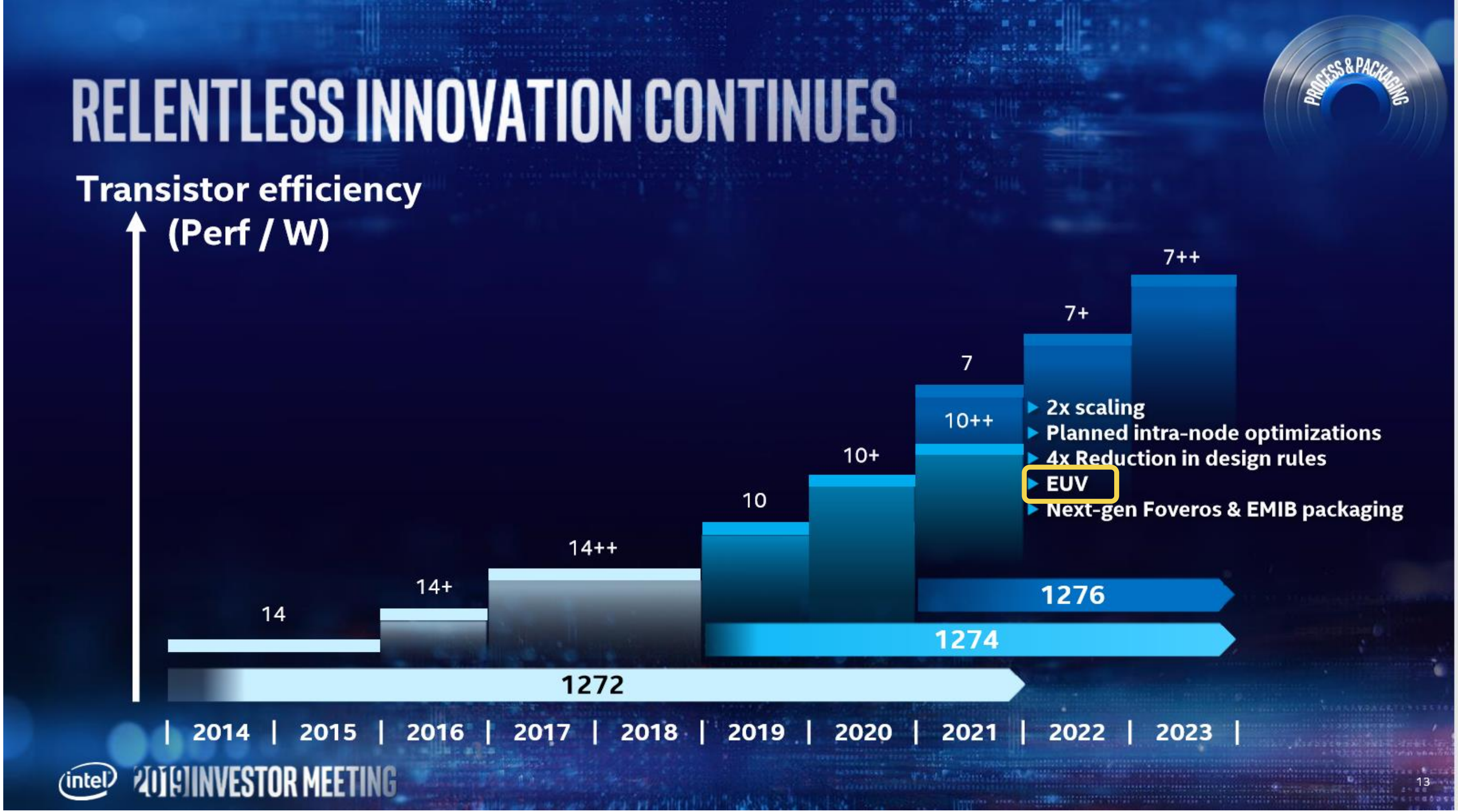
EUV Resists: Can we move fast and light?

Anna Lio
Intel Corporation

Outline

- Intro
- A historical perspective
- EUV photoresists status and progress
- A new paradigm for the future
- Conclusions


RELENTLESS INNOVATION CONTINUES
PROCESS & PACKAGING
Transistor efficiency
(Perf / W)
14
14+
14++
10
10+
7
10++
7+
7++
2x scaling
Planned intra-node optimizations
4x Reduction in design rules
EUV
Next-gen Foveros & EMIB packaging
1276
1274
1272
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2019 INVESTOR MEETING
13

EUV technology extended for both 0.33NA and 0.55NA
Supporting applications beyond the next decade

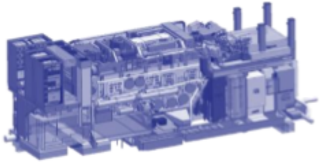
ASML
Public
Slide 4
SPIE 2019

EUV 0.33 NA

EUV 0.33 platform will be extended to provide state of the art overlay and node to node productivity improvements

	2016	2017	2018	2019	2020	2021	2022	2023	...2025
EUV 0.33 NA 13nm	**NXE:3350B** 4.0 | 125wph	**NXE:3400B** 3.0nm | 125wph		**Overlay** 2.5nm / **TPut**[1] 155	**NXE:3400C** 2.5nm | 170wph		**NXE Next** <2.5nm | ≥ 185wph		
0.55 NA 8nm									**EXE:5000** 1.7nm | 185wph

