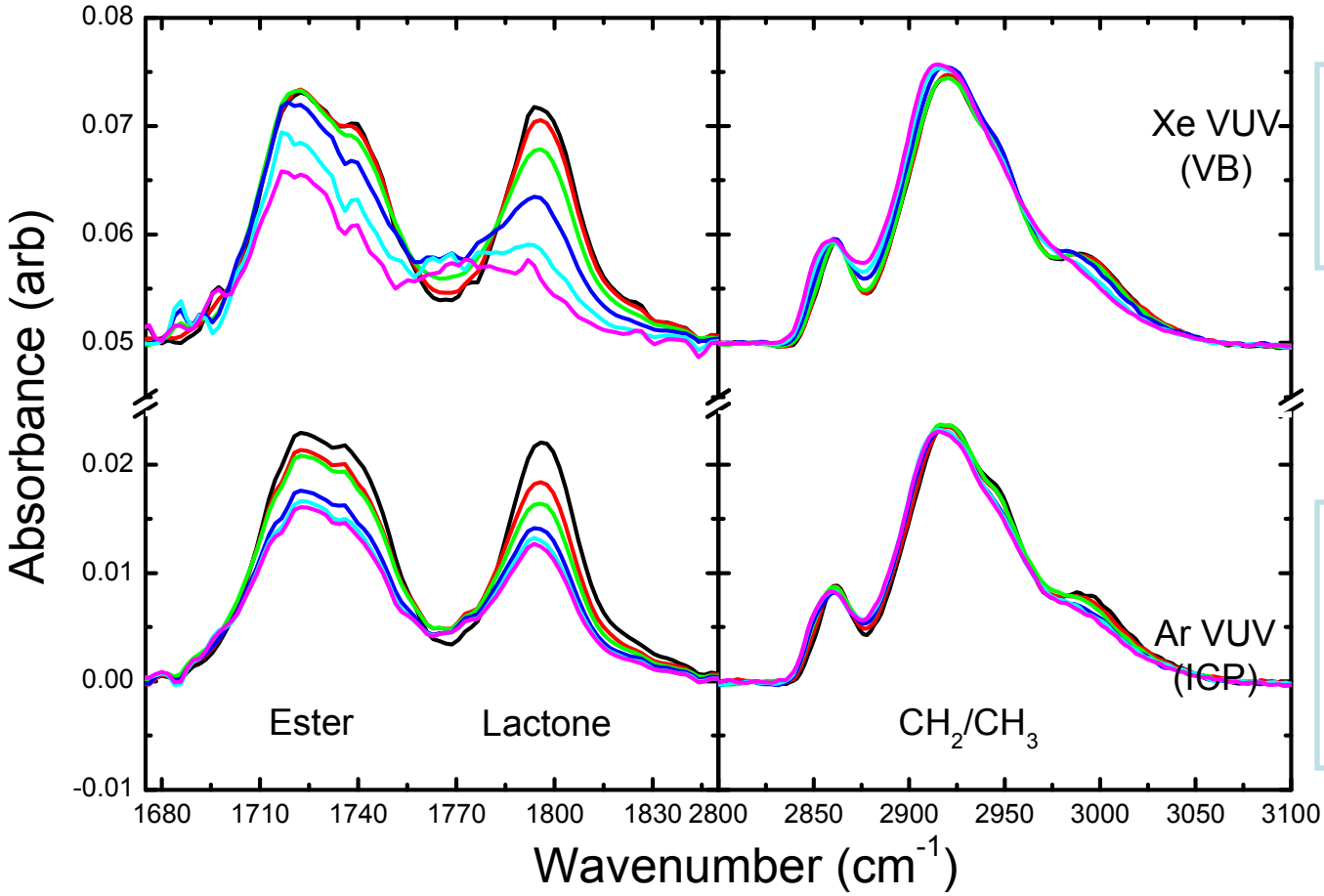
Plasma "Cure": VUV + Low Energy Ions



*E. Pargon et al., Appl. Phys. Letters **94**, 3 (2009).*
*E. Pargon et al., J. Appl. Phys. **105**, 11 (2009).*
A. Bazin et al., in SPIE, edited by C. L. Henderson (SPIE, 2008), p. 8.

Plasma Cures: 193 nm PR Bulk Modifications due to C=O and C-O-C Photoabsorption

193 nm PR FTIR Spectra



Vacuum Beam Conditions:

- Xe VUV
- 1.9 x 10^{14} photons /cm^2/s
- 1min – 120 min exposures

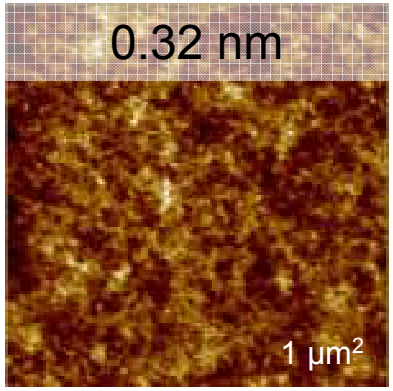
Conditions:

- Ar ICP, 10 mT, 70 W
- 2.9 x 10^{15} photons /cm^2/s
- No Bias, 16 eV ions
- 5 s – 300 s exposures

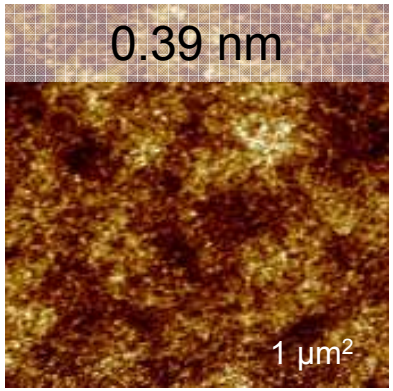
Titus, M. J. et al. J. Phys. D. Applied Phys., **42**, 2009.

193 nm PR Remains Smooth with Plasma "Cure" Conditions

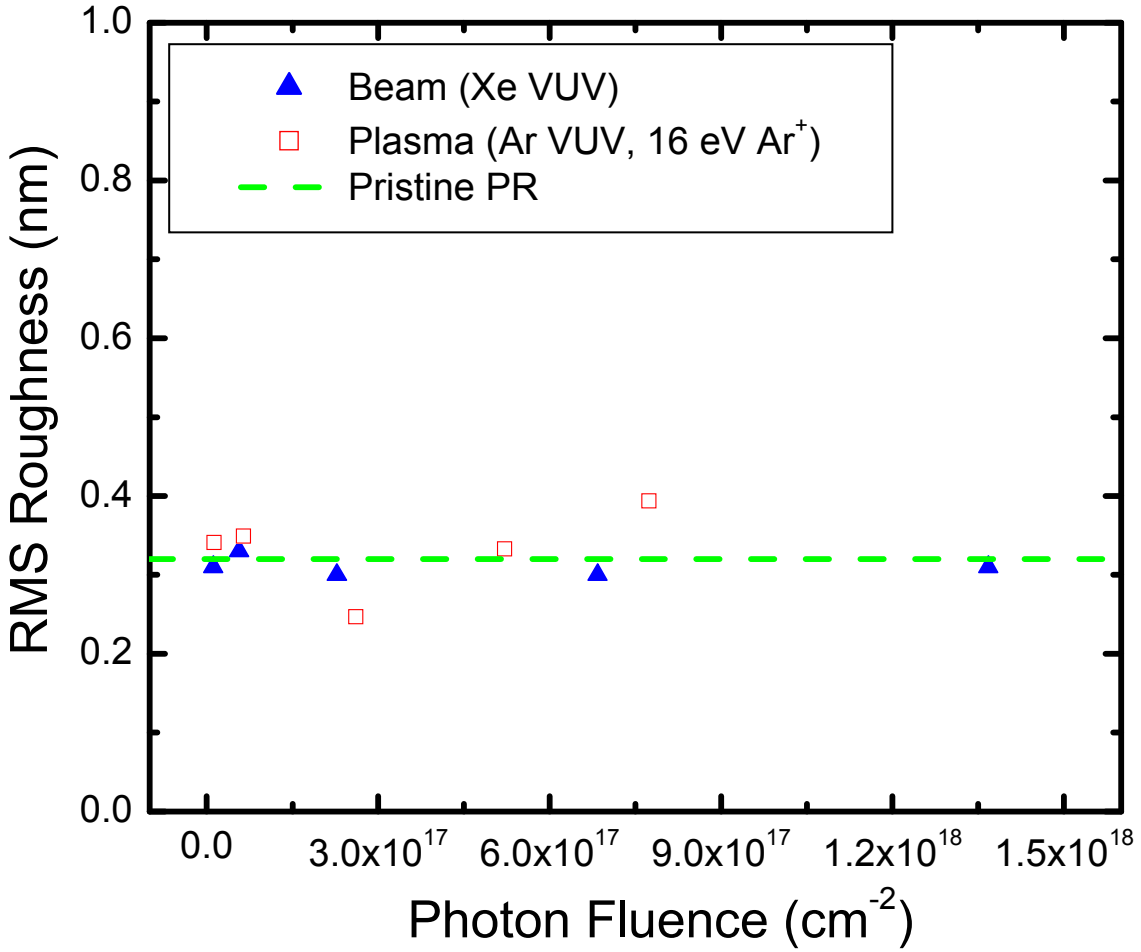
0 min



5 min



"Plasma Cure" & VUV Exposure



Bulk Modifications and Changes in Mechanical Properties Correlate with the Smoothing of 193 nm PR

