Understanding Underlayer Physical Properties and their Effect on EUV Resists

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I. Introduction

II. Underlayer Compositional Effects

III. Underlayer Crosslinker Effects

IV. Conclusions

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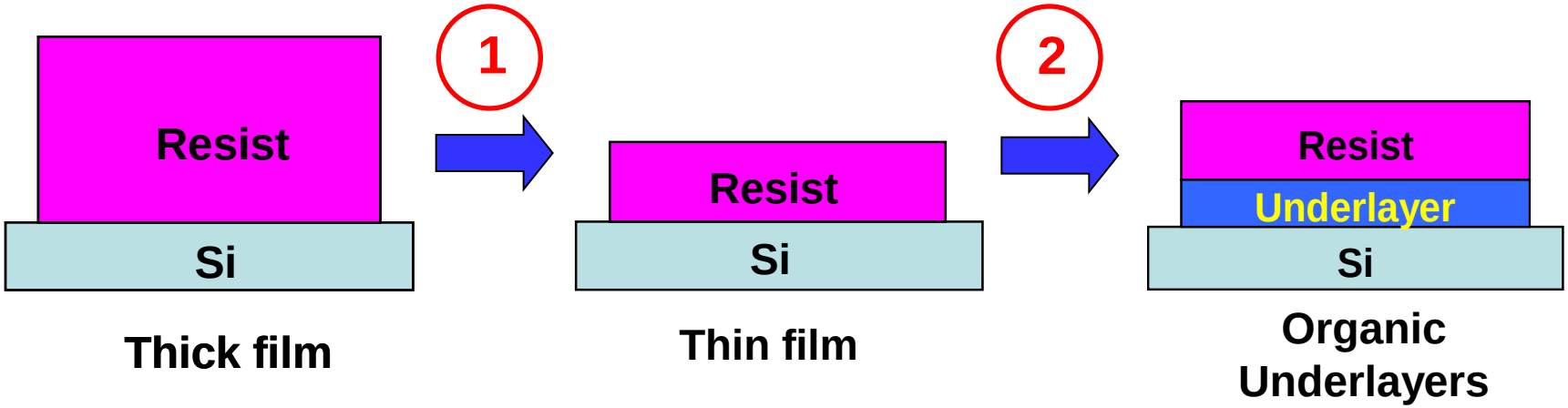
I. Ultra-thin EUV Resist and Underlayer Fundamentals



Control of Material Variation
Synthesis and Formulation

Physical Properties
Tg, CTE, surface polarity, H_2O Contact Angle

Lithographic Properties

CTE = Coefficient of Thermal Expansion

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Introduction

1 Discovery:

Underlayer UL4 gave unexpectedly good adhesion despite low water contact angle.

→

2 UL4 has relatively low CTE

→

3 Hypothesis:

A) Matching CTE is key to good adhesion.

B) Important to LER?

Results

1 Prepared 9 compositional variations of UL4.

2 Studied 4 Crosslinker Levels of UL8.

→

Resist Adhesion and LER

VS.

Underlayer CTE and WCA

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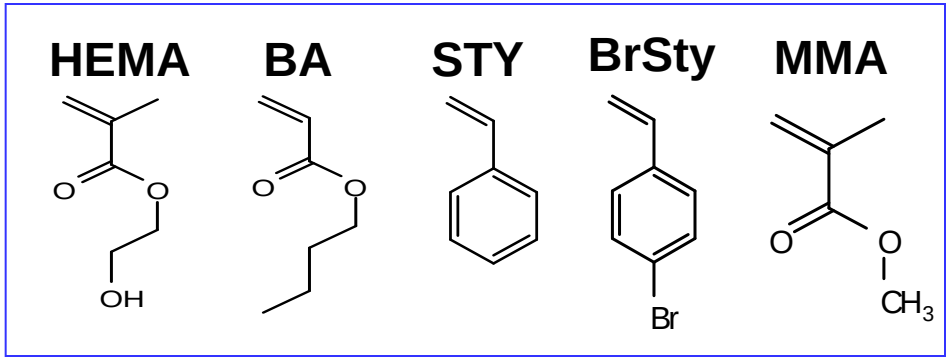
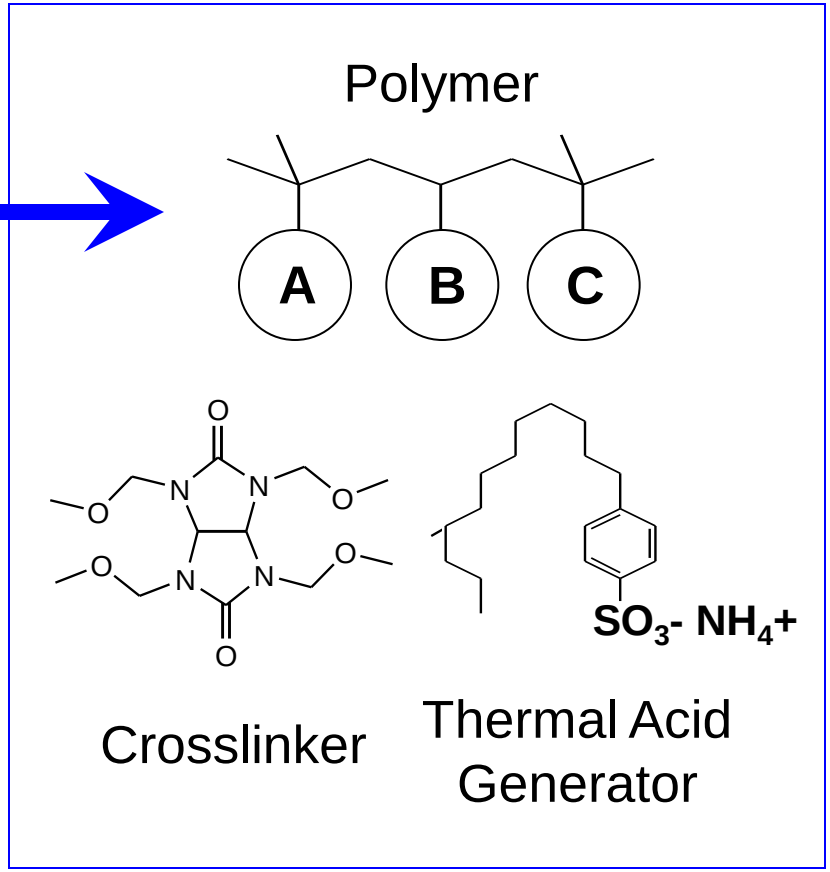
EUV Underlayer Scheme

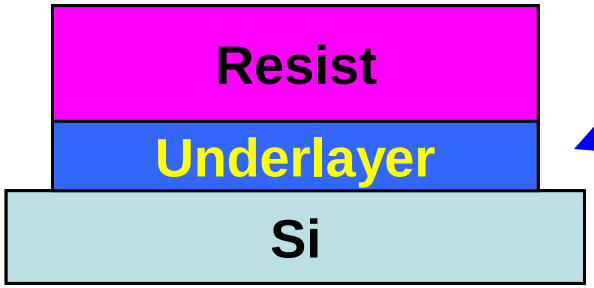
Goal: Design, synthesize, coat and crosslink acrylic underlayers

Monomers



Underlayer





Thin film

TAG = Thermal Acid Generator

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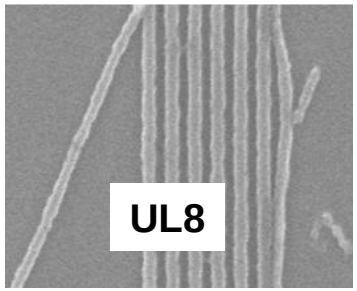
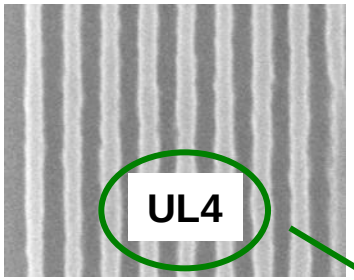
Lithographic Imaging on Underlayers

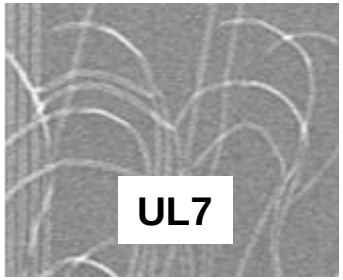
CD of Adhesion Failure

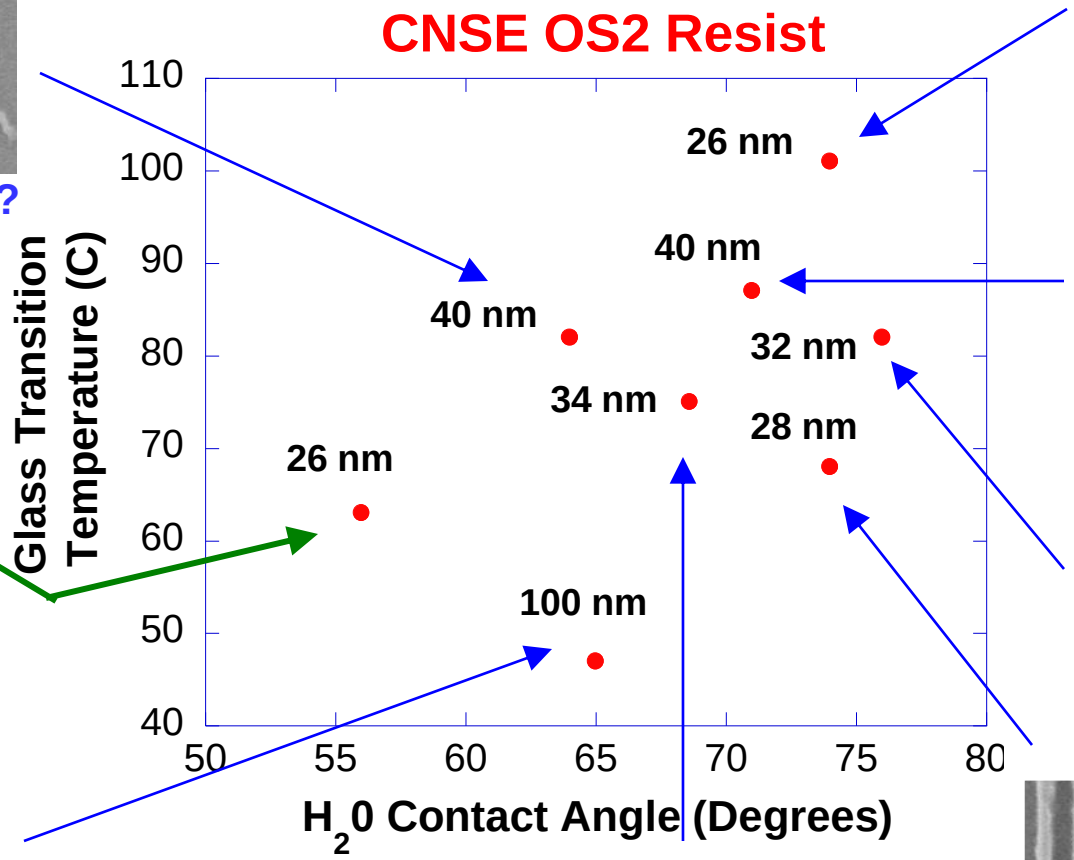


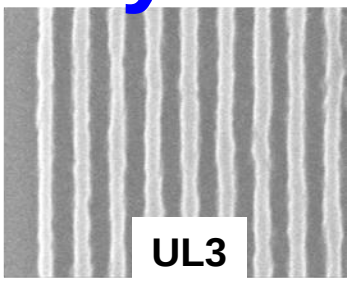
Can we improve?