Product
On-Product Overlay | Throughput



EUV 0.55 NA

High NA introduction at 3nm

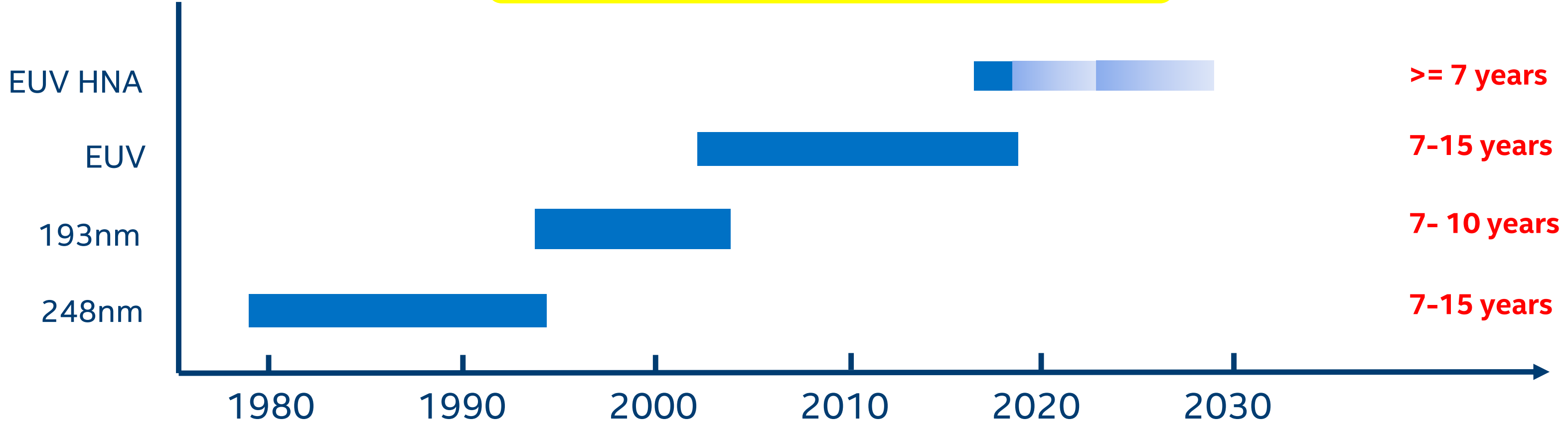
[1] TPut: Throughput upgrade (WpH)

Public

SPIE AL'19 – "High NA EUV Lithography", J. Van Schoot et al

A Historical Perspective on Photoresist Development

What does this tell us?



Significant advances in photoresist have required 7+ years
Continuous improvements continue long after that

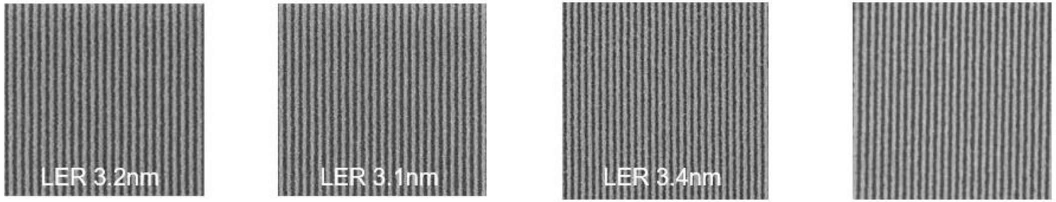
When existing formulations are extendable, the timeline is shorter

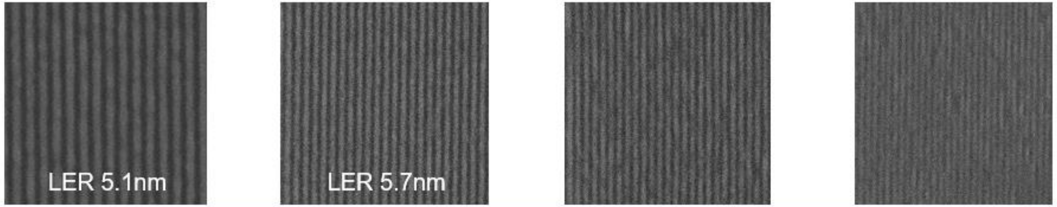
When novel materials are required, the timeline is significantly longer

EUV Photoresist Resolution – Synchrotron

PAUL SCHERRER INSTITUT PSI | ASML

Highlights of the Resist Screening Program 2017-2018





Resolution [HP]	13nm	12nm	11nm	10nm
Inorganic resist	LER 3.2nm	LER 3.1nm	LER 3.4nm	
Dose (mJ/cm^2)	67	67	77	67
CAR resist	LER 5.1nm	LER 5.7nm		
Dose (mJ/cm^2)	43	55	57	Collapse Limited 71

SPIE AL'19 Progress in EUV resists towards high-NA EUV lithography, Xiaolong Wang et al.

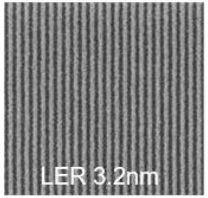
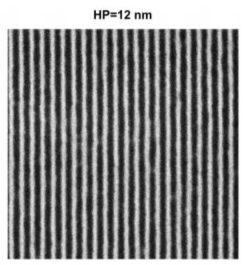
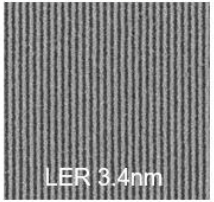
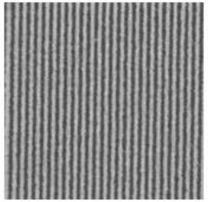
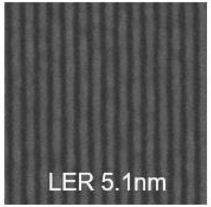
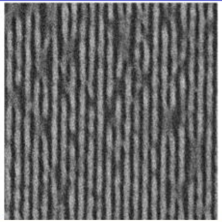
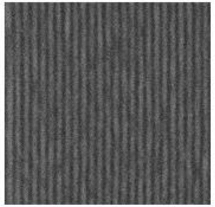
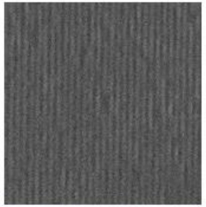
Slide 9