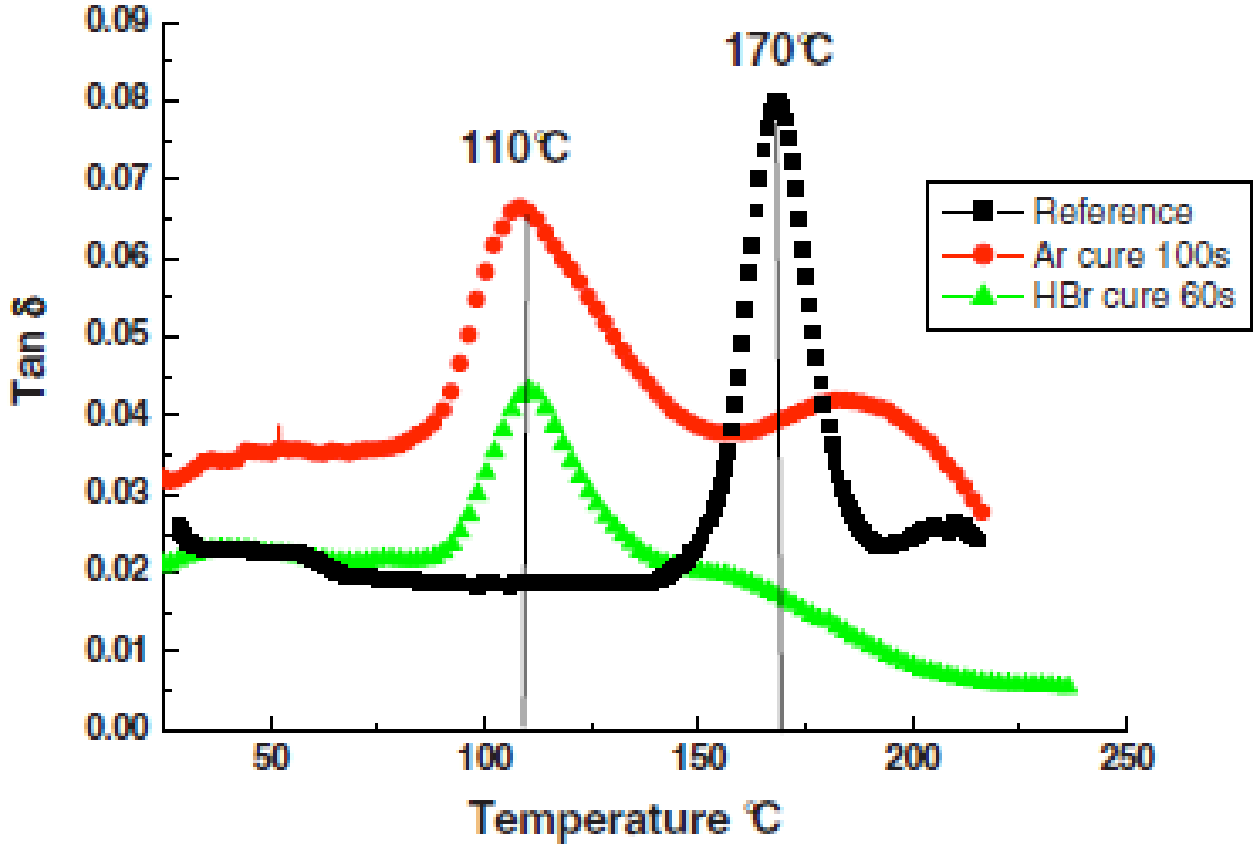
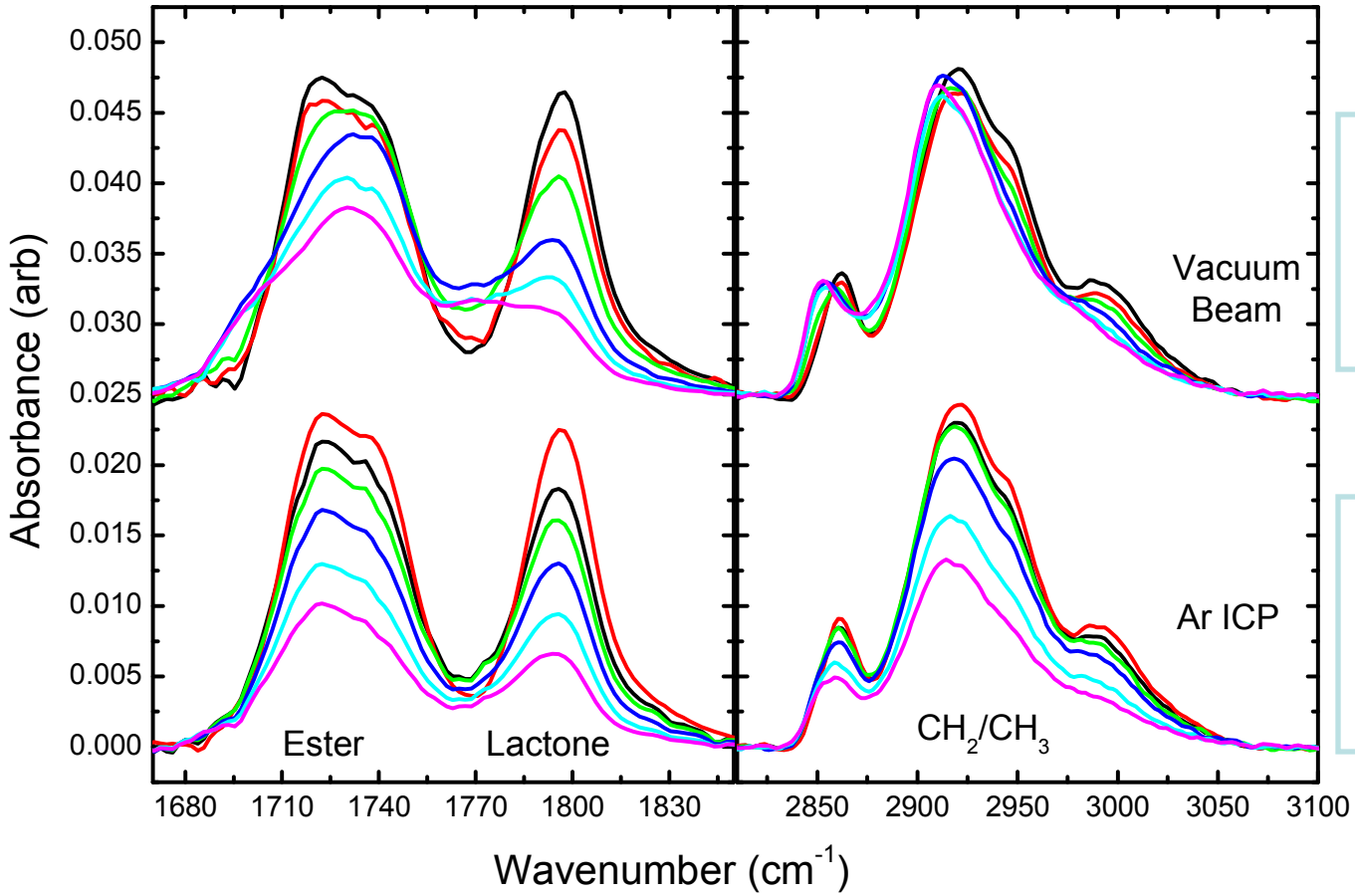


FIG. 13. (Color online) Glass transition temperature T_g before and after Ar and HBr cure plasma treatments determined by DMAs.

Pargon, E. et al., J. Appl. Phys. 105, (2009).

VUV & Ion Synergy Results in both Physical & Chemical Modifications

193 nm PR FTIR Spectra



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- 150 eV Ions
- 1min – 120 min exposures

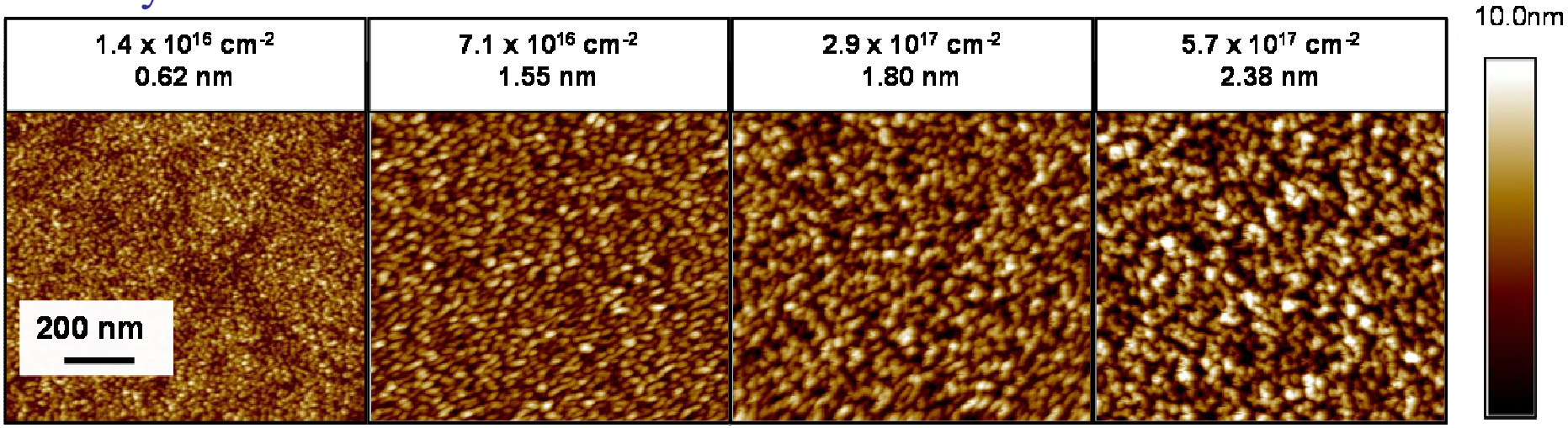
Conditions:

