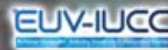
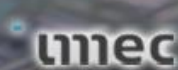


2023 EUVL WORKSHOP & SUPPLIER SHOWCASE

JUNE 3RD - 7TH, 2023
HELD IN-PERSON AT IMEC



WWW.EUVLITHO.COM



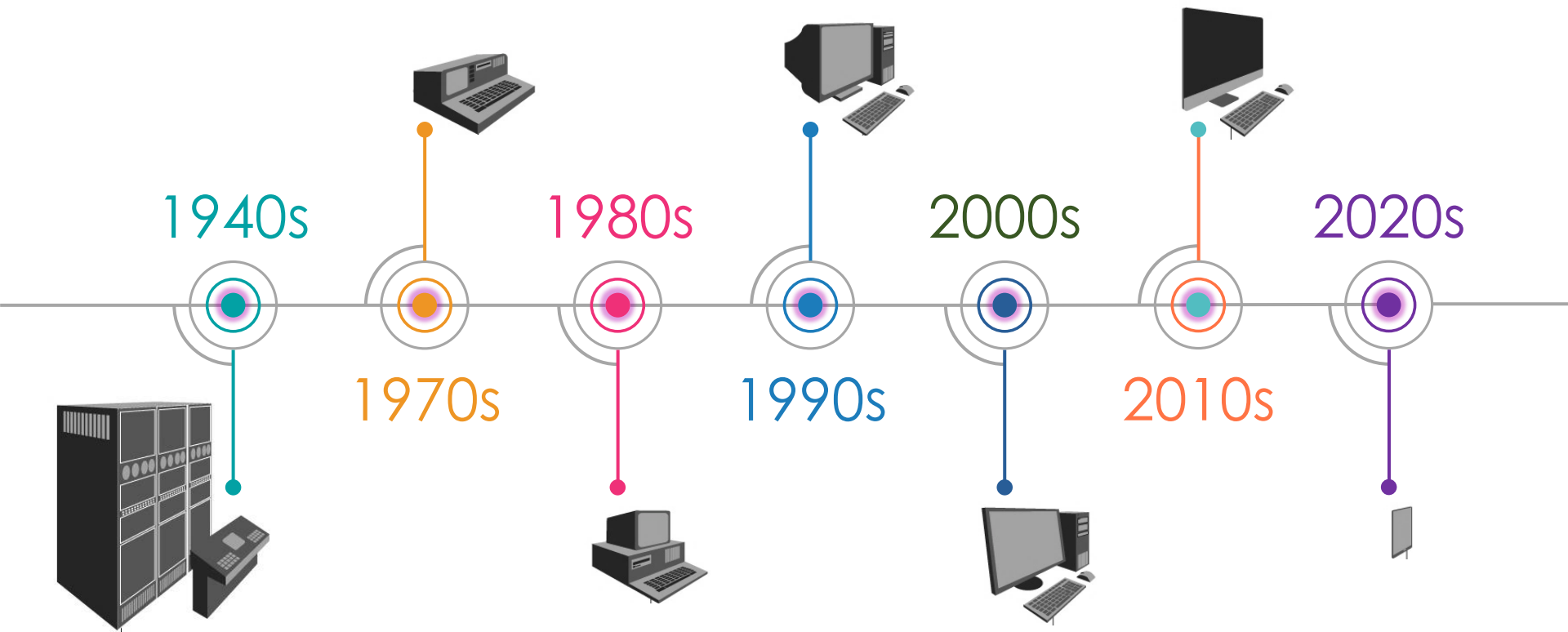
imec

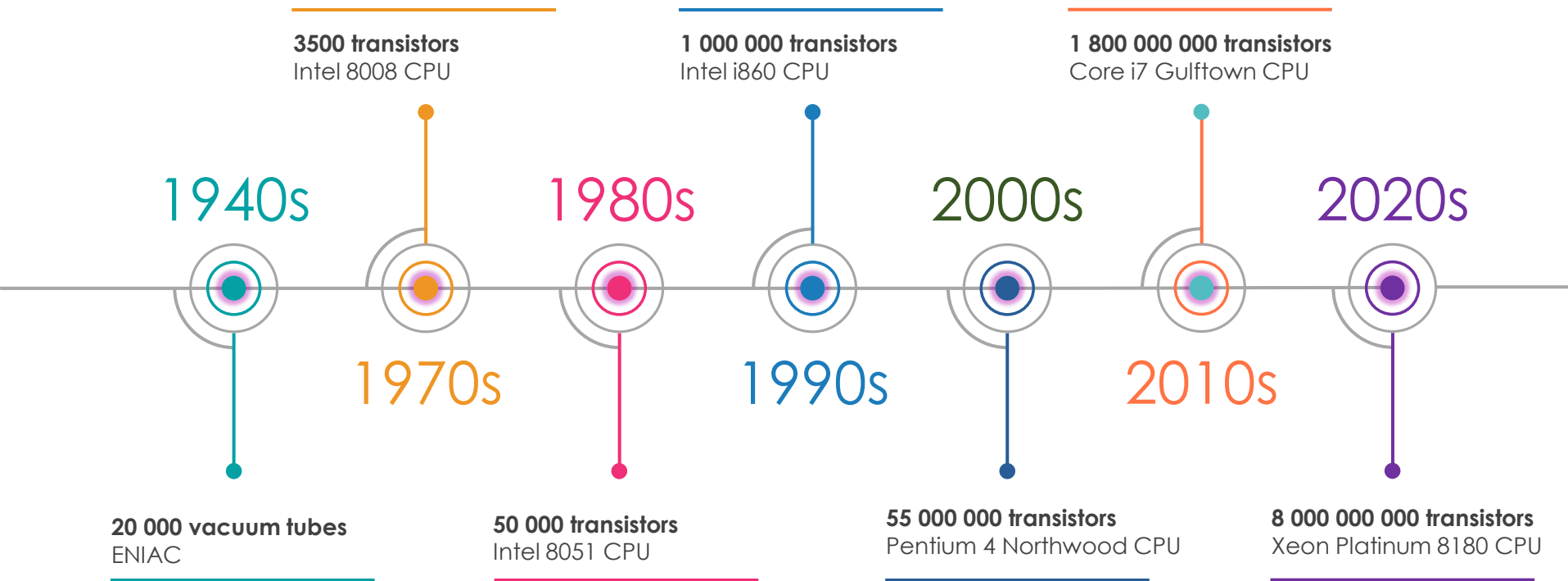
EUV lithography patterning towards device nano scaling

