EUV Resist Stochastics

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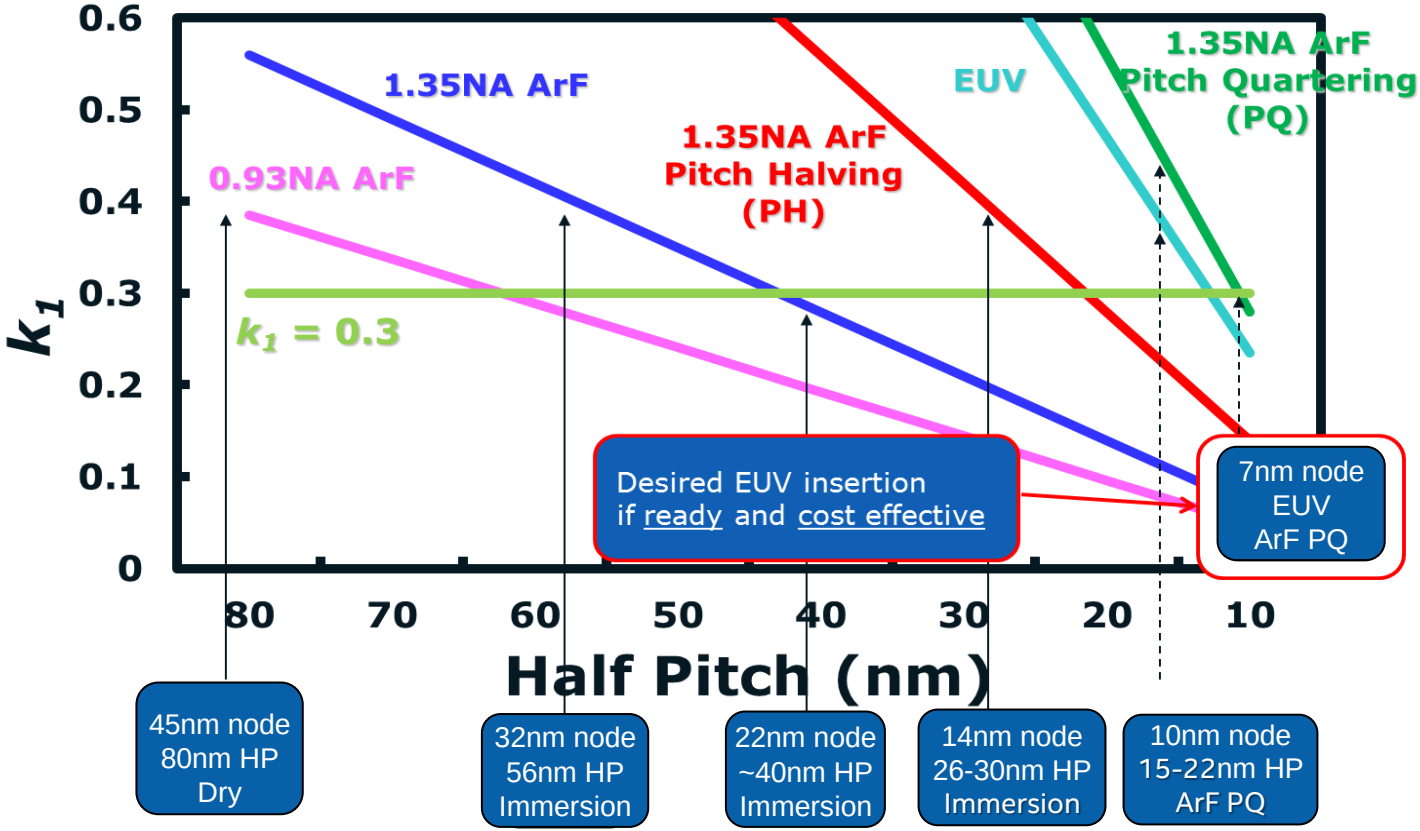
Intel Corporation

Outline

- Resists and the Path to HVM
- Edge Placement Control
- Stochastics
- Conclusions