EUV Photoresist Resolution – Synchrotron

PAUL SCHERRER INSTITUT PSI — ASML

Highlights of the Resist Screening Program 2017-2018

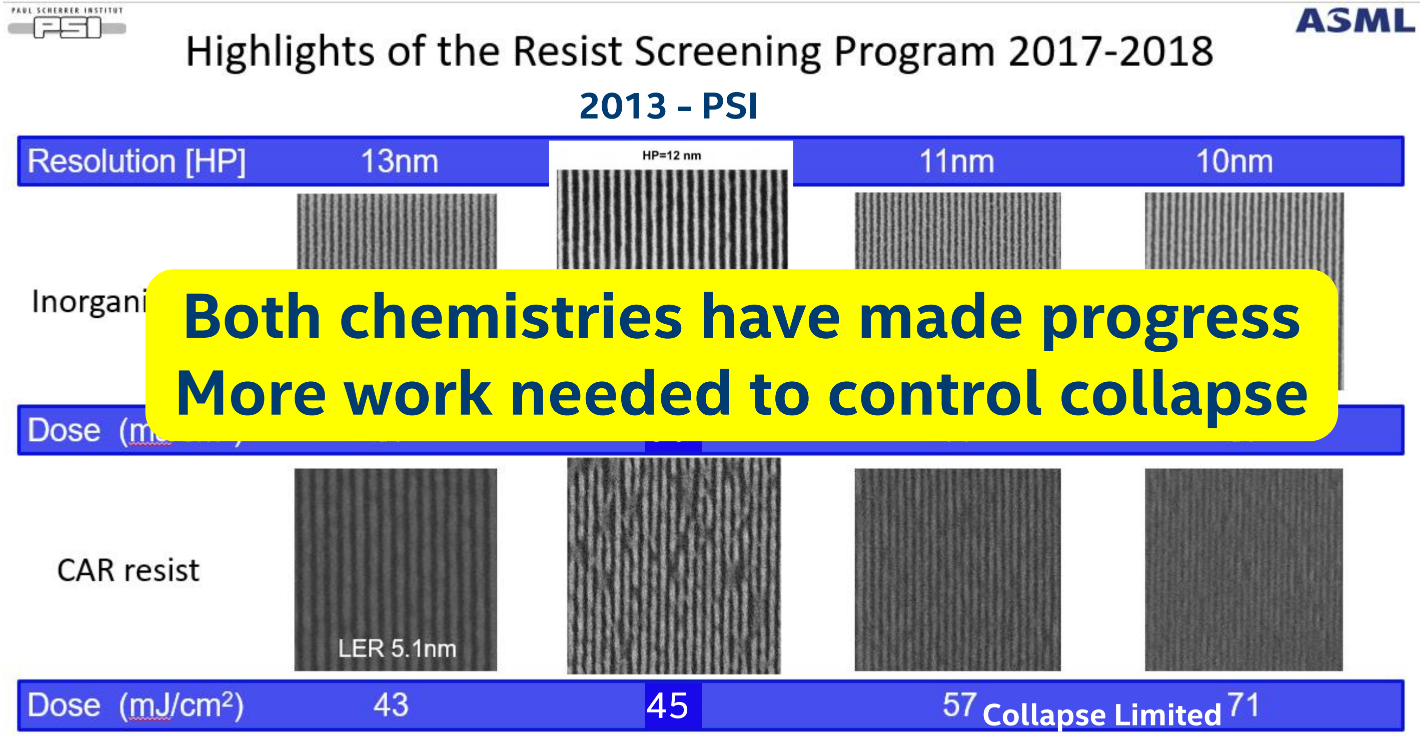
2013 - PSI

Resolution [HP]	13nm		11nm	10nm
Inorganic resist				
Dose (mJ/cm²)	67	80	77	67
CAR resist				
Dose (mJ/cm²)	43	45	57 **Collapse Limited**	71

SPIE AL'19 Progress in EUV resists towards high-NA EUV lithography, Xiaolong Wang et al.

Slide 9

EUV Photoresist Resolution – Synchrotron



SPIE AL'19 Progress in EUV resists towards high-NA EUV lithography, Xiaolong Wang et al.

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EUV Photoresist Resolution – Synchrotron

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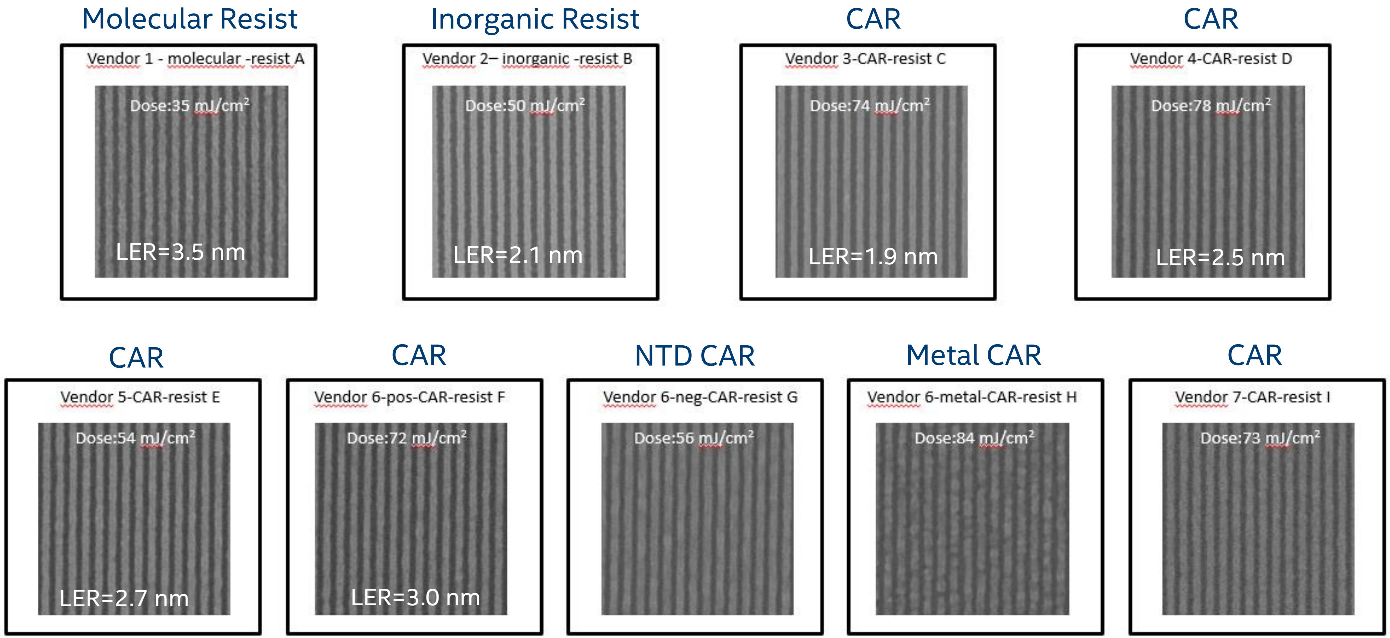
Tested EUV resist results for HP16 nm



SPIE AL'19 Progress in EUV resists towards high-NA EUV lithography, Xiaolong Wang et al.