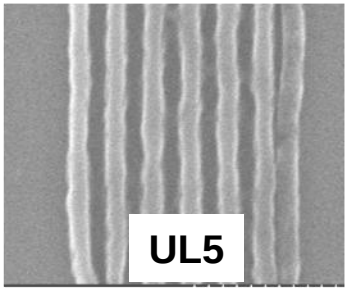


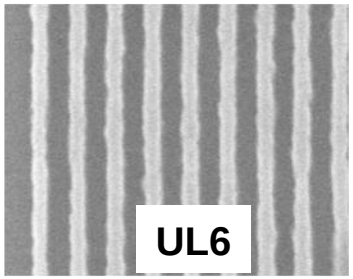
Surprisingly good

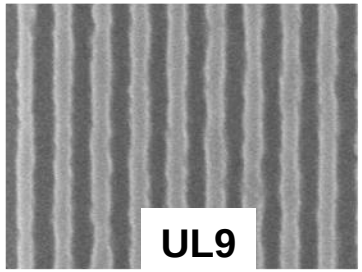


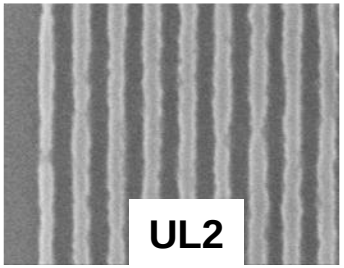






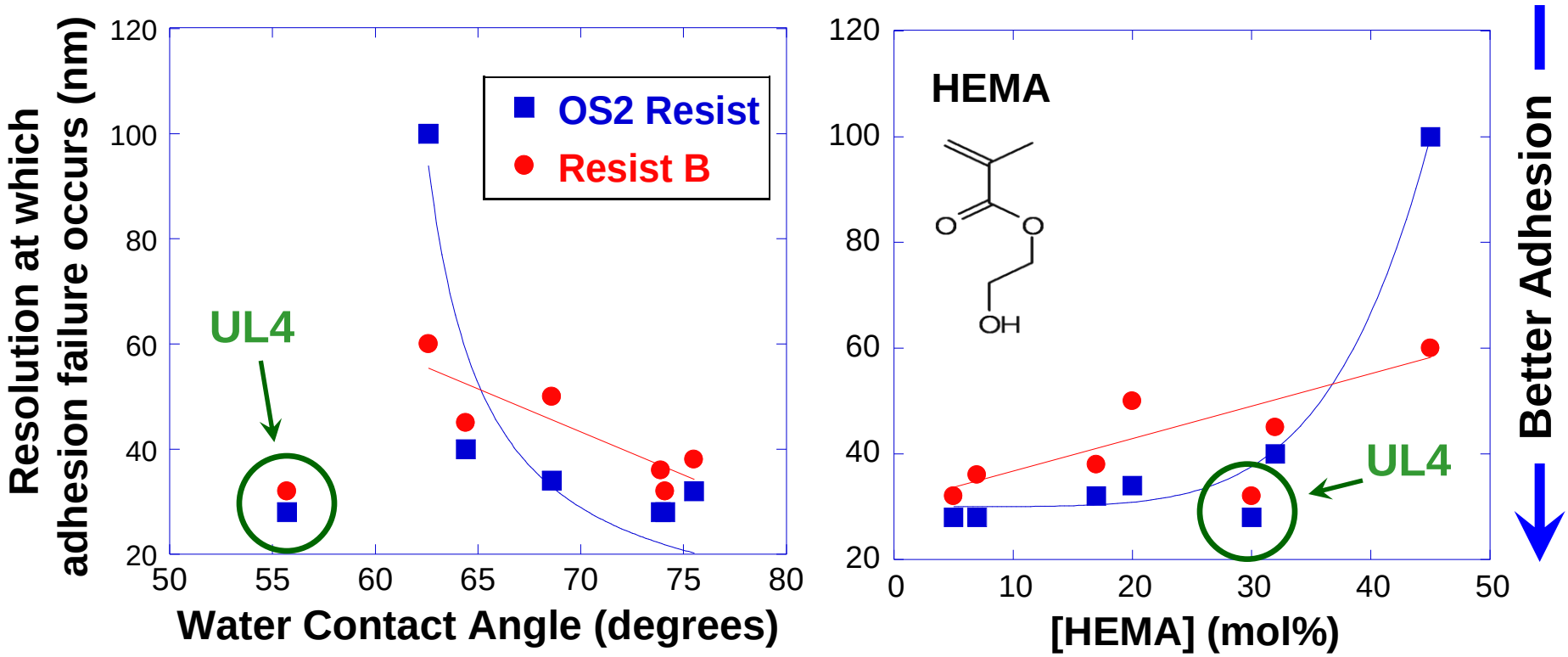






Resist Thickness = 60 nm
Underlayer Thickness = 30 nm
Exp: LBL MET 0.3 NA Annular

Resist Adhesion on Underlayers



- Resist adhesion influenced by contact angle and [HEMA]
- UL4 shows good adhesion despite small contact angle and [HEMA]

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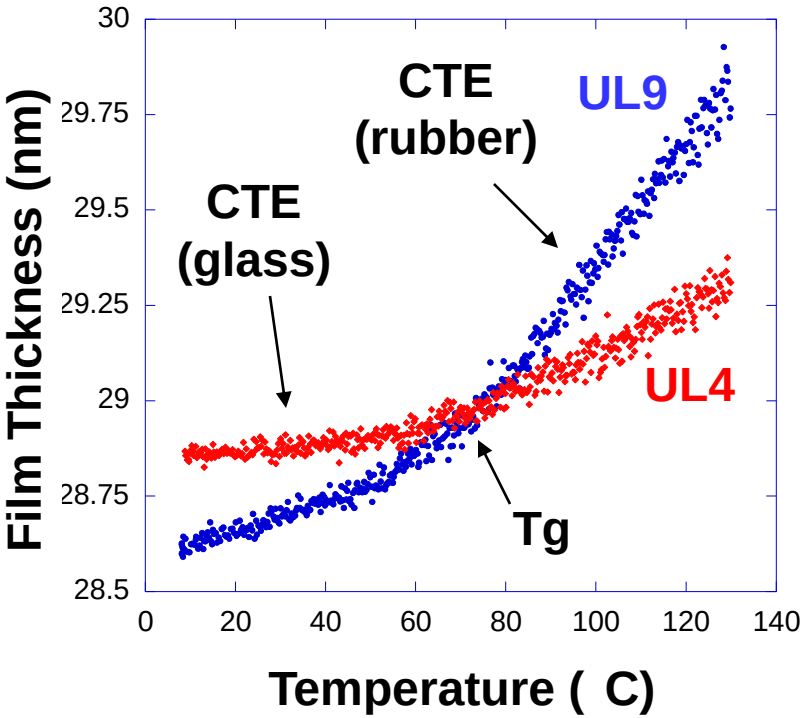
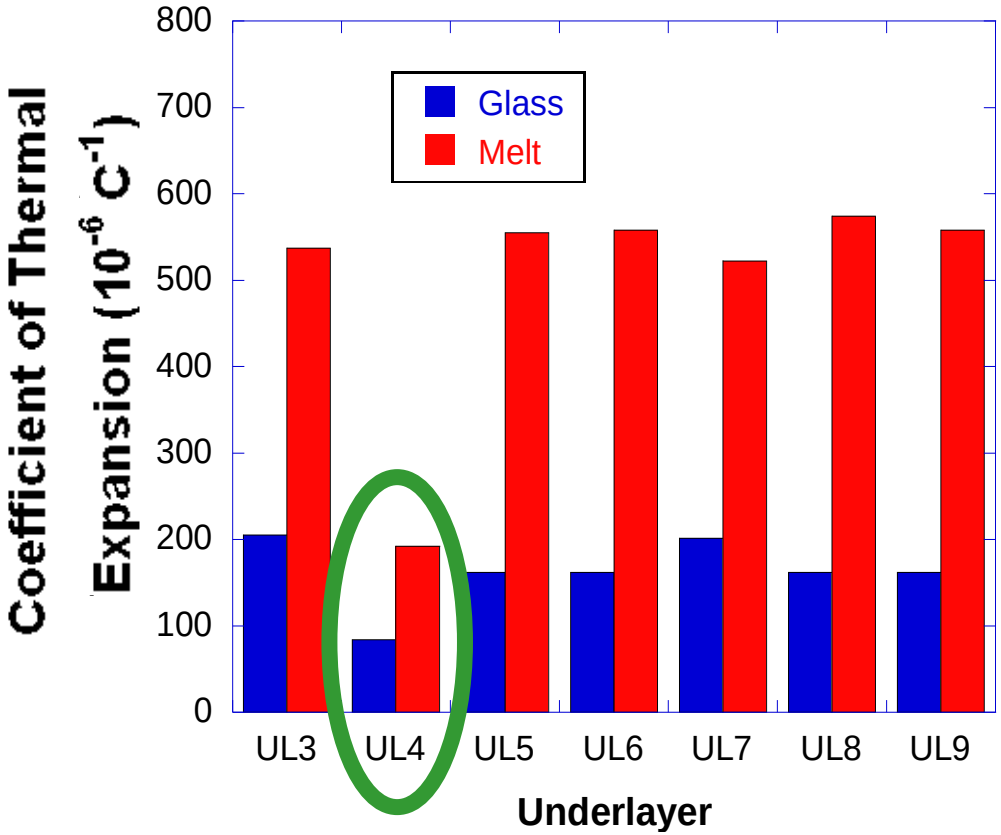
Coefficient of Thermal Expansion

UL4 has a Very Low CTE!





Underlayer Formulation:
6 wt% x-linker

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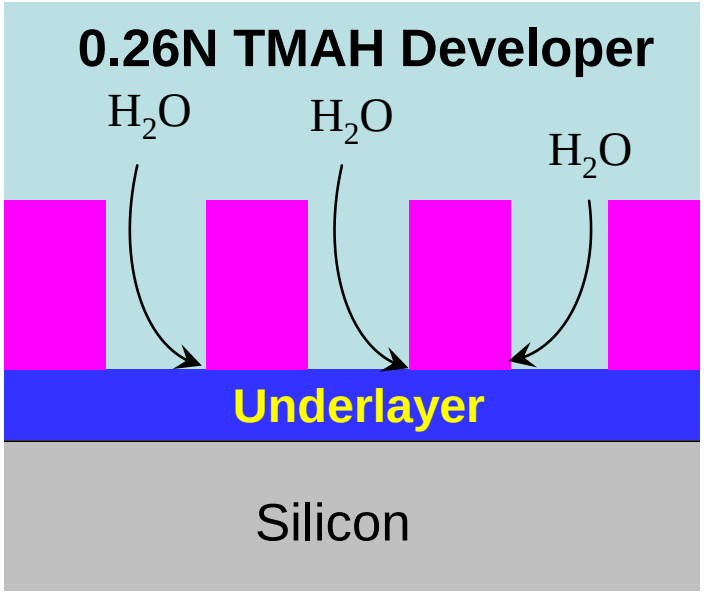
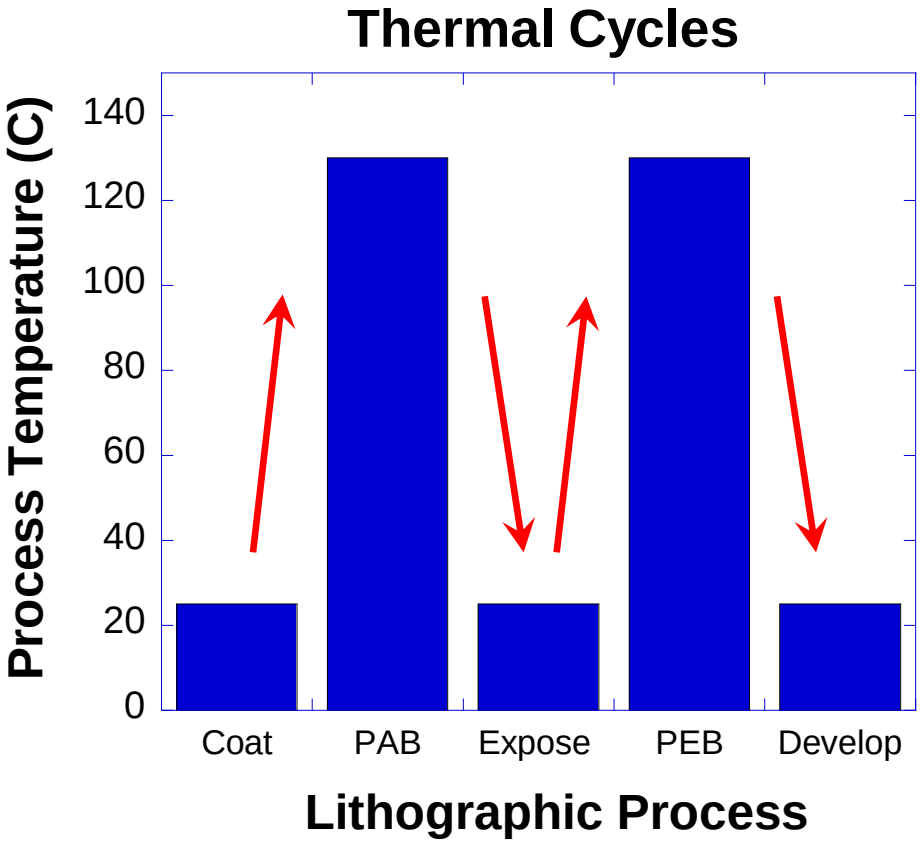
Does CTE Matter?

