



Effect of Polymer Molecular Weight and Resist Sensitivity on LER and AFM Morphology of EUV Resists

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I. Introduction

II. Base Study

A. LER

B. AFM

III. Polymer Mw Study

A. LER

B. AFM

IV. Thermal Smoothing

V. Conclusions

**Partial Support
by
DARPA and EUV-LLC**

Introduction:

Line Edge Roughness (LER)

Why is LER Important?

- Low LER will give better control of gate CD required by future devices
- SIA Target for 45 nm node is 2 nm – much lower than current capability

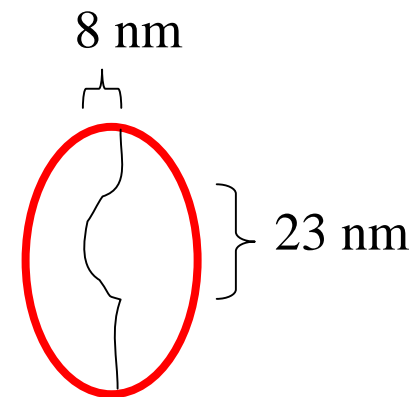
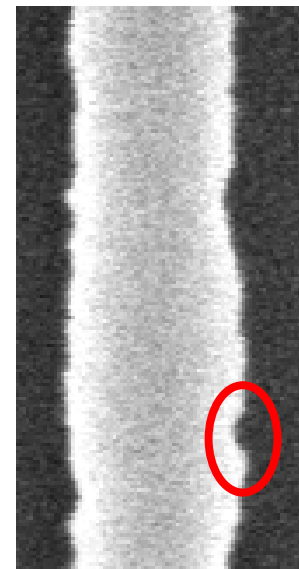
What are possible sources of LER?

Materials:

- Polymer M_w
- AFM Polymer Aggregate Size
- Dissolution Properties
- Base Loading / Chemical Contrast
- Acid Diffusion Effects

Aerial Image

100 nm Line 8 nm 3- σ LER



Introduction:

Atomic Force Microscopy (AFM)

Why use AFM to Study EUV LER?

- High sensitivity and resolution
- Development of unexposed resist surfaces show “polymer aggregates”
- Polymer aggregates indicate non-uniformity in dissolution properties

Typical AFM Process:



UFTL =
Unexposed Film Thickness Loss,
or Dark Loss

AFM Conditions

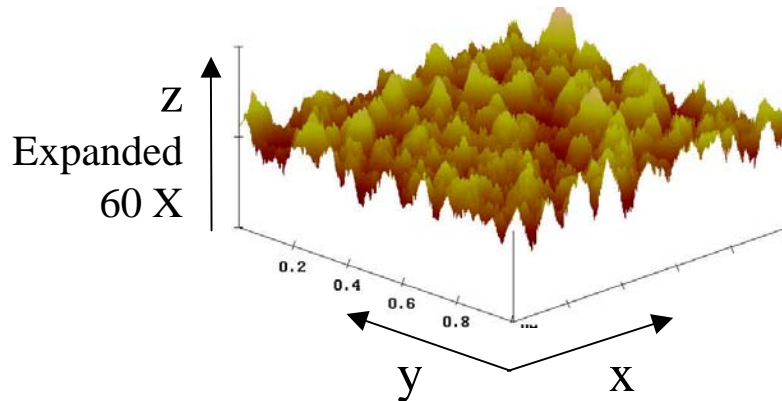
- Tapping Mode (Res = 1-5 nm)
- Si Tip, Radius = 5-10 nm
- 1 μ m field size, 1 Hz scan speed
- 10 nm Z scale

Introduction:

AFM was used to Determine two Values

AFM Surface Roughness

z-direction

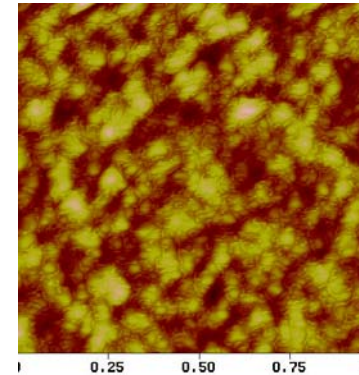


Average Roughness Determined by AFM

Roughness Range: 0.2 – 1.0 nm

AFM Grain (Aggregate) Size

x/y plane



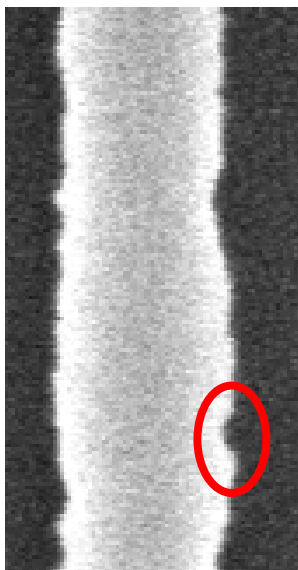
10-15 Grains Selected for Measurement

Diameter Range: 30-80 nm

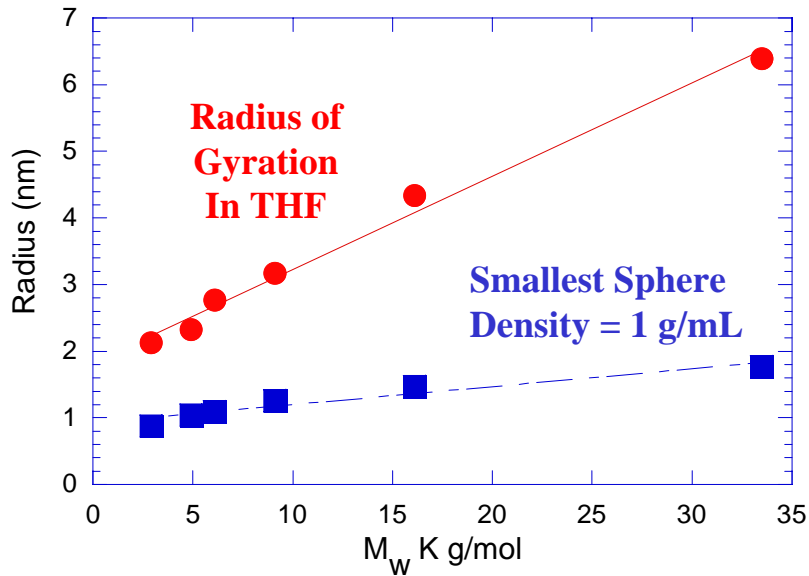
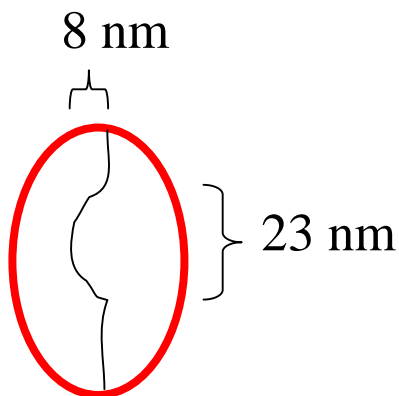
Aspect Ratio of AFM Features (z/x) ~ 1 / 100

Does Polymer M_w Effect LER or AFM Morphology?