Lithography Options for Intel Technology Nodes



Source:
Mark Phillips

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Resists and the Path to HVM

- **Patterning Requirements**
  - CDU & LWR/Edge Placement Control/Stochastics
    - The Deal Breaker
  - Stable in-FAB performance
  - Sensitivity
    - It is OK to start. Dose to target lower than 20 mJ/cm^2
  - Resolution
    - Good improvements at high dose to target, but good resolution is not sufficient
- **Quality Control**
  - Stable chemistry and shelf life
  - Defects
  - Manufacturability
  - Outgassing
- **Cost**

The Path to HVM – Resist Quality Control and Cost

- Resist Batch Scalability and Quality Control are key to EUV insertion in HVM
  - Resist Suppliers need to plan for capacity and have excursion recovery plans
  - Raw materials quality control and shelf life are critical – only chemistries that are stable can be considered for HVM
  - Metal contamination level in the resist must meet HVM SPECs
  - Resist Suppliers need to make plans for resist batch qualification

- EUV HVM implementation depends on Cost
  - Resist cost is part of EUV COO. Adequate efforts are needed to reduce resist cost as volumes increase

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This is the time to get ready!

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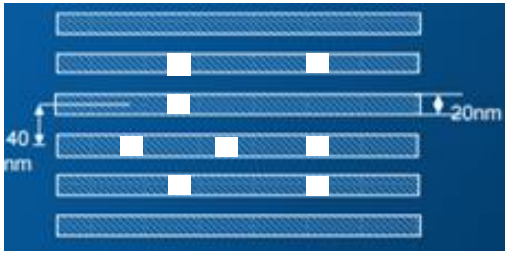
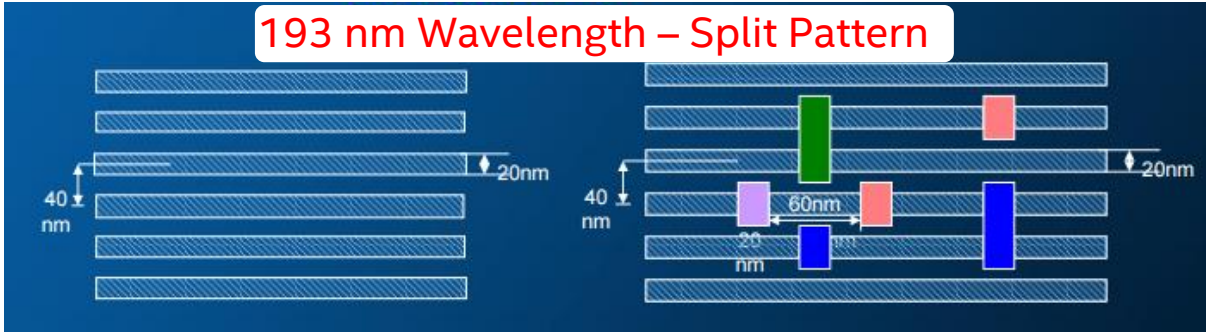
Multiple Patterning and Edge Placement Control

Desired Pattern (MT)



193 nm Wavelength – Split Pattern



1 mask + SDP

4 Cut masks

5 masks total

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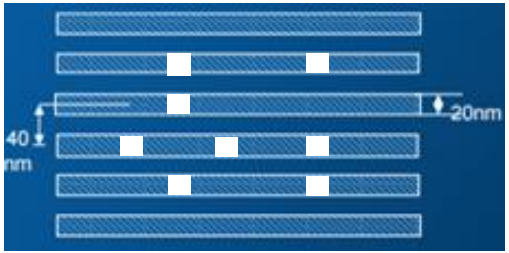

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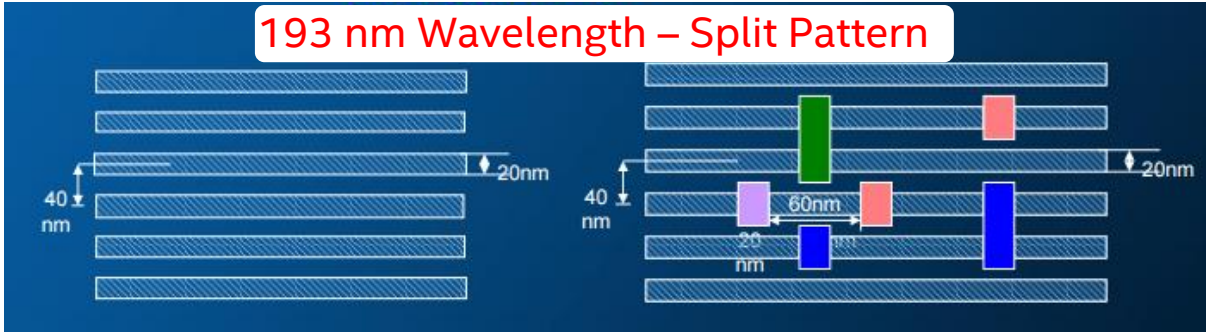