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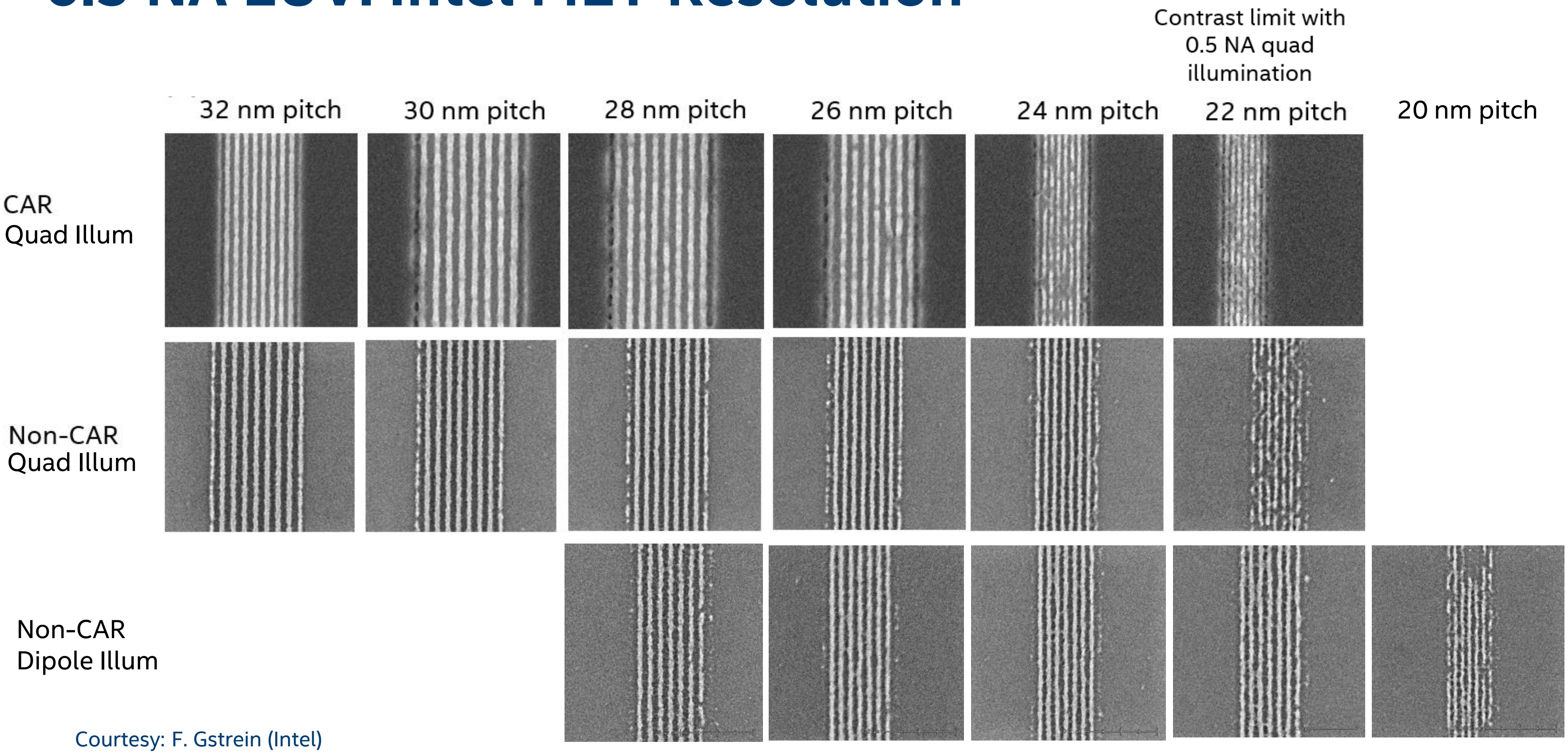
0.5 NA EUV: Intel MET Resolution