6 New Polymers $M_w = 3-33$ K g/mol



100 nm Line
8 nm 3- σ LER

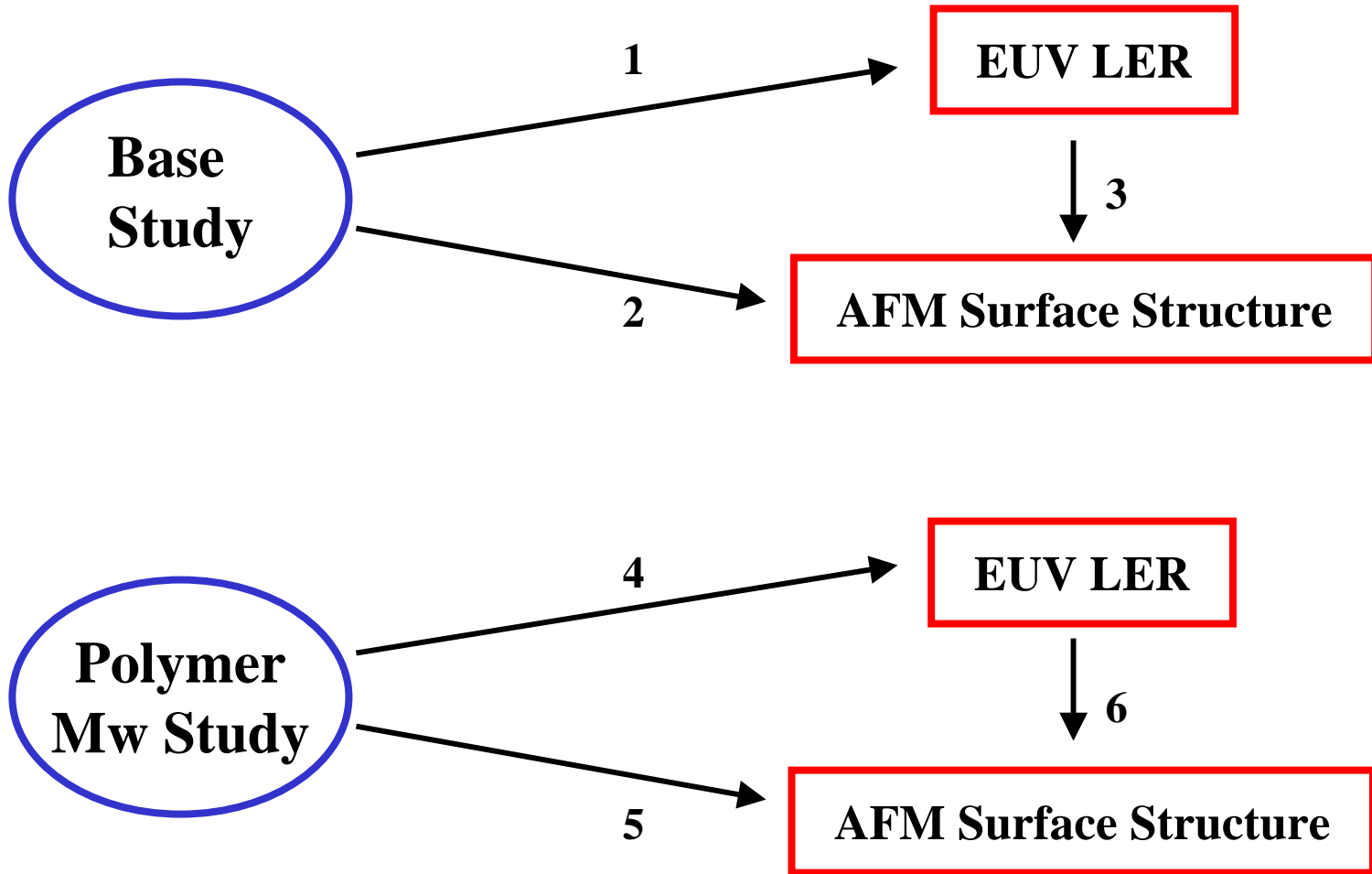


$R_g = 2-6$ nm
Diameter = 4-12 nm

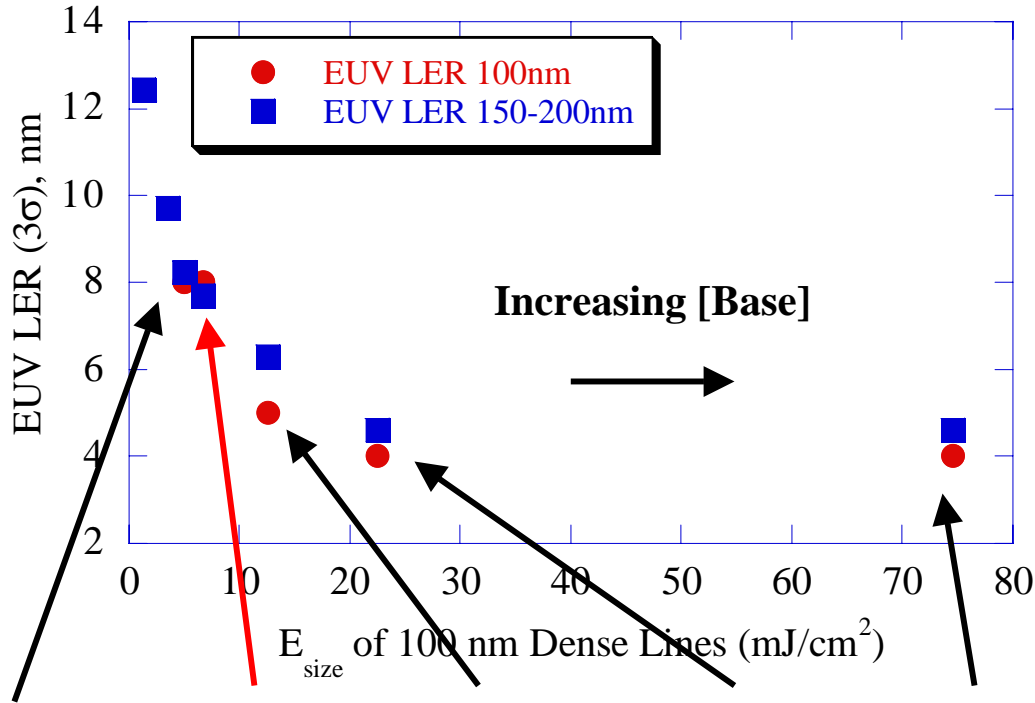


$R = 0.9-1.8$ nm
Diameter = 1.8-3.6 nm