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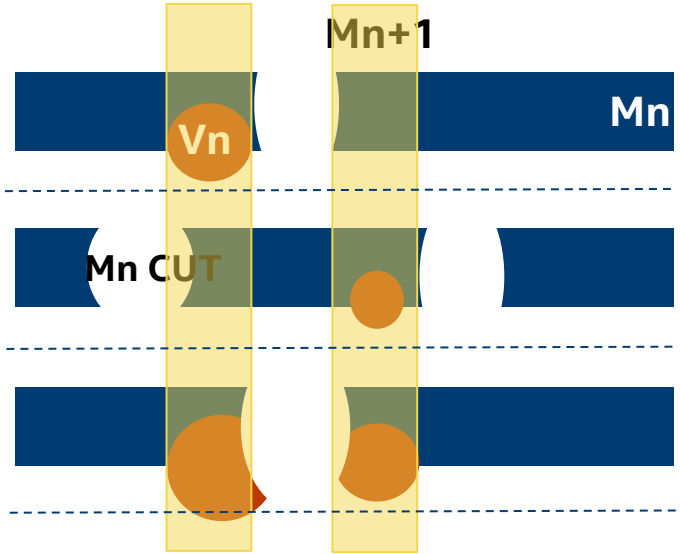
It is the improved resolution AND the need to reduce overlay and process induced variability that make EUV A NECESSITY

Edge Placement Control



- Re-combining multiple 193 masks in one EUV mask helps minimize one contribution to EPE, overlay (EPE_{OL})

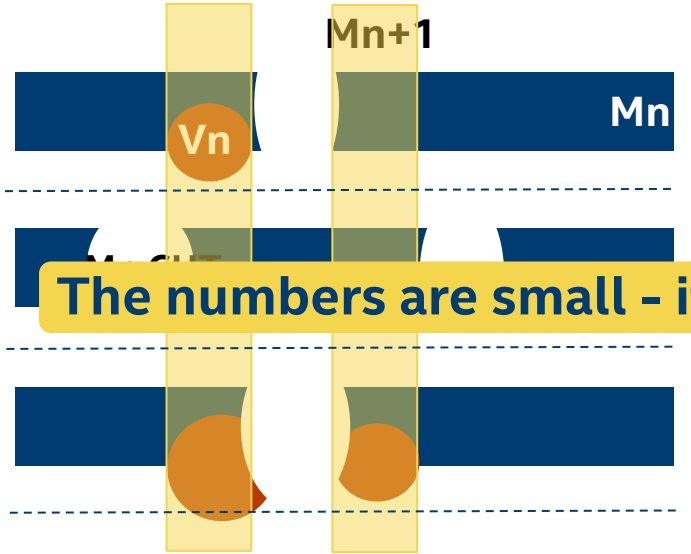
- **Sources of CD variability (CD3σ)**
  - Mask and field effects (MF)
  - Focus/Dose (Fz, Ex)
  - OPC errors (OPC)
  - Etch bias and post litho processing (EB)
  - Gratings Error (GE)
  - **Resist Stochastics (LCDU, roughness, profiles)(RS)**

For 20 nm VIAs

CD3σ(RS) ~ 3 nm

Adapted from
Yan Borodovsky, 2012
International Workshop on
EUV Lithography

Edge Placement Control



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- **Sources of CD variability (CD3σ)**

The numbers are small – it needs much more focused attention

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How difficult is it?

- Today's microprocessors have ~1.3 B transistors
- If every VIA has to work for a die to yield, for a 99% probability of the die to yield (Y) , the probability of a VIA failure (f) is

$$f \sim (1-Y)/Z$$

If number of VIAs $Z = 10^{10}$

$$f \sim E^{-12}$$

The Failure rate per VIA must be on the order of 1 part per Trillion!!!

