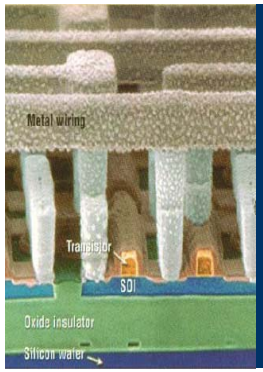
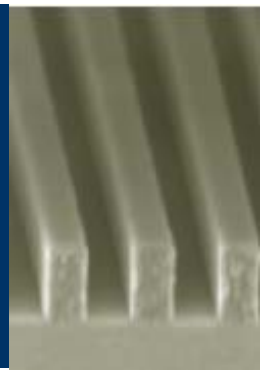



# Reduction in LER of EUVL patterned wafers via directed self assembly of water dispersible block copolymers



*Ya-Mi Chuang, Han-Hao Cheng, Imelda Keen, Anguang Yu, Thomas Bennett, Kristofer Thurecht, Kevin Jack, Andrew Whittaker and Idriss Blakey*

The University of Queensland, Australia

Associate Professor Idriss Blakey

i.blakey@uq.edu.au

Centre for Advanced Imaging

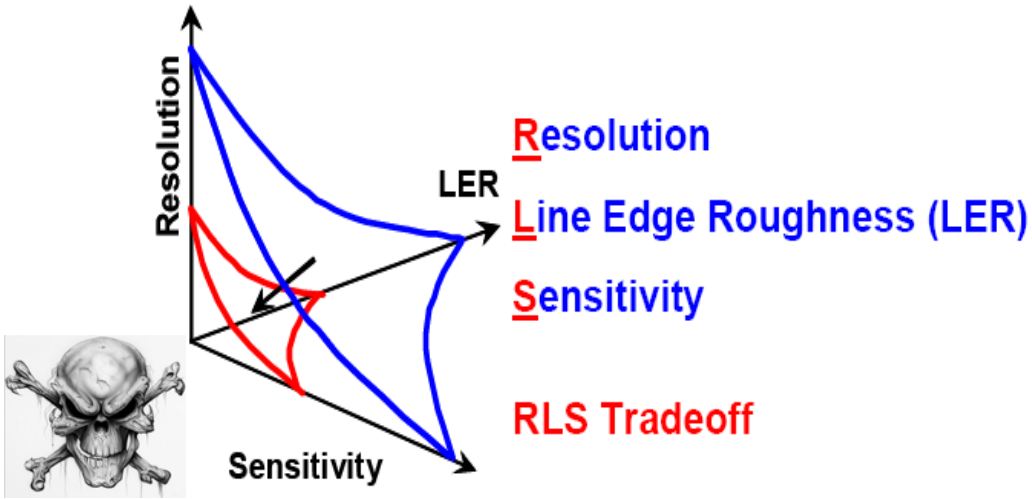
The University of Queensland Australia

Australian Institute for Bioengineering and Nanotechnology

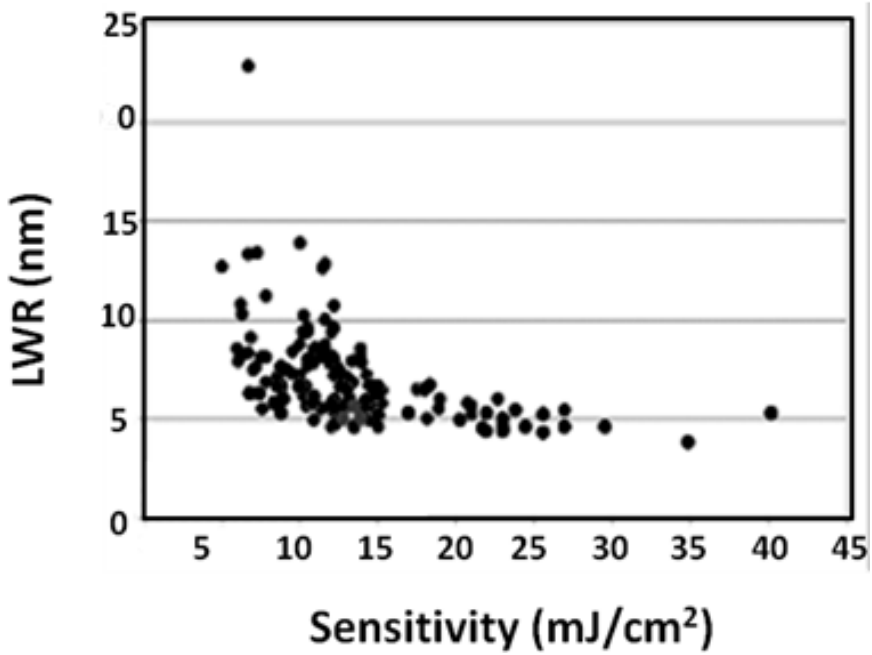
# Overview of Presentation

- **Motivation – Overcoming RLS trade-off**
- Concept 1 – Grapho-epitaxy Based DSA
- Concept 2 – Charge Directed Self Assembly
  - Generation 1 Materials
  - Generation 2 Materials

# Motivation for research



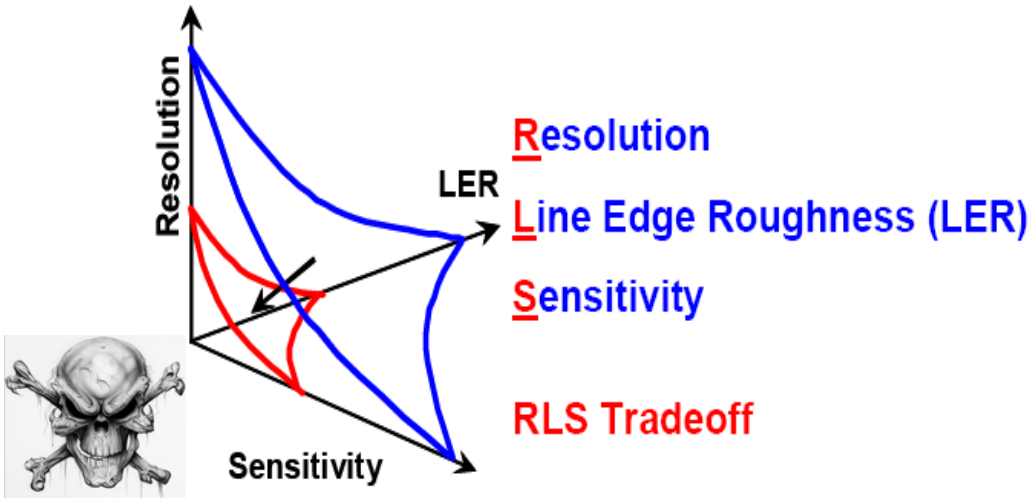

Brainard et al.



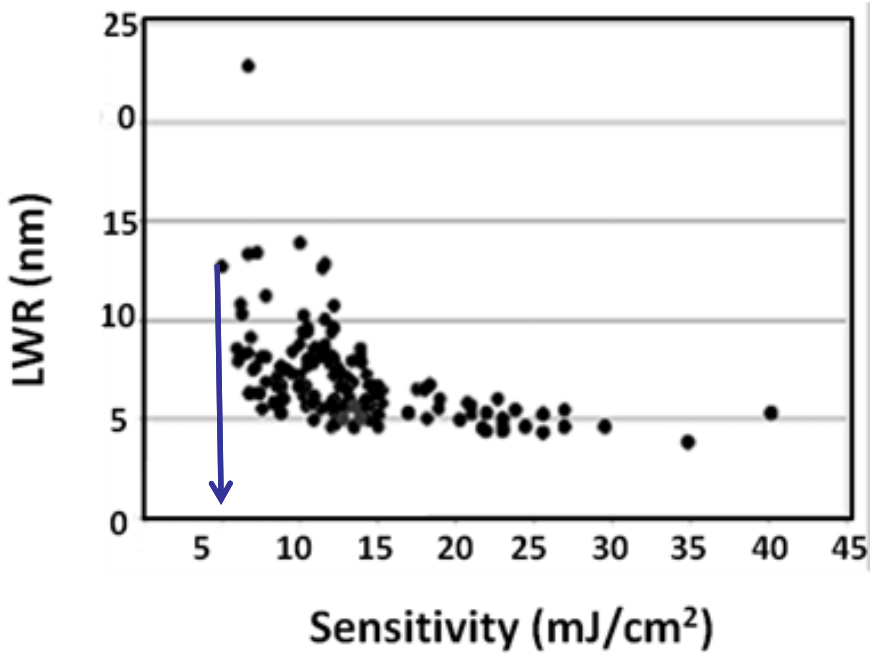

Cho et al., EUVL & Litho extensions, 2009.

- Can we design new materials to overcome the triangle of death to simultaneously improve RLS?

# Motivation for research




Brainard et al.



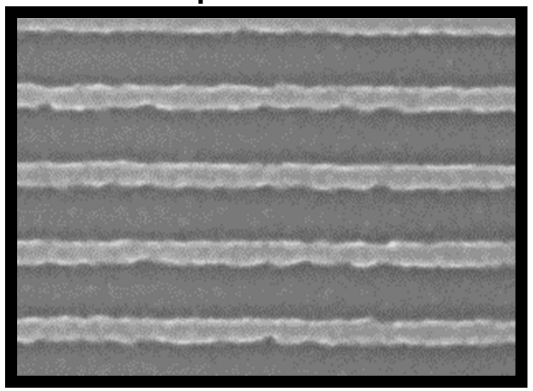

Cho et al., EUVL & Litho extensions, 2009.

- Can we design new materials to overcome the triangle of death to simultaneously improve RLS?