How Photoresist Adhesion is typically viewed:

Processed at room temperature





However, there are thermal cycles during resist post apply bake and post exposure bake which are prior to development.

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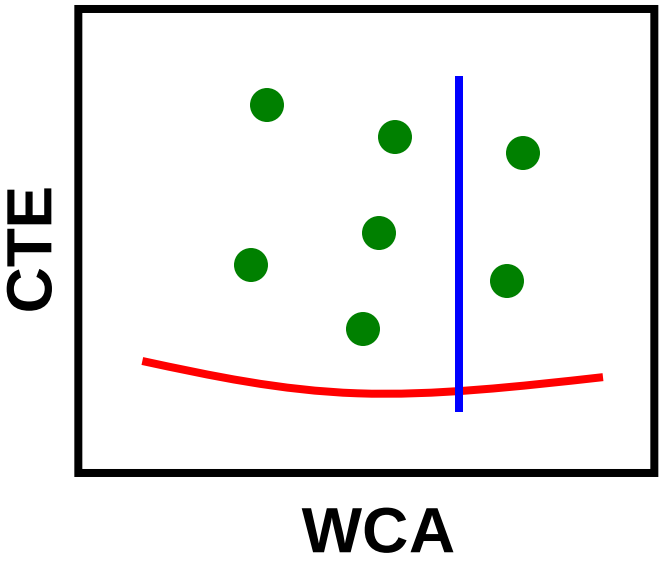
Goals

2 Underlayer DOEs → Academic
→ Commercial



In Progress

Academic

1 UL4 Copolymer Series

2 CTE / WCA Underlayer Modeling

3 Set of UL's with constant WCA and range of CTE

Three Vendors of Hardmasks

Milestones → 2 DOEs

Plan → 6 DOEs

CTE = Coefficient of Thermal Expansion
WCA = Water Contact Angle

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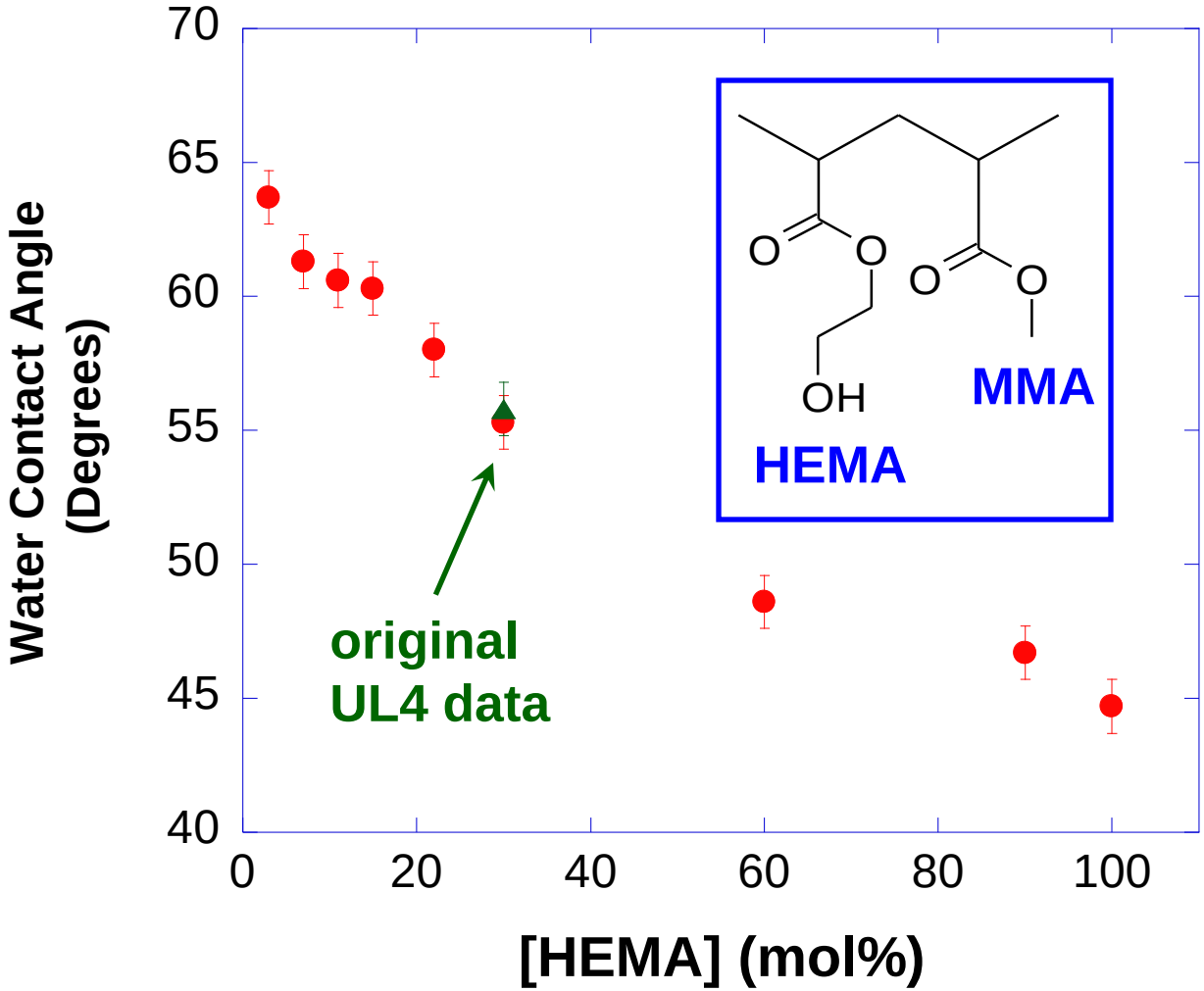
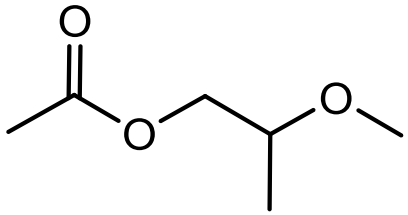
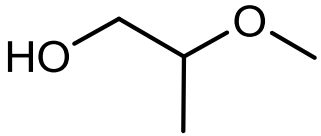
II. Results: 9 compositional variations of UL4



Original UL4 polymer synthesized in PMA



New copolymers synthesized in PM



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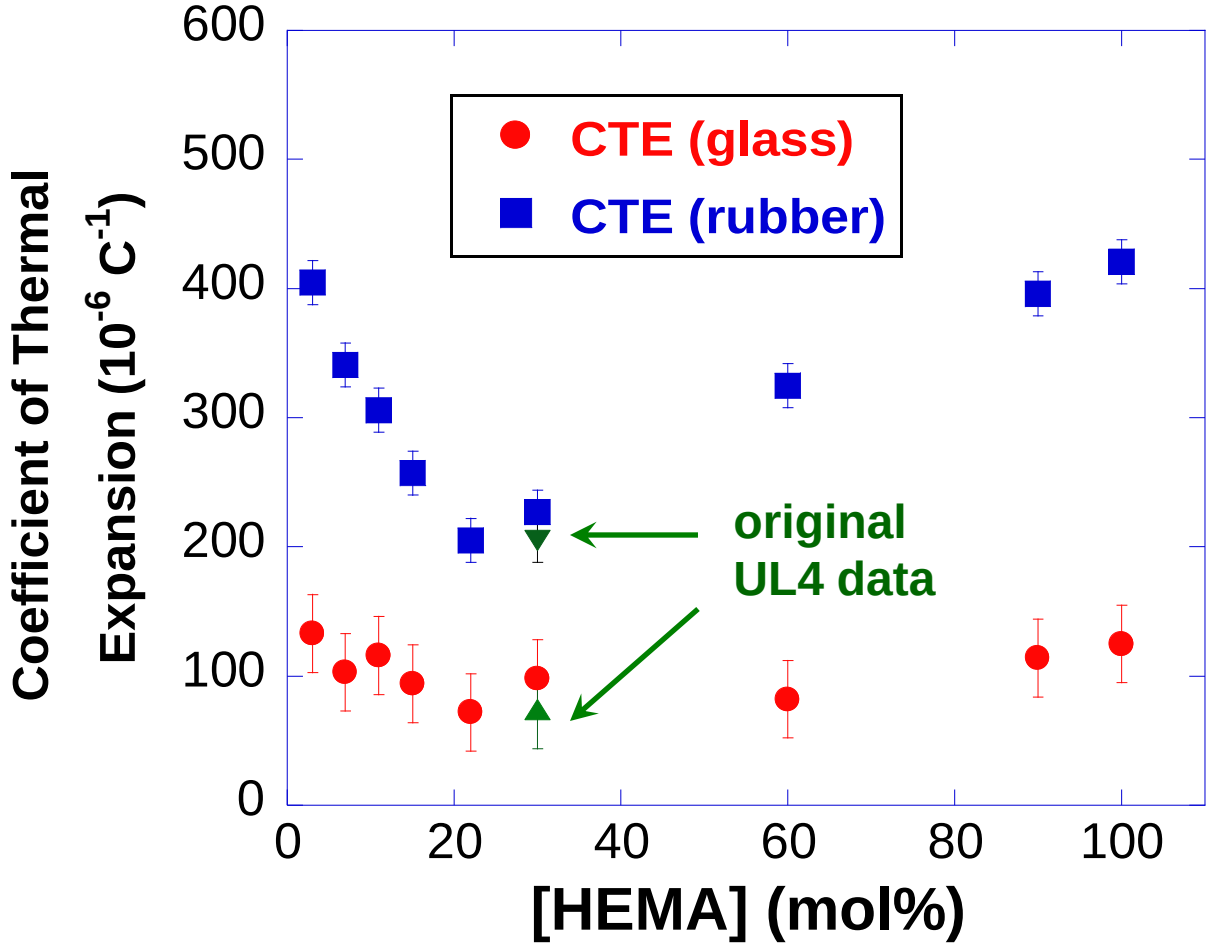
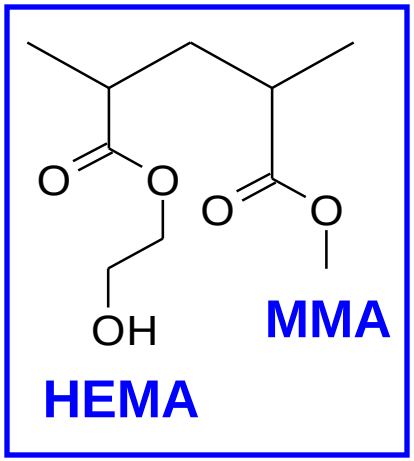
CTE of HEMA/MMA Copolymer Underlayers





Minimum CTE obtained at 15-30 mol% [HEMA] in rubber regime

CTE decreases in glass regime at higher [HEMA]