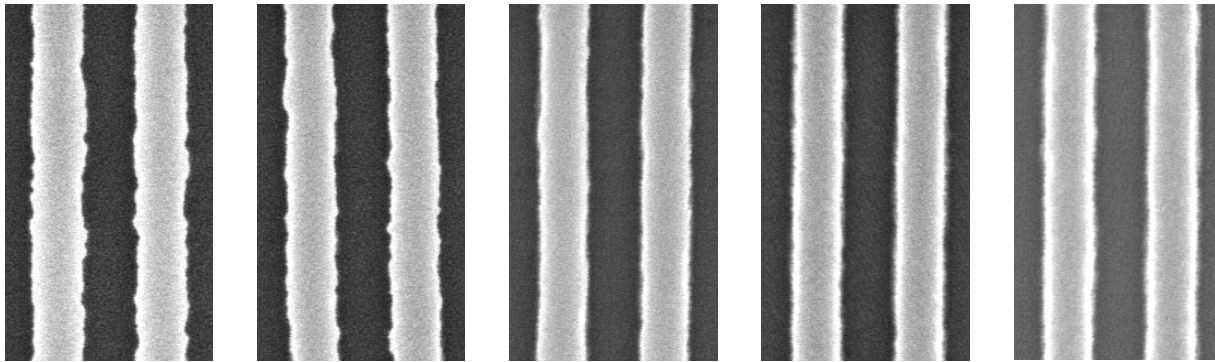
Introduction: What was Studied Here



II. Base Loading Study



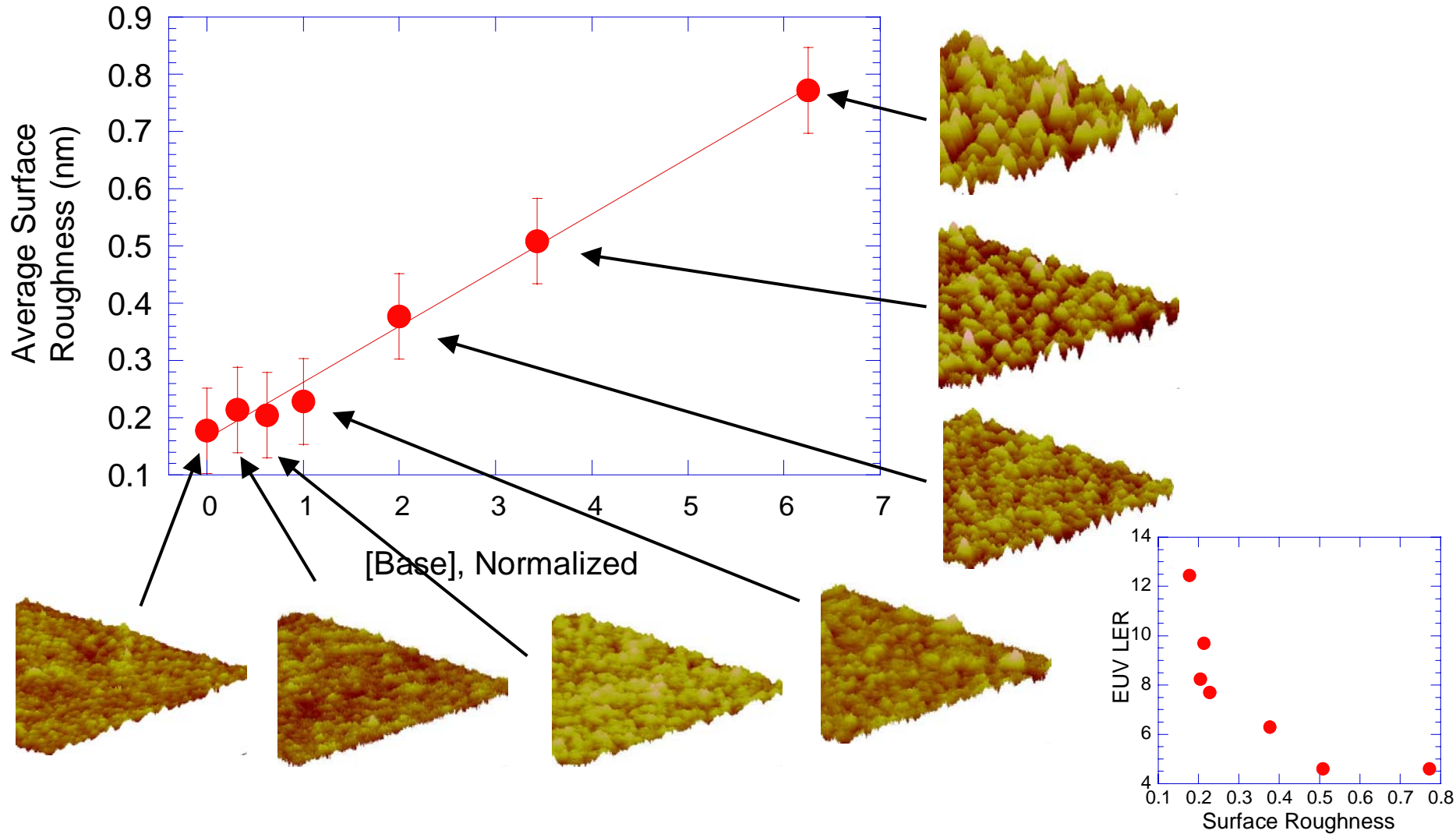
LER Decreases with Increasing Base
But at a Great Cost in Sensitivity