# Our approaches

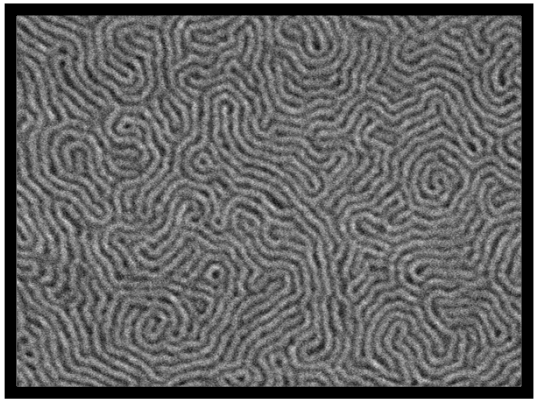
## 1. Achieving sub-10 nm resolution

Top down



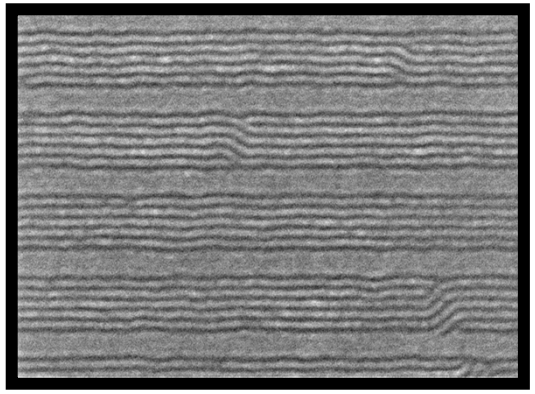
+

Bottom up

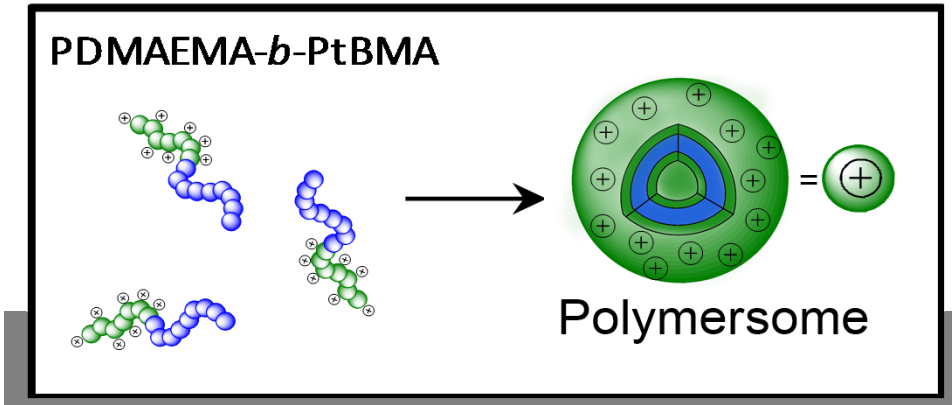


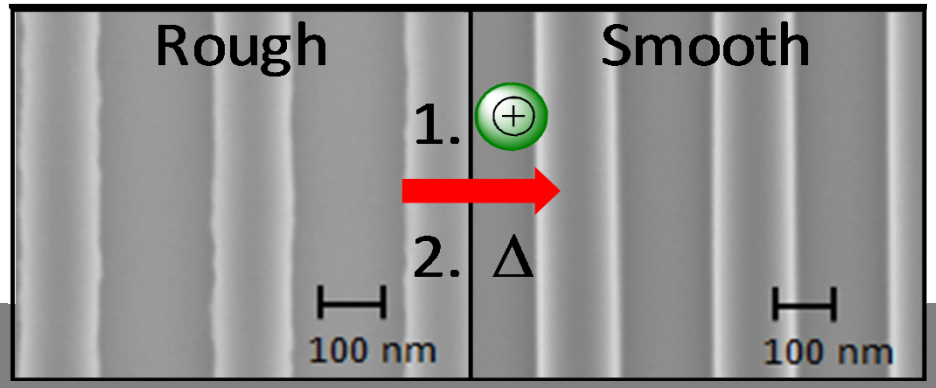
=

Top down
+ bottom up



## 2. Healing of roughness



# Overview of Presentation

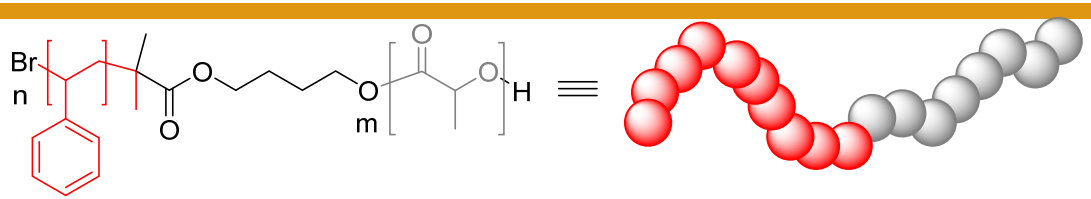
- Motivation – Overcoming RLS tradeoff
- **Concept 1 – Graphoepitaxy Based DSA**
- Concept 2 – Charge Directed Self Assembly
  - Generation 1 Materials
  - Generation 2 Materials

Imelda Keen

Han Hao (Elliot) Cheng

Anguang Yu

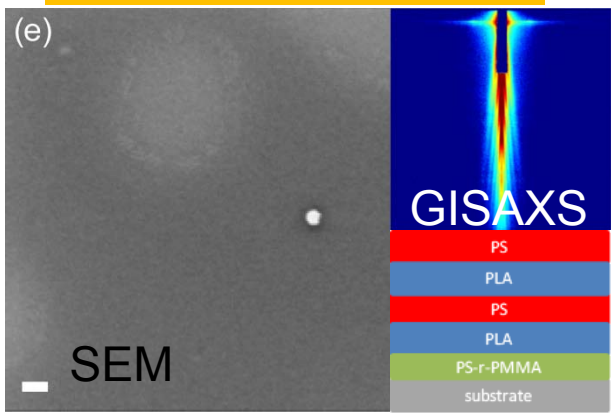
# Polystyrene-*block*-Polylactic acid (PS-b-PLA)




- High χ parameter – 0.217
  - 5 nm features reported (bulk)
  - PS-*b*-PMMA, 0.041
- Synthesis by 'living' polymerisation
  - Can control feature size/morphology
  - 7.9 – 14 nm domains (hp)
- Have detailed understanding of interfacial properties

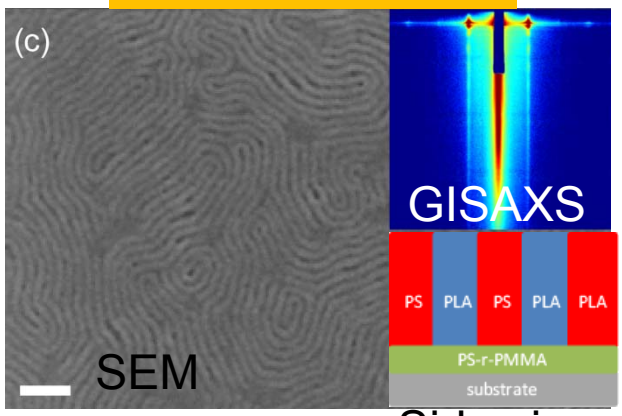
Keen, ... Blakey *et al*., *Langmuir,* 2012, **28,** 15876.

Preferential substrate



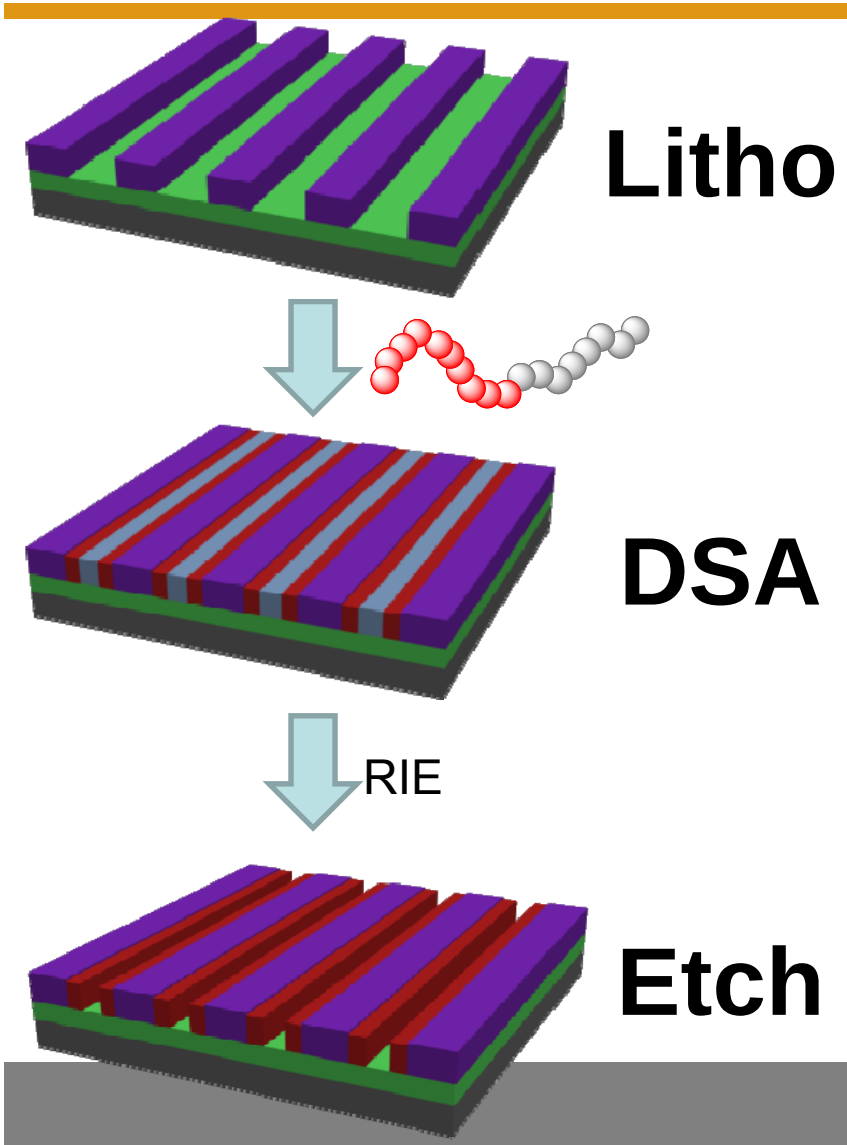

Side view

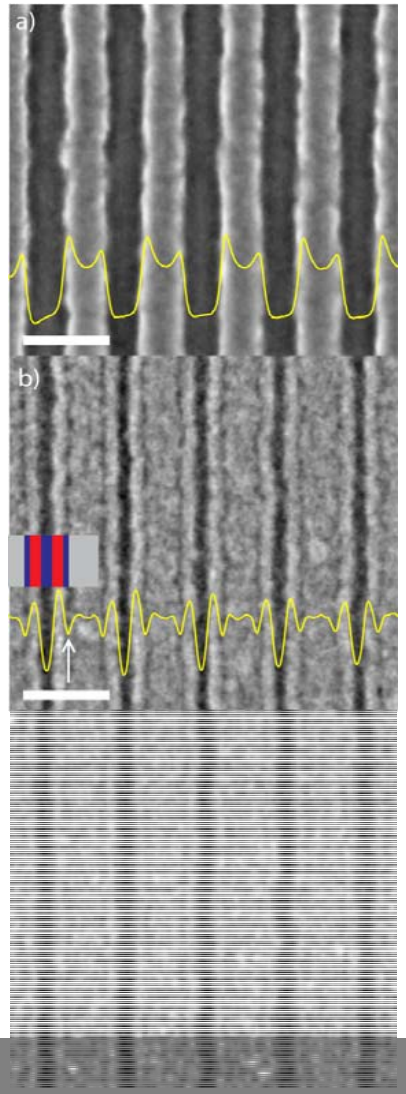
Neutral substrate




Side view

# Directed Self Assembly - Graphoepitaxy



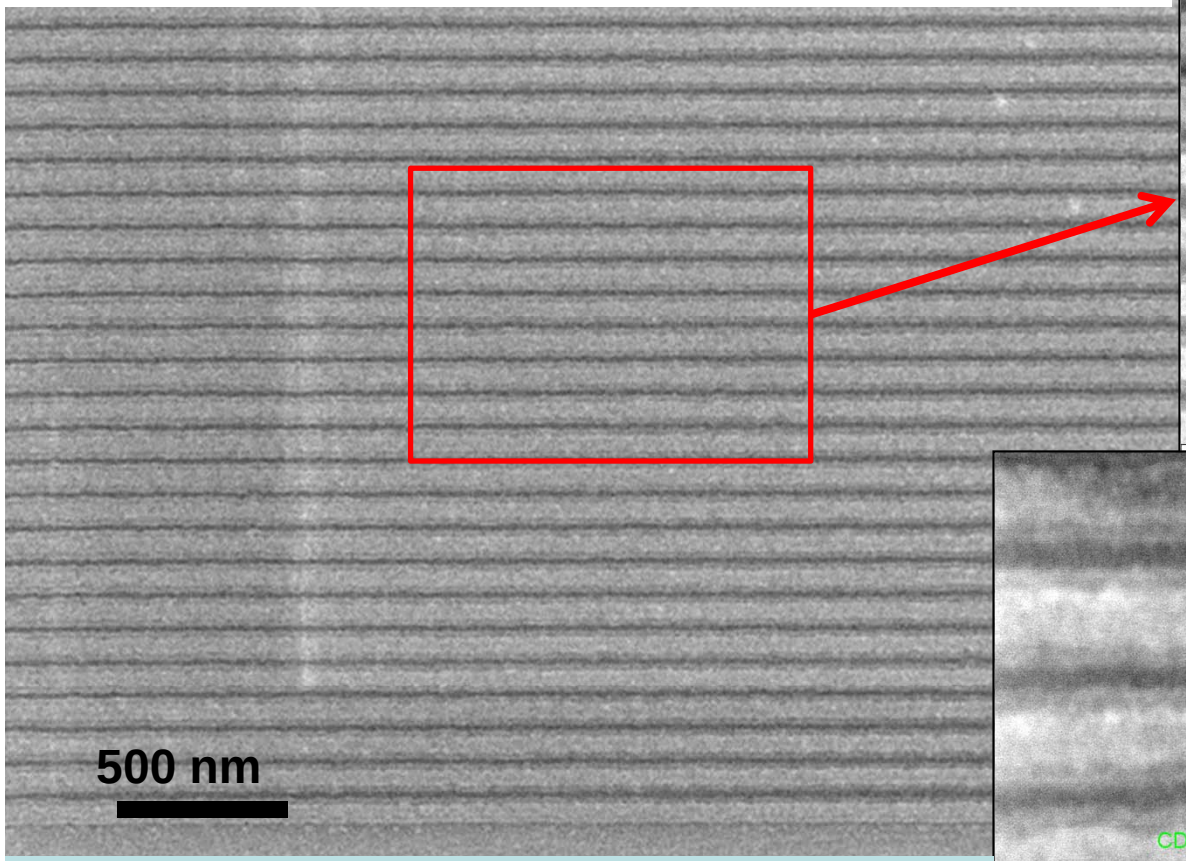

DSA with PS-*b*-PLA

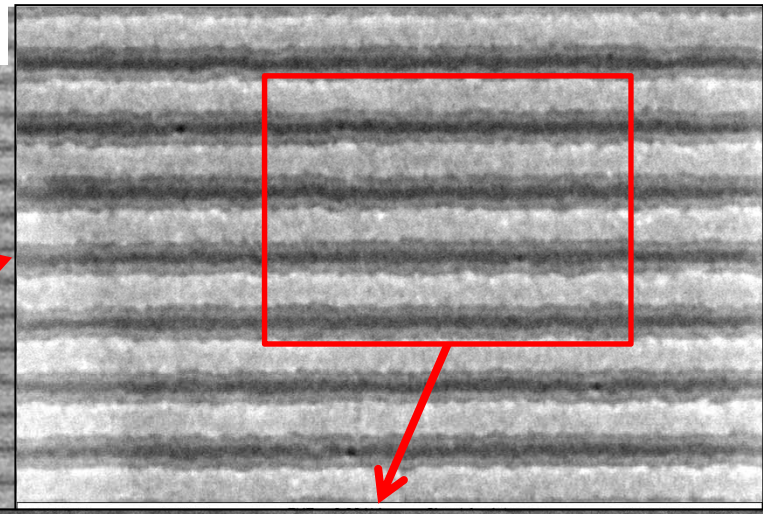
- Resist freezing not required
  - Can be spin coated from a non-solvent for PHOST based resists
  - $T_{Anneal}$ ~100 °C (< most resists)
- Etch selectivity for PS to PLA is 1:4