- Ar ICP, 10 mT, 70 W
- 2.9 x 10^{15} photons /cm^2/s
- 120 eV Ions
- 5 s – 300 s exposures

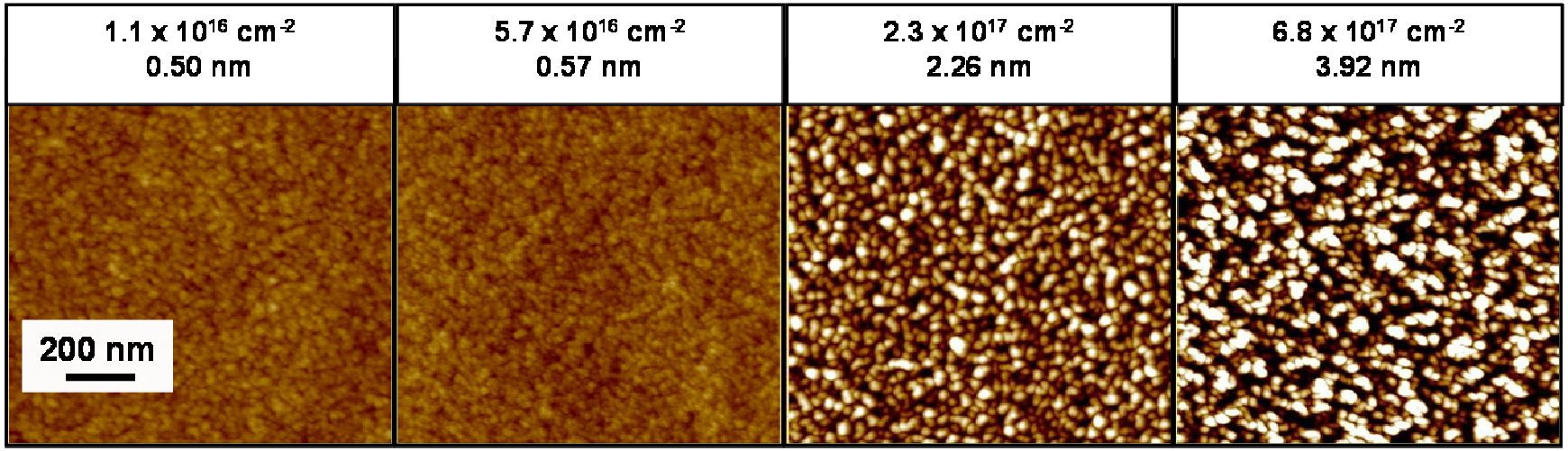
Titus, M. J. et al. J. Phys. D. Applied Phys., **42**, 2009.

VUV & Ion Synergy Enhances Roughening of 193 nm PR

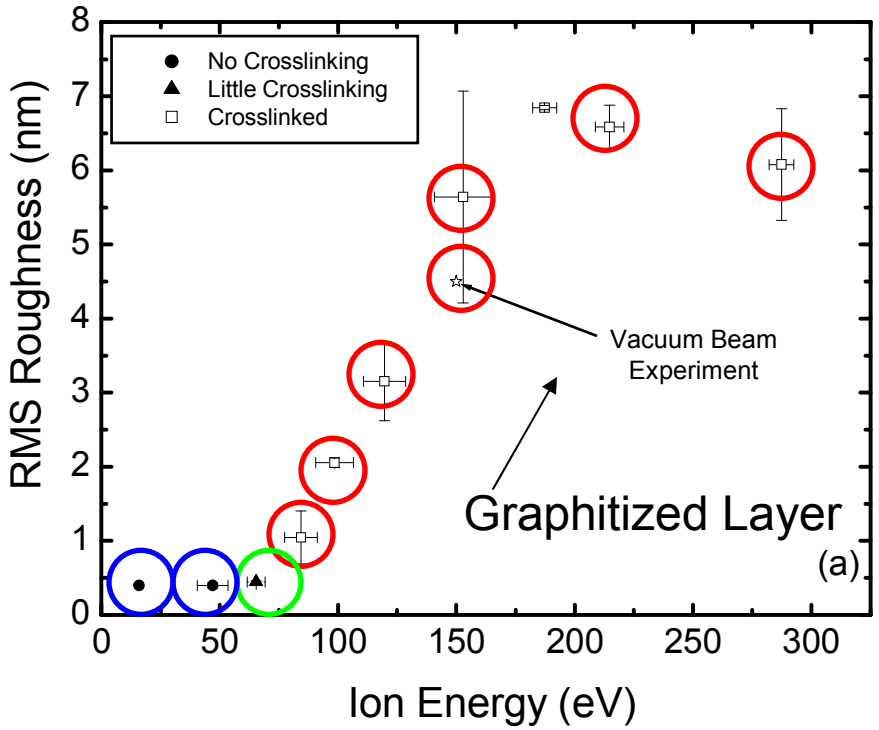
ICP System

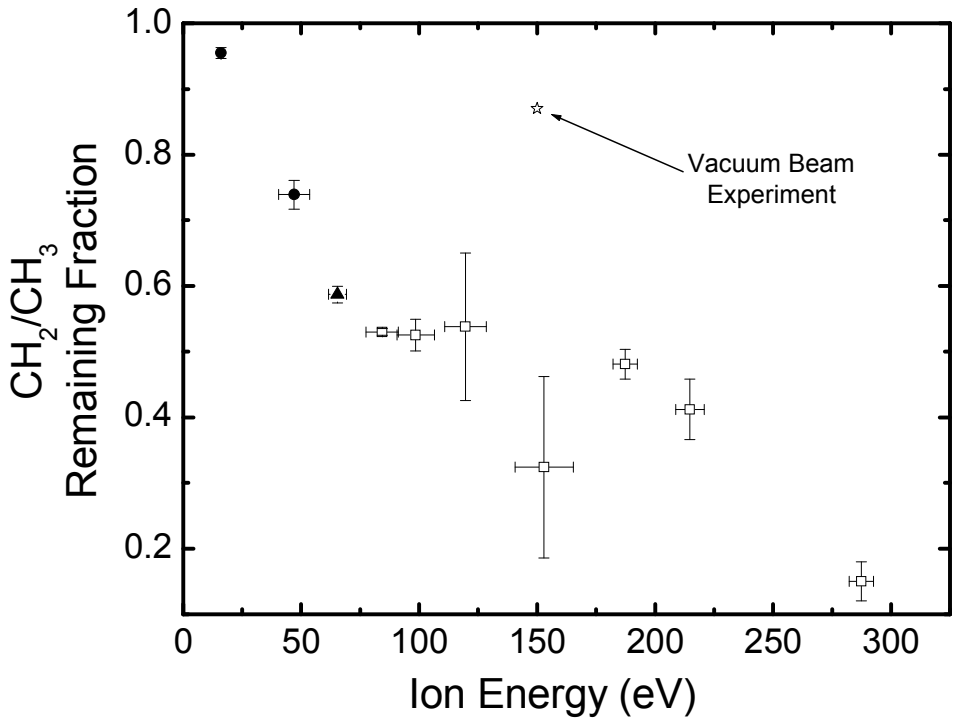


Vacuum Beam System

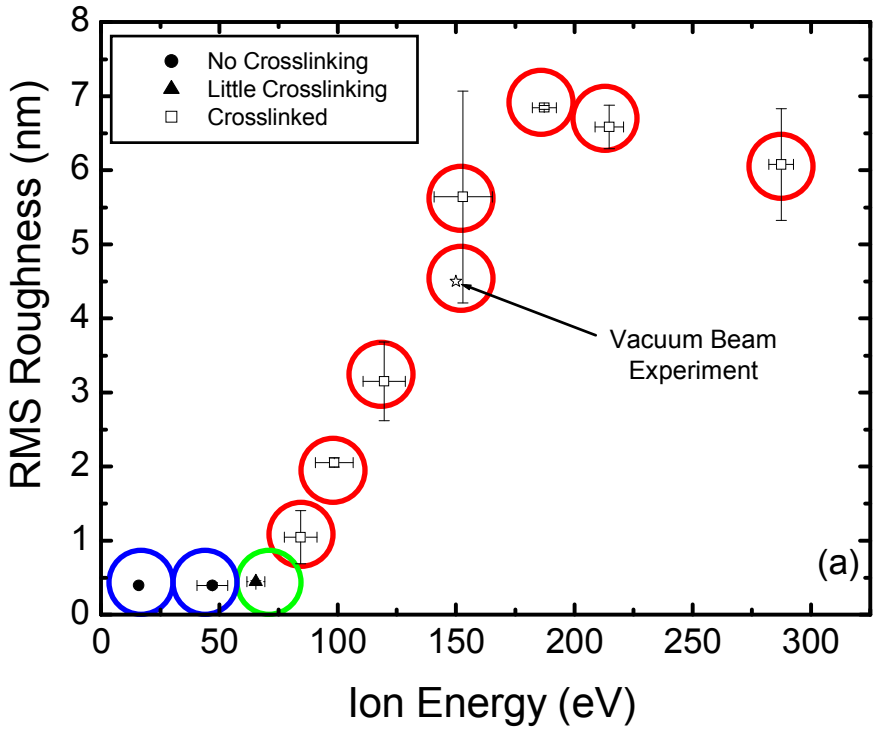


Threshold Energy for PR Roughening and Formation of a Dehyrogenated (Graphitized) Layer