Danilo De Simone

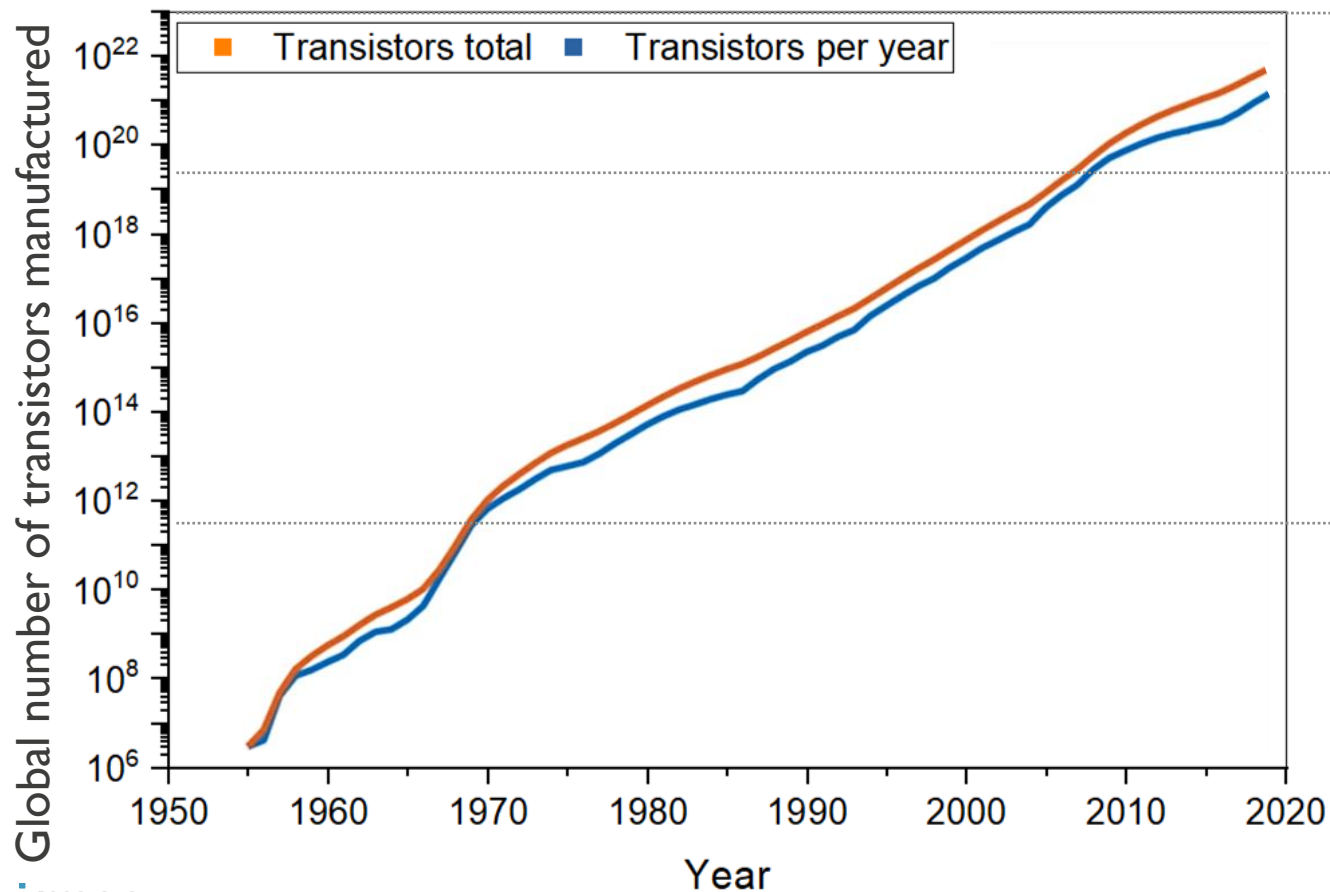
June 6, 2023

Introduction: Moore's Law





Moore's Law: The number of transistors on microchips doubles every two years



?

Number of rice grains
on a chess board



Number of stars in the Milky Way



Number of stars in the observable universe ($\sim 10^{23}$)

The image is a composite of various astronomical elements. In the center, a bright yellow star with a prominent lens flare shines. Surrounding it are several planets: a large gas giant with orange and white