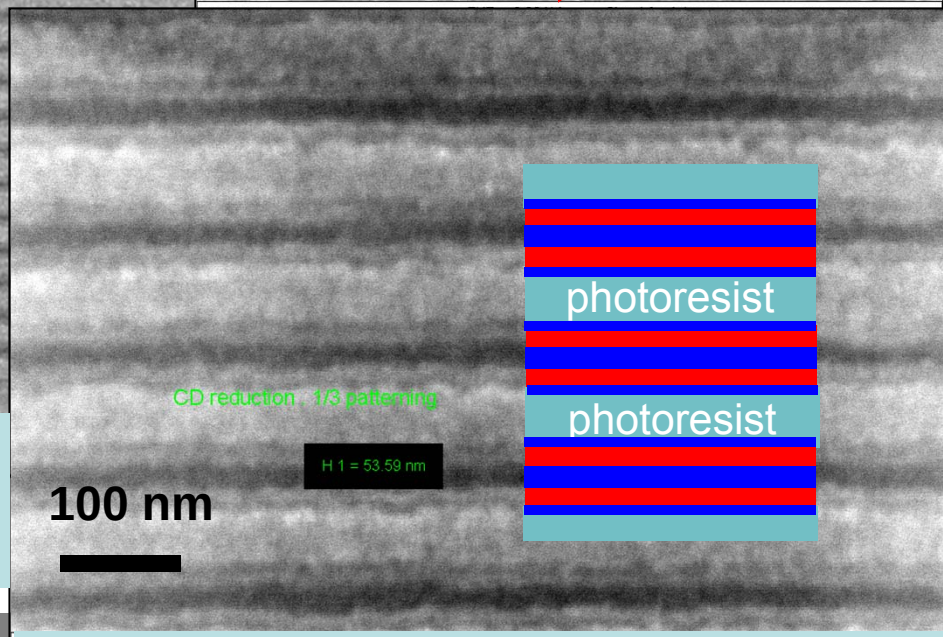
Keen, ... Blakey *et al.*, *manuscript in preparation 2013*.

# Uniformity of Coverage (2 $L_0$)

BCP coverage for 48.3 nm CD lines 21 k PS-*b*-PDLA






CD Shrink: 48 - 12 nm (75%)
Excellent BCP coverage

30% reduction in LER observed

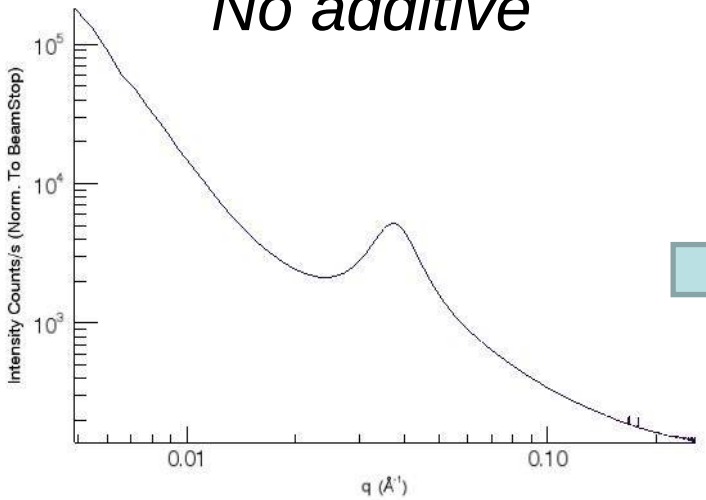
# Effect of additives

- Doping additives to PS-b-PMMA
  - Can we increase the $\chi$ parameter of BCPs?
  - Can we tune $L_0$ / commensurability?
  - Can we tune morphology?

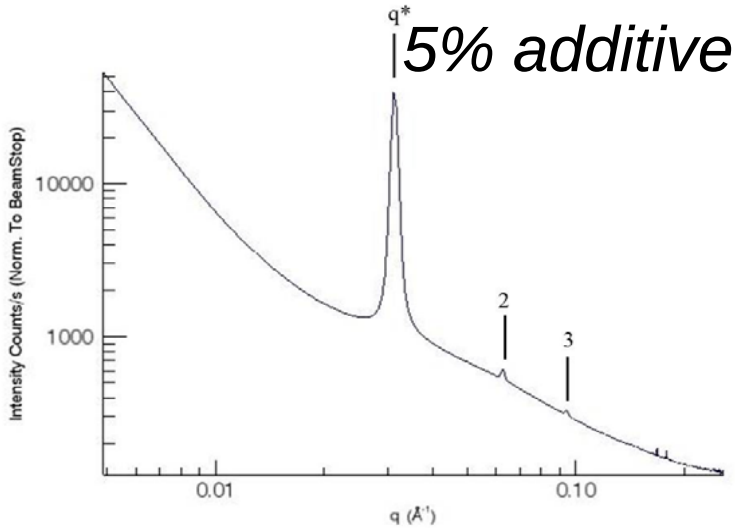
  - Potential advantages include:
    - Use currently available BCPs
      - Shallower learning curve?
      - Less need for more polymer synthesis
      - Reduced defectivity?

Thomas Bennett
2nd year PhD Student
(project currently
not industry funded)

# Can additives be used to influence $\chi$?



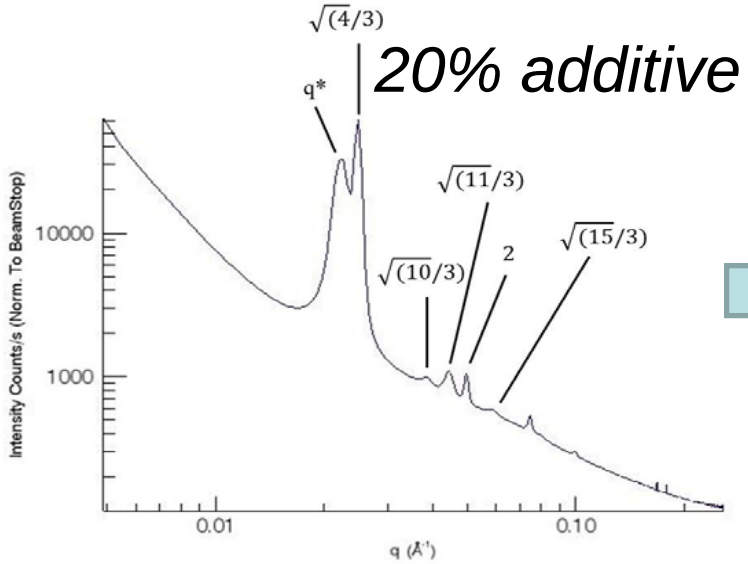

Disordered



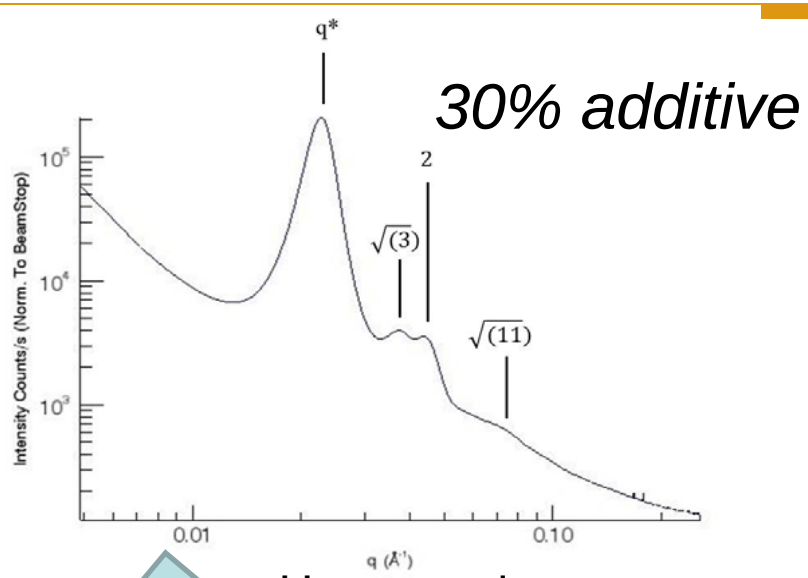

Lamellar

- Addition of additives (5 volume %) induced order in a disordered PS-b-PMMA (10k-b-10k)
- $\chi$ has effectively been increased!
- Effect observed as low as 5k-b-5k $\Rightarrow$ $\chi$ at least tripled