PR Roughening is Attributed to Compressive Stress Generated by Bombarding Ions



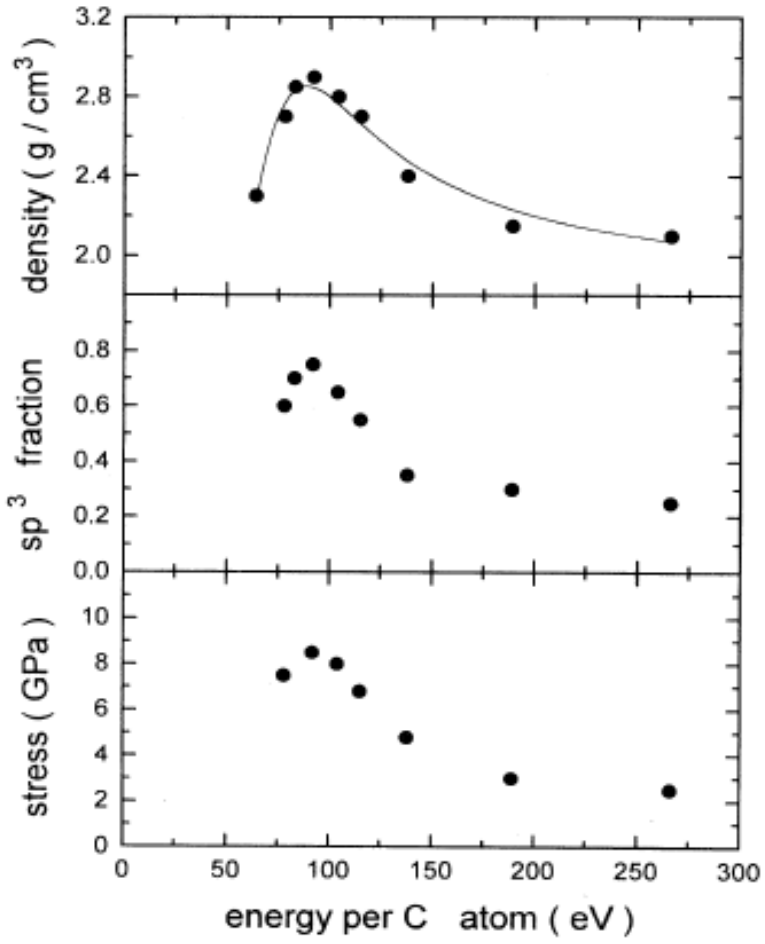
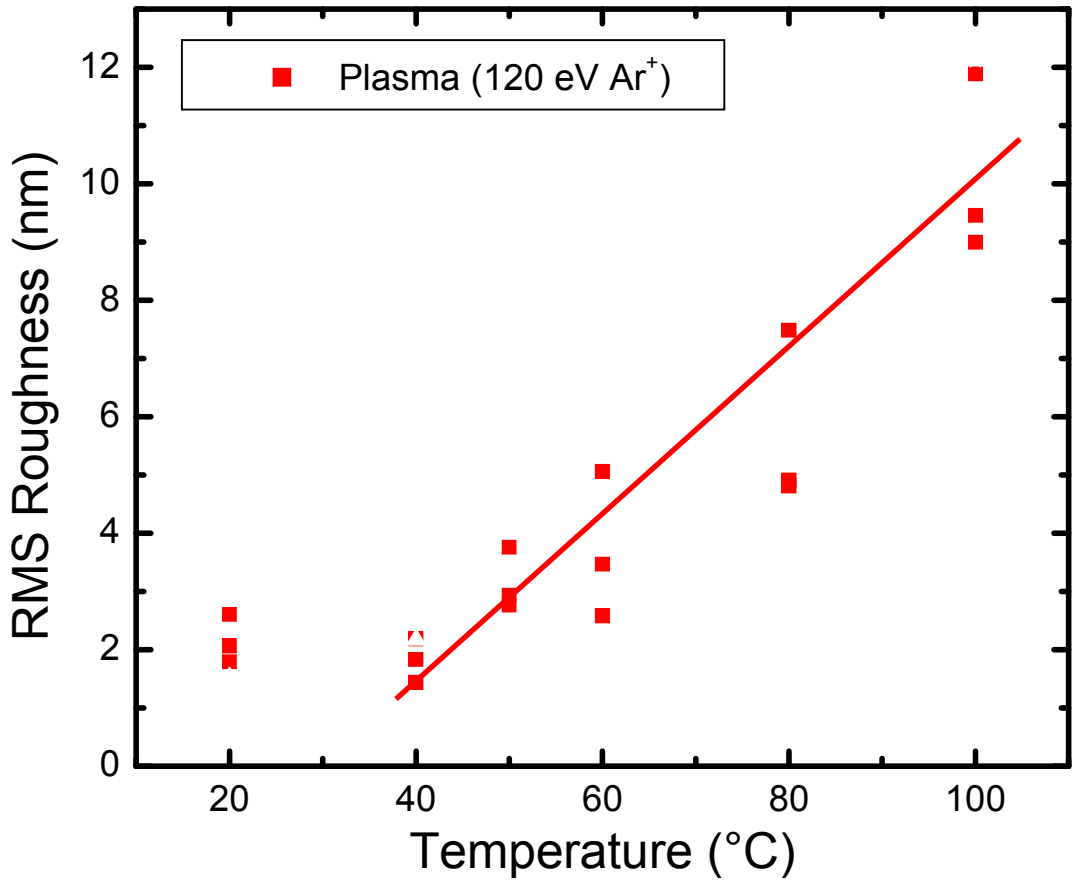


FIG. 5. Variation of the mass density, sp^3 fraction, and intrinsic stress of ta-C:H as a function of ion energy per C atom. The energy per C atom is 46% of the original $C_2H_2^+$ ion energy. Also shown is a fit of Eq. (15) to the density.

Weiler, M., et al. Phys. Rev. B., 53 (3), 1996.

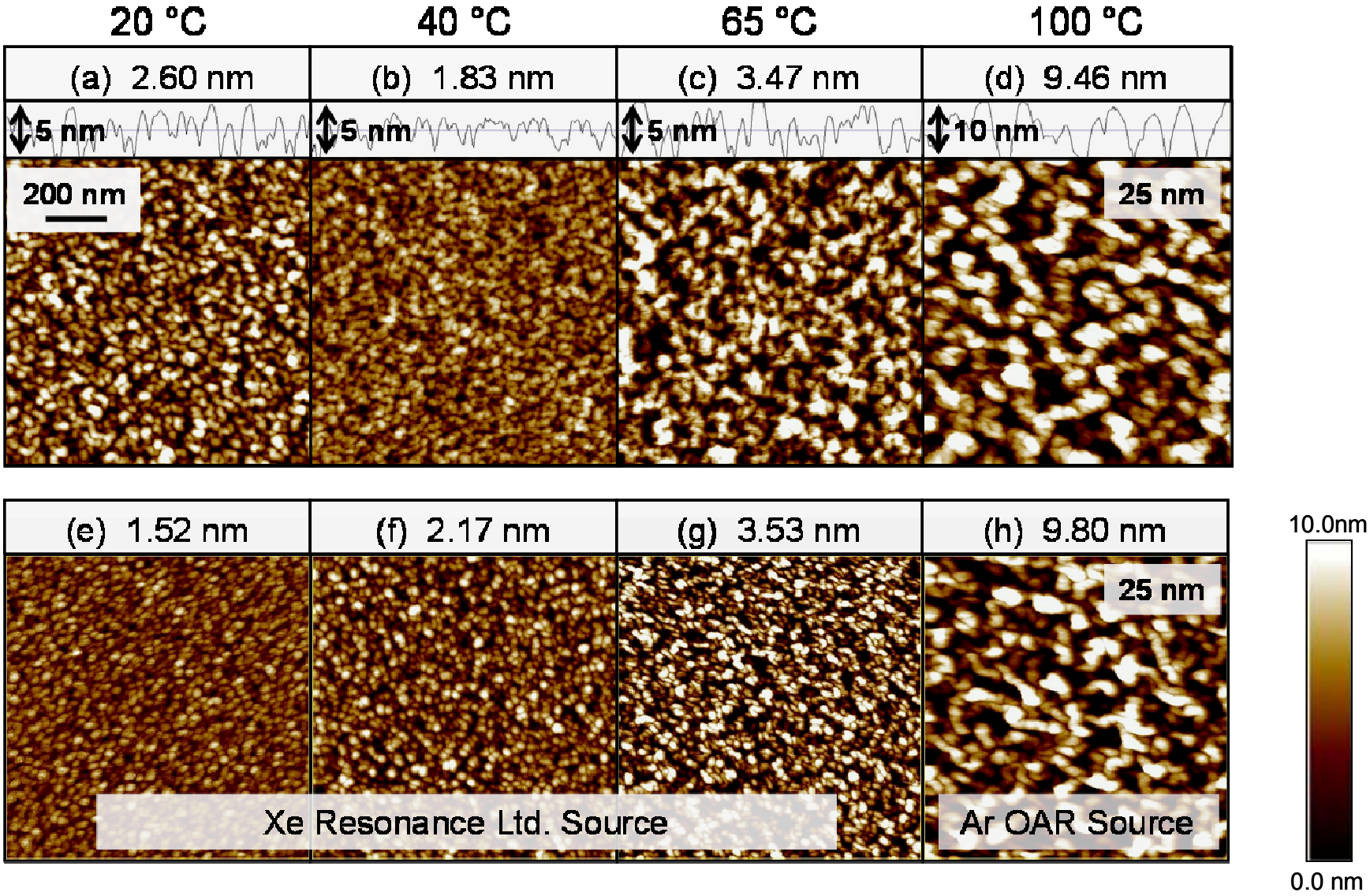
Substrate Temperature Enhances193 nm PR Roughening