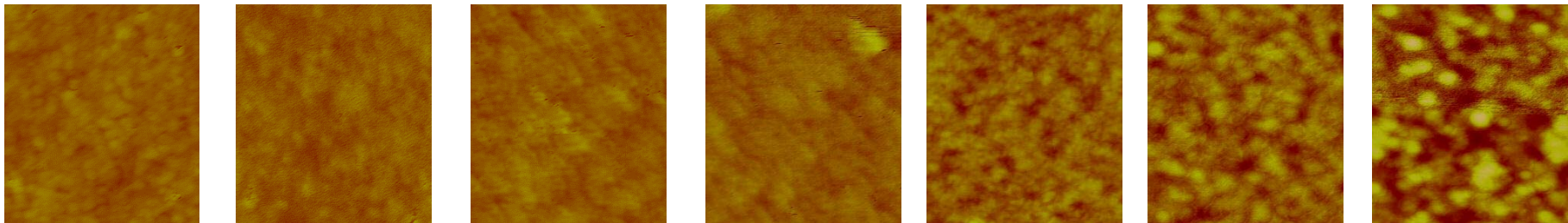
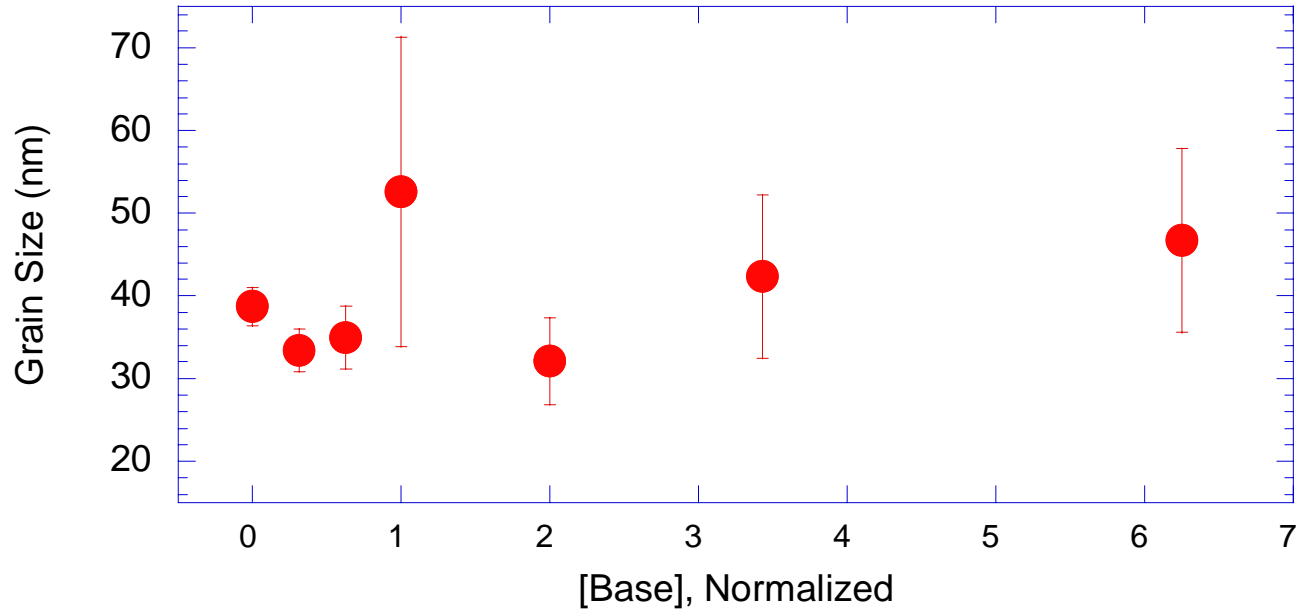
100 nm Dense Lines

EUV-2D

II. Base Loading Study: Surface Roughness (R_{ave})

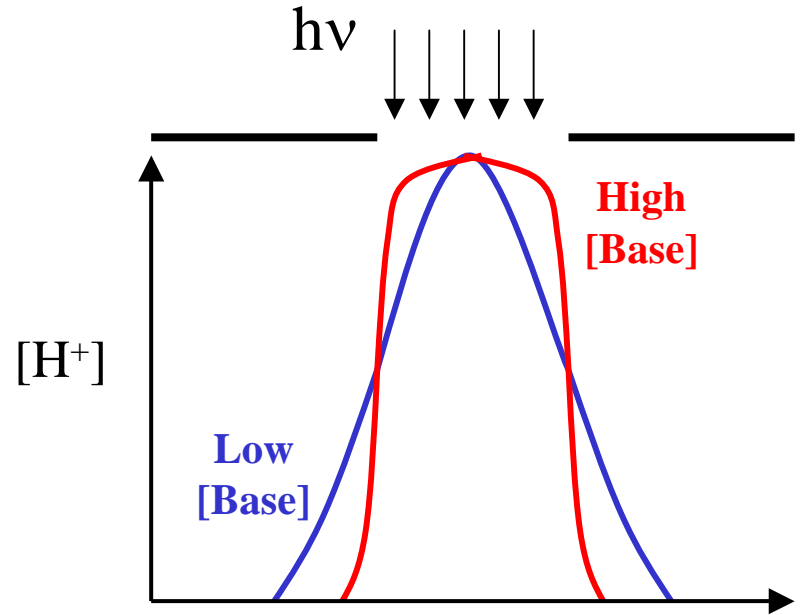
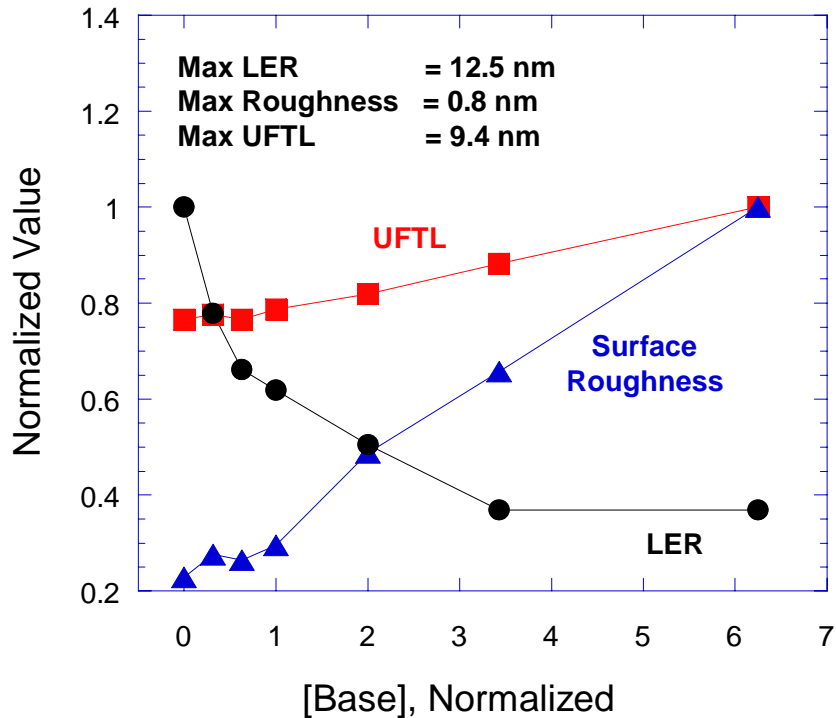