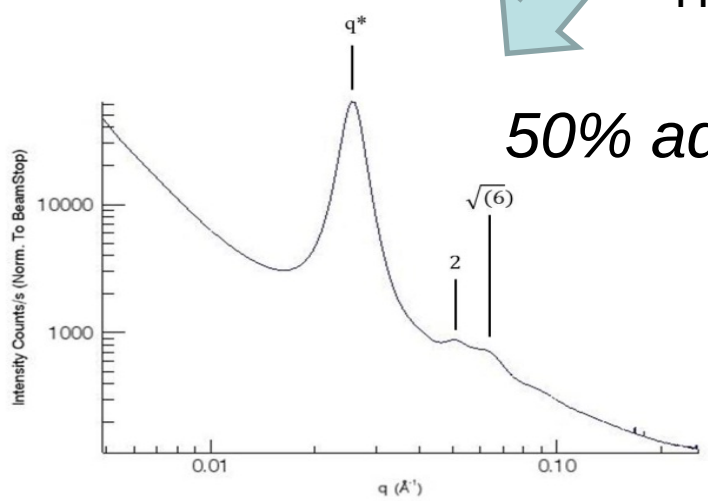
# Morphology of BCPs can also be tuned




Gyroid

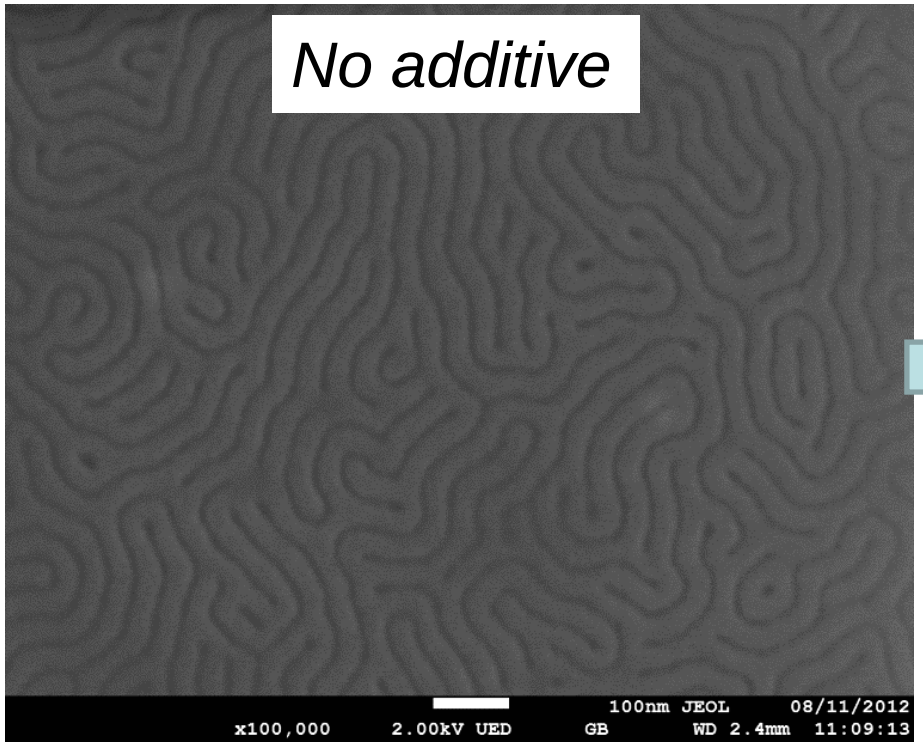



Hexagonal

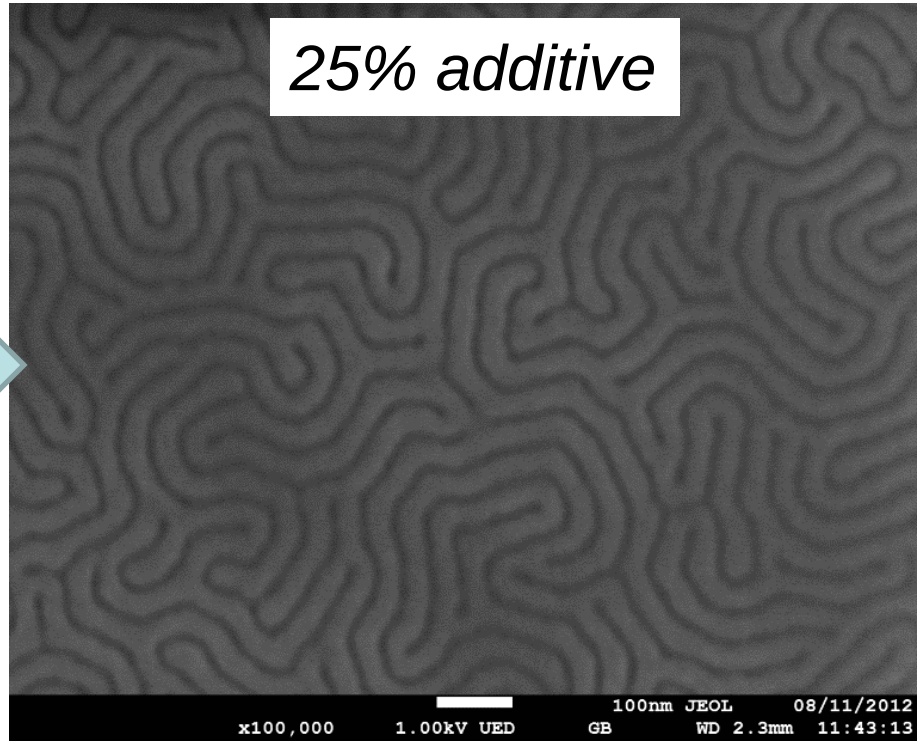



Cubic BCC

# Works for Thin Films - $L_0$ Tuning




$L_0$ = 36.2 nm




$L_0$ = 40.7 nm

Same neutral surface was used in both cases

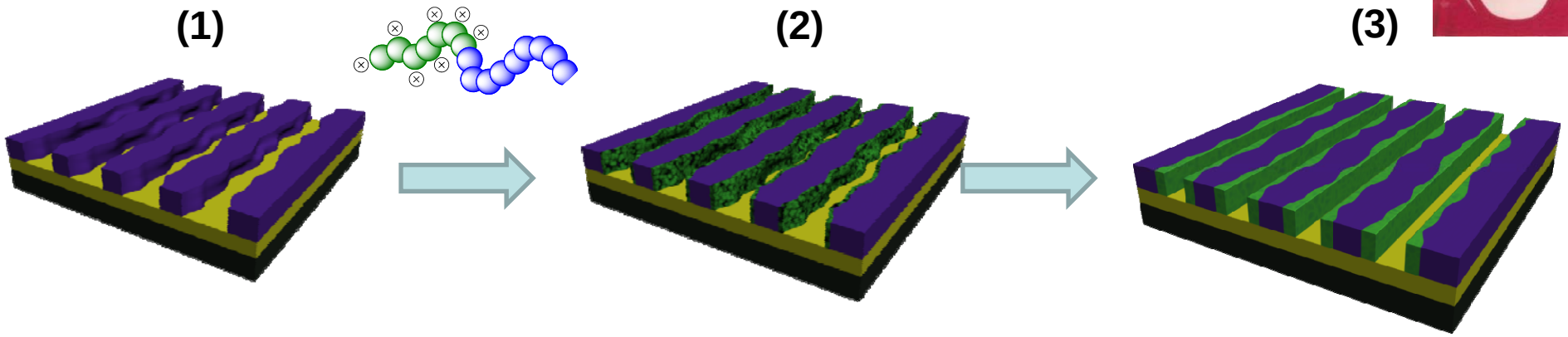
Will tuning of $L_0$ result in less defects?

# Overview of Presentation

- Motivation – Overcoming RLS tradeoff
- Concept 1 – Grapho-epitaxy Based DSA
- Concept 2 – Charge Directed Self Assembly
  - **Generation 1 Materials**
  - Generation 2 Materials

# Gen 1- Charge Directed Self Assembly

Ya-Mi Chuang

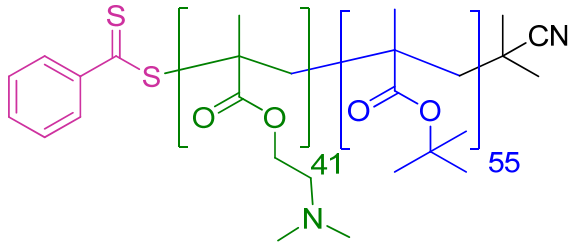


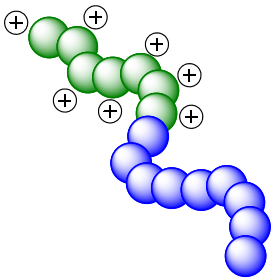

1) Sidewalls of CAR resists are typically negatively charged.
2) Allows attachment of positively charged block copolymers.
3) Annealing at temperatures above $T_g$ of non-charged block allows polymer to re-arrange to minimize surface tension and reduce LER.

Advanced Functional Materials, 2013, 23, 173-183.

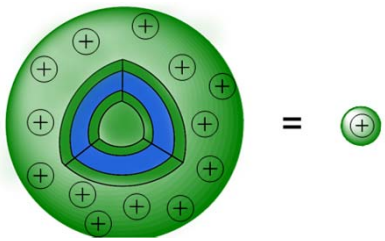
.

# Block Copolymers / Solution Properties

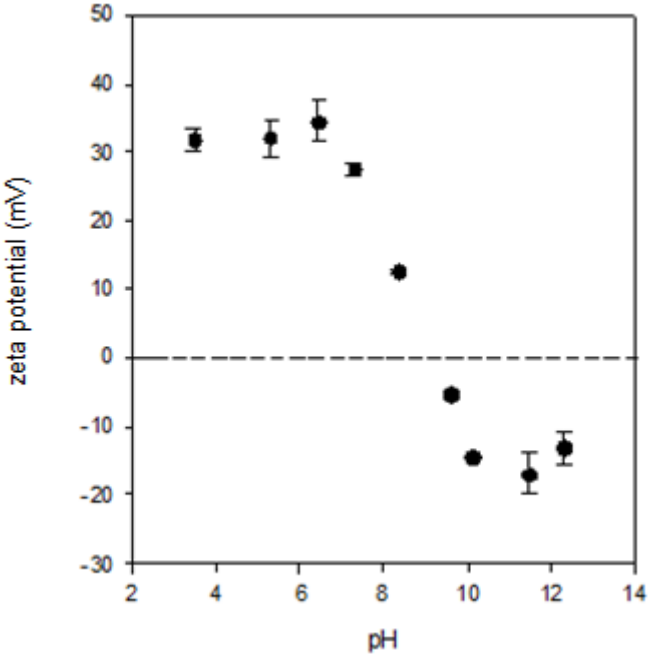


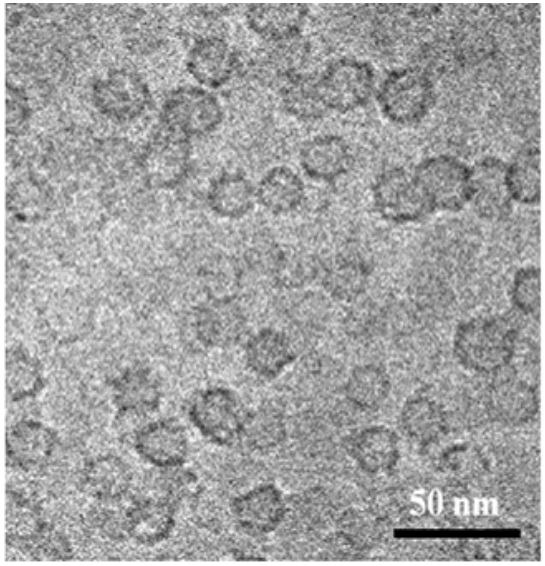
PDMAEMA-*b*-PtBuMA




Zeta potential




Cryo - TEM




Zeta potential measurements of polymer solutions reveal particles are positively charged below pH 8

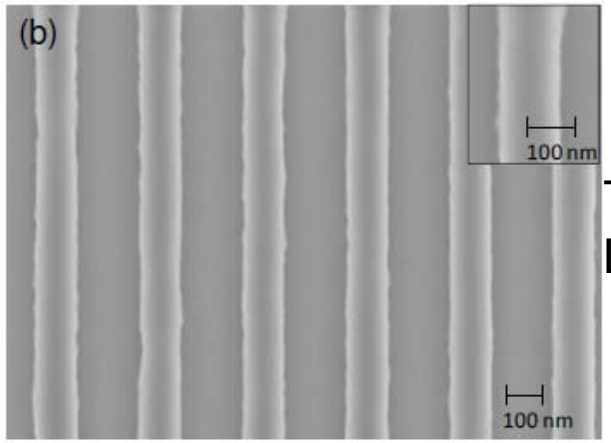
Block copolymer was found to self assemble into vesicles in aqueous solution (~18 nm)



Advanced Functional Materials, 2013, 23, 173-183.

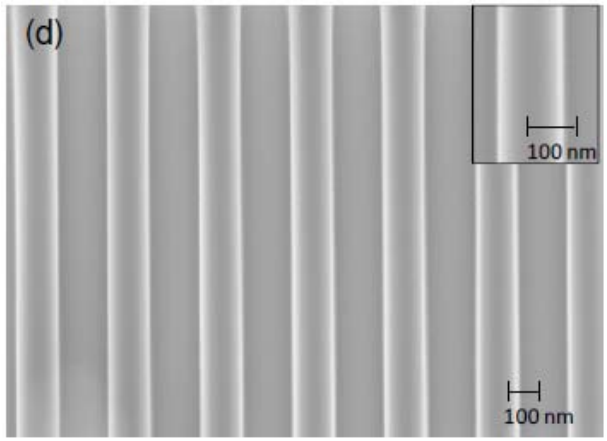
.

# Healing of Patterned Features



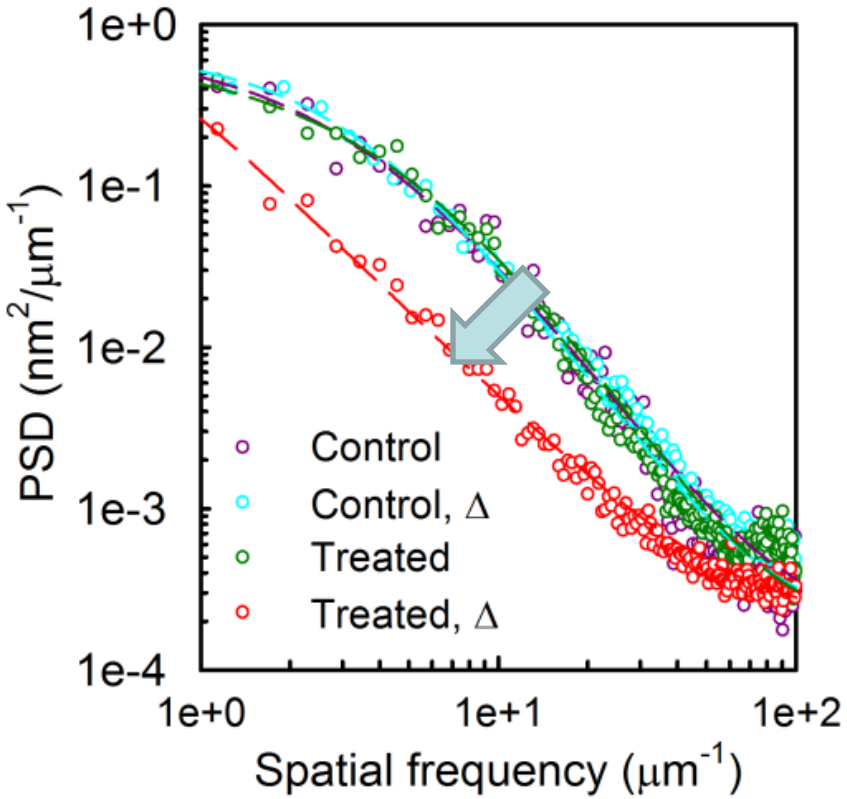

Control

Trench 174 ± 5 nm
LER 5.8 ± 0.4 nm




Treated ⊕ + △

Trench 160 ± 1 nm
LER 3.4 ± 0.3 nm




Treatment reduced LER from 5.8 to 3.4 nm (41%)
Smoothing observed over all frequency ranges.