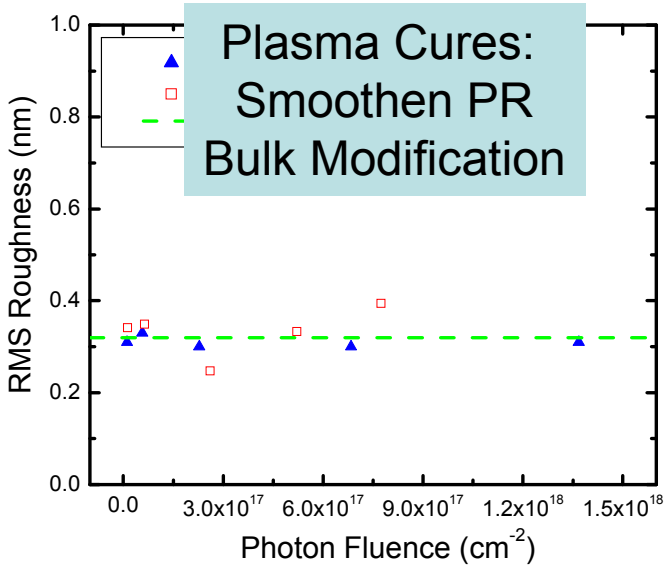
Conditions:

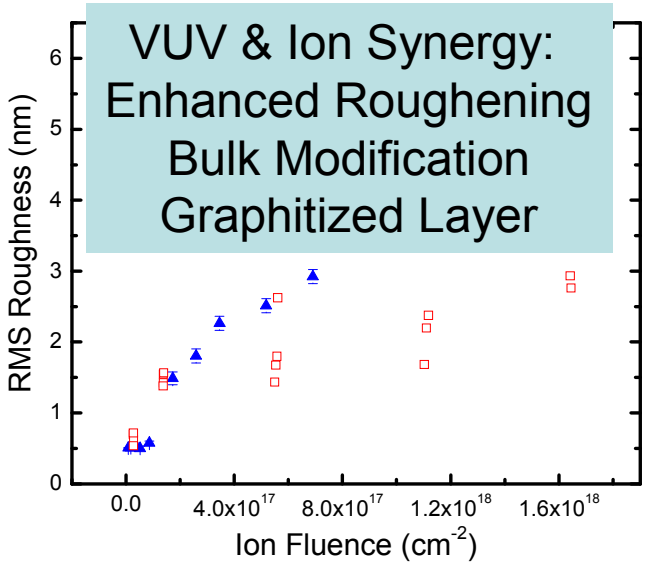
- Ar ICP, 10 mT, 70 W
- 120 eV Ar^+
- 300 s exposures
- 9 x 10^{17} ions/cm^2

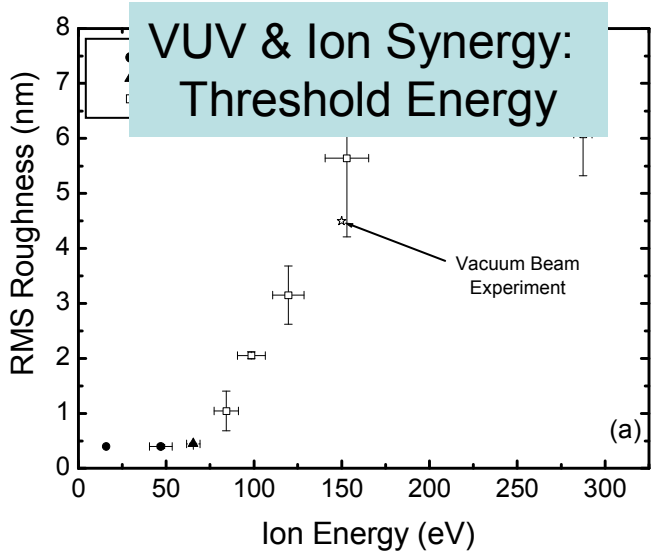
Substrate Temperature Enhances193 nm PR Roughening

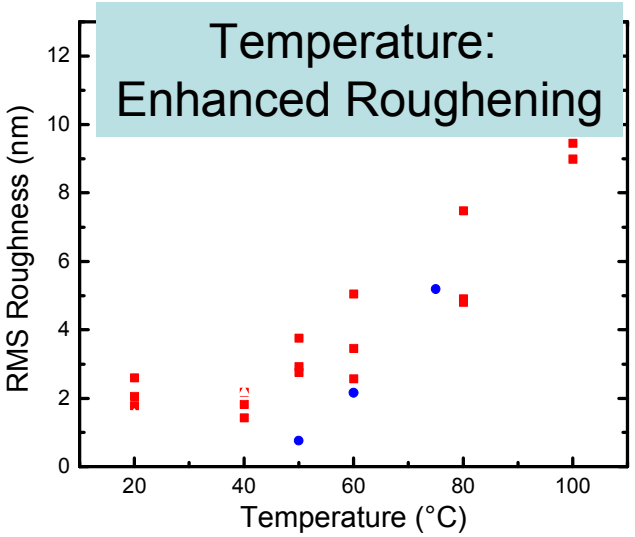


Conclusions Drawn from Blanket PR Studies

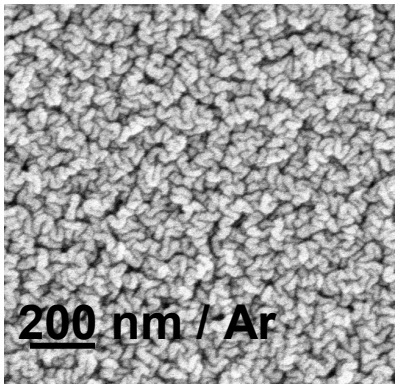




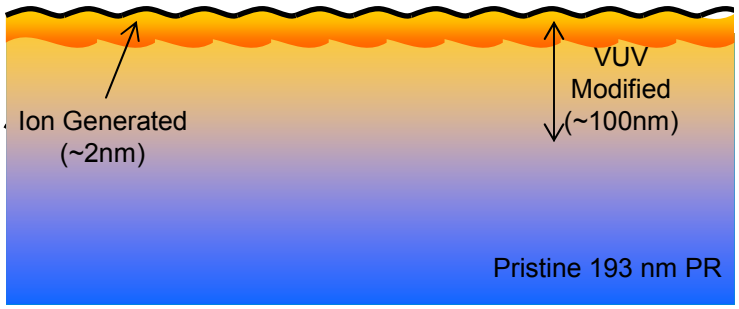


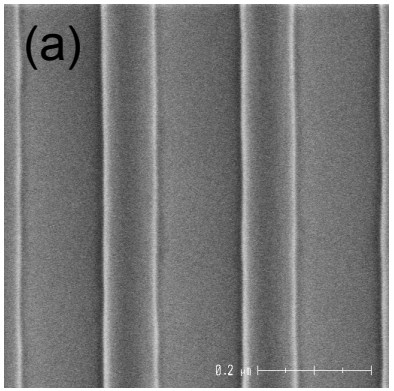


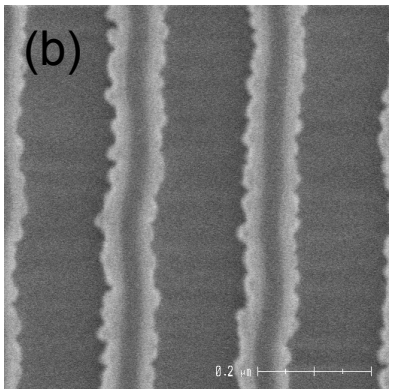
Does the Mechanism Describing the Roughening of Blanket Samples Apply to Patterned Samples?