II. Base Loading Study: Grain (Aggregate) Size



Increasing [Base] →

Interpretation of Base Effect



- Higher Base gives Better Chemical Contrast, Improving LER
- Higher Base increases UFTL. When more material is removed, surface roughness increases
- AFM Grain Size Unaffected by [Base] change

Effect of Polymer M_w on LER and AFM Morphology

Problem:

- Large changes in polymer molecular weight will drastically alter the dissolution properties of the resist

Approach:

- Vary Polymer M_w from 3 to 33 K g/mol
- Vary [PAG] and [base] to compensate for changes in M_w



[PAG] and [Base] Variations over Wide Polymer M_w Range

Round 2

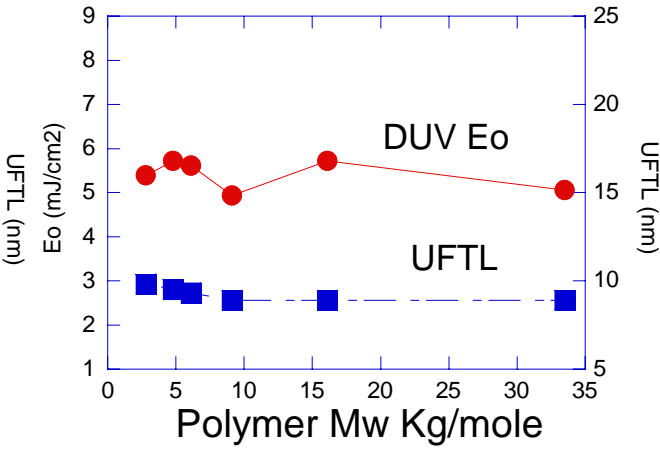
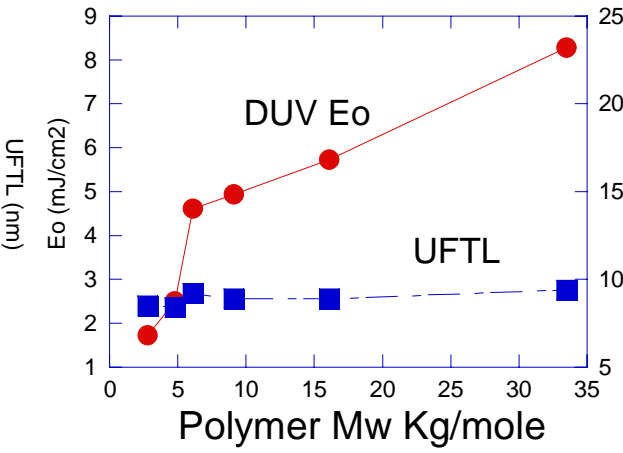
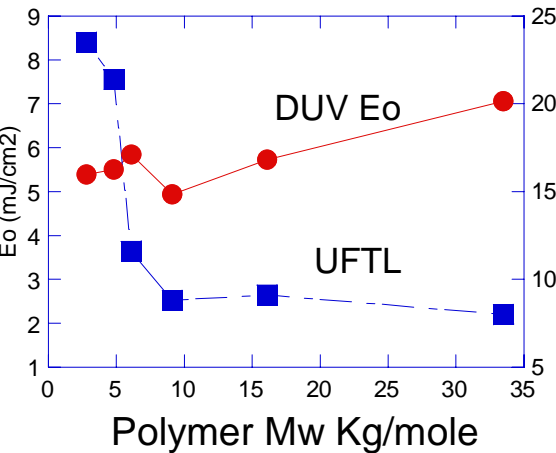
6 Mws
Changing UFTLs

Round 3

6 Mws, 6 [PAG]
Constant UFTL
Changing Eo

Round 4

6 Mws
6 [PAG], 6 [Base]
Constant UFTL, Eo



Effect of M_w on LER

Round 2

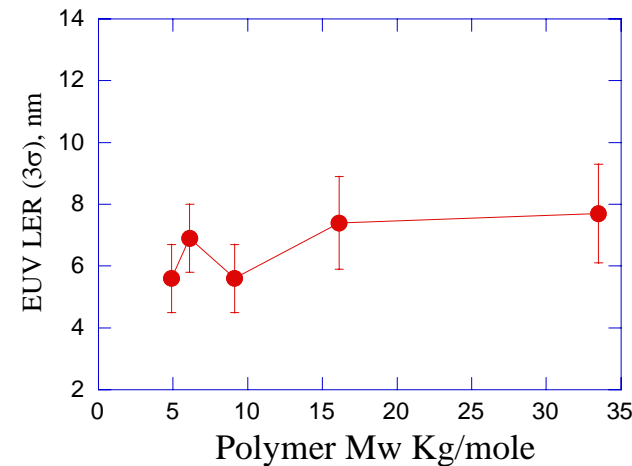
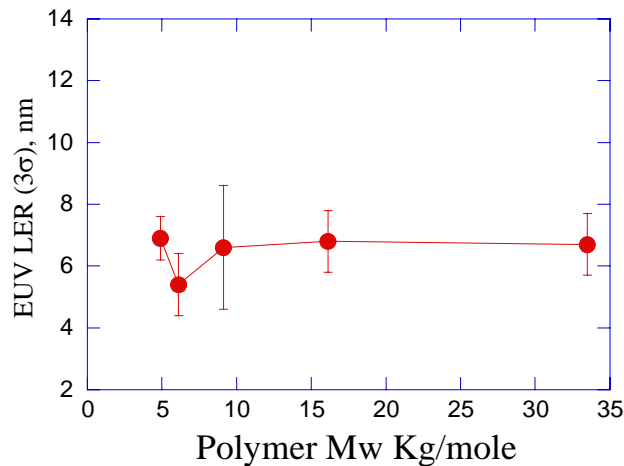
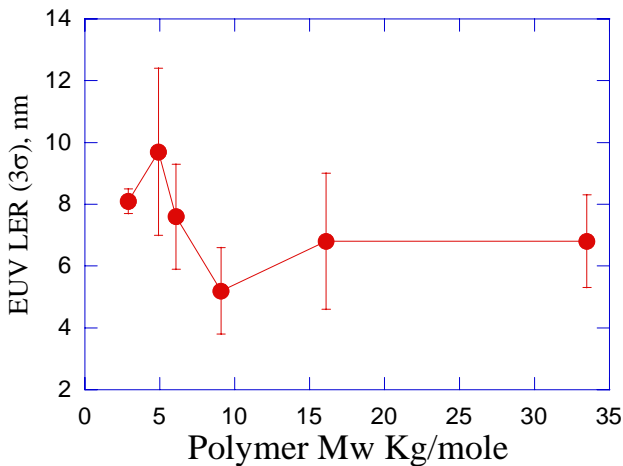
6 Mws
Changing UFTLs