EBL, SEM,
LER Analysis

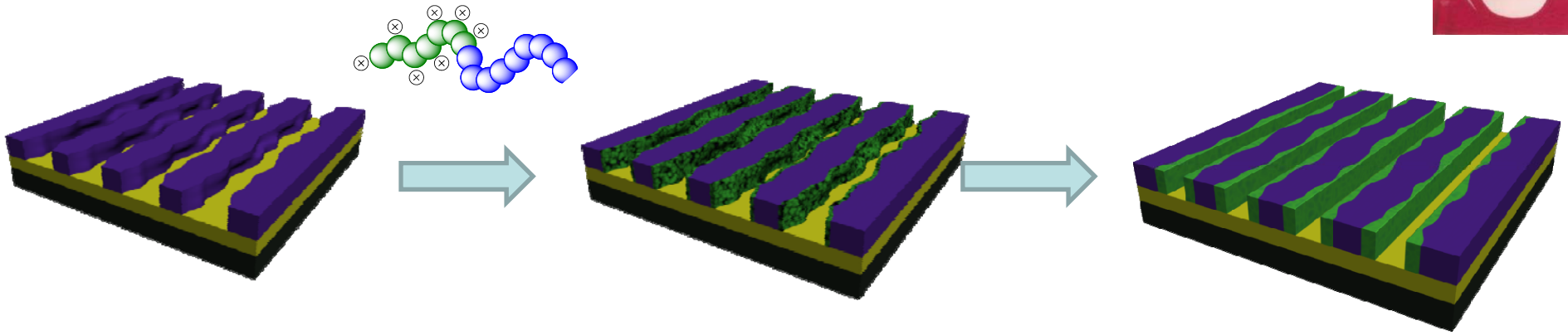
Adv Func Mater, 2013, 23, 173.

# Overview of Presentation

- Motivation – Overcoming RLS tradeoff
- Concept 1 – Grapho-epitaxy Based DSA
- **Concept 2 – Charge Directed Self Assembly**
  - Generation 1 Materials
  - **Generation 2 Materials**

# Charge Directed Self Assembly – Gen 2

Ya-Mi Chuang

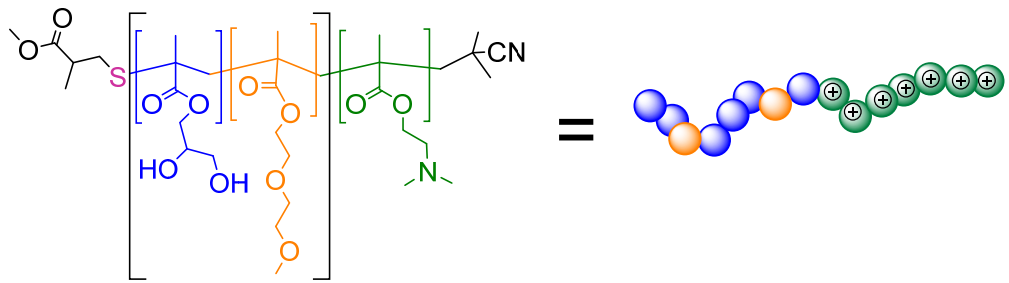


- Particle size of Gen 1 materials was 20 nm and flattened to 40 - 50 nm on surfaces
- To overcome this Gen 2 BCPs were designed to be double hydrophilic – No aggregation



Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Synthesis of Double Hydrophilic BCPs

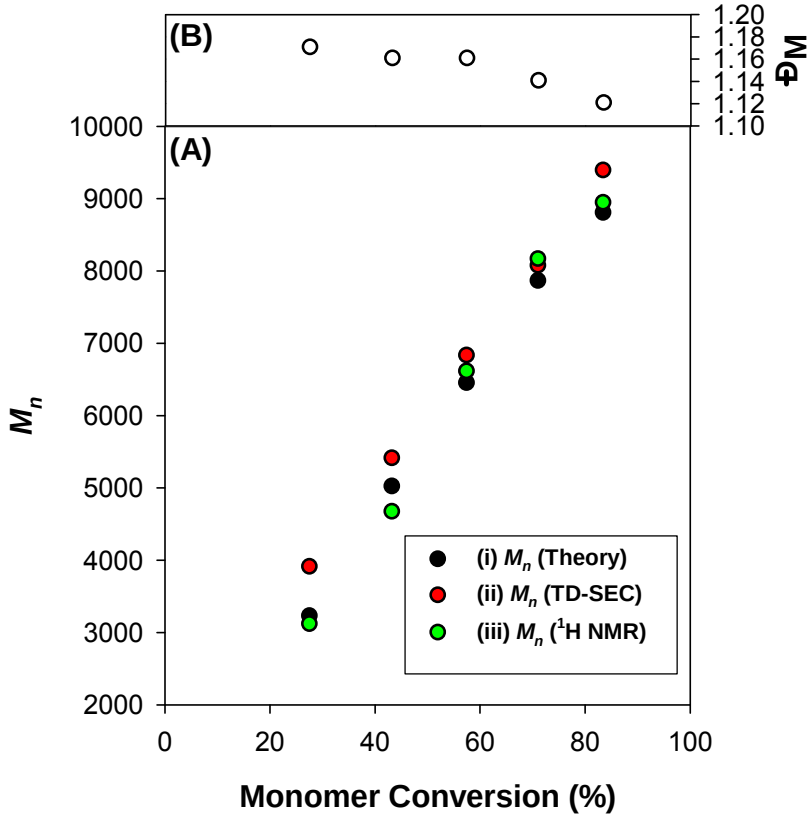



Green Block:
Included to impart positive charge to polymer

Blue / Orange Block :
Included as "healable" component
(RT < $T_{g\ block}$ < $T_{g\ resist}$)

Blue component :
High $T_g$

Orange component :
low $T_g$



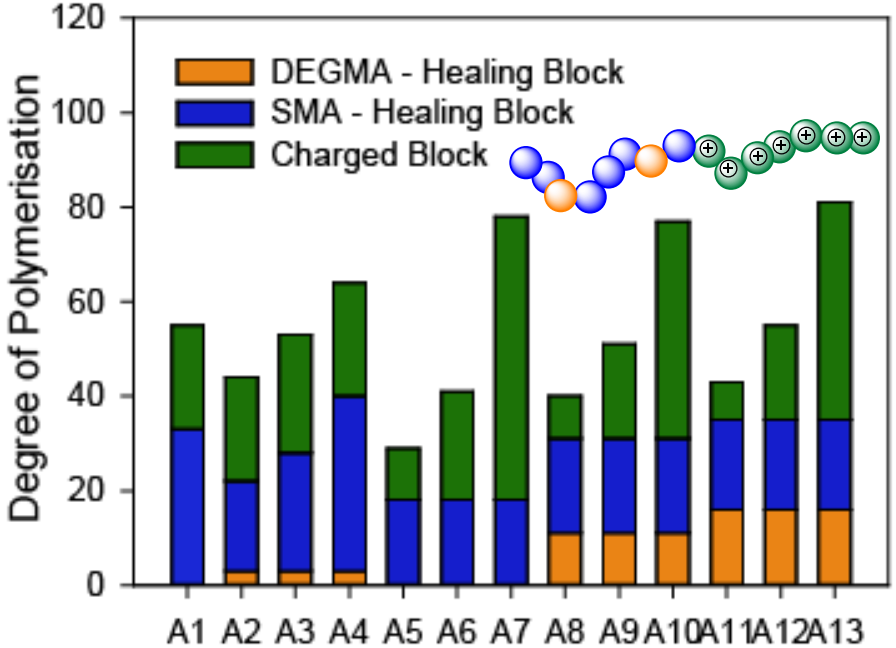

Use controlled polymerization (RAFT) so get controlled size ($M_n$) and dispersity of size (PDI).



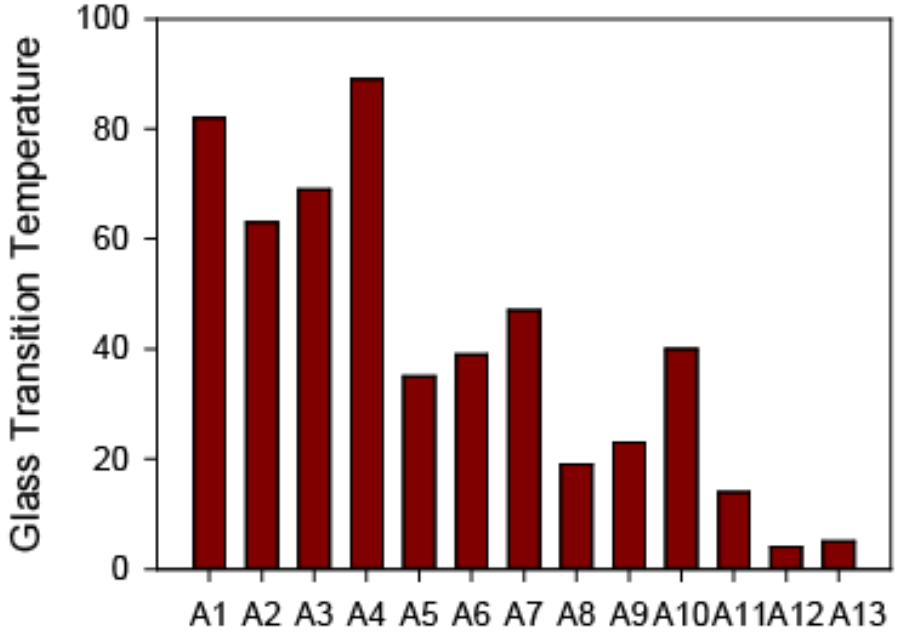
Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Characterisation

## Composition and Size




## Glass Transition Temp



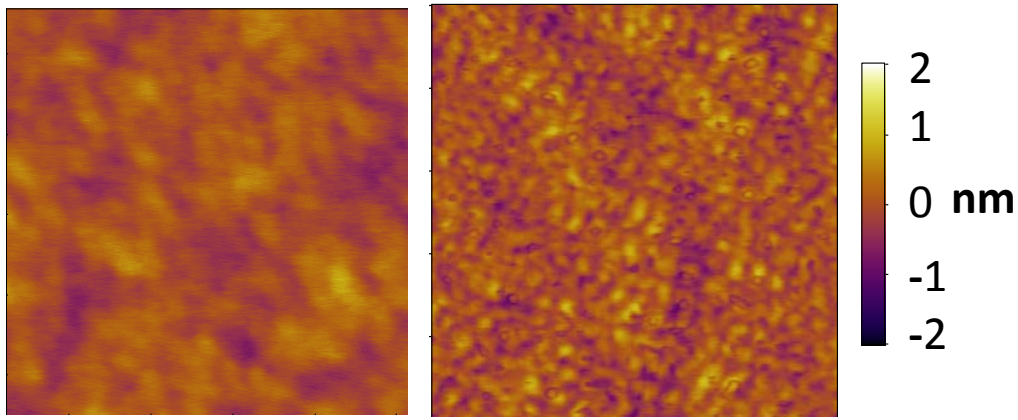

Series has a diverse range of compositions, molecular weights and glass transition temperatures



Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Evidence for Adhesion to Surfaces