How difficult is it? More difficult than we may think

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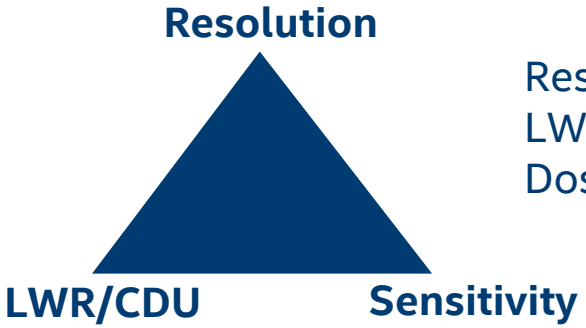
Patterning processes must be very robust
We must control variability and stochastics – Resolution is not sufficient
Dose to target needs to be reasonable

The RLS Triangle



Resolution: Smaller is better
LWR/CDU: Smaller is better
Dose: Smaller is better

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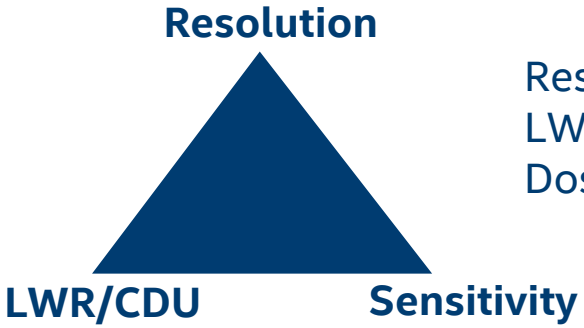

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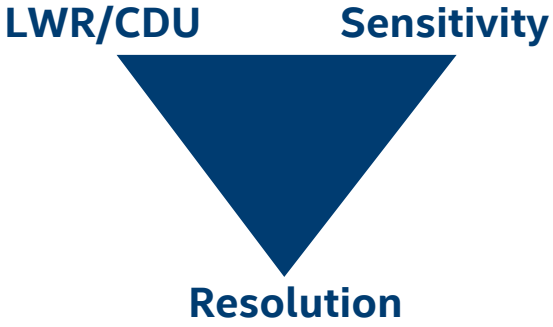
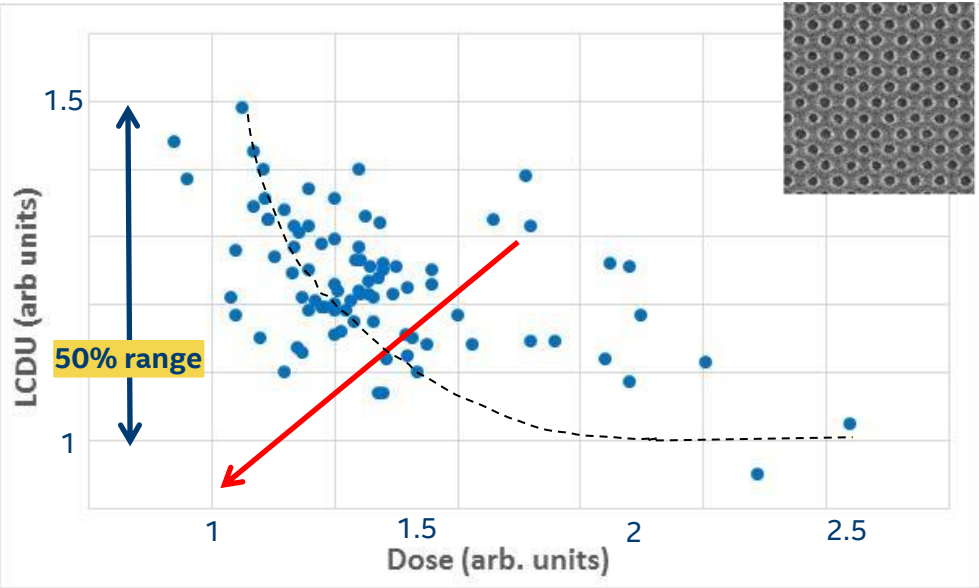


Resolution is like a single drop in the ocean without adequate variability control

CAR Resists today – LCDU for holes



Sufficiently clear evidence that LCDU depends on:

- Sensitivity/#photons

- Resist Chemistry

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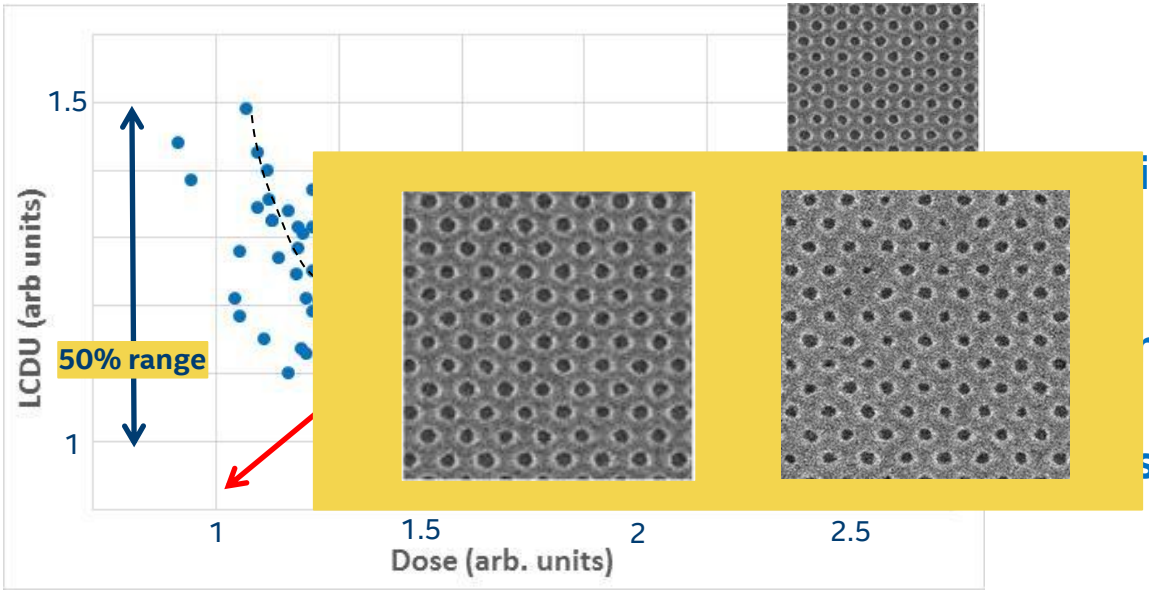

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LCDU depends on:

nsitivity/#photons

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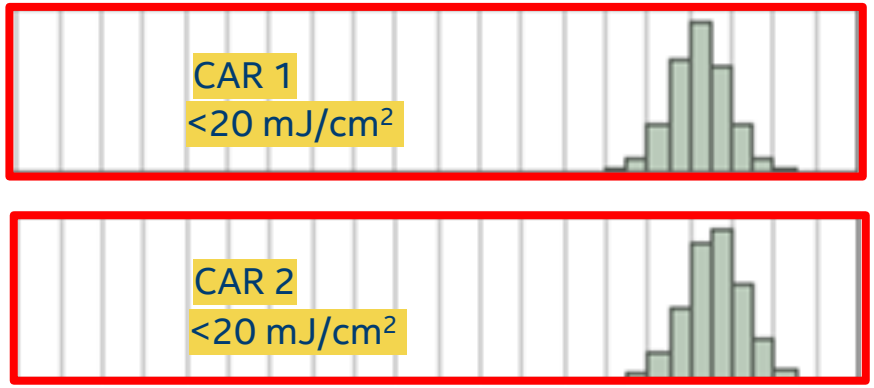
We need to <u>accelerate</u> innovation to move beyond small incremental improvements