bands (Jupiter), a ringed planet (Saturn), a blue planet (Neptune), a small red planet (Mars), and the Earth. The background is a deep black space filled with numerous stars of different colors (blue, white, red, orange) and sizes. At the very edges, a complex web of galaxies and intergalactic matter is visible, representing the large-scale structure of the universe.

Lithography and device scaling

Lithography

Si wafer + Transfer layer

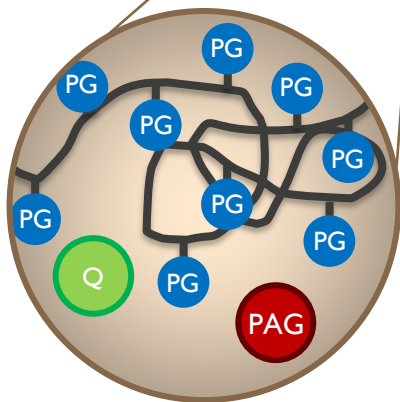
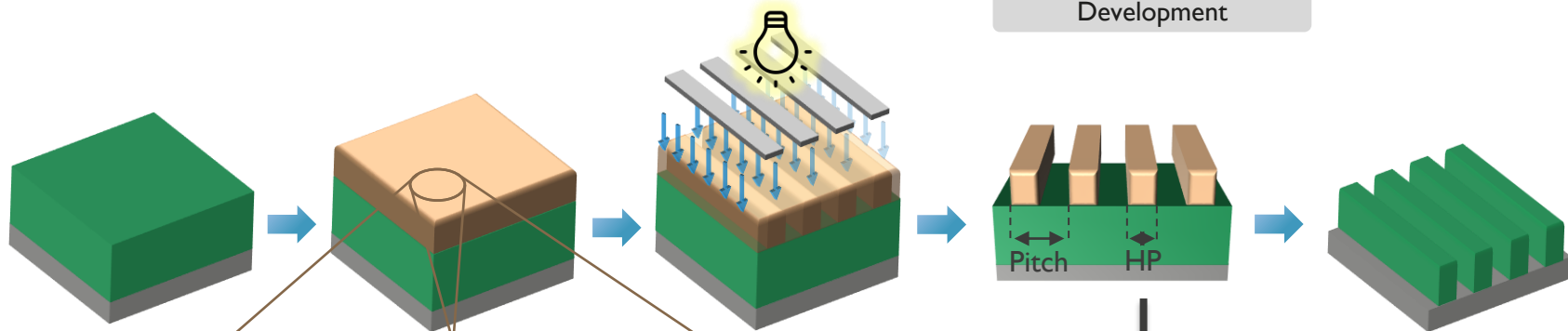
Apply resist