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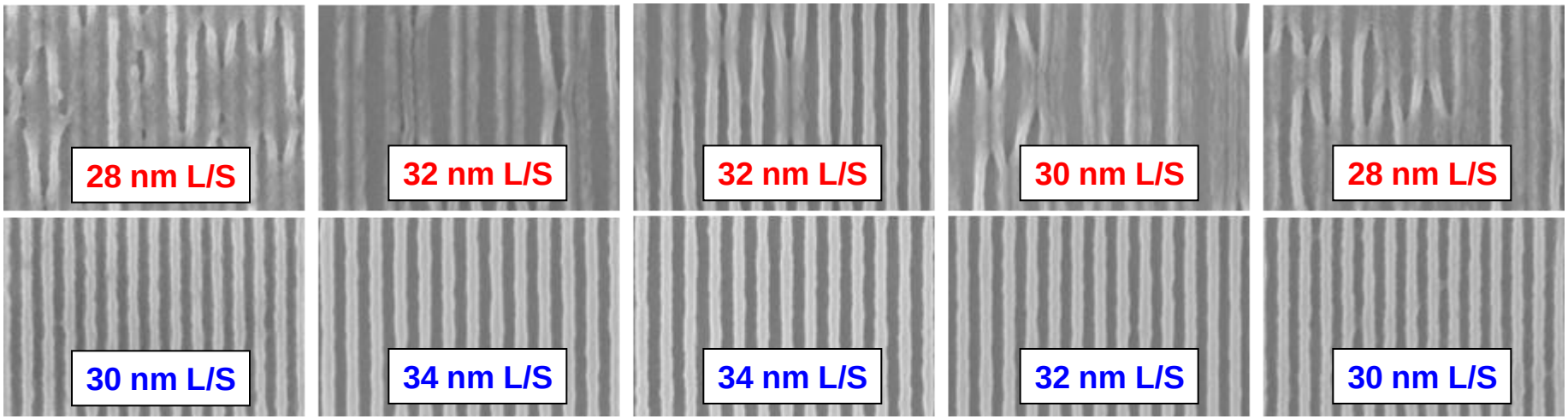
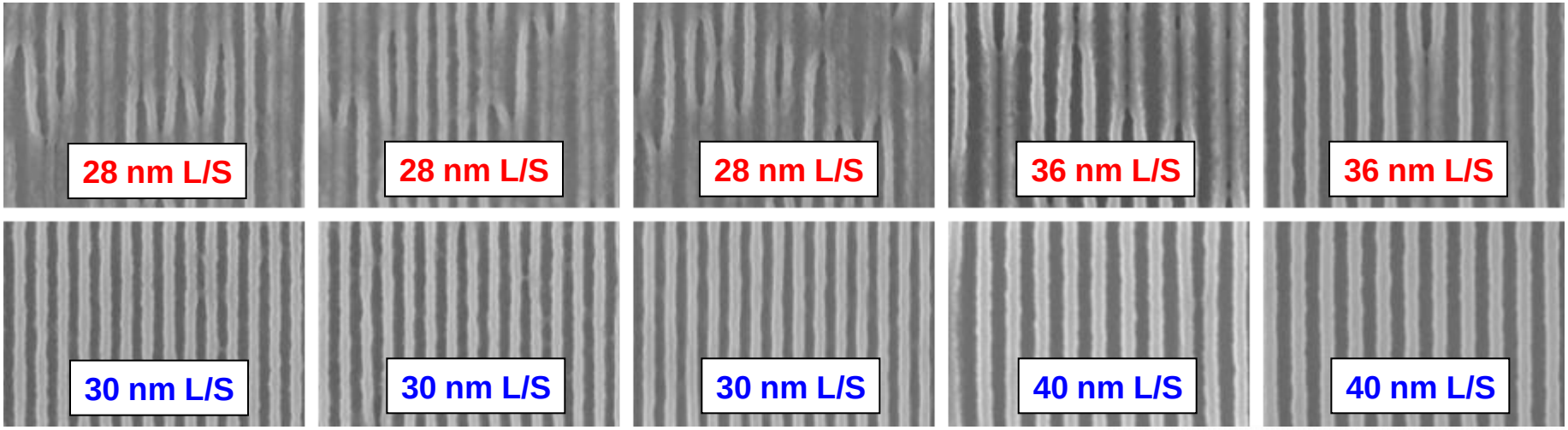
OS2 Resist Adhesion on HEMA/MMA Copolymer Underlayers

60 nm resist thickness
30 nm underlayer thickness
BMET Annular

← HEMA/MMA Composition →

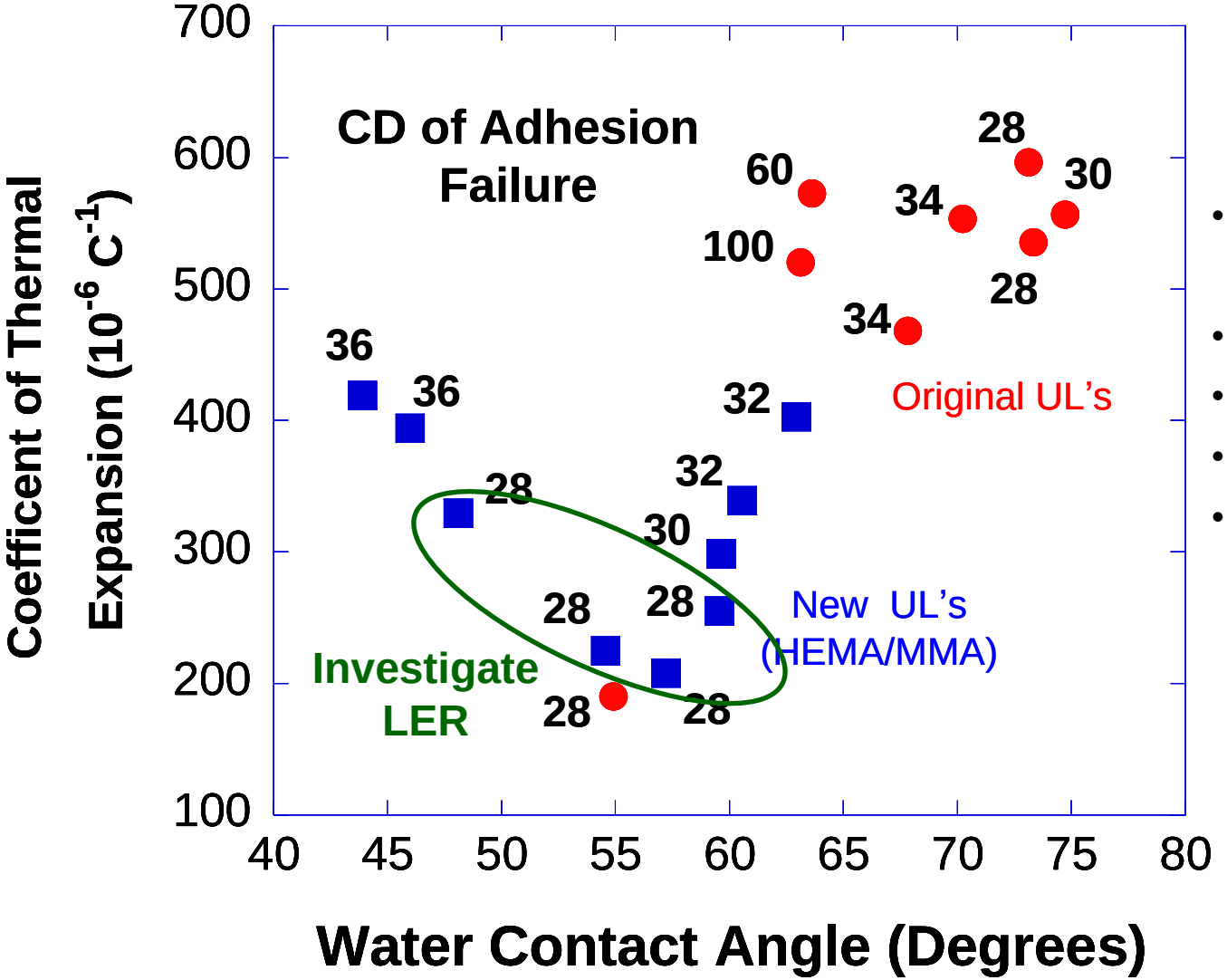


HMDS | 3/97 UL | 7/93 UL | 11/89 UL | 15/85 UL



22/78 UL | 30/70 UL | 60/40 UL | 90/10 UL | 100 UL

Resist Adhesion *vs* CTE and WCA



Test Conditions:

- CTE of underlayer above Tg
- OS2 Resist
- 60 nm resist thickness
- 30 nm UL thickness
- 12 wt% crosslinker in underlayer formulation

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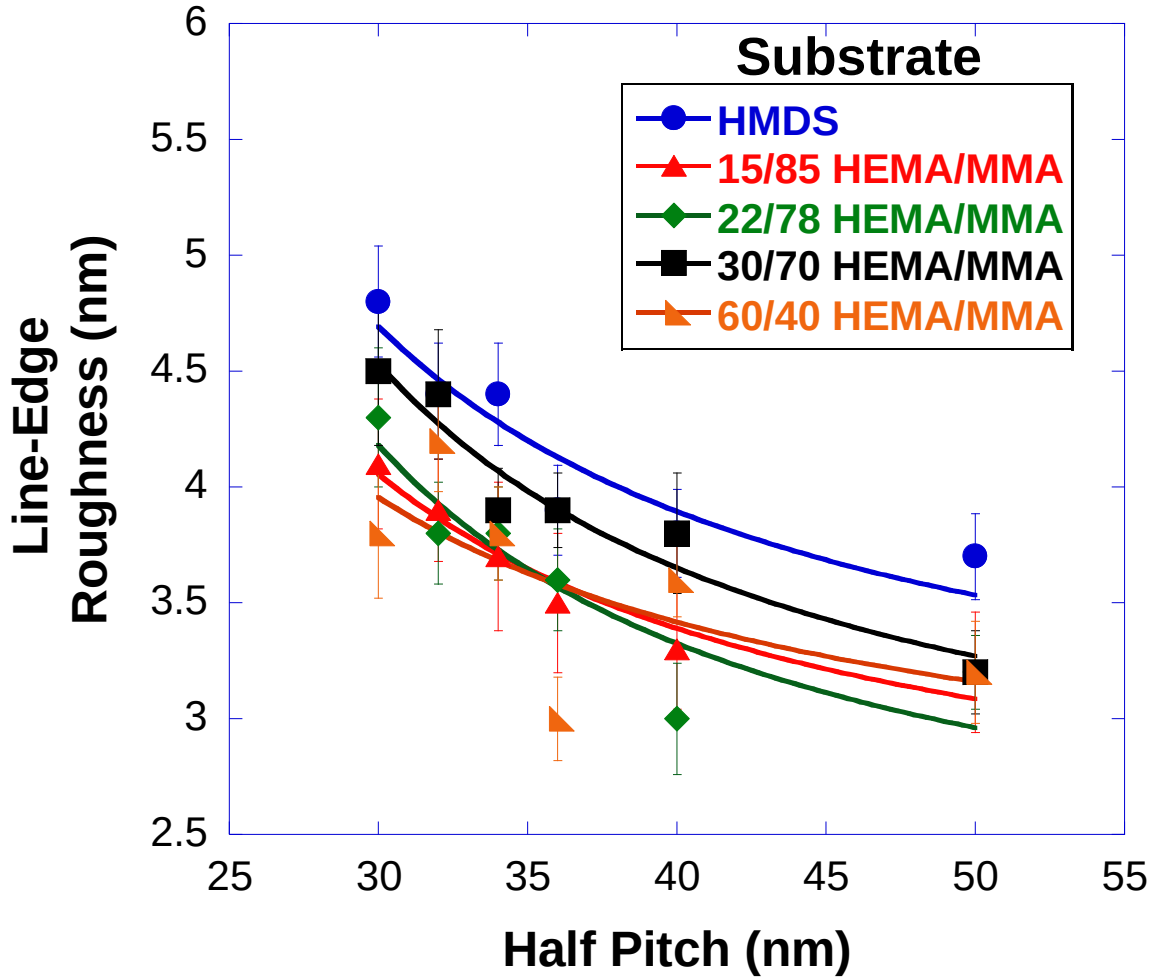
LER Through Pitch: HMDS and Underlayer



Data shown for underlayers that had good adhesion at 30 nm L/S

LER improvements on Underlayers at all pitches

60 nm OS2 resist thickness
30 nm underlayer thickness
BMET with Ann. Ill.