Round 3

6 Mws, 6 [PAG]
Constant UFTL
Changing E_o

Round 4

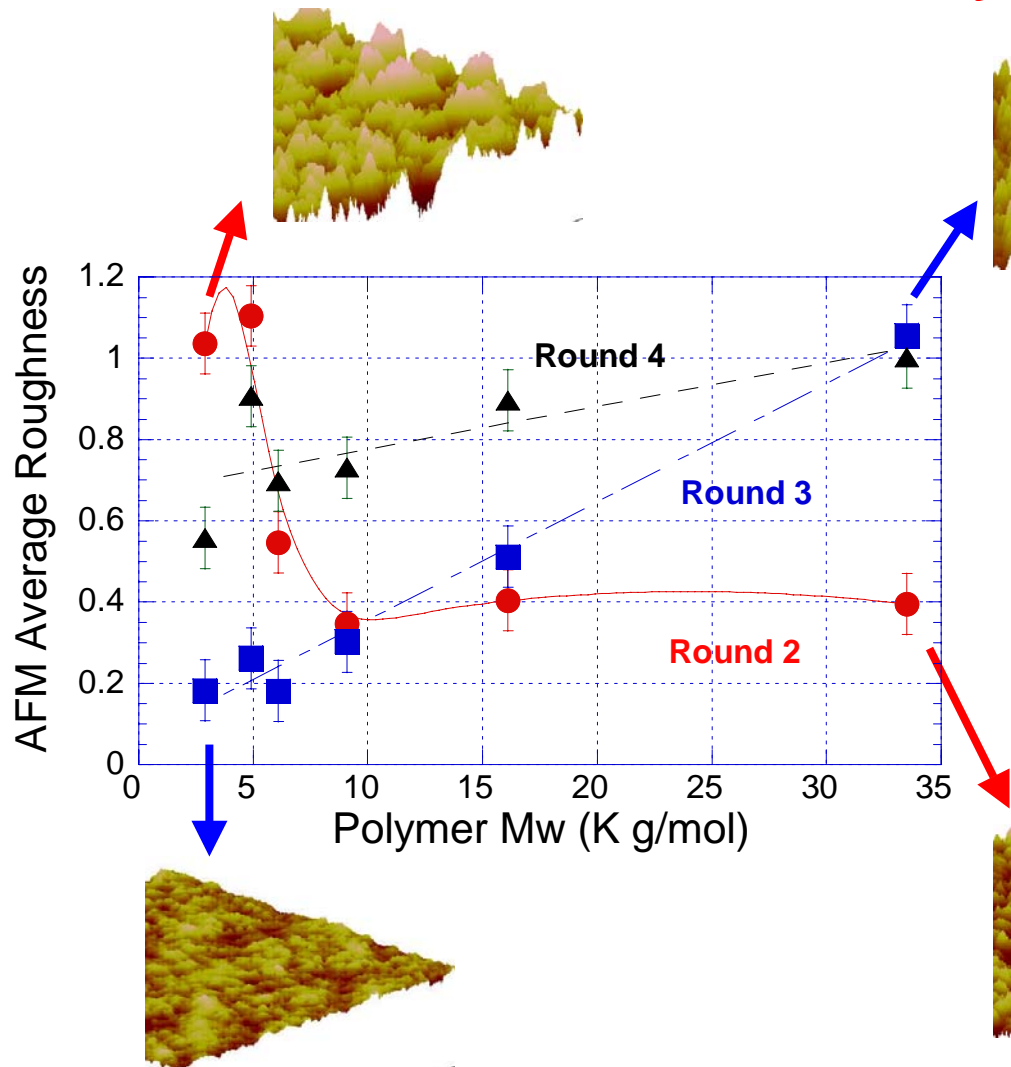
6 Mws
6 [PAG], 6 [Base]
Constant UFTL, E_o



LER is **HIGHER AT LOW** Mw in Round 2 – probably because of higher UFTL

LER is **UNAFFECTED** by an order of magnitude change in polymer M_w when UFTL is held constant (Rounds 3 and 4)

AFM Surface Roughness (R_{ave}) vs. Polymer M_w



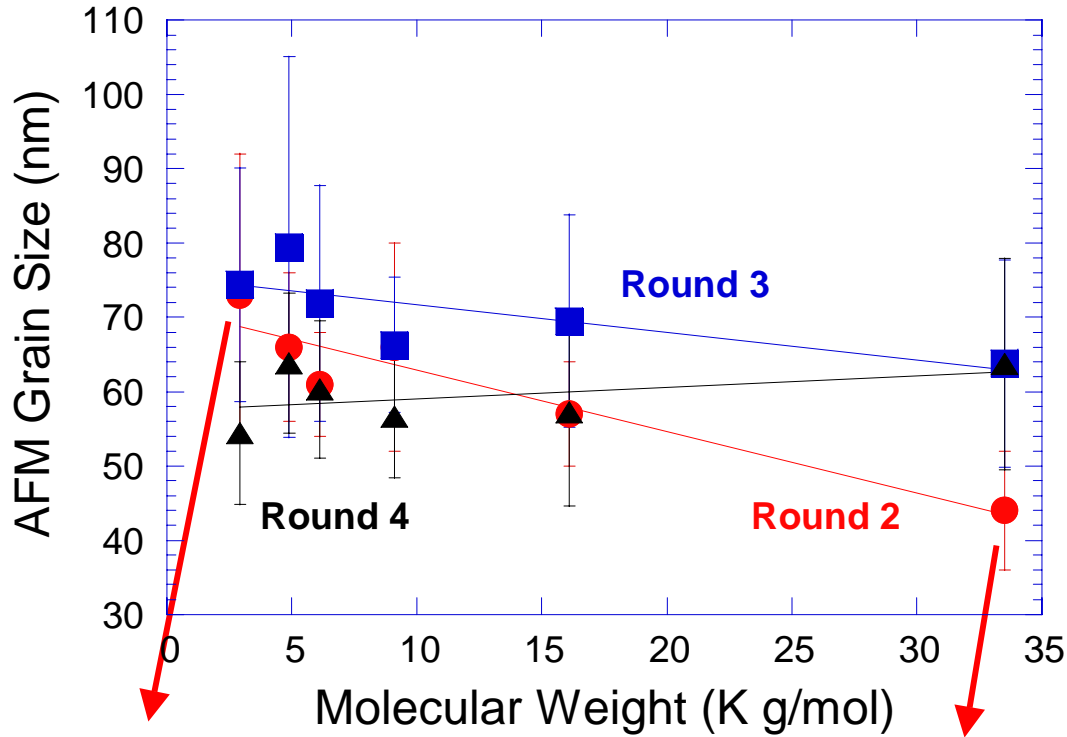
Round 2:

Direct change in M_w causes R_{ave} to decrease. Probably because UFTL decreases.