Image transfer

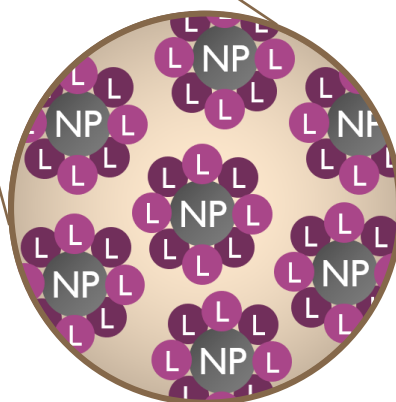
Post-exposure bake

Transfer

Development



Chemically amplified resist



Metal-oxide resist

$$R = k_1 \frac{\lambda}{NA}$$

λ → wavelength
 k_1 → constant
 NA → numerical aperture



Resist



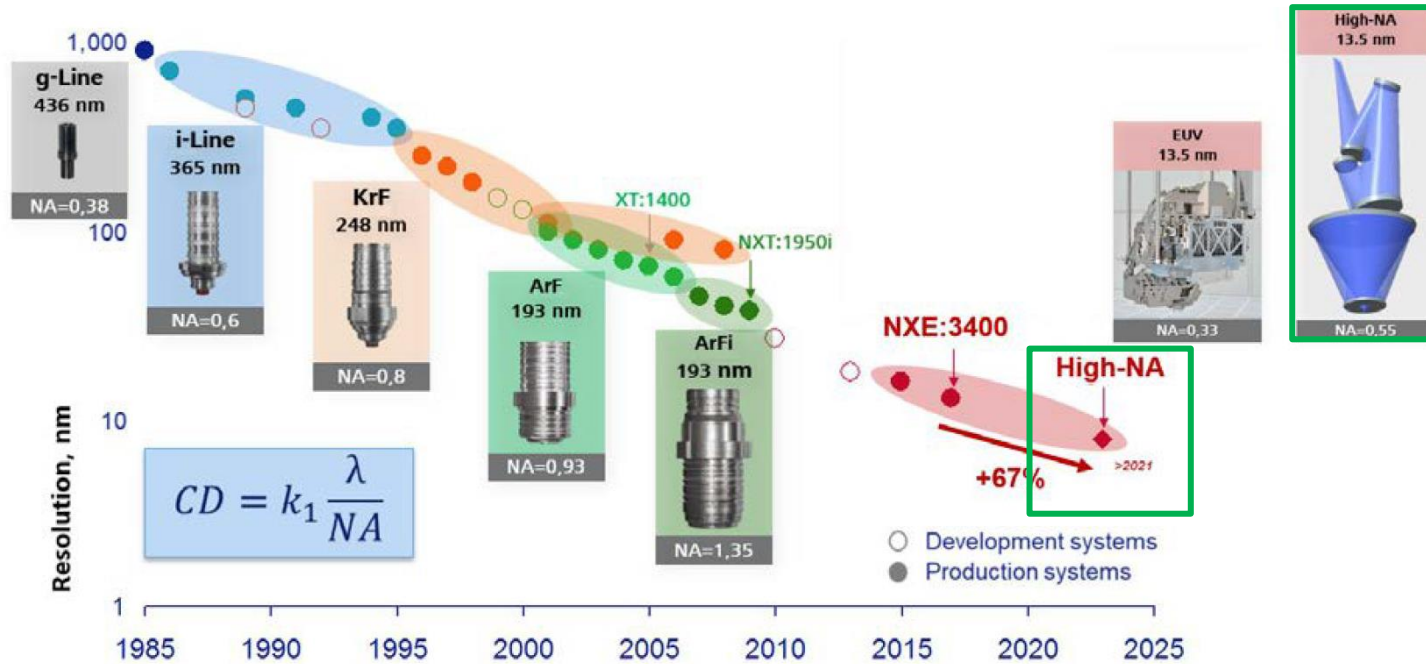
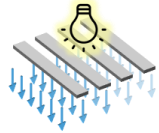
Transfer layer