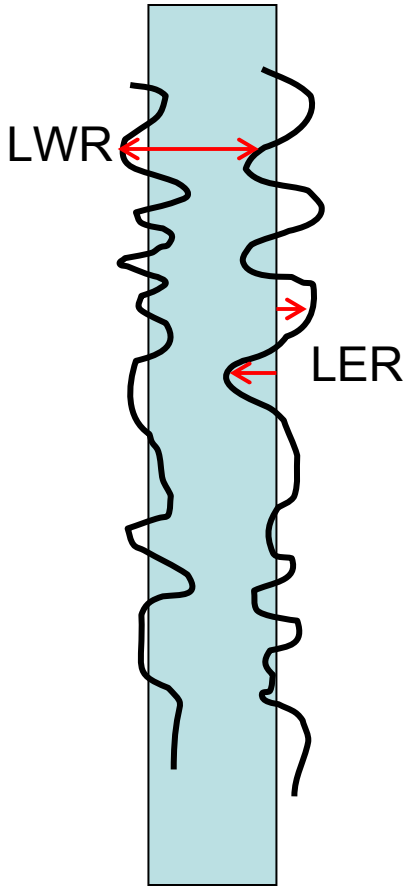
S. Engelmann, UMD





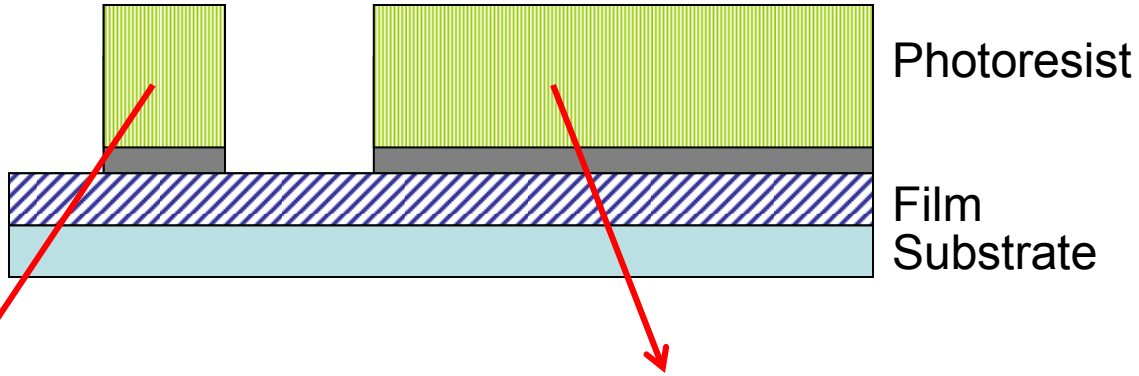


Yoko Yamaguchi, Lam Research

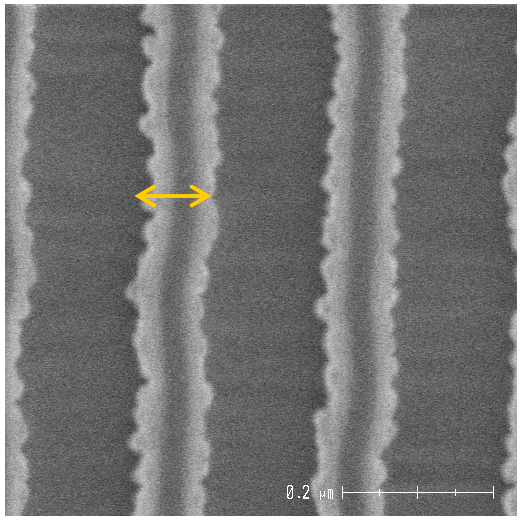


Patterned Samples (Lam Research) Processed in Ar ICP: LWR Measurements Compared to RMS Roughness

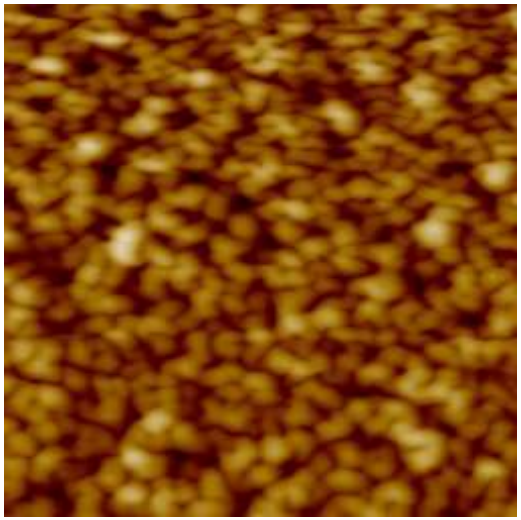
I. Plasma Cure
II. VUV & Ion Synergy
    I. Time
    II. Temperature
    III. Ion Energy