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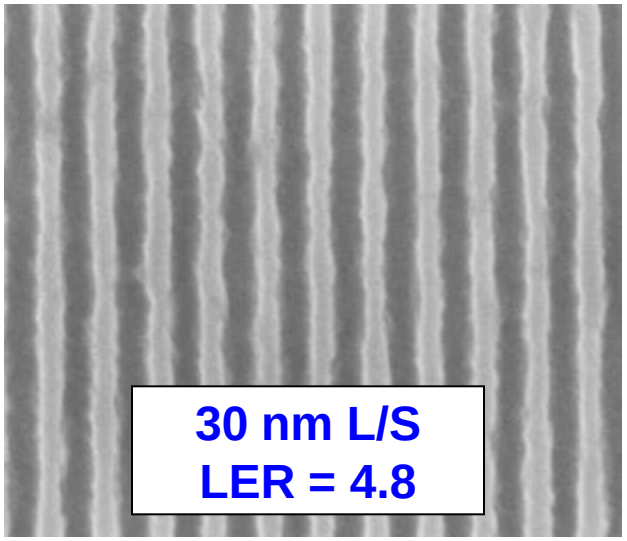
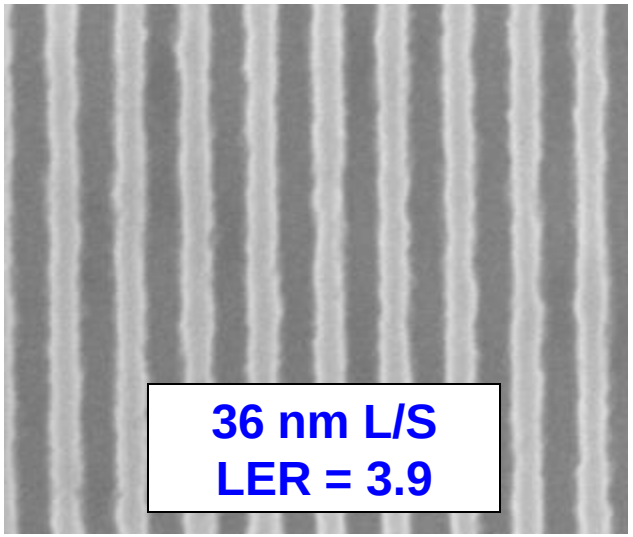
HMDS vs. 60/40 HEMA/MMA Underlayer



HMDS



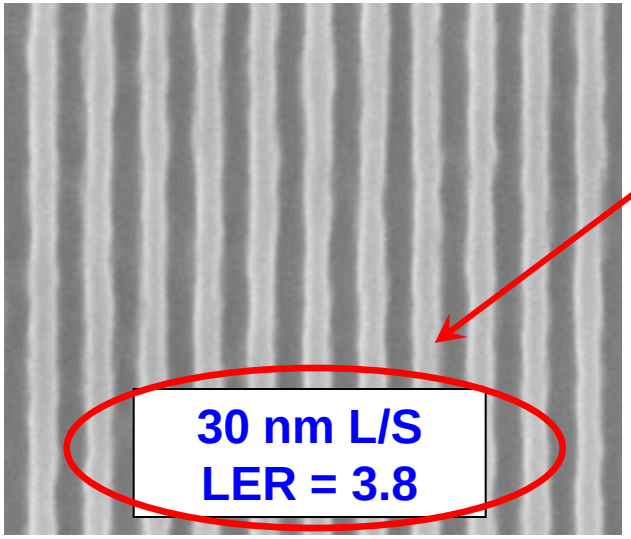
OS2 resist

BMET annular

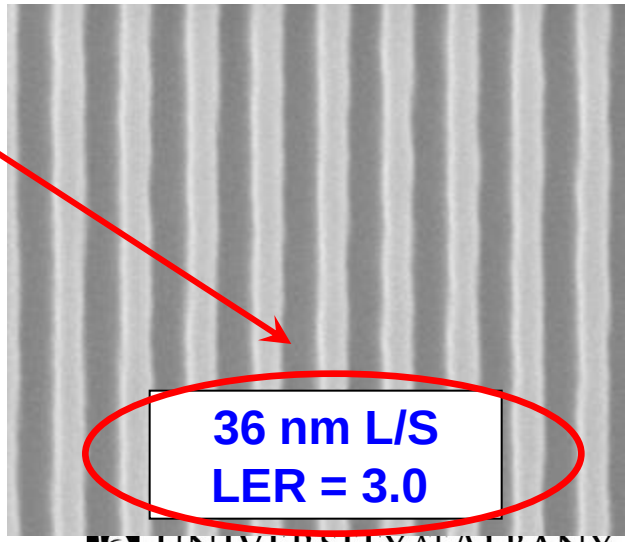
60 nm resist thickness

30 nm underlayer thickness

Best OS2 Resist LER to Date!



60/40 HEMA/MMA Underlayer



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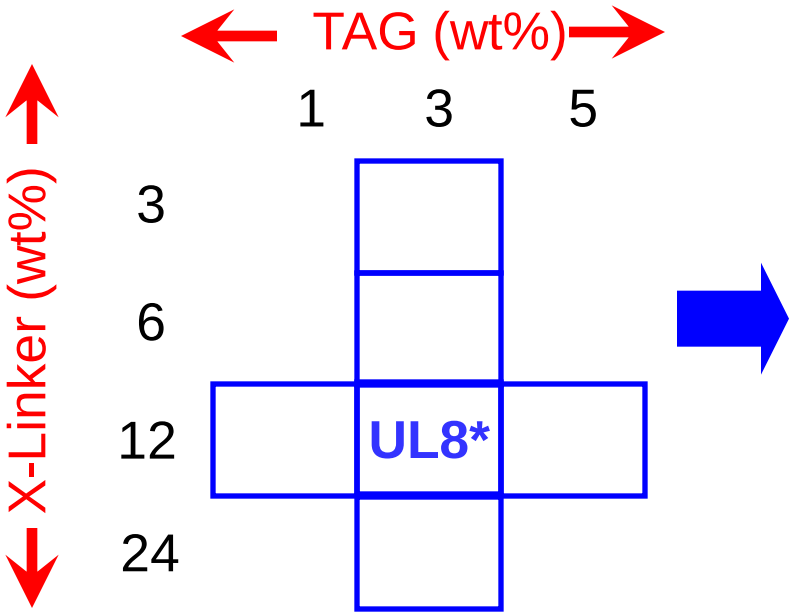
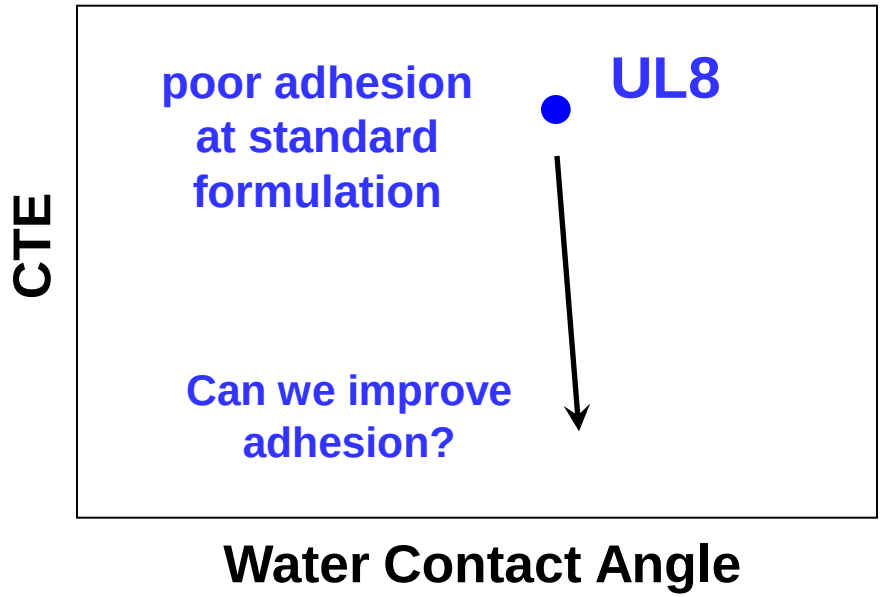
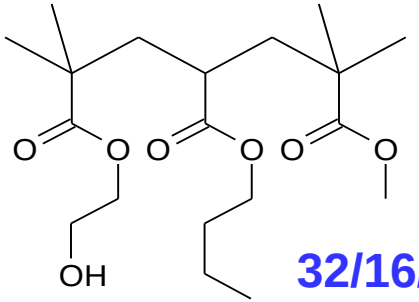
III. Underlayer UL8 Formulation Effects





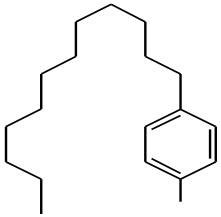
*** = standard formulation**

UL8:



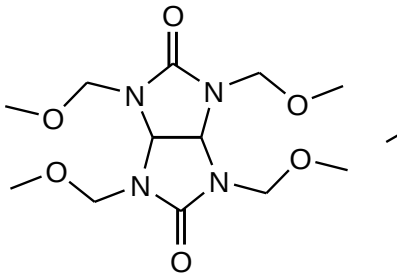
32/16/52

TAG:



SO_3- NH_4+

Crosslinker:



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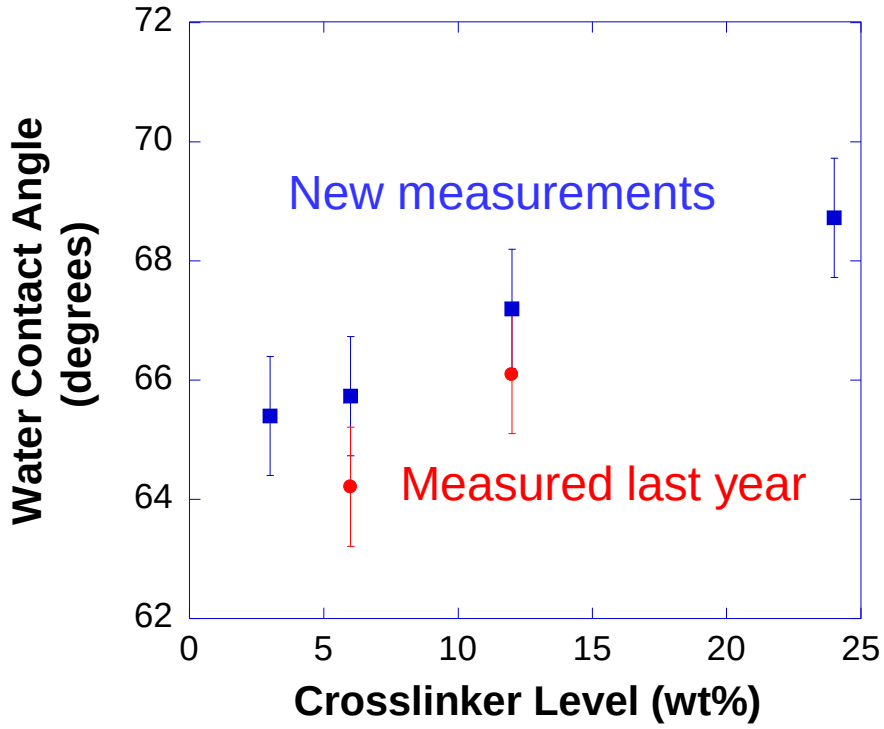
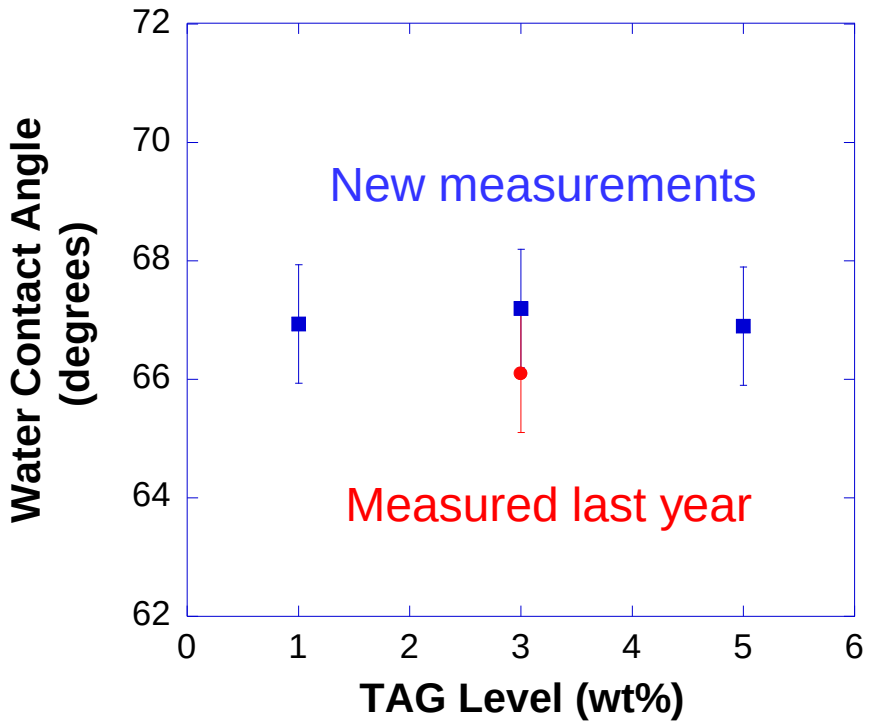
Formulation Effects on Water Contact Angle