Si

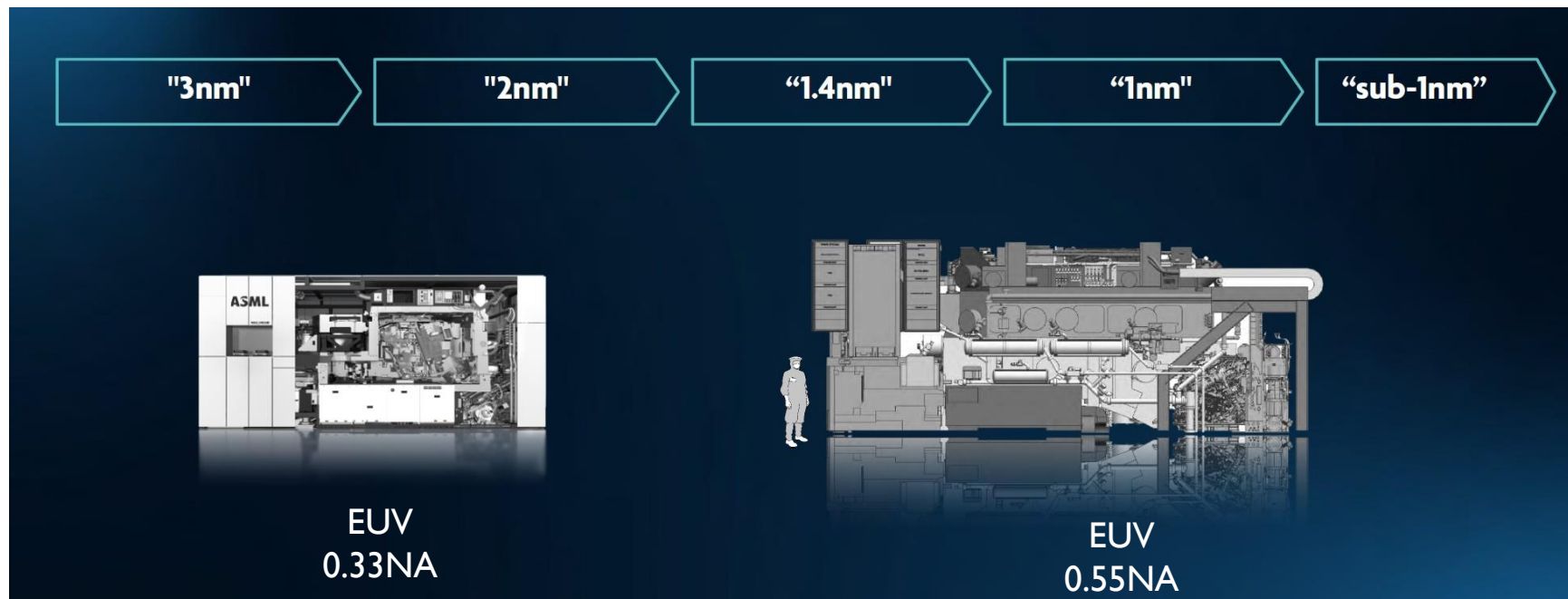
Scaling is continuing enabled by the Lithography Roadmap