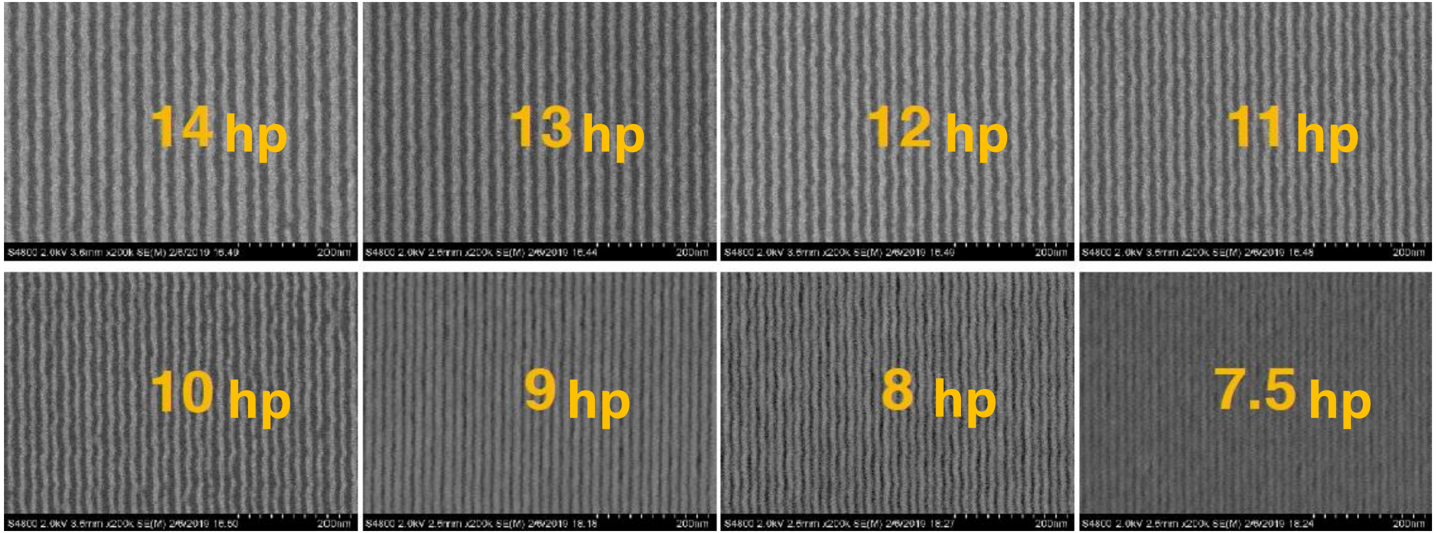


Courtesy: F. Gstrein (Intel)

0.5 NA EUV: BMET Resolution

Substrate	Si
Resist	Inpria YATU series MOx
Thickness	20 nm
Spin Speed	1500 RPM 45 sec
Post Application Bake	100 C / 120 sec
Post Exposure Bake	170 C / 120 sec
Hard Bake	200 C / 300 sec

Inpria MOx

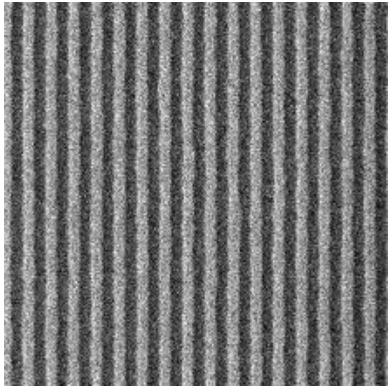


SPIE AL'19 - Overview and status of the 0.5NA EUV microfield exposure tool at Berkeley Lab, C. Anderson et al

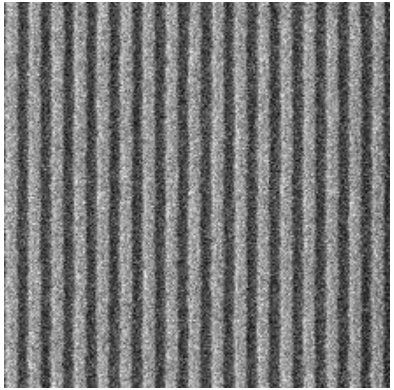
EUV Photoresist – CAR vs MOx

Intel NXE3400, 0.33 NA, P32 L/S

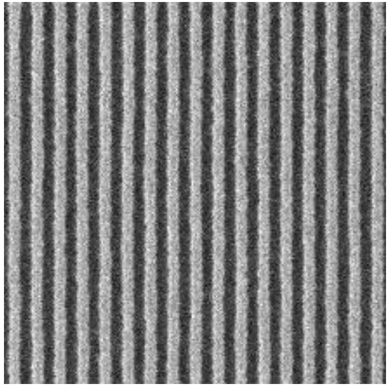
CAR1, Abs=ref
Dose=ref



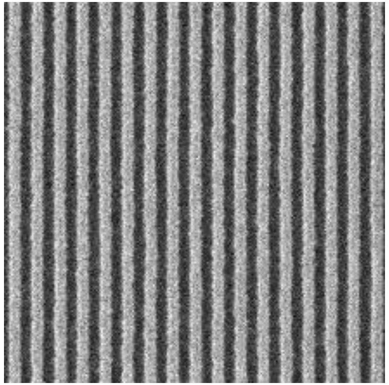
CAR2, Abs=ref
Dose ~1.5X ref



MOx1, Abs>>ref
Dose~1.5X ref



MOx2, Abs>> ref
Dose~2X ref



EUV Photoresist – CAR vs MOx

Intel NXE3400, 0.33 NA, P32 L/S

CAR1, Abs=ref
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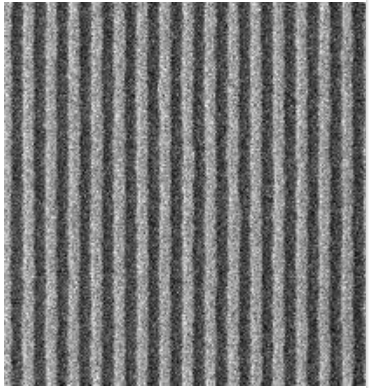
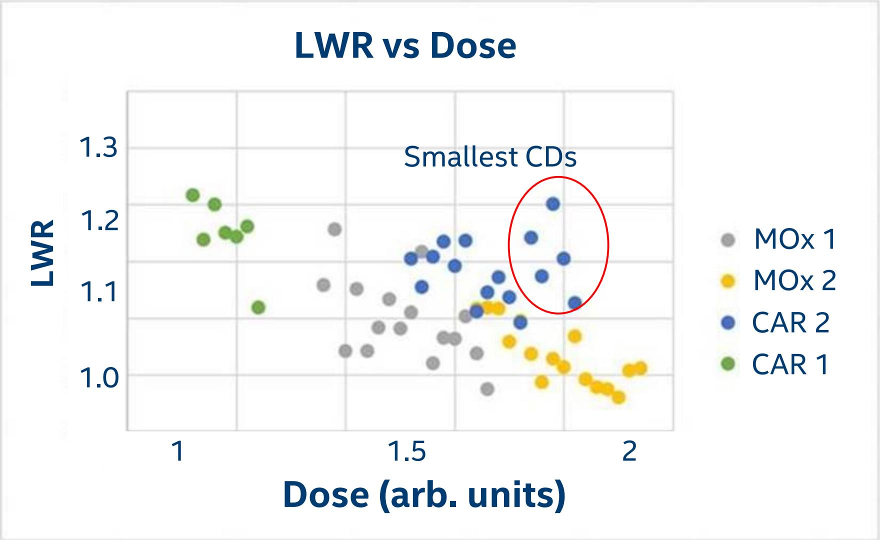
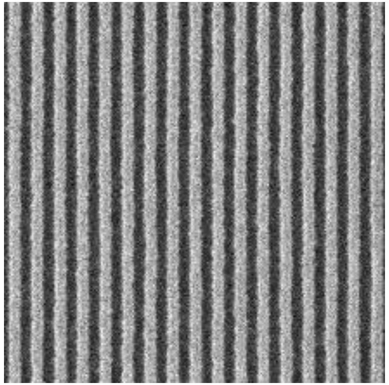