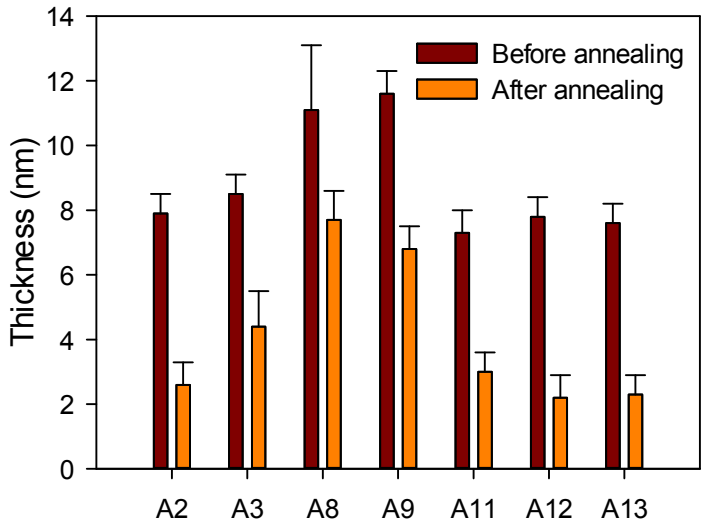
**AFM**




Flat negatively charged surface
RMS 0.3 ± 0.2 nm

After treatment with BCP (A3)
RMS 0.4 ± 0.1 nm

**VUV-VASE**

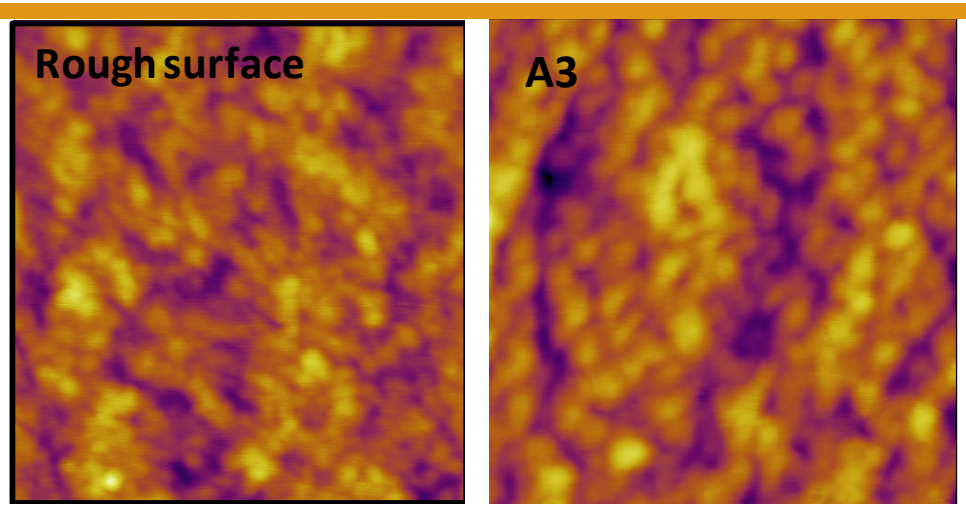


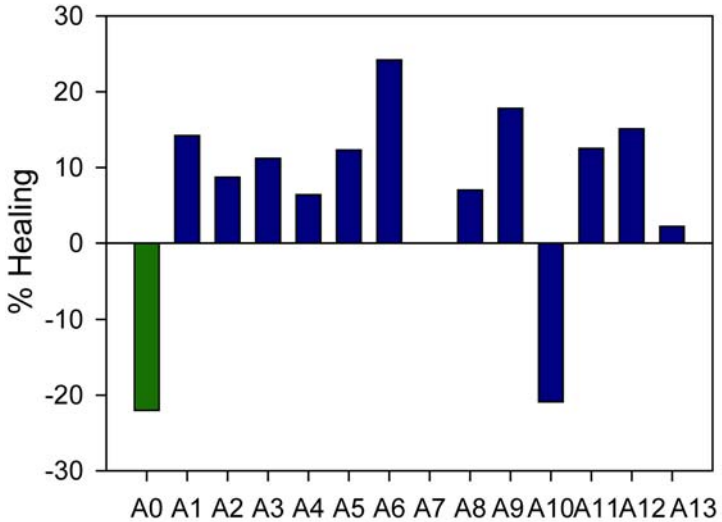

- AFM – change in morphology consistent with adhesion
- VUV-VASE – increase in thickness demonstrates adhesion
- Inherent roughness of BCP on flat substrate ranged from RMS 0.24 – 0.93 nm (3σ LER equivalent 0.72 – 2.8 nm)



Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Healing planar rough surfaces

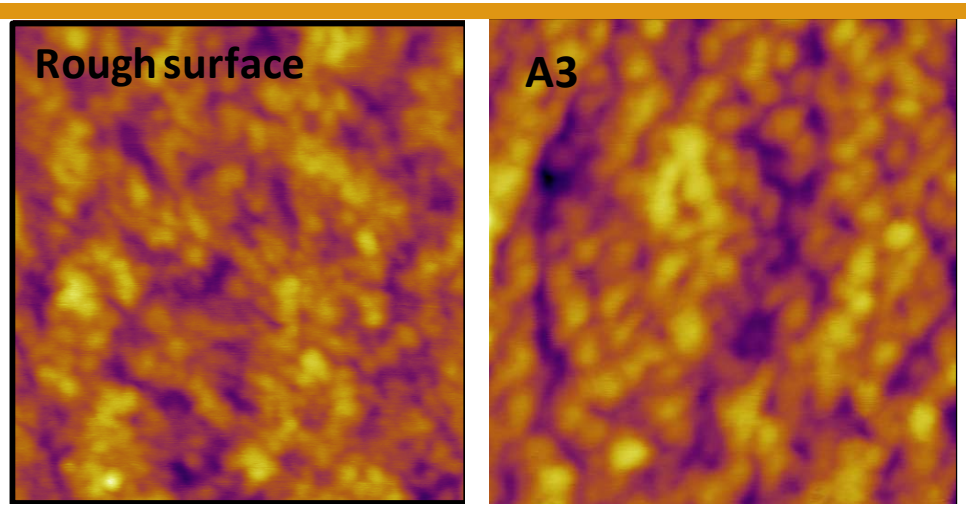


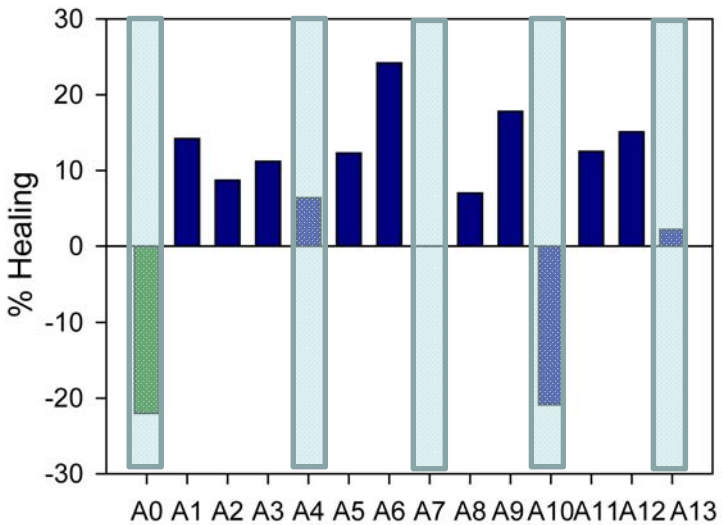




Prabhu et al., *Adv Mater, 2010*

- Planar rough surface - PHOST resist

# Healing planar rough surfaces



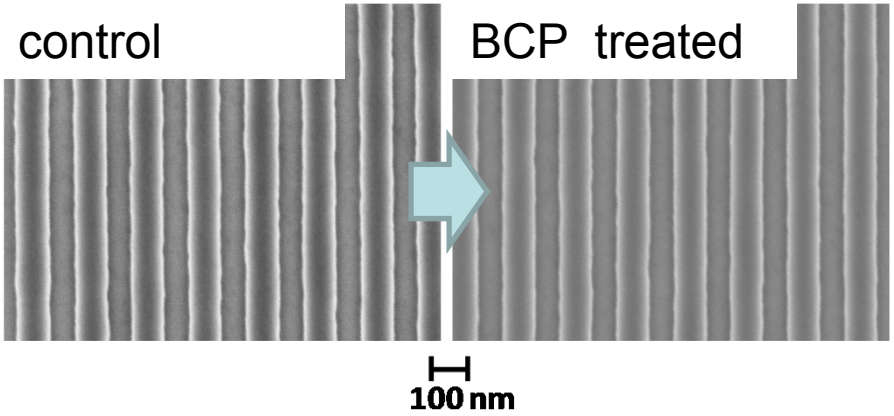



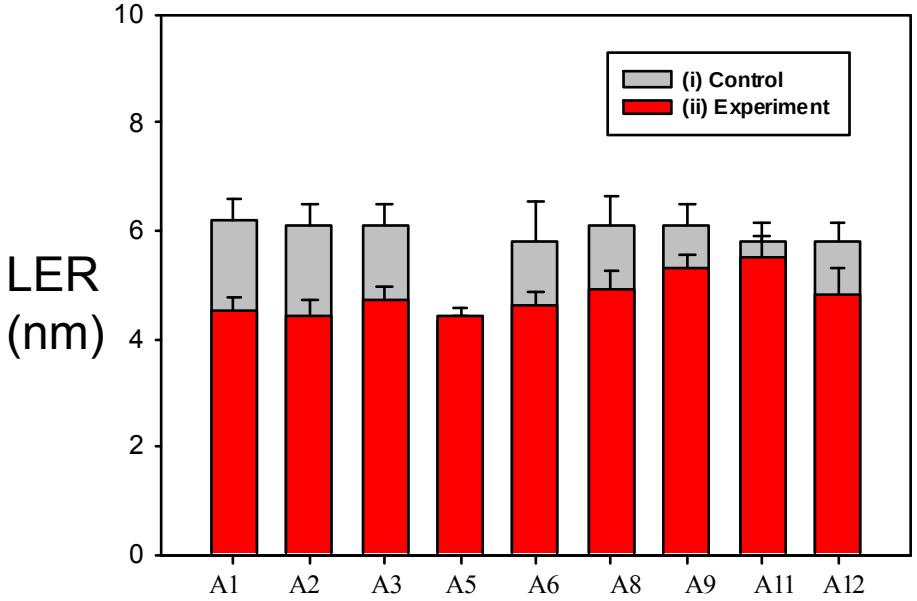

- Planar rough surface - PHOST resist
- Homopolymer of charged block and BCPs with a large charged block performed poorly in healing studies.



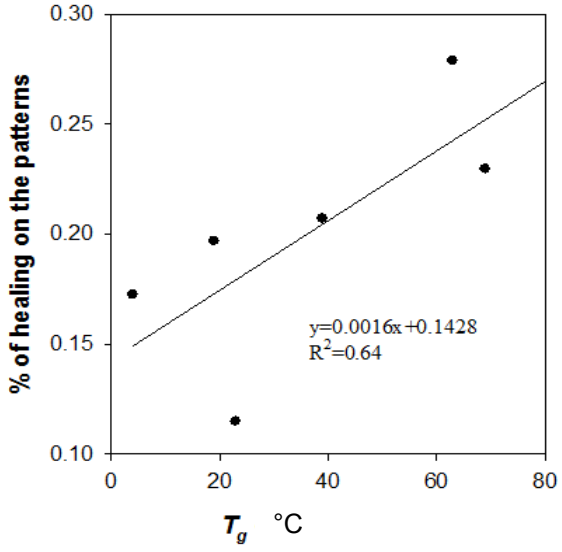
Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Healing of EBL patterns