High NA EUV is the next step managing complexity, turn around time and cost



Source: Paul Graeupner et al. EUV optics: status, outlook and future SPIE2022

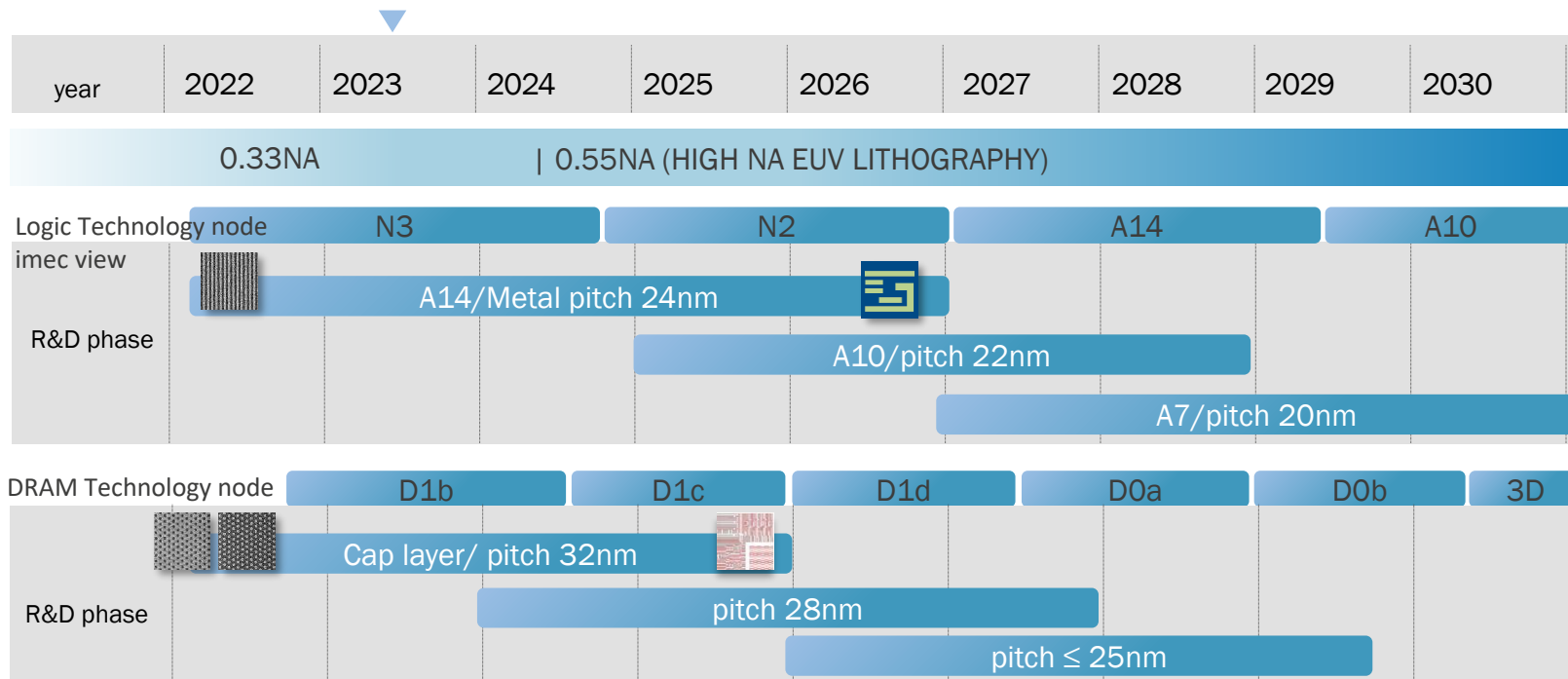
High NA EUV Lithography introduces the angstrom era of device scaling



- 1.7x smaller features, 2.9x increased density
- Higher imaging contrast enables 40% improvement in LCDU
- Reduction of multi patterning, less mask = less defectivity
- Dose reduction with higher contrast, improved edge place error