MOx2, Abs>> ref
Dose~2X ref

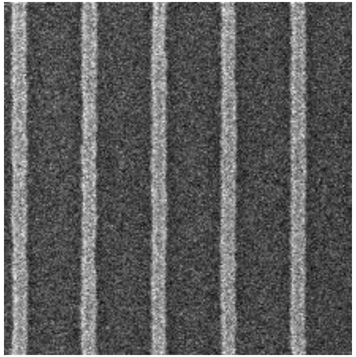


LWR trends with dose in a similar way for both, even though MOx 1 and 2 have much higher absorption
What we need from new chemistries is a differentiation in RLS

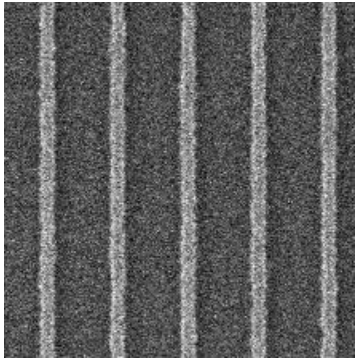
EUV Photoresist – Beyond 1:1 L/S

Intel NXE3400, 0.33 NA, conventional illumination – 20 nm Line (1:5)

PCAR <20mJ/cm²
LWR= ref



High absorption
MOx >40 mJ/cm²
LWR=1.2 ref



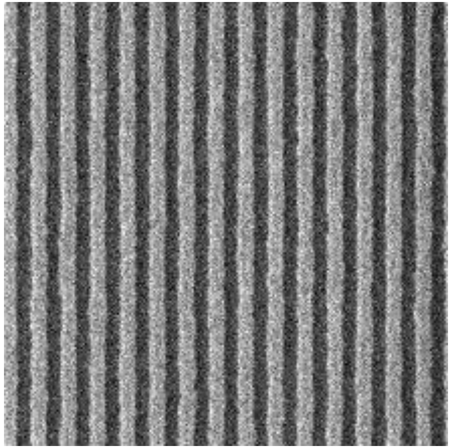
MOx
High Absorption √
>2X Dose – X
Higher LWR – X

MOx: High absorption, much higher dose, higher LWR
High resolution is not enough
Tunability to print different patterns is important
Increase in absorption needs to be combined with chemistry advances

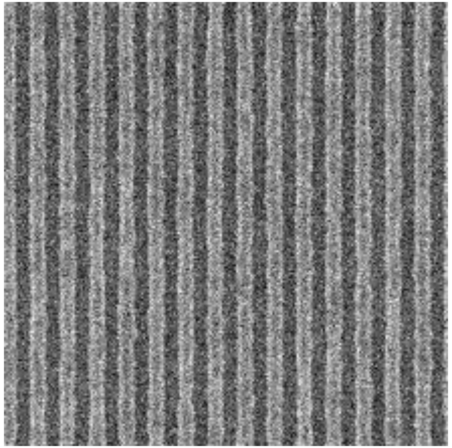
EUV Photoresist – Adding Secondary Electrons

Intel NXE3400, 0.33 NA, P36 L/S , CAR

Ref



Special Substrate

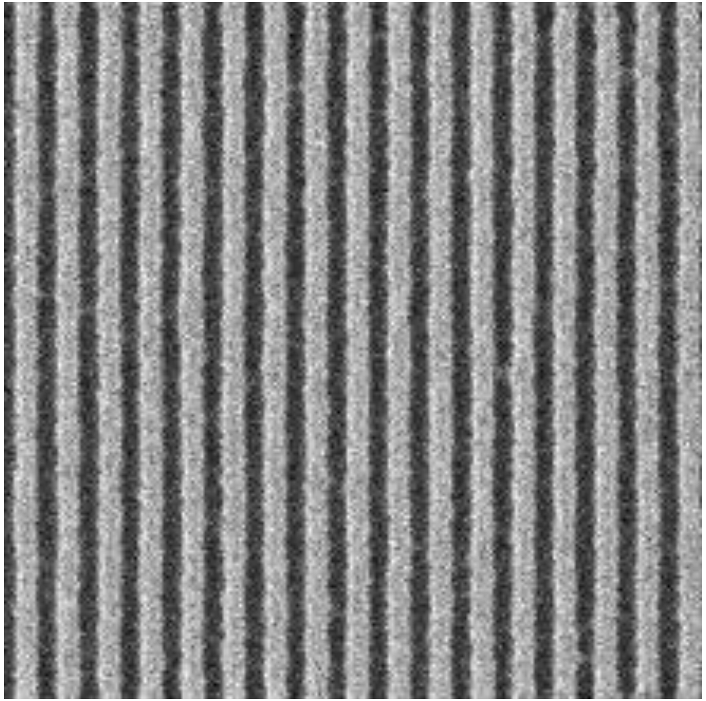


1.2X Ref Dose
1.2X Ref LWR

Adding secondary electrons can degrade resist performance – the extra electrons can increase the noise instead of the signal if the resist cannot use them