Rounds 3 and 4:

When UFTL is held constant by changing [PAG], R_{ave} increases with increasing M_w

AFM Grain Size vs. Polymer M_w

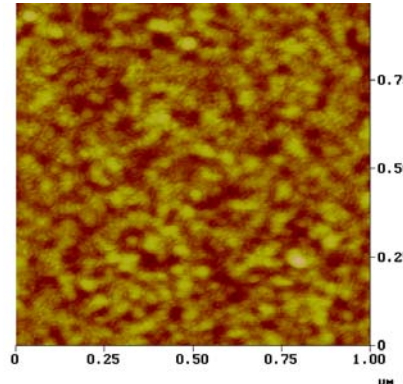
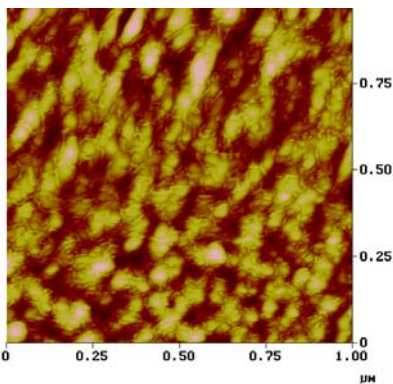


Round 2:

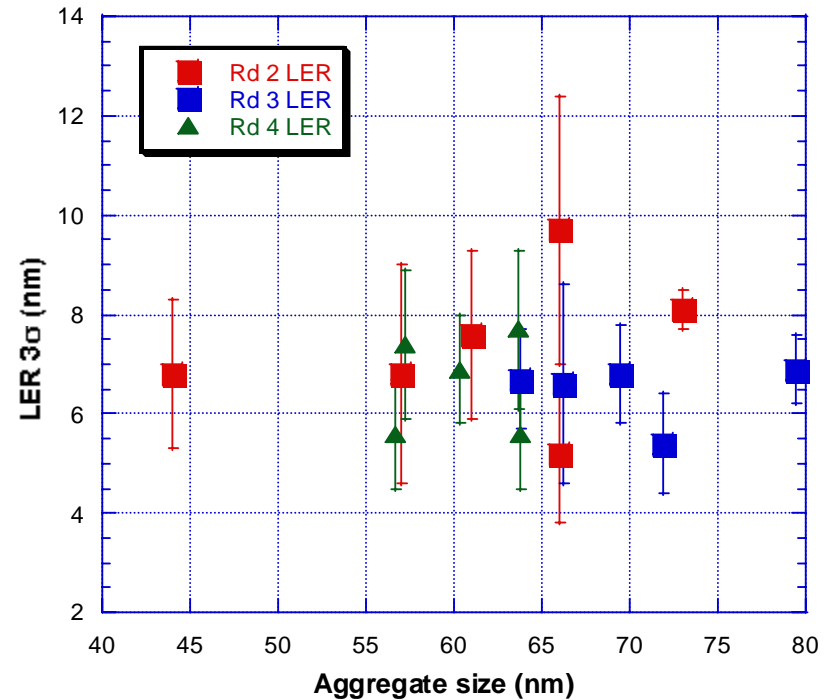
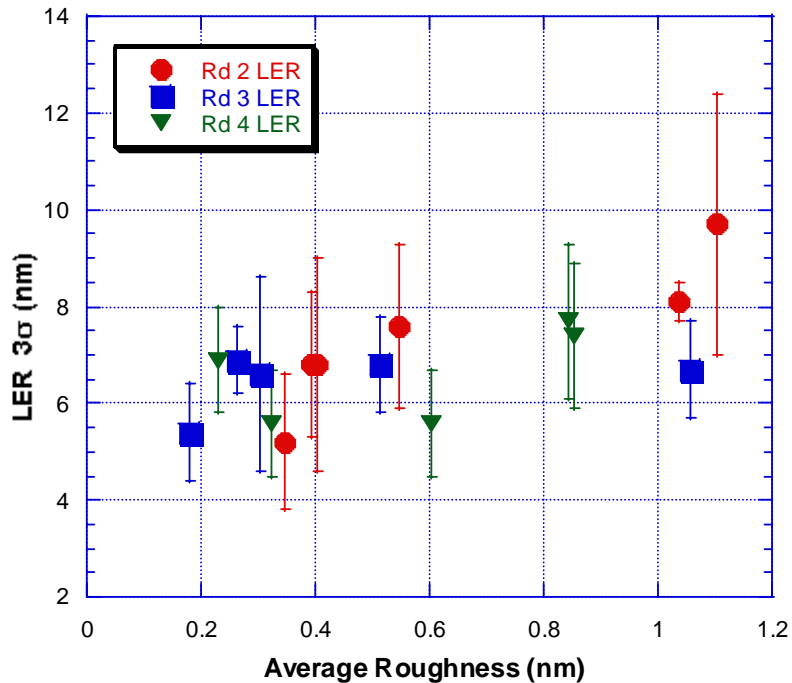
Direct change in M_w causes grain size to decrease slightly.