Source: Greet Storms et al. SPIE2022

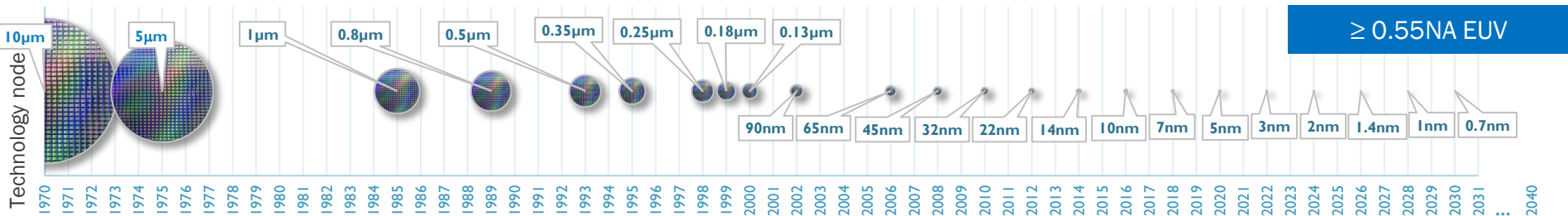
Critical features sizes and R&D timeline for device scaling



From the materials perspective

...the chemistry has been playing and still plays a big role in the Lithography Roadmap

The chemistry and the light-matter interaction in the CMOS technology landscape



50 years have past, and 18 generations of successfully-shrinking CMOS technologies moved to production

R&D

Lithography Patterning scaling

g-line, i-line

248nm

193nm

EUV

?

Resist

DNQ/Novolac

PBOCST

Acrylate and alicyclic

PBOCST, Acrylate, MOR, others?

Light-matter interaction

non-ionizing radiation
photochemistry
 $M + h\nu \text{ (UV/DUV)} \rightarrow M^*$

ionizing radiation
radiation chemistry
 $[C, H, O, \dots] + h\nu \text{ (92eV)} \rightarrow e^-/p^+$

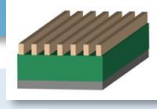
More disruptive chemistry needed

Technology challenges towards the Angstrom era of device scaling

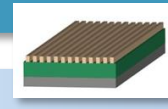


Features and films scaling

≤ 2017 (DUV)



≥ 2018 - **0.33NA EUV**



≥ 2023 - **0.55NA EUV**

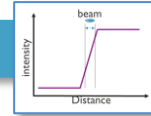
RLS



RLSF



RLSF & thin films



R = Resolution
L = Line edge roughness
S = Sensitivity
F = Failures

iArF

organic resist

BARC

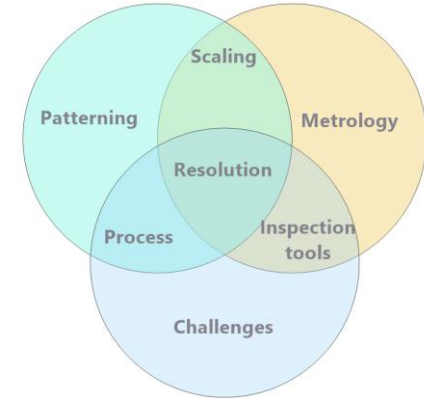
EUVL 0.33NA



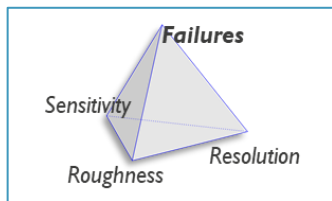
organic resist

inorganic resist

underlayer

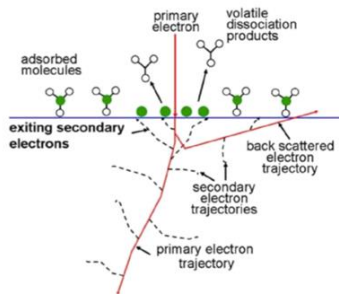


- The RLS triangle tradeoff moved to the tetrahedron shape. Stochastic failures must be considered.
- Metal containing resists have been introduced in the patterning landscape
- The scaling of feature sizes is challenging both Patterning (materials) as Metrology equipment performance to maintain the pace of their own “Resolution”.