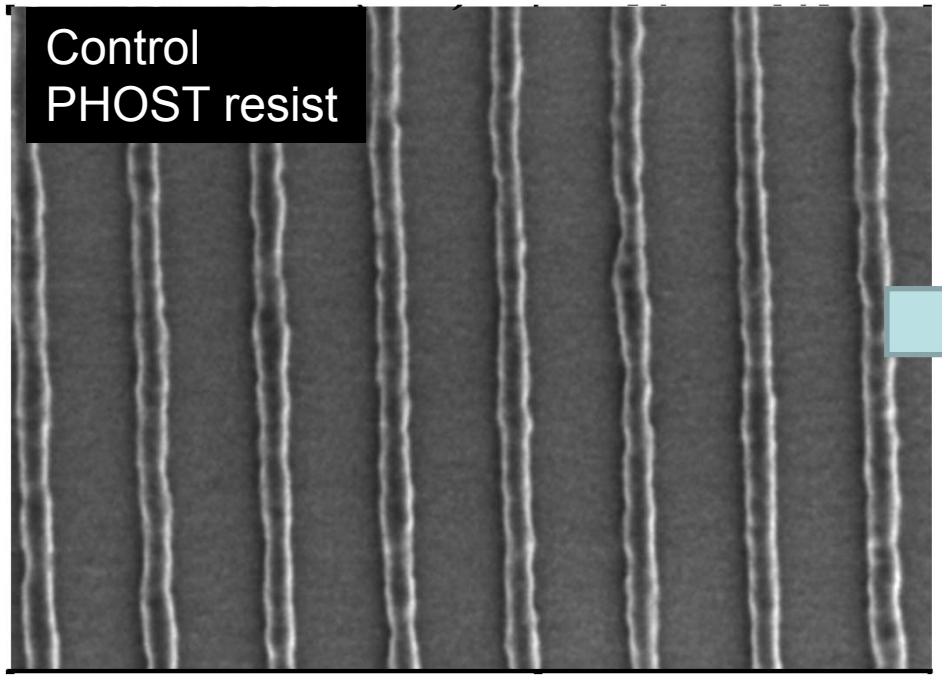

**% Healing vs $T_g$**

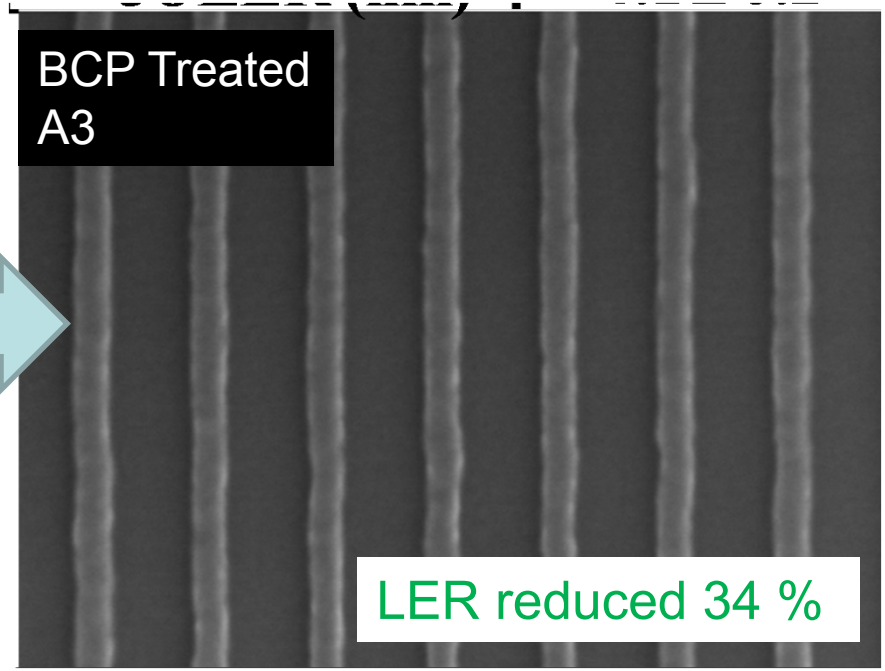



- Patterned open source PHOST resist
- Trend differs from planar rough surfaces
- Weak correlation with $T_g$ of BCP, other factors could also contribute.

Chuang ... Blakey et al manuscript in preparation 2013
Provisional Patent Filed

# Healing EUVL printed features



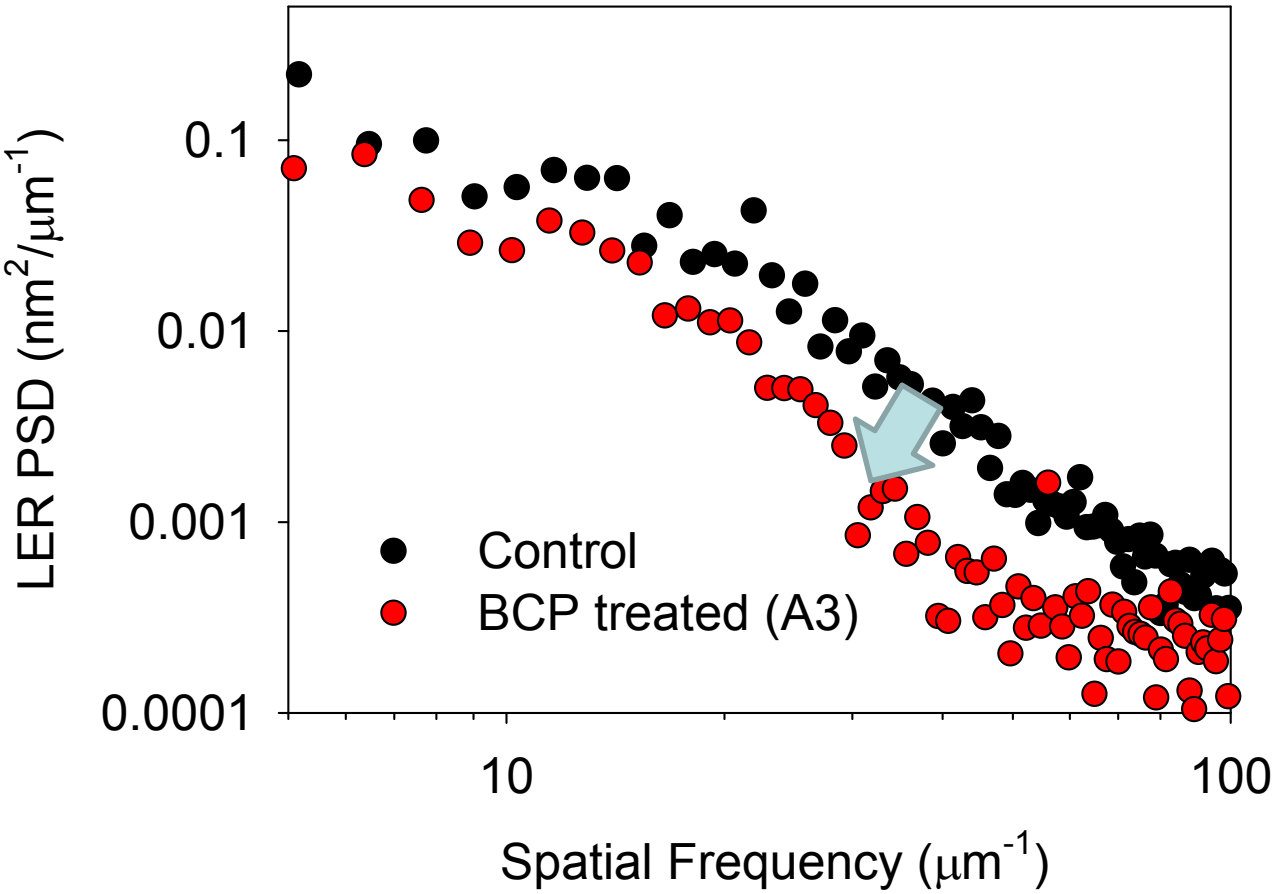




CD 38.9 ± 0.4 nm
LER 6.1 ± 0.3 nm

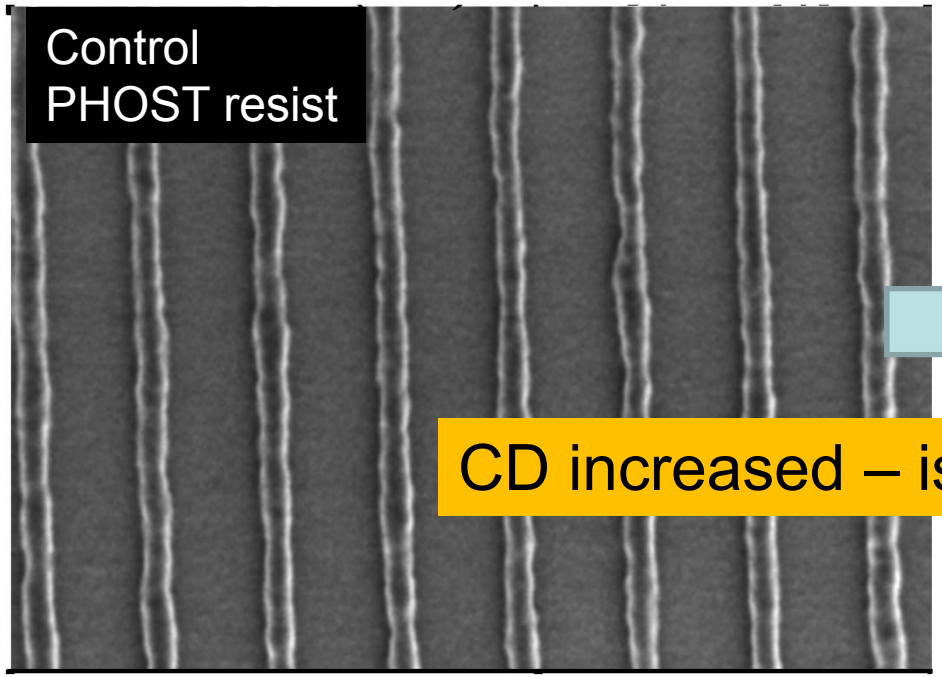
CD 46.7 ± 0.4 nm
LER 4.0 ± 0.2 nm

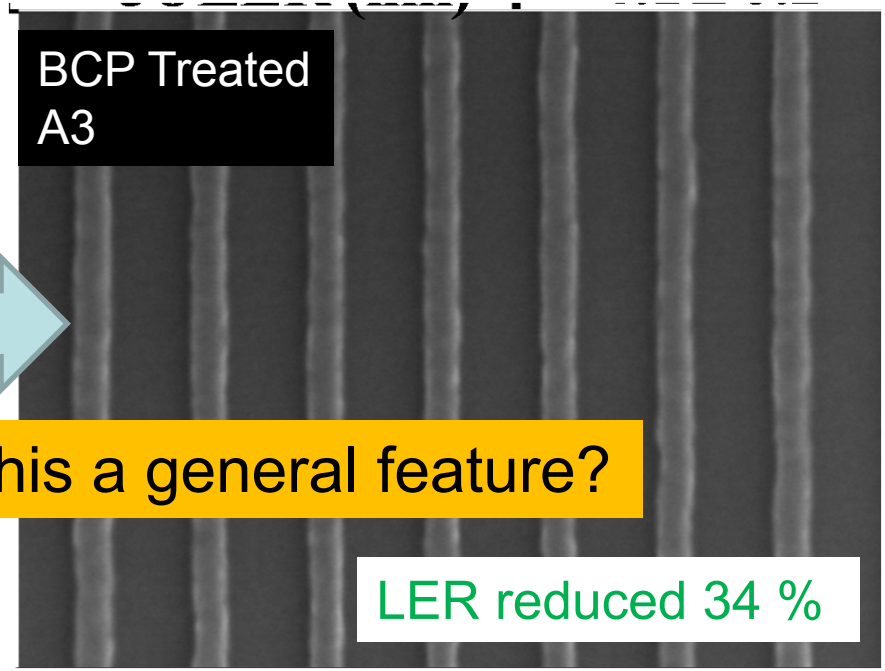
EUVL Patterned Resist – Thanks to Michael Leeson @ Intel. PHOST based resist

# Low frequency LER reduced



# Healing EUVL printed features




CD increased – is this a general feature?