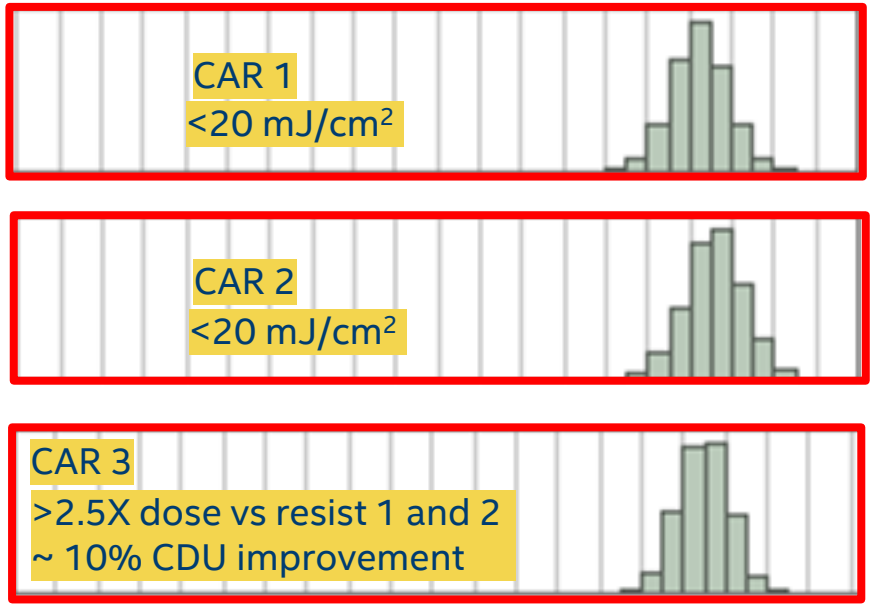
Can an increase in dose fix it all?



NXE3300, 28 nm hole

72000 measurements

Can an increase in dose fix it all? Apparently not



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Variability is high. High dose buys <10% CDU improvement
No strong evidence it is Photon Shot Noise limited

Why does the high dose resist only marginally improve CDU?
If we could use dose of 40-50 mJ/cm² today, what for?

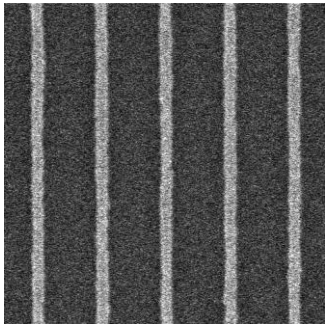
This is the Deal Breaker

Can higher EUV Absorption do it all?

Increased absorption should help … BUT, high(er) absorption does not necessarily imply higher sensitivity and better variability

NXE3100, conventional illumination – 20 nm Line

PTI <20mJ/cm^2



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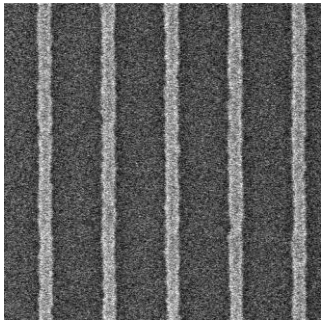

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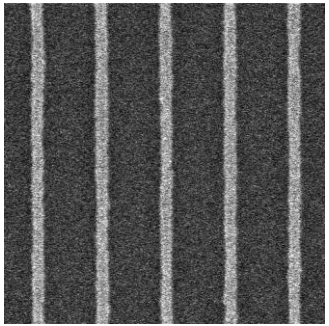

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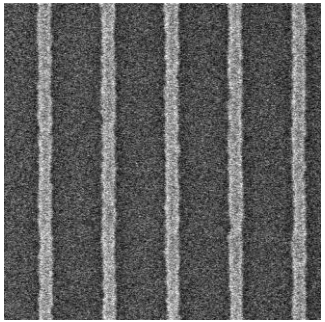
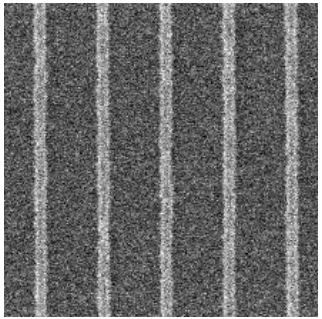
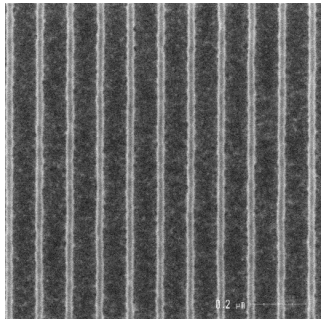


>2X absorption vs CAR
Novel1 >>30mJ/cm^2



2X absorption vs CAR
Novel2 ~30mJ/cm^2



Are an amplification mechanism and/or more efficient reactions needed to realize the benefits of higher absorbance in novel resists? Are there competing reactions within the resist?