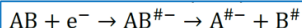


Stochastics in EUV patterning materials

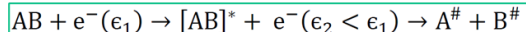
EUV lithography is driven by electron-mediated chemistry



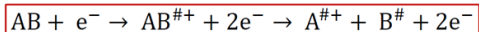
Dissociative Electron Attachment (DEA):



Neutral Dissociation (ND):



Dissociative Ionization (DI):

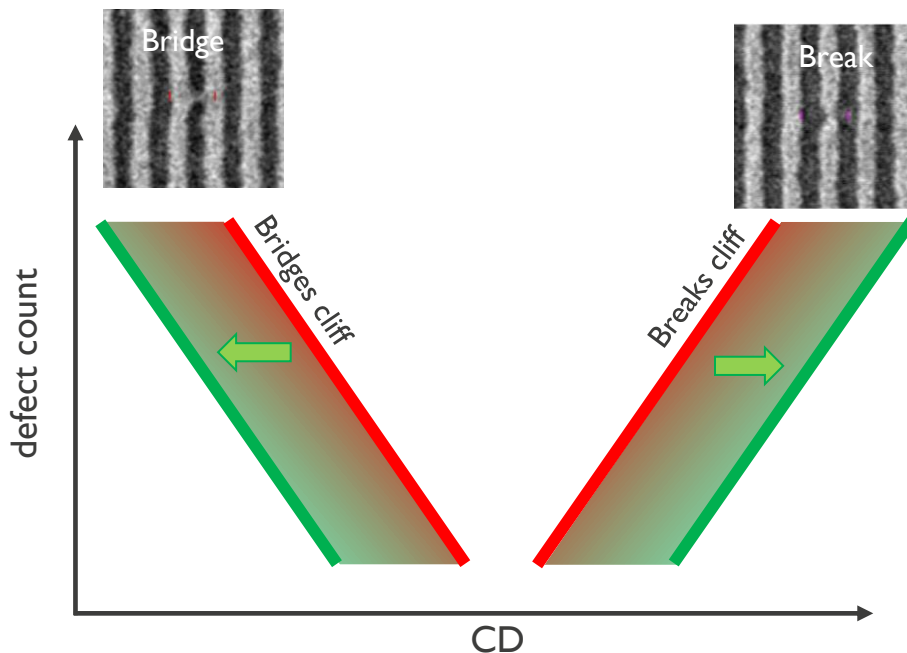


Thorman et al. *Beilstein J. Nanotechnol.* 2015, 6, 1904–1926

≠ Chemistry → ≠ Processes

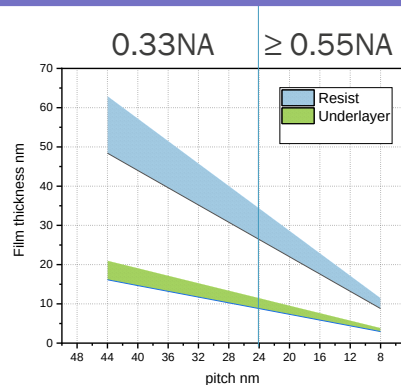
- → ≠ Performances
- → ≠ Products

Chemistry resist noise



Ultra-thin film materials

1. Material film thicknesses decrease as features scale down

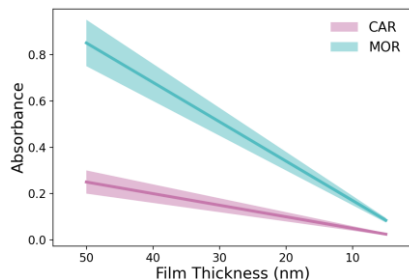


NA, Resolution $\uparrow$

Thickness $\downarrow$

Thinner resist and underlayer to retain performance

2. Material EUV absorption $\downarrow$ as film thickness scales down



Thickness $\downarrow$

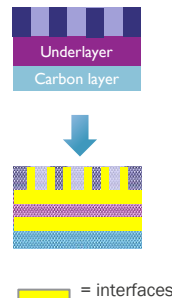
+

Absorbance $\downarrow$

=

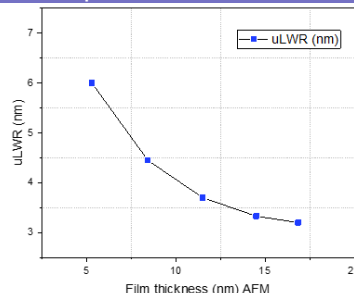
Less information in resist

3. Interface effects start dominating



- Non-linear behavior of nanometer-thick film vs bulk
- Properties of the stack $\neq$ sum of isolated materials
- Stochasticity plays an important role