- **Crosslinker levels caused only slight change in water contact angle (~4°C)**
- **TAG levels had no effect on water contact angle**

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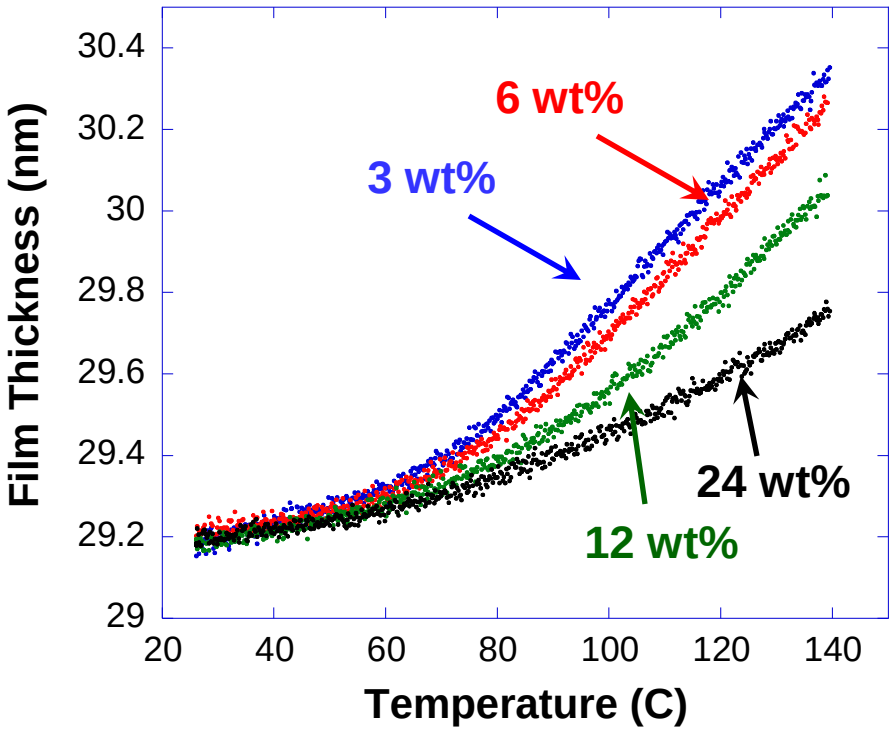
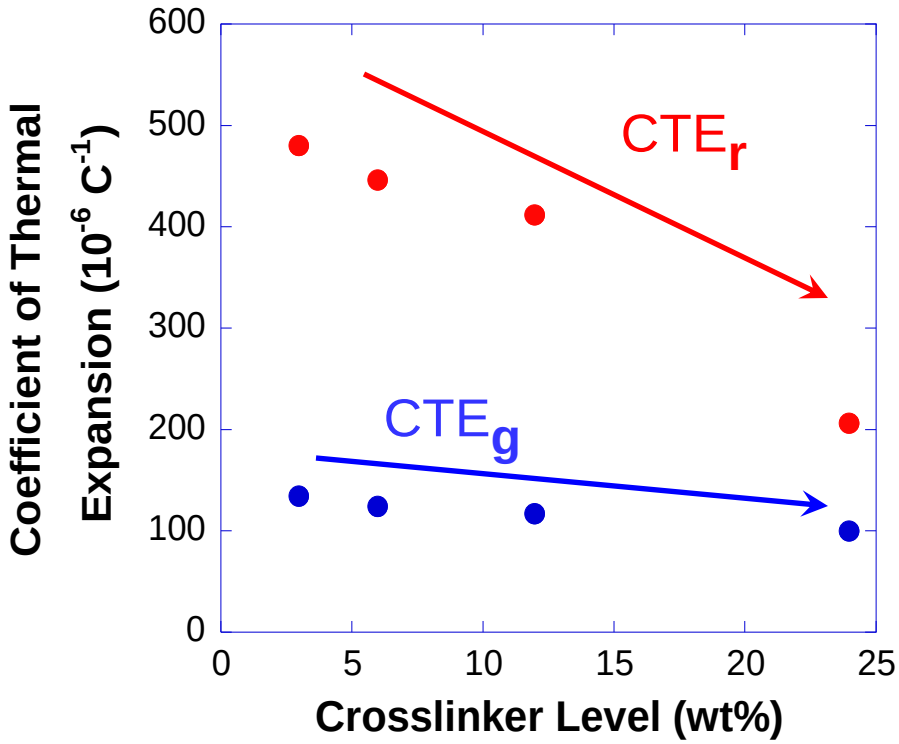
Crosslinker Level Effects on CTE





- Large decrease in CTEr at higher crosslinker loadings
- Small decrease in CTEg at higher crosslinker loadings

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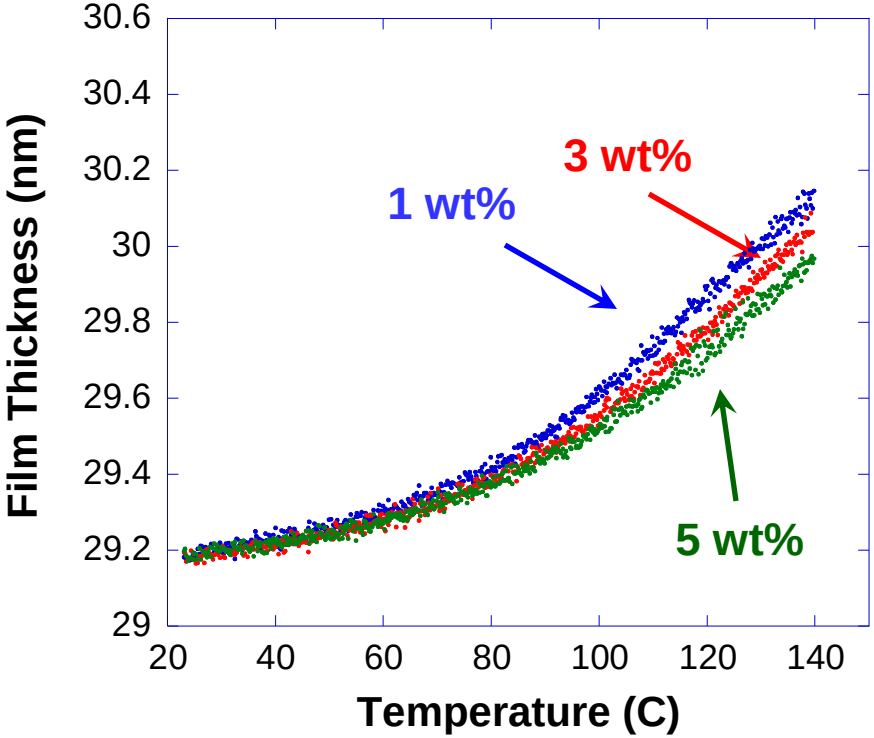
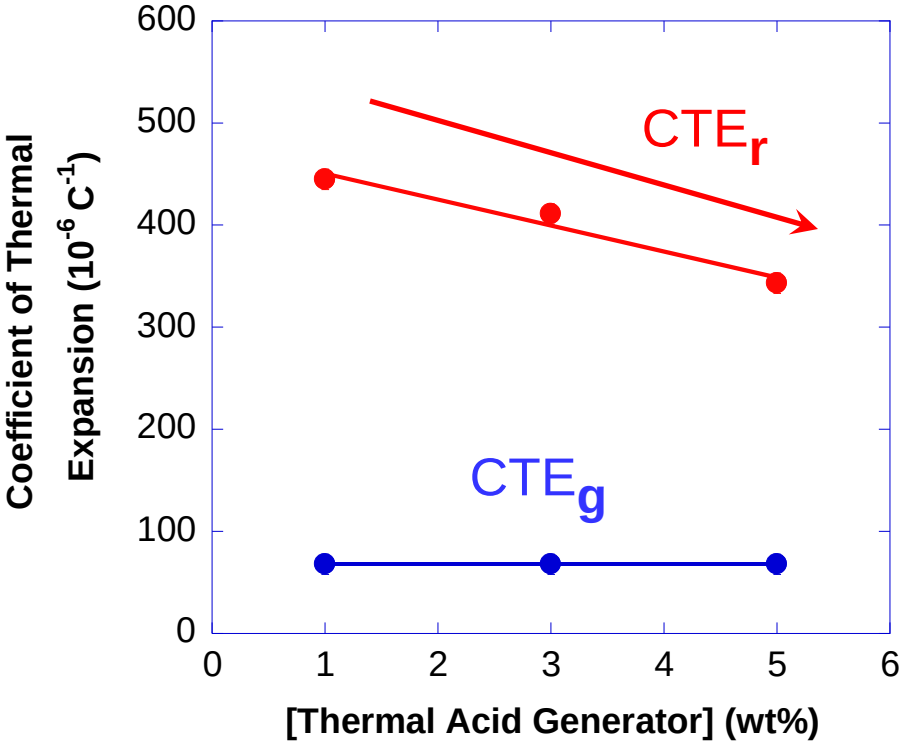
Thermal Acid Generator Level Effects on CTE





- Small decrease in CTEr at higher TAG loadings
- No change in CTEg at higher TAG loadings