EUV Photoresist - Failures

Intel NXE3400, 0.33 NA, P32 L/S , non-CAR

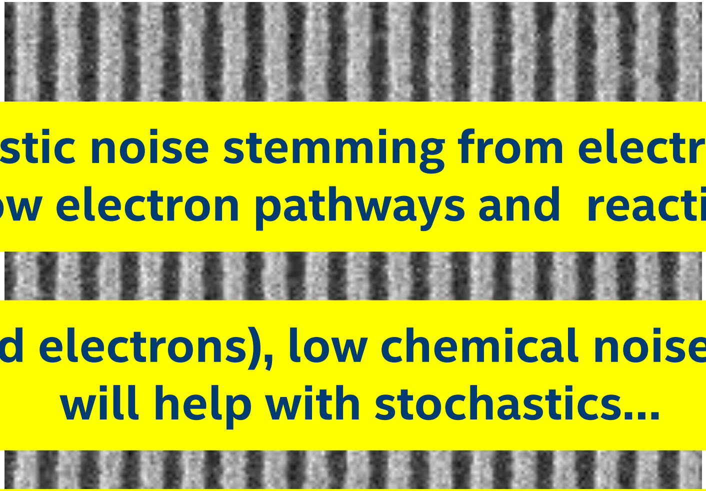


Microbridging at 70 mJ

EUV Photoresist - Failures

Intel NXE3400, 0.33 NA, P32 L/S , non-CAR

Microbridging at 70 mJ

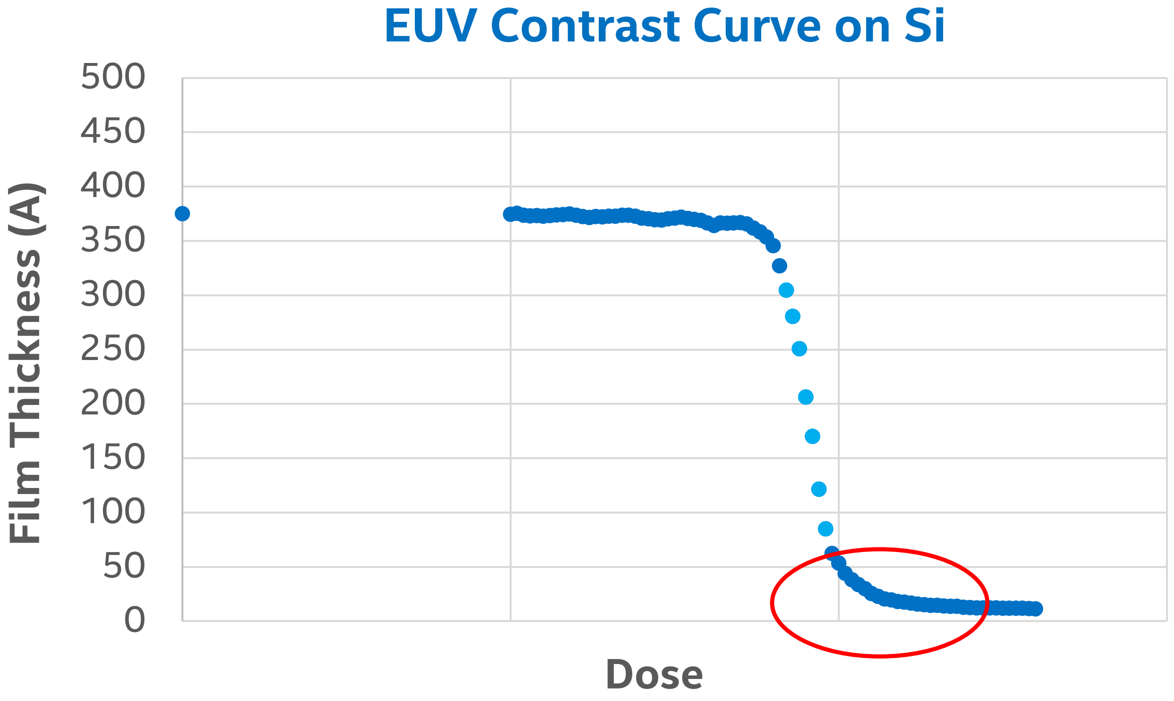


Is stochastic noise stemming from electron noise?
We need to know electron pathways and reactions in the resist

More photons (and electrons), low chemical noise resist chemistries will help with stochastics…

…but not until we understand how to control electron noise by designing resists that use all or most electrons for useful chemistry – for any resist

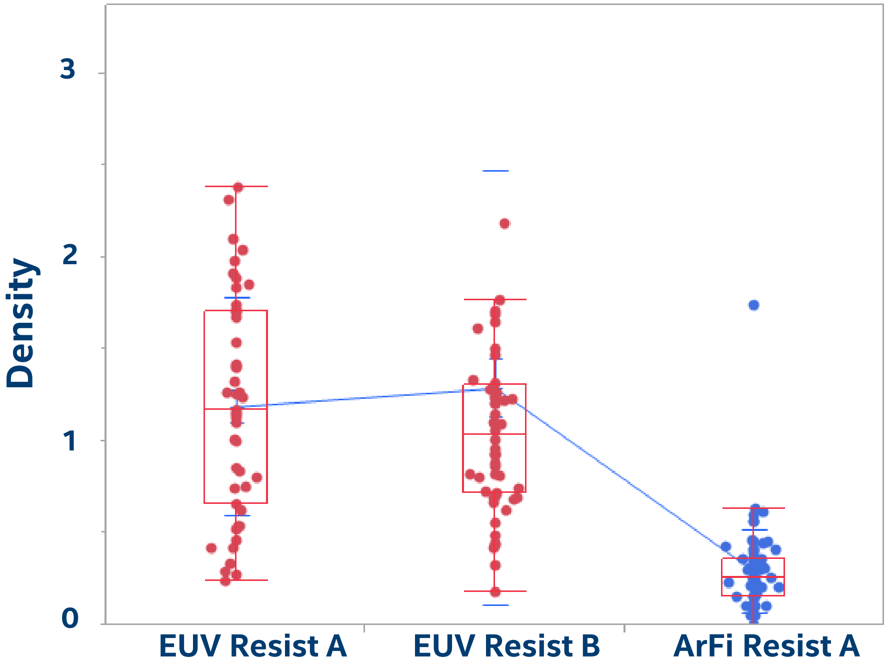
EUV Photoresist - Dissolution and Interface Effects



We need to understand and eliminate these effects because they affect resolution and stochastics control

In general, more work and focus are needed to improve the dissolution process. This is one area that can provide significant improvements

EUV Photoresist – Defects



Significant improvement still needed to match immersion resists

EUV Photoresist – Where Do We Go From Here?