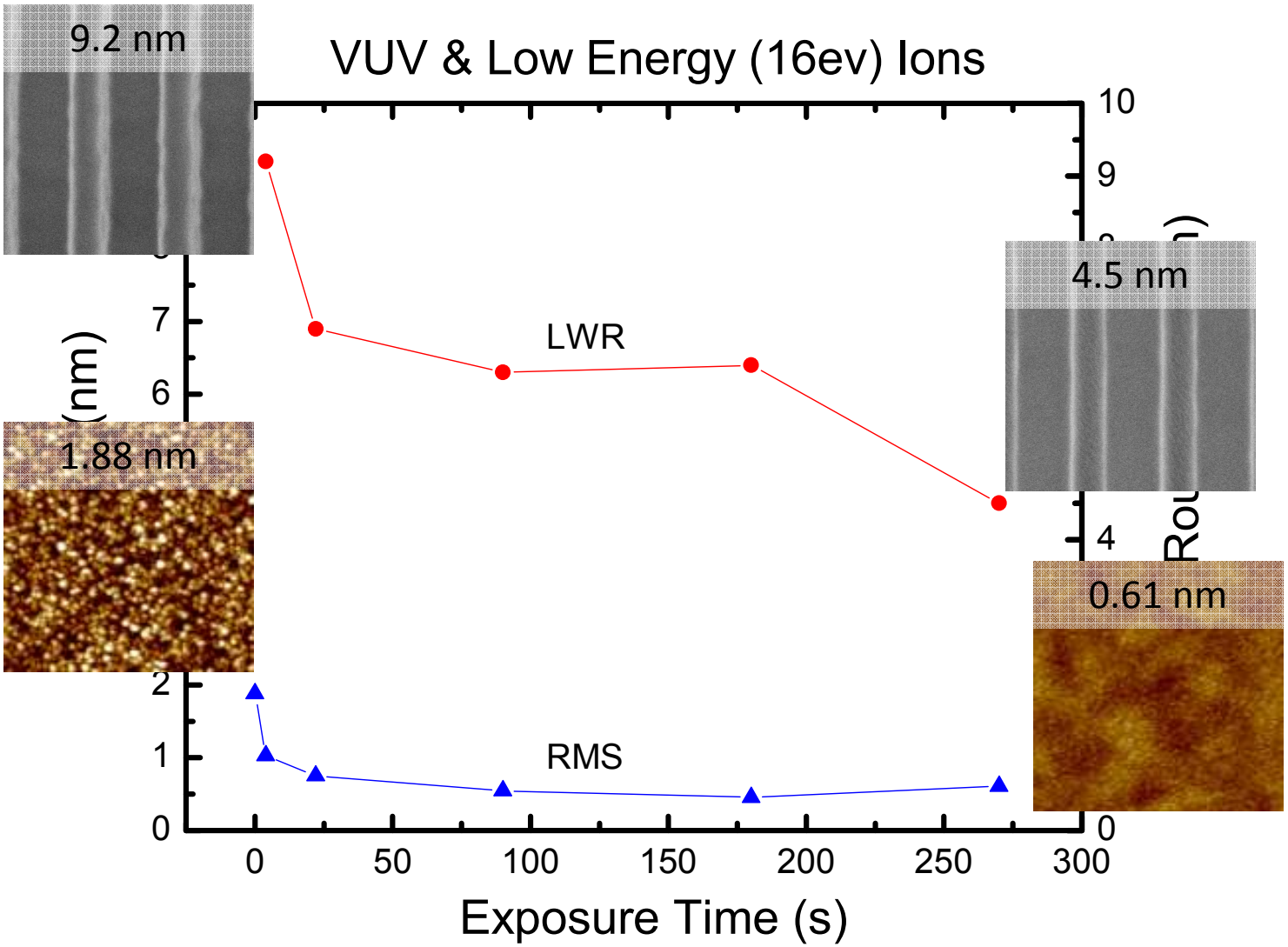
SEM: LWR



AFM: RMS



Preliminary Assessment Demonstrates that LWR and RMS Roughness may be Correlated



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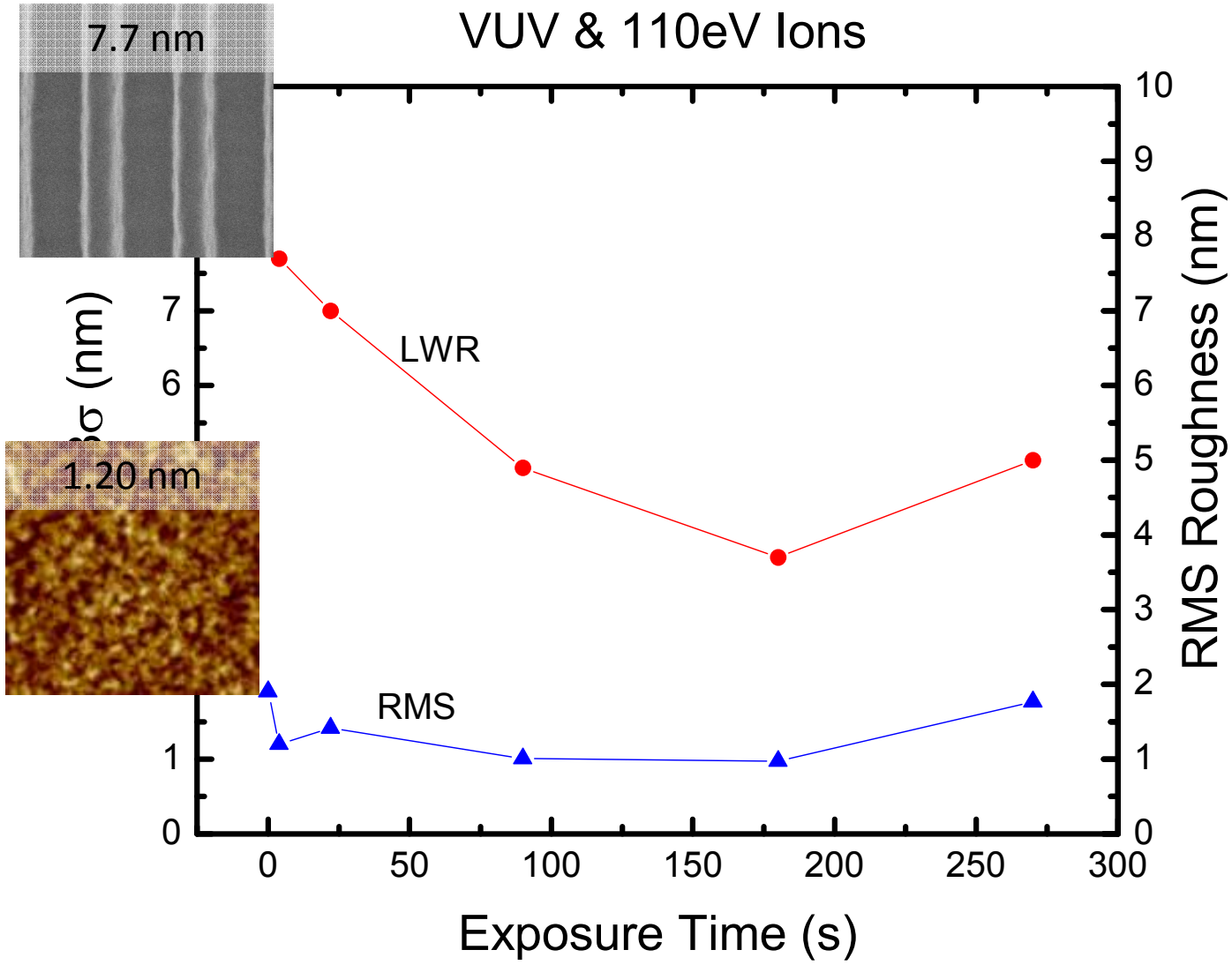

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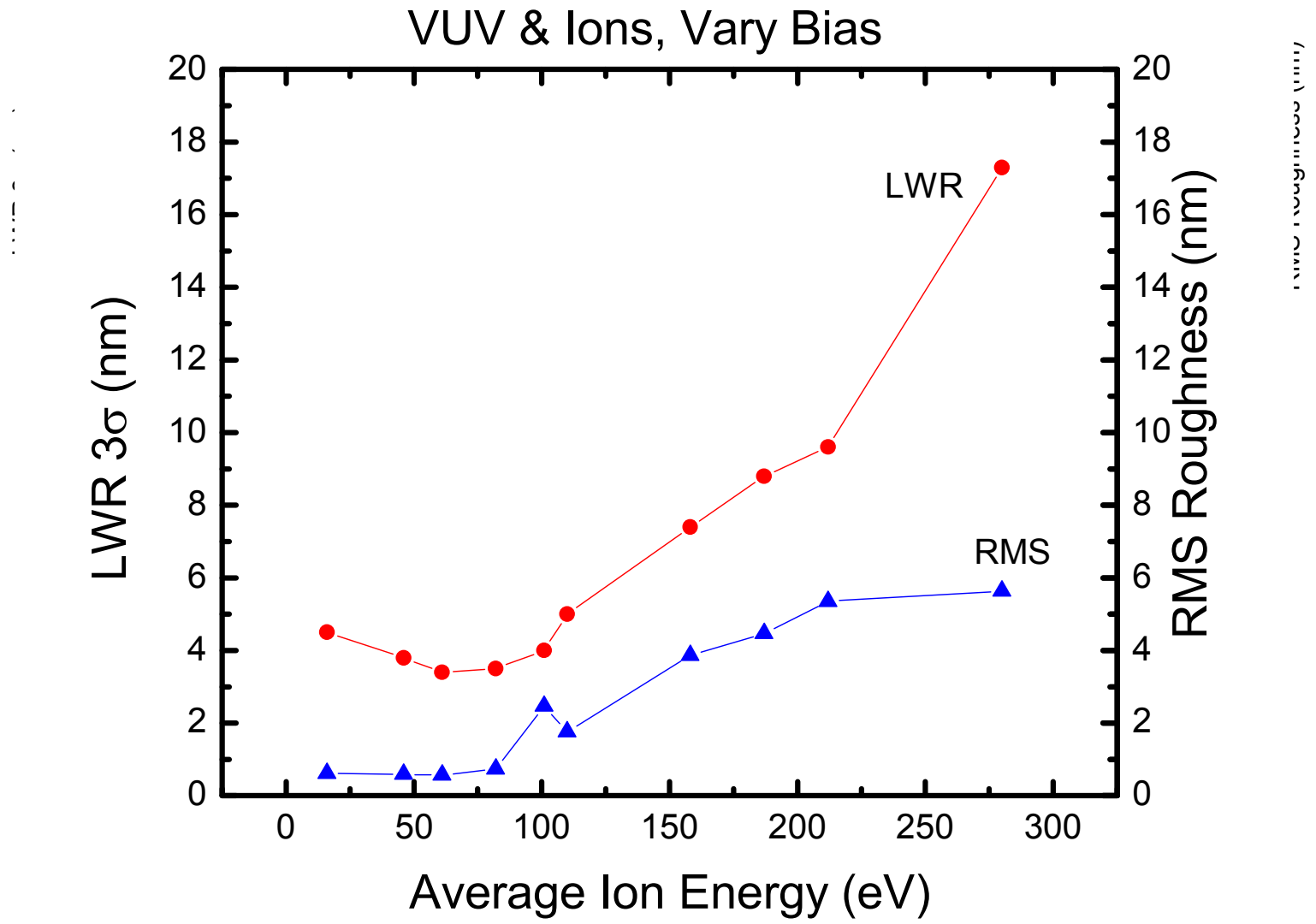
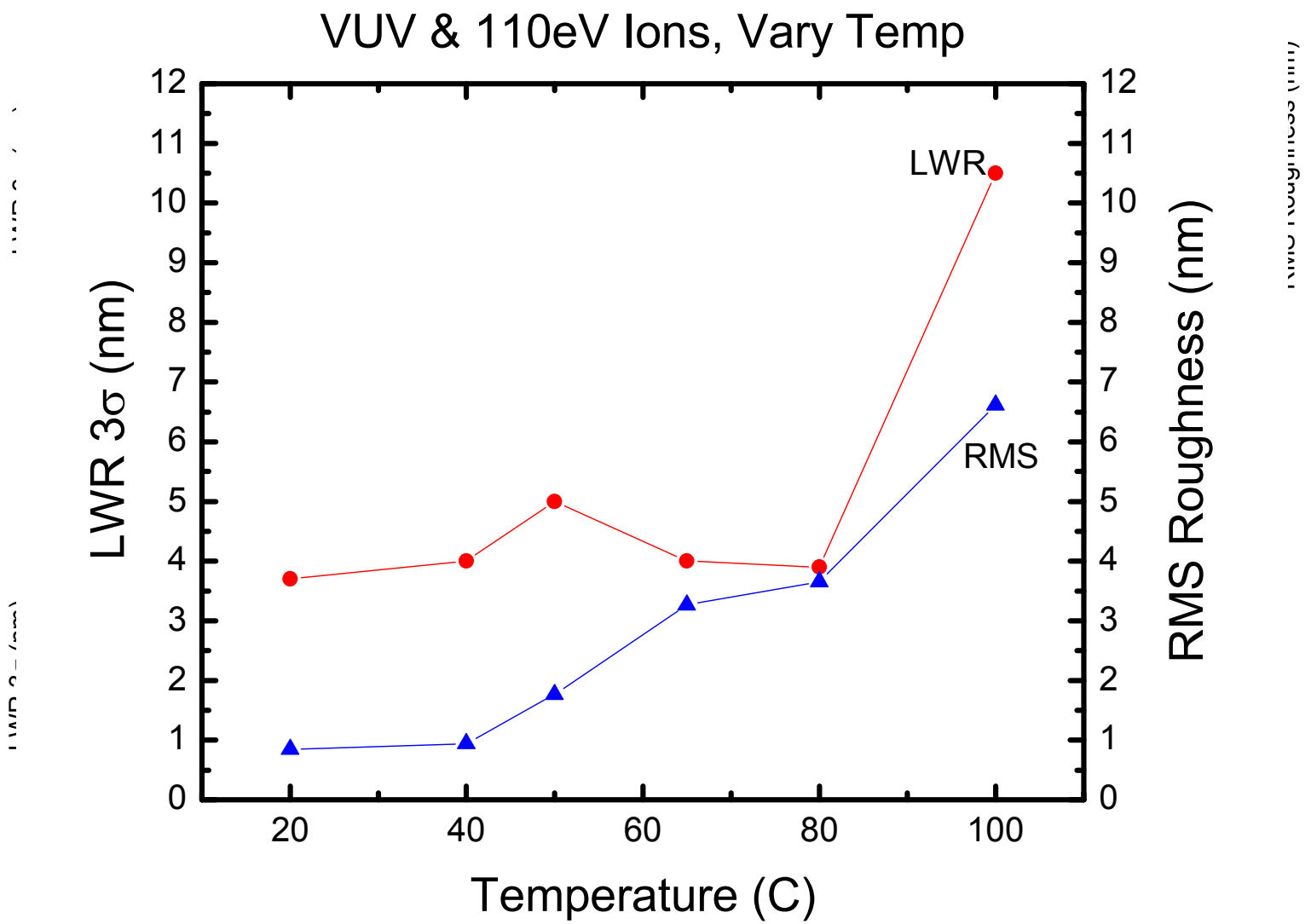