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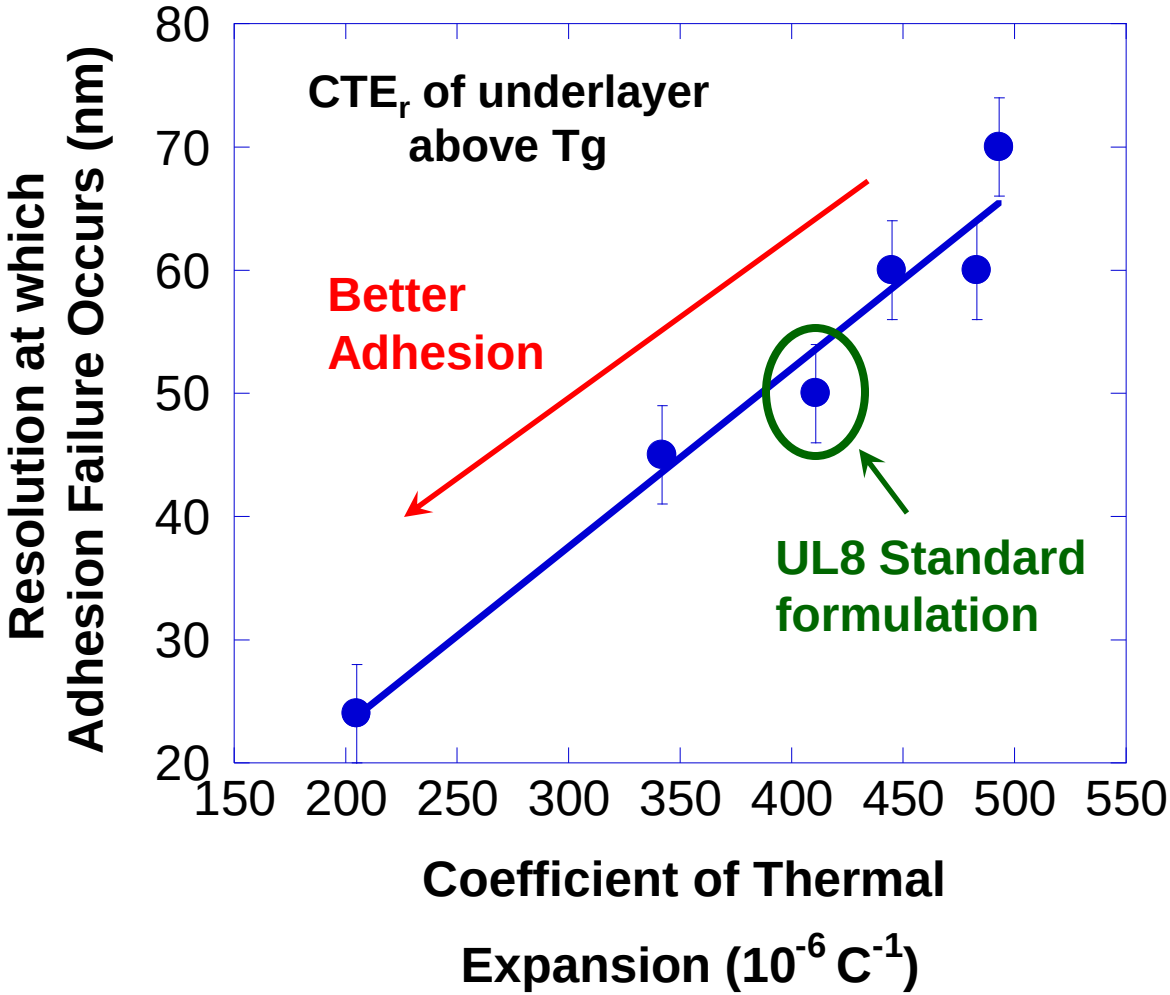
Resist Adhesion vs. Underlayer CTE



Underlayer UL8

CTE varied by changing crosslinker and TAG level

Better adhesion observed at lower CTE

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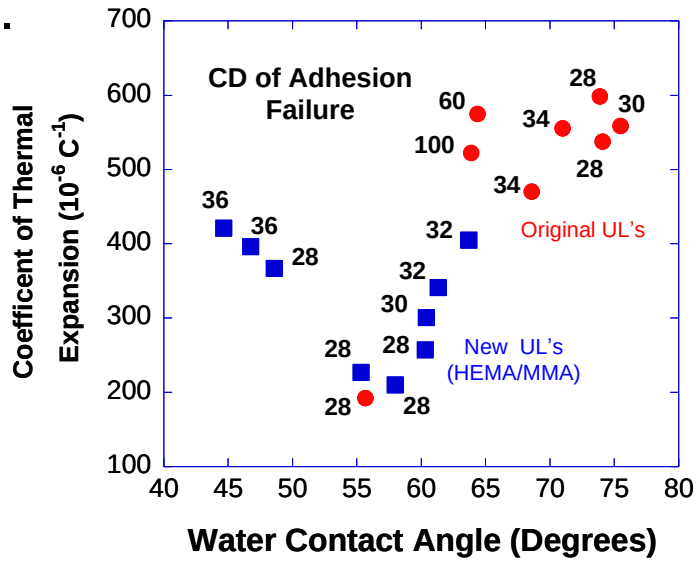
IV. Summary

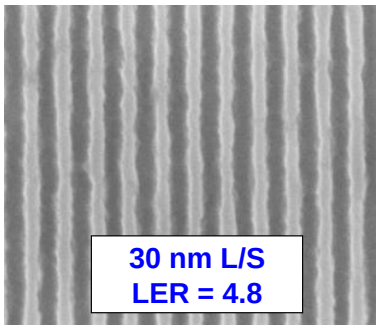
- 9 HEMA/MMA copolymer underlayers synthesized and physically characterized and tested lithographically.



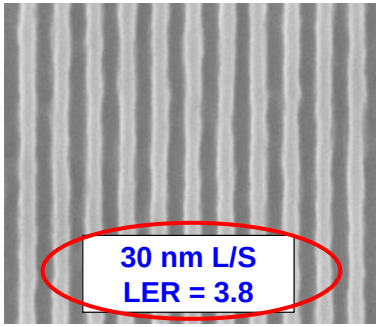
- Correlation between resist adhesion and CTE still observed.

- Similar LER improvements of ~1 nm observed for OS2 resist on underlayer compared to HMDS.

With HMDS

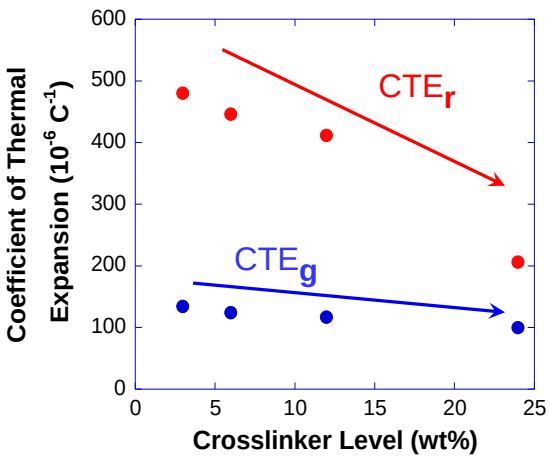


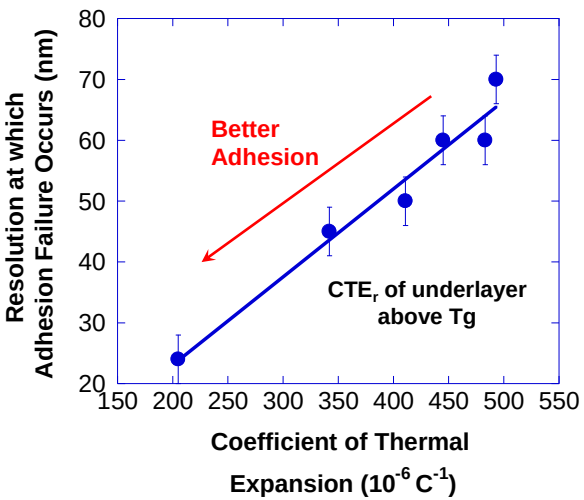
With Underlayer



Conclusions

- Underlayers designed to have lower CTE through both polymer composition and higher levels of higher crosslinker and/or thermal acid generator can improve resist adhesion.
- Underlayers can play a critical role in determining the lithographic performance of EUV resists
- Polarity and CTE are important parameters in characterizing the interaction between UL and resist thin films





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Acknowledgments

Group Members

Past and Present

Brian Cardineau

Srividya Revuru

Additional Help From

Charles Settens

Albany RMDC

Berkeley MET Team

SEMATECH for Financial Support

SEMATECH

Accelerating the next technology revolution.

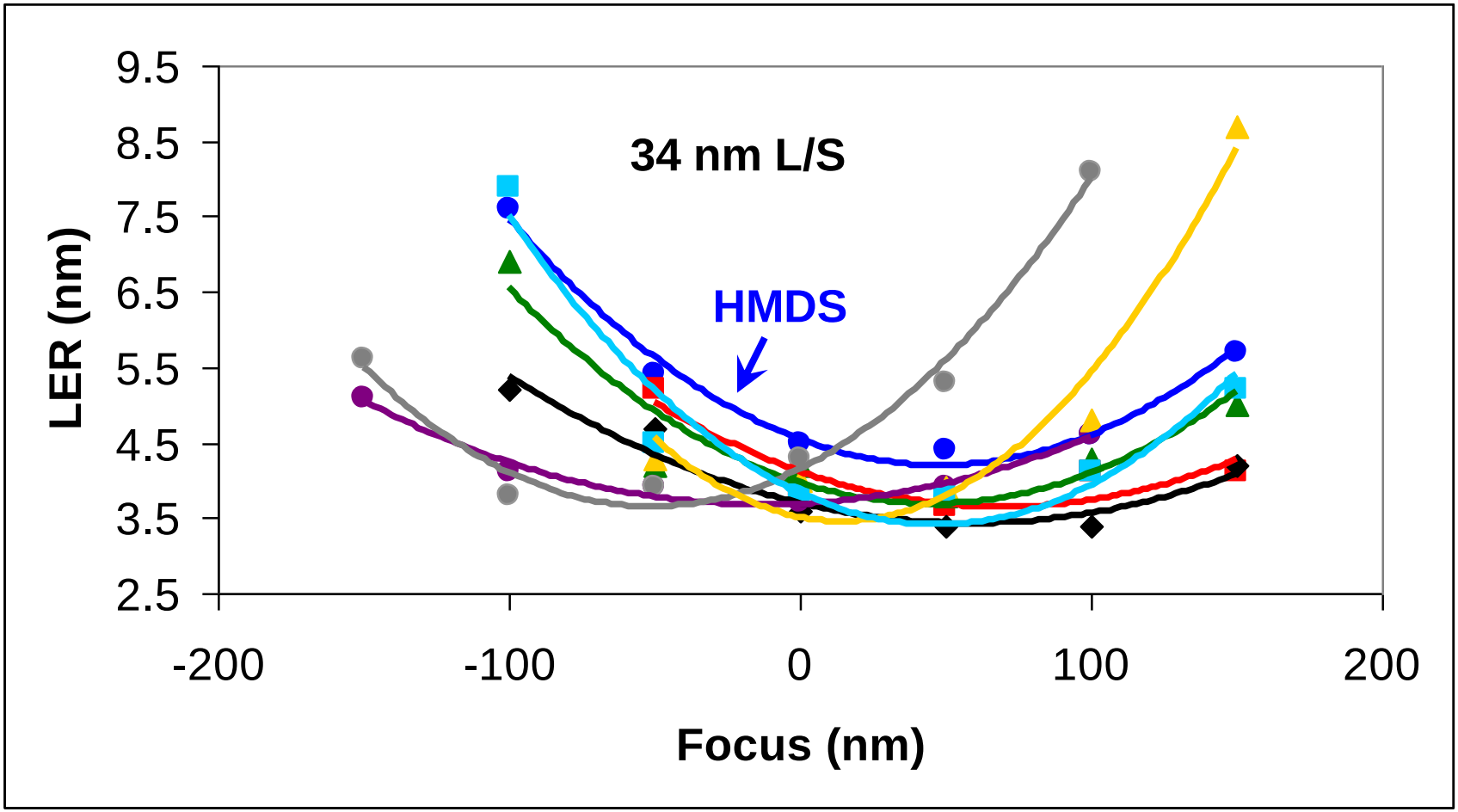
Materials

DuPont for Supplying ESCAP Polymer

Resist Vendors for Supplying Resists

King Industries for Supplying Thermal Acid Generator

Appendix



60 nm OS2
30 nm UL

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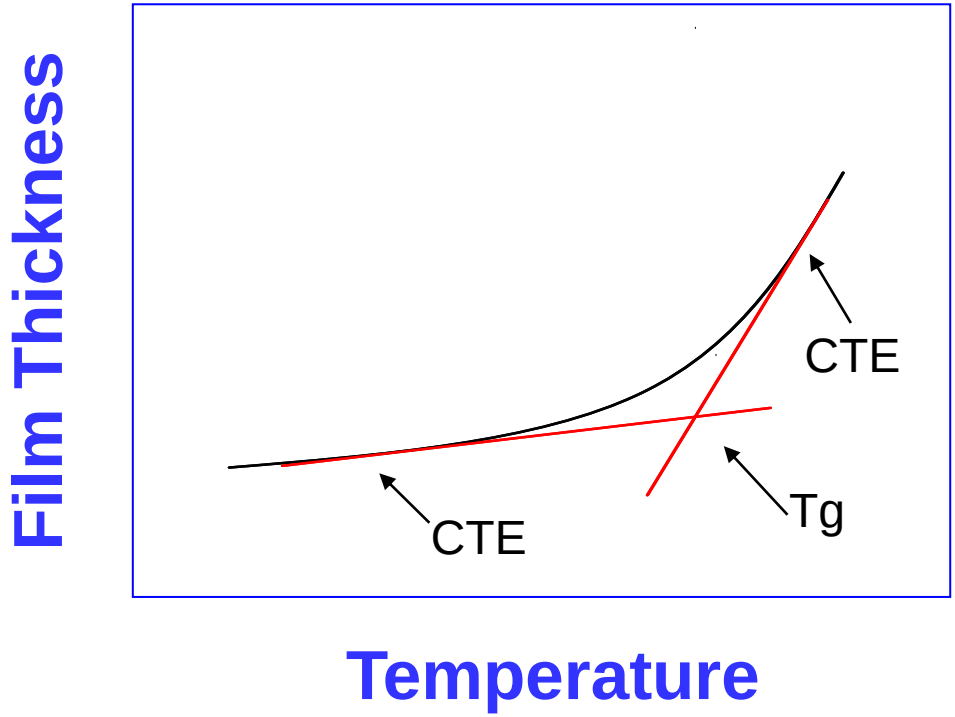
Tg and CTE Measurement Methods