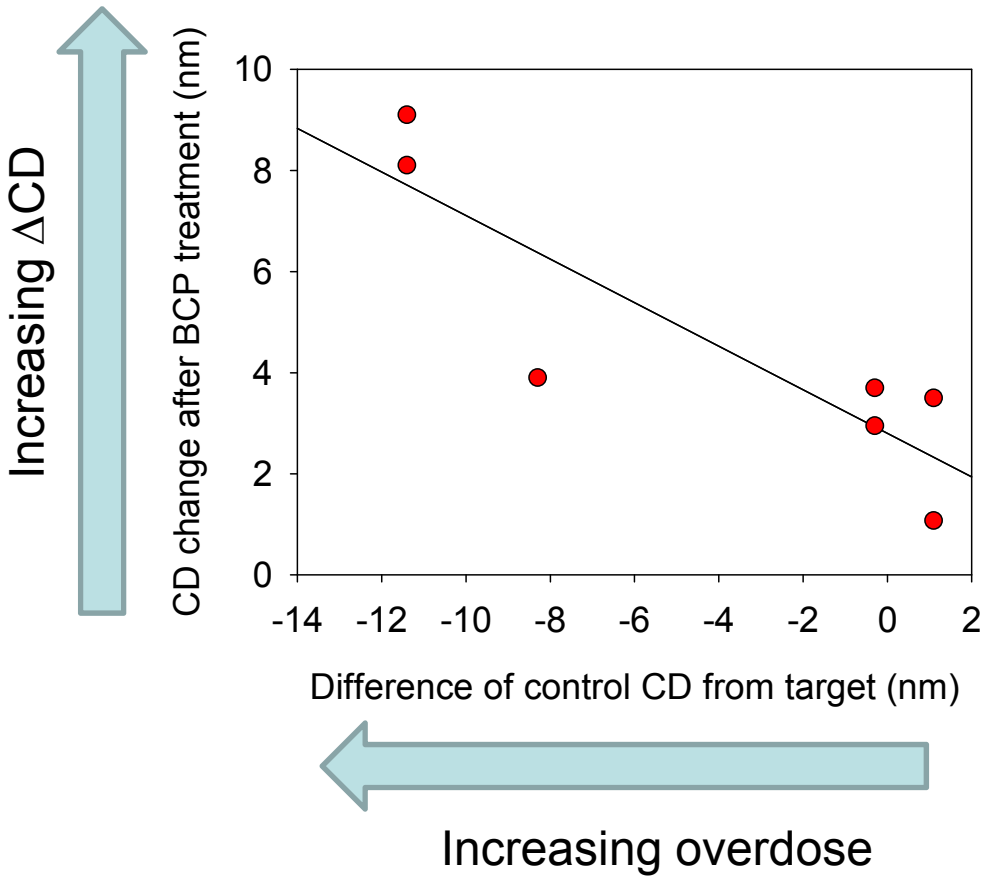
CD 38.9 ± 0.4 nm
LER 6.1 ± 0.3 nm

CD 46.7 ± 0.4 nm
LER 4.0 ± 0.2 nm

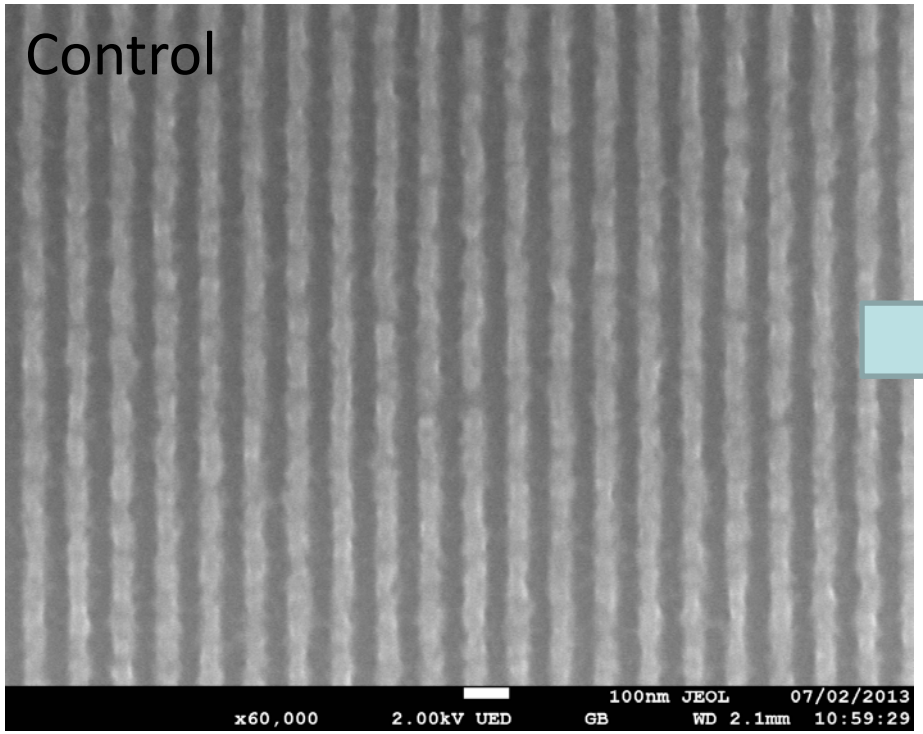
EUVL Patterned Resist – Thanks to Michael Leeson @ Intel. PHOST based resist

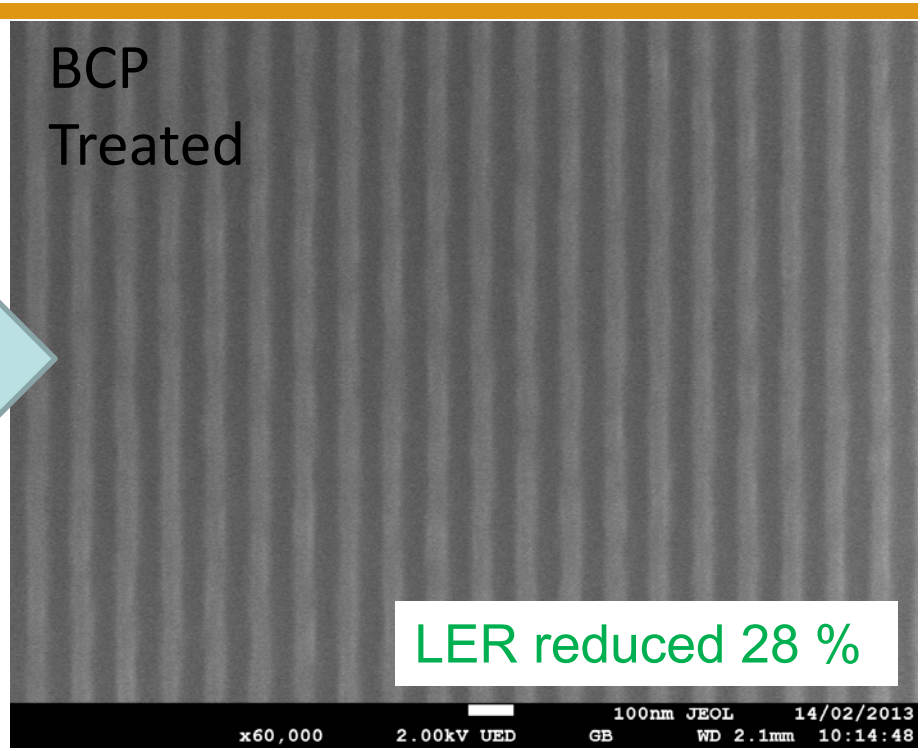
# Overdosed patterns have >ΔCD after BCP treatment

- CD change during BCP treatment seems to be correlated to degree of overdose for the line space patterns
- Perhaps due to sidewall charge??



# Results from another EUV resist




CD = 42.5 ± 0.2 nm
LER = 9.7 ± 0.3 nm

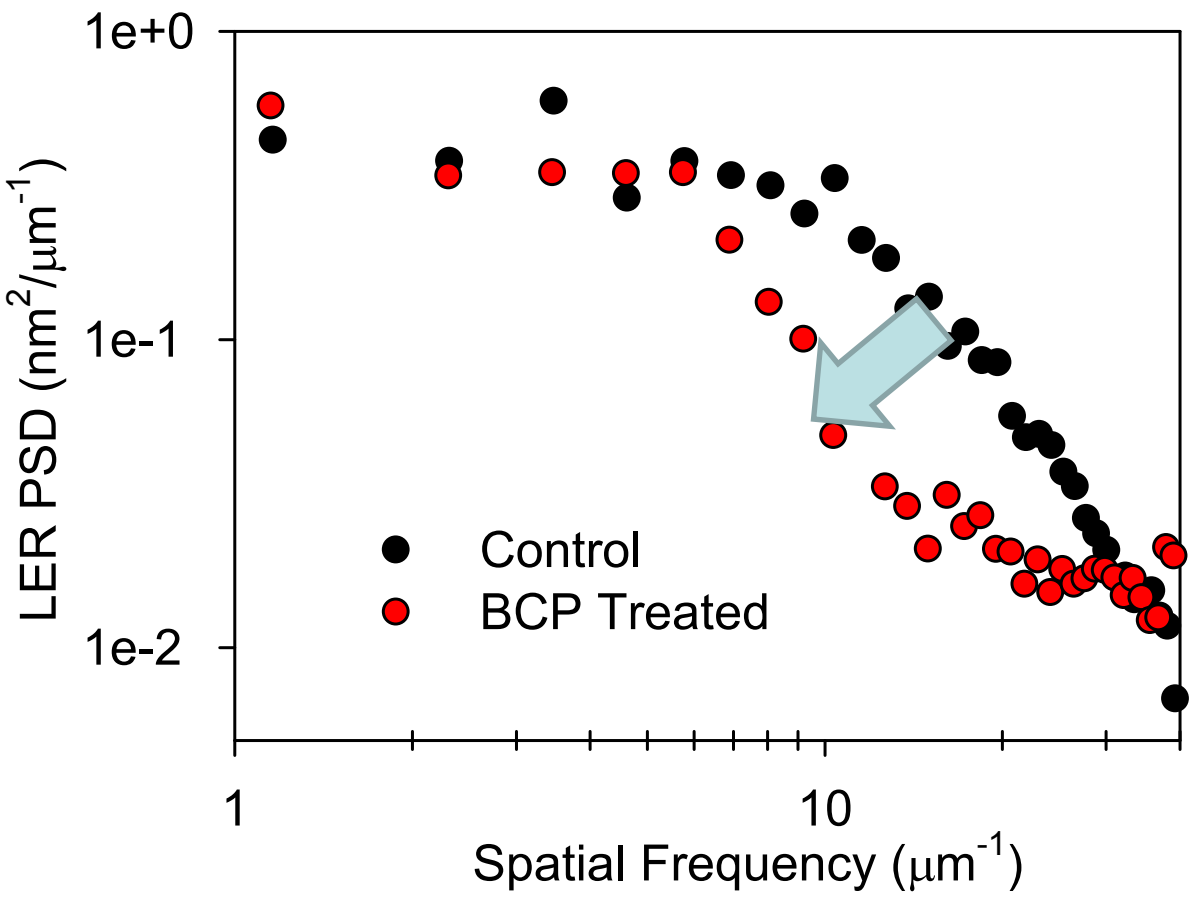
CD = 42.2 ± 0.3 nm
LER = 6.9 ± 0.2 nm

No significant CD change - consistent with low degree of overdose



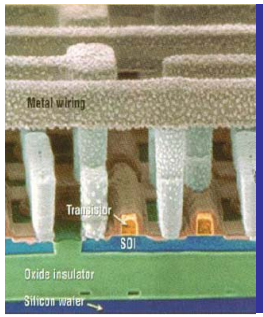
EUVL Patterned Resist – Thanks to (Jay) Jun Sung Chun and Mark Neisser @ Sematech

# Low frequency roughness reduced

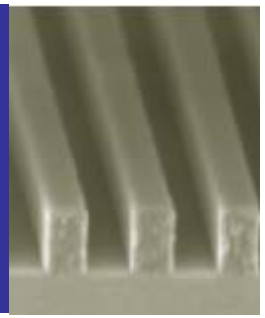


# Summary

- Graphoepitaxy DSA – PS-*b*-PLA
  - No freezing required (coated from non solvent / $T_{anneal} < T_g$ resist ✓
  - Oriented Line-spaces (lamella) < 10 nm hp ✓
  - Additives able to increase $\chi$ of PS-b-PMMA and tune morphology as well as $L_0$/pitch ✓
- Gen 1 Charge directed self assembly - Amphiphilic BCPs
  - 41 % healing give 3σ LER of 3.4 nm ✓
  - Large particle size (18 nm) ✗
- Gen 2 Charge directed self assembly - Hydrophilic BCPs
  - 34 % healing to give 3σ LER of 3.7 nm ✓
  - Good understanding of factors to optimise to improve healing ✓
  - No aggregation (particle sizes < 10 nm) – suitable for healing small features ✓




# Acknowledgements




- **PS-PLA and LER healing**
  - **Ms Ya-Mi Chuang** (concept 2)
  - **Dr Elliot Cheng**
  - **Dr Imelda Keen**
  - **Dr Anguang Yu**

    (concept 1)
  - Dr Kevin Jack (CMM)
  - Dr Michael Leeson (Intel)
  - Dr Todd Younkin (Intel)

    EUV wafers
  - Dr Jun Sung (Jay) Chun (Sematech)
  - Mark Neisser (Sematech)

    EUV wafers
  - Prof. Andrew Whittaker

- **Additives**
  - **Mr Thomas Bennett**
  - Dr Kristofer Thurecht
  - Dr Kevin Jack

- Facilities
  - CMM/AMMRF
  - ANFF-ACT
  - ANFF-Q
  - CAI
  - AIBN
- Funding
  - Discovery Projects
  - Linkage Projects
  - Future Fellowship
  - Linkage Infrastructure Equipment and Facilities

intel

Australian Government
Australian Research Council

The University of Queensland Australia

Centre for Advanced Imaging

Australian Institute for Bioengineering and Nanotechnology