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Resist Stochastics

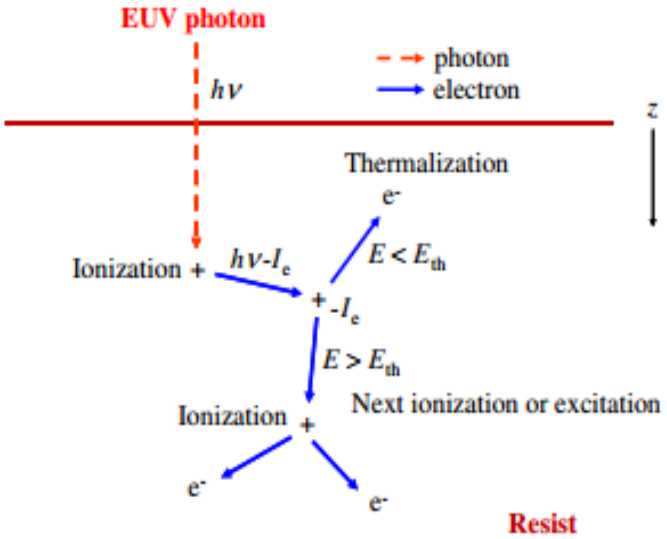
- **Traditional CAR**
  - Photons
  - Electrons
  - Absorption
  - Acid
  - PAG
  - Quencher
  - Protecting groups
  - Development process
  - etc

- **Novel Chemistries**
  - Photons
  - Electrons
  - Absorption
  - Environment
  - Shelf Life components
  - ?
  - ?

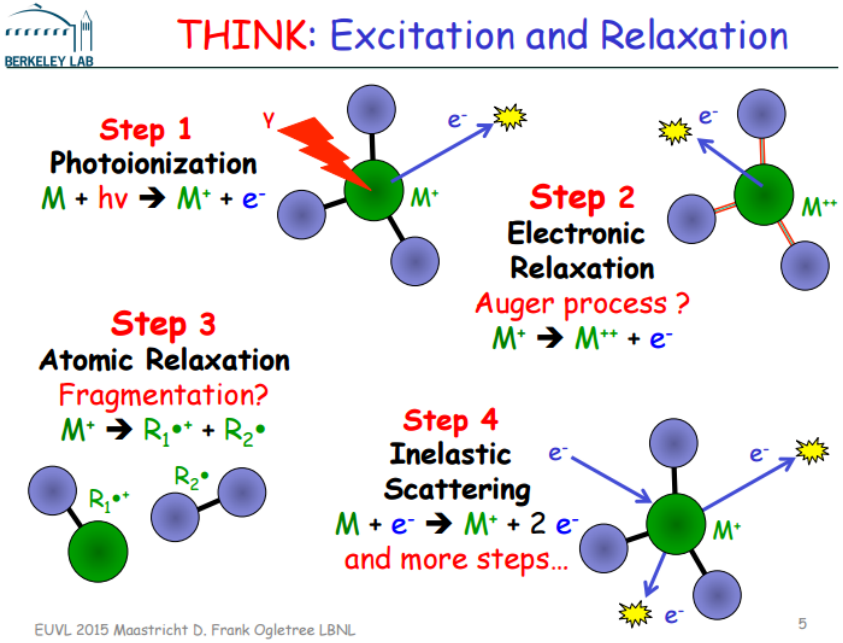
Do we understand the interaction of EUV radiation with resists, CAR and/or novel?