Spectroscopic Ellipsometry (SE)



$$h(T) = w\left(\frac{M-G}{2}\right)\ln\left[\cosh\left(\frac{T-T_g}{w}\right)\right] + (T-T_g)\left(\frac{M+G}{2}\right) + c.$$

Forrest and Dalnoki-Veress (2000)

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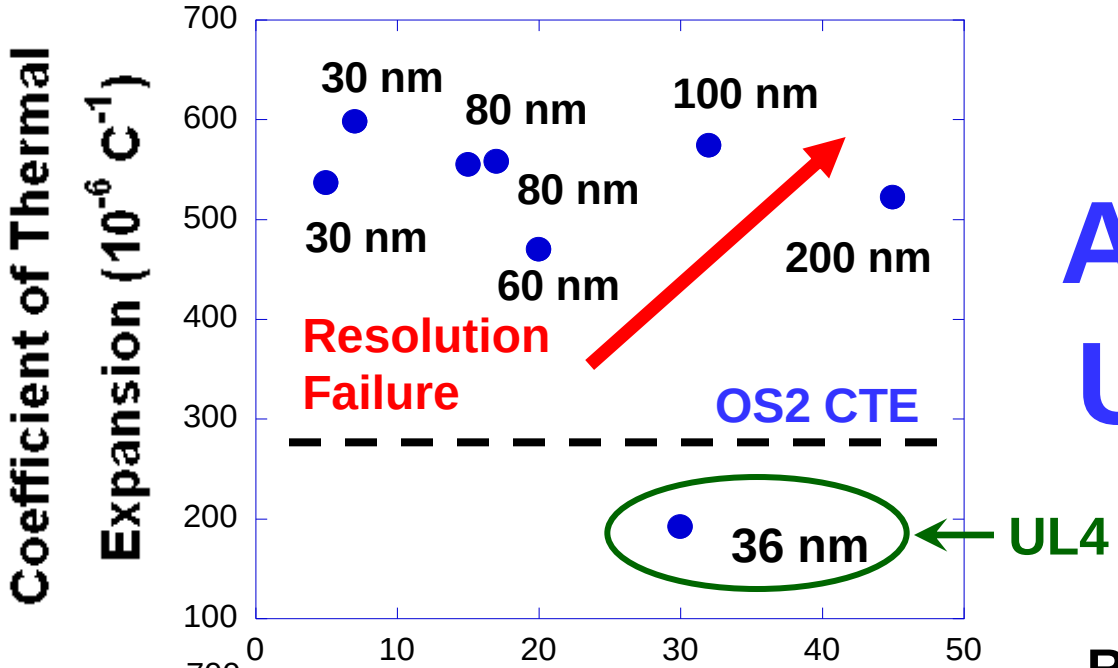
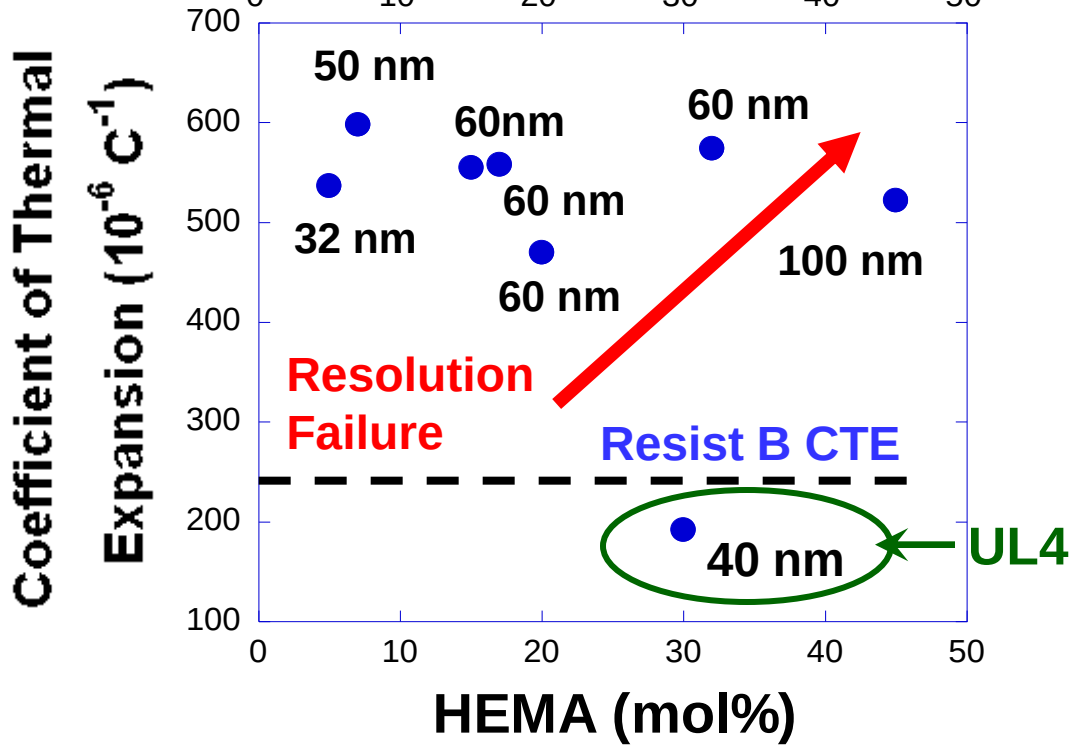
Resist Adhesion on Underlayers





Resist resolution adhesion failure as a function of underlayer CTE and [HEMA]

Resist Thickness: 60 nm
Underlayer Thickness: 30 nm
6 wt% Crosslinker

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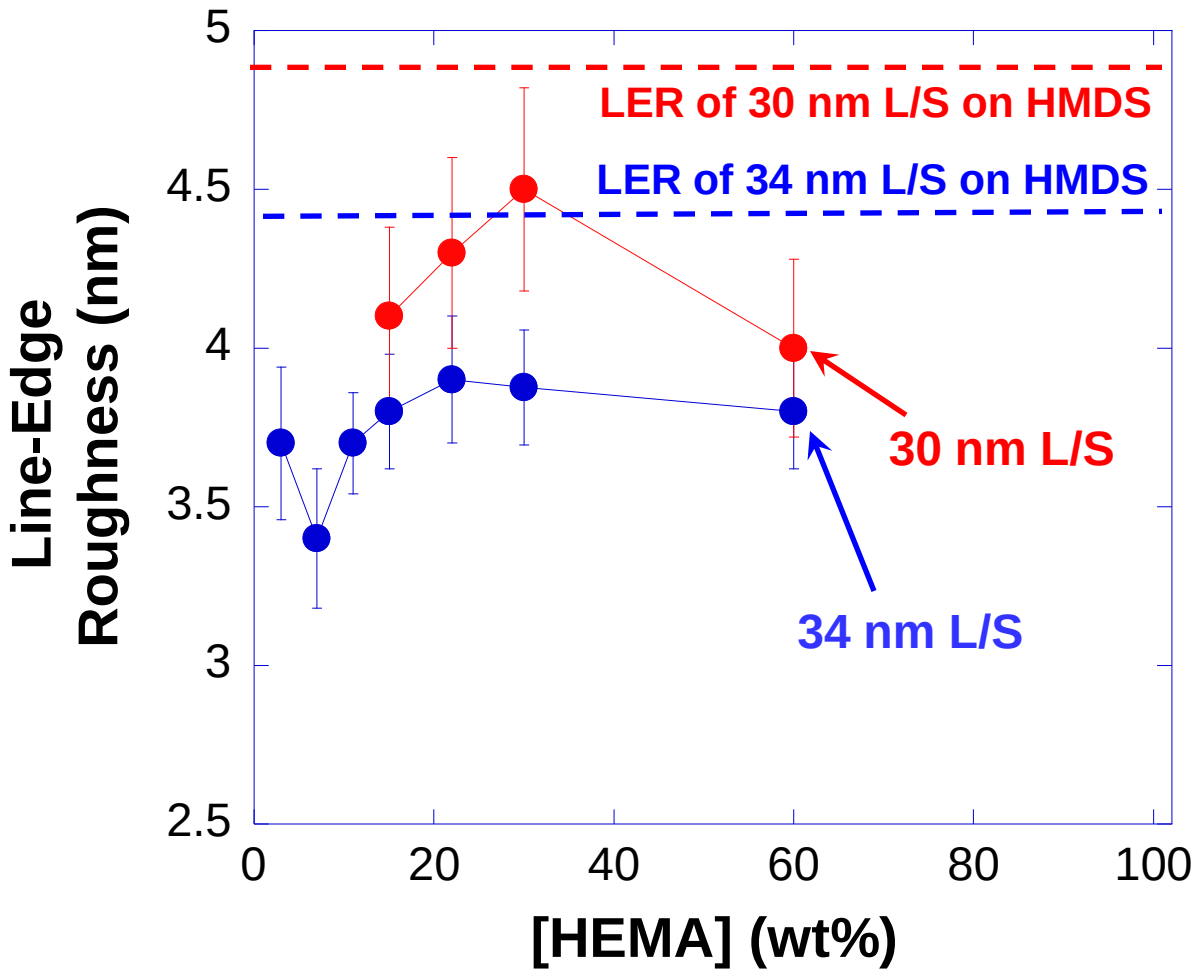
LER vs. Underlayer and HMDS



Improved LER on underlayers

90 and 100% HEMA had adhesion failure at 34 nm dense lines

60 nm OS2 resist thickness
30 nm underlayer thickness
BMET with Ann. Ill.

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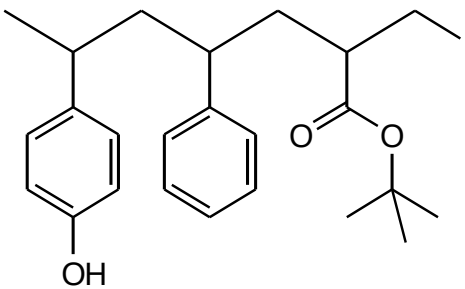
Resist Composition

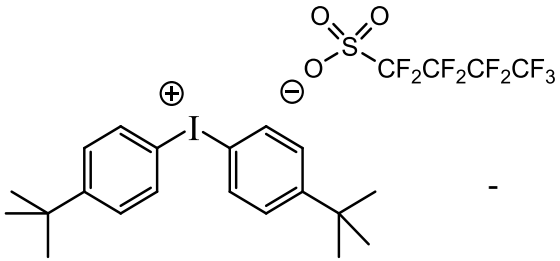
CNSE Resist

OS2

Polymer

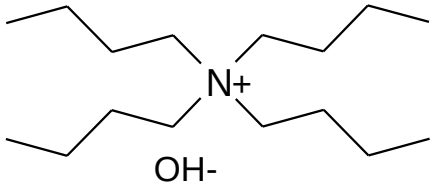


PAG (15 wt%)



Base

(1.5 wt%)



Commercial Resist

Resist B

Unknown

Composition

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