Highlights

- Progress in both L/S and Hole resolution at a rate almost comparable to previous technologies
- Since SPIE AL'16, EUV community has increased focus on stochastics and speak a new common language
- Intensive wafer based metrology for assessment of stochastics failures is widely used
- A few new resist chemistries have been proposed in the past 5 years
- 0.5 NA MET tools are operational

Lowlights

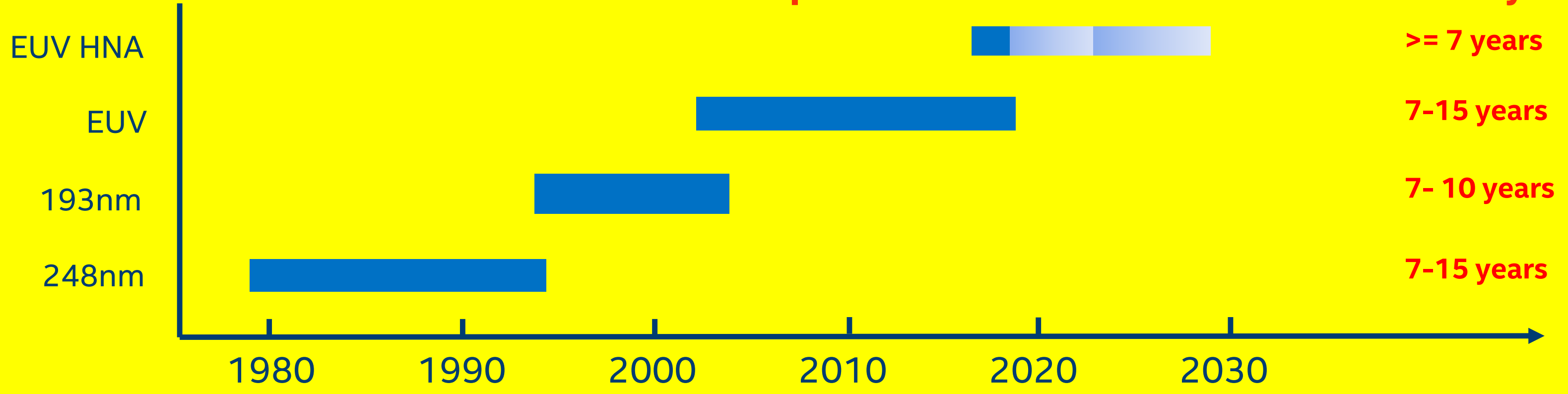
- The rate of photoresist development does not match EUV roadmaps and goals
  Wafer based information turns alone are slow for making adequate progress
- Too small a progress in understanding EUV radiation chemistry and the role of electrons in particular
- New chemistries are needed and tunability to print a variety of features needs to be demonstrated
- Resist chemistries are currently inefficient in their use of photons and overall stochastics control

EUV Photoresist – Where Do We Go From Here?

Highlights

- Progress in both L/S and Hole resolution at a rate almost comparable to previous technologies
- Since SPIE AL'16, EUV community has increased focus on stochastics and speak a new common language

Unless we move faster and can further optimize current resists we are already late



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Moving Faster - Lessons from Fast and Light Alpinism

- In the mountains speed is safety: moving fast means spending less time exposed to the risks of being in the mountains
- A pack that is too heavy can be the difference between succeeding and failing, because being too slow is not an option
- To climb fast and light one has to rely on skills and experience acquired over time
- Reducing the weight to carry means careful planning and execution so that safety remains paramount


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Photoresist Development – Can We Lighten Up Our Pack?

- **Do we have what it takes?**
  YES
  Photoresist community (industry, academia, National Labs) has acquired strong expertise and experience over the last 30+ years

- **What would allow us to lighten up our pack and move faster?**
  Achieving fundamental understanding, via measurements and modeling, of what goes on inside the resist – wafer based learning is not sufficient and too slow. Planning and execution have to help mitigate risks

- **How to sustain a faster pace in the long run?**
  -Fundamental understanding has to guide further improvement of current chemistries and development of new chemistries
  -Fundamental studies and new resist development have to be a priority for academia, national labs, commercial partners and government, including funding agencies
  -Any concern for contamination to the tool from a new chemistry should be quickly assessed and a path forward identified – we can't let this slow us down

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  Achieving funda … ling, of what goes on inside the re… ow. Planning and execution have …

YES and we can do so long term,
but it takes planning
We can't slip

- **How to sustain a…**
  -Fundamental understanding has to guide further improvement of current chemistries and development of new chemistries
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Photoresist Development – Fundamentals

Enhance and measure photon absorption in the resist

Count electrons generated in the film

Electron energy spectrum

Measure electron and chemical blur

How many more *electrons can be* generated?

How many electrons is the resist using for good chemistry?

How many more electrons can the resist use for good chemistry?

What are the reactions occurring in the resist?

What else matters?

Are there good and bad ways to increase absorption?

Are all electrons created equal?

What should the resist look like to use these electrons?

What reactions occur in the resist?
Are there competing reactions? Can they be suppressed?

Photoresist Development – Fundamentals

Enhance and measure photon absorption in the resist

Count electrons generated in the film

Electron energy spectrum

Measure electron and chemical blur

Every photon has to count to improve stochastics and control noise

ters?

can be generated?

How many electrons is the resist using for good chemistry?

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Conclusions

- EUV is in HVM. Roadmaps extend well into the future with High NA Photoresist is central to current and future EUVL success

- Today's resists should be further optimized to bridge the gap with High NA. No chemistry today can support the full range of applications planned for EUVL long term – <u>New Chemistries</u> are needed for long term EUV success. They need to be tunable and provide stochastic control

- Photoresist development needs to be "Fast and Light" to keep us on track and accelerate the rate of improvement beyond historical trends. This can be achieved by focusing on Fundamentals, using our collective knowledge and expertise, careful planning to control risk

- This needs support from <u>everyone</u> – academia, government and industry- including adequate funding

One can have the best gear in the world and be fit and strong, but without a plan as to how the day's going to pan out, that is all worthless

(Matt Helliker)

Acknowledgements

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Thank – you very much for your attention!

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