Rounds 3 and 4:

When UFTL is held constant by changing [PAG], grain size is unchanged with increasing M_w



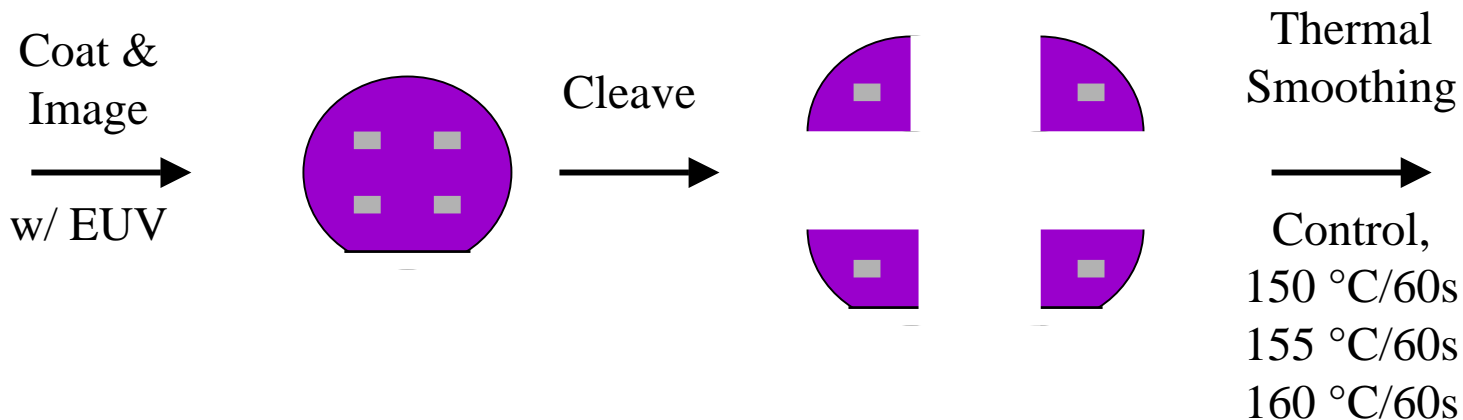
LER vs. Aggregate Size and Surface Roughness



This Work has Shown no Correlation between AFM Grain Size, or AFM Surface Roughness and LER, unless caused by High UFTL

IV. Very Recent Thermal Smoothing Results

Work by Intel¹ and Others² showed that high temperature bakes after imaging at other wavelengths could improve LER.



EUV-2D and EUV-12A Tested

1. Bryan Rice, et. al, EUV Symposium 2003.
2. Tony Novembre, Microelec Eng. Vol 46, p271.

Thermal Smoothing of EUV-2D and EUV-12A

Hard Bake

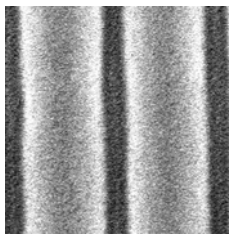
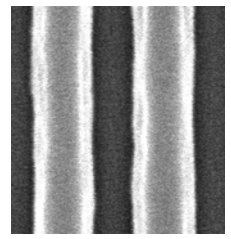
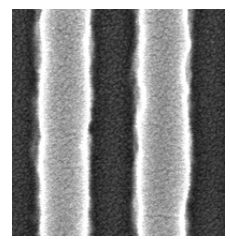
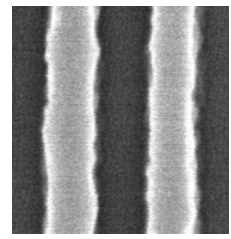
None

150 °C/60s

155 °C/60s

160 °C/60s

EUV-2D
6.8 mJ/cm²



LER' (nm)

7.2

5.1

4.3

4.3

LWR' (nm)

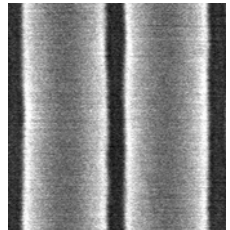
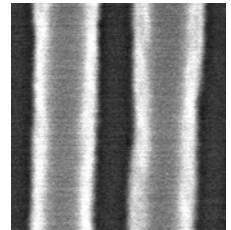
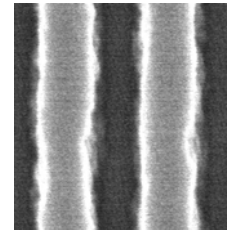
11.9

7.9

5.5

9.1

EUV-12A
2.4 mJ/cm²



LER' (nm)

8.2

4.7

3.3

LWR' (nm)

11.2

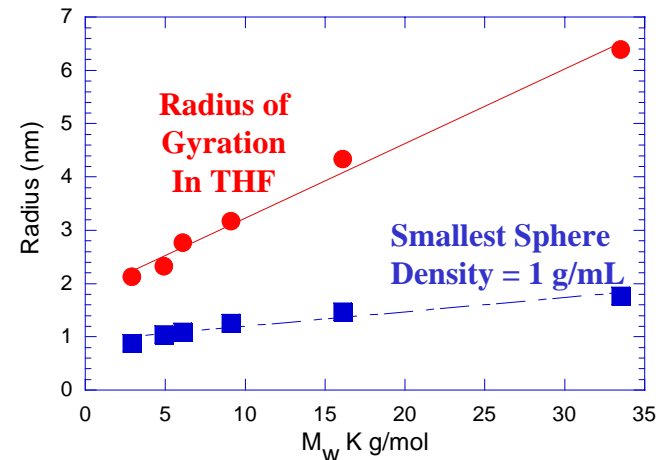
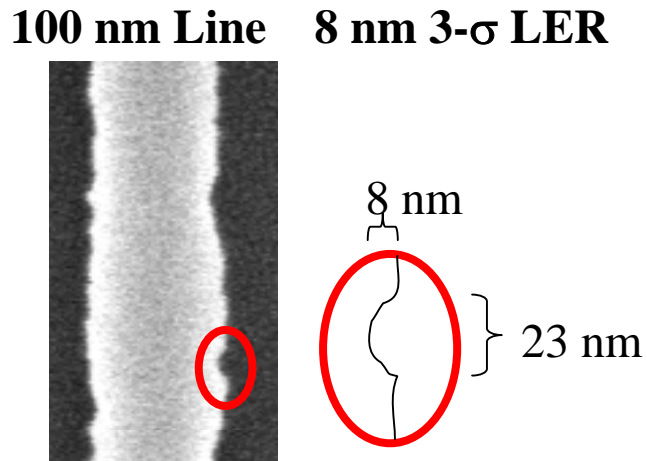
9.4

4.9

V. Conclusions

LER:

- Base improves LER because it improves chemical contrast
- Too much UFTL makes LER worse
- Changing polymer M_w does not effect LER in this system
 - *LER features may be too large to be influenced by polymer size*



Surface Roughness:

- Not correlated with LER
- Seems to result from increased material loss and statistical roughening
- However, if UFTL is held constant, roughness increases with increasing M_w and decreasing PAG

AFM Grain Size:

- Grain Size not correlated with:
 - LER
 - Base Level
 - Polymer M_w when UFTL is constant
- Very slight effect of decreasing grain size with increasing polymer M_w

Thermal Smoothing:

- Early Results Show that 20-60% Improvements in LER and LWR



Acknowledgements

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Pramod Kandamarachchi, Chuck Szmanda, Peter Trefonas, Gary Taylor**