Probably not, but we have to

EUV Chemistry

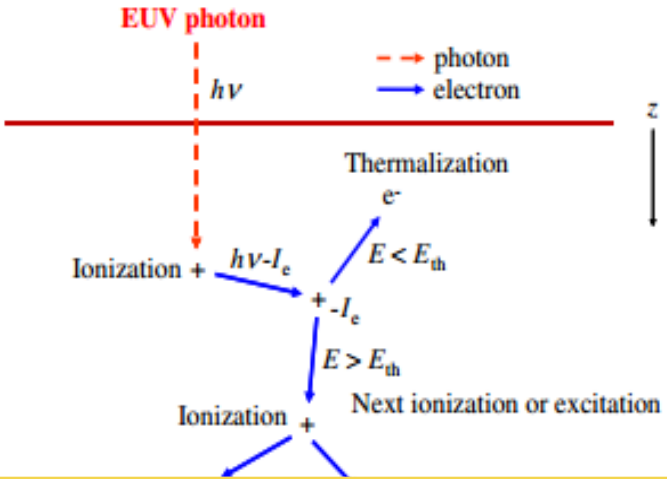


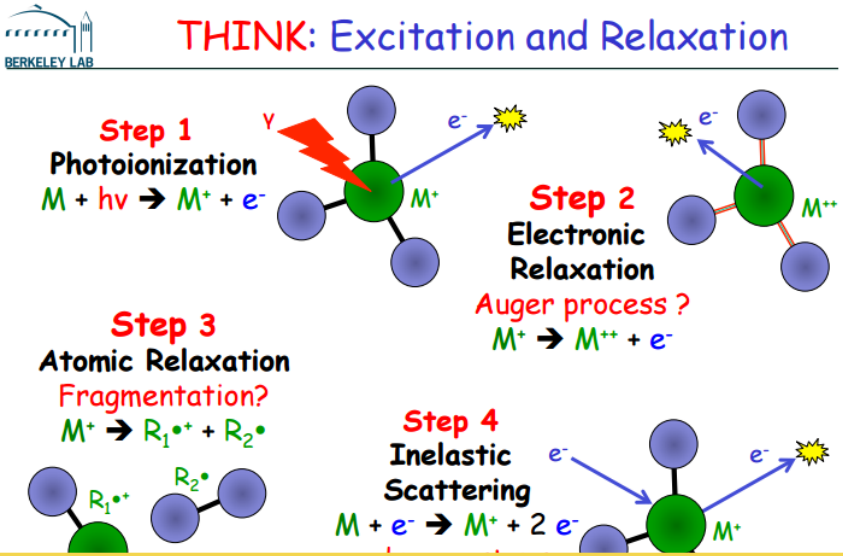
T Kozawa and S Tagawa , Jnp. J. Appl. Phys, 2010



F. Ogletree, EUVLS'15 (Maastricht)

EUV Chemistry





How do we know all electron generation paths? How do we know what chemistry can/do these electrons do? Not just a question of how many electrons are generated – but rather how to do the right chemistry with them

<u>We need active collaborations between spectroscopists and resist chemists and to pursue answers to these questions</u>

EUV Stochastics

#Photons/nm² for 15 mJ/cm²

193	EUV
145	10

#Photons/nm² for 40 mJ/cm²

193	EUV
388	27

CAR Resist	30 nm Hole	24 nm Hole
Area	700 nm^2	450 nm^2
Volume	21000 nm^3	13500 nm^3
Dose	**15 mJ/cm^2**	**15 mJ/cm^2**
Incident photons	7200	4500
Absorption	**5/μm**	**5/μm**
Absorbed photons open frame	1000	640
Absorbed photons	**710**	**460**
Number PAG * (0.15/nm^3)	3200	2040
Quencher/PAG 0.2	**640**	**410**
7σ Q variation	28%	35%

*P/Q concen. from Biafore et al, SPIE8325

Resist statistics can dominate over Photon statistics

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What about the high dose resist? Photon shot noise should improve
Is resist stochastics still largely dominating variability?
How does the quencher interact with electrons?

We need to build ANY resist with stochastics in mind

*P/Q concen. from Biafore et al, SPIE8325

Resist statistics can dominate over Photon statistics

Summary and Conclusions

- **Variability is the Deal Breaker. The power is held by the resist chemistry**
  Today high variability is seen with current resists at moderate dose as well as high dose
- Can current resists take us into the **future**? Current evidence suggests no. We must innovate
- Increase in **absorption** should improve sensitivity and reduce photon shot noise **if** the chemistry is right and understood – dose to target needs to be in control, resists need to be compared at similar dose to target
- Use **Spectroscopy and modeling** to determine what happens in the resist
  - Understand reaction paths in current CAR and novel resists
- Design resists with **stochastics** in mind from the start
- Don't forget about **developers** for both current resists and future chemistries
  - Developer material and process can have a large impact and should be considered

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Think Stochastics first!

The Failure rate per VIA must be on the order of 1 part per Trillion

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Acknowledgements

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Thank – you very much for your attention!


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