Preliminary Assessment Demonstrates that LWR and RMS Roughness may be Correlated



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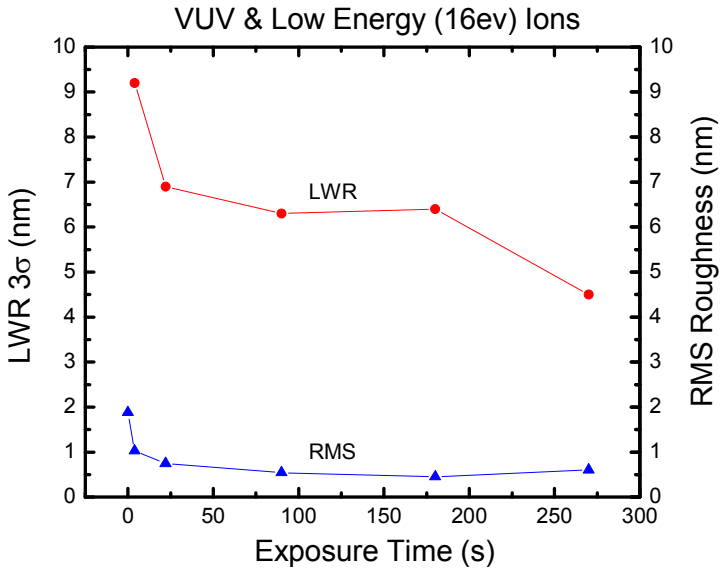
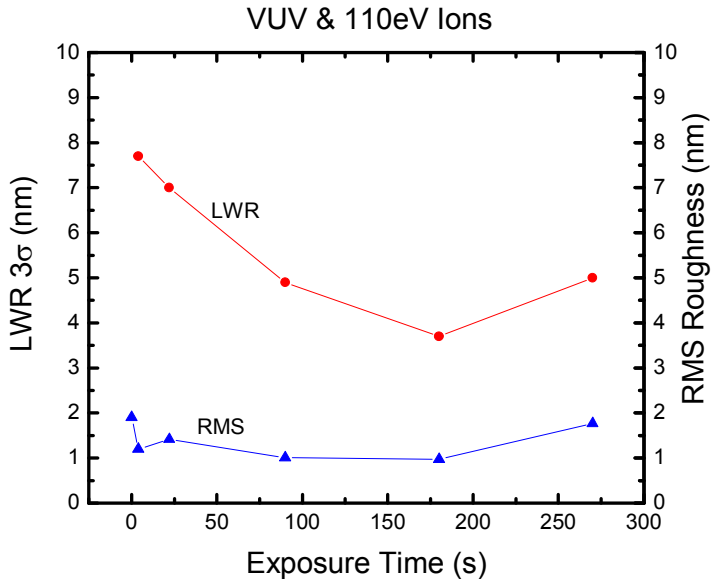
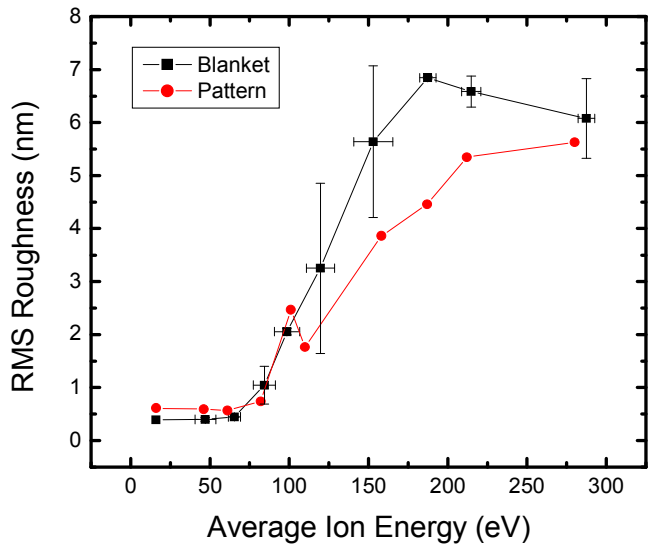
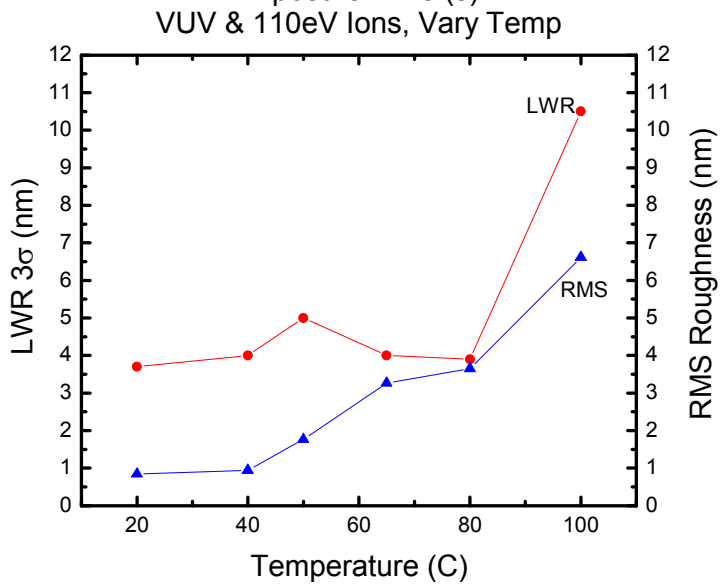


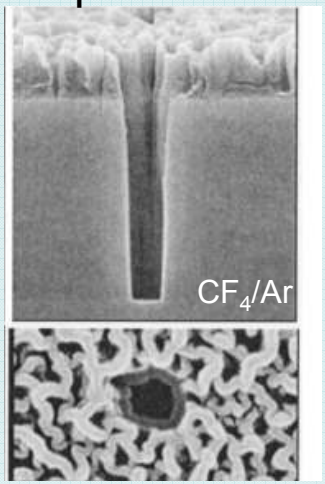






Roughening of 193 nm PR in Plasmas due to VUV Photon and Ion Synergy is Established and Leads the way to Understanding Roughening of Patterned Features

Complex Plasma



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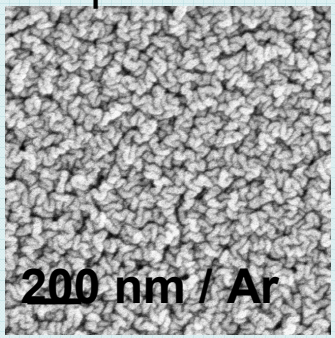
Simple Plasma



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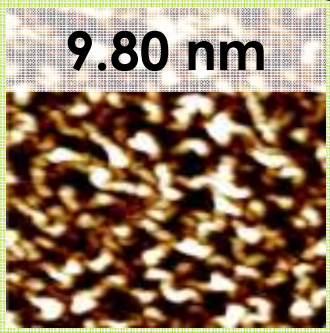
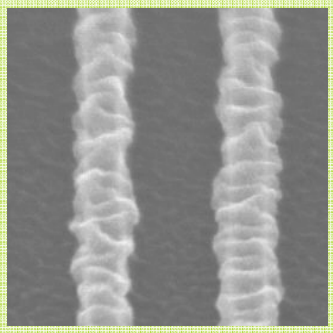
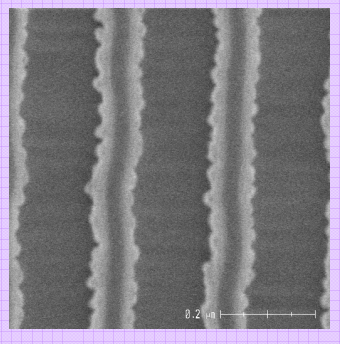
Vacuum Beam System

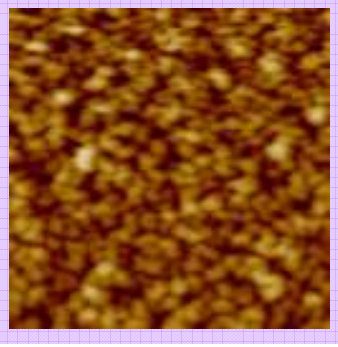
Synergy: VUV, Ions & Temperature





Simple Plasma: VUV & Ion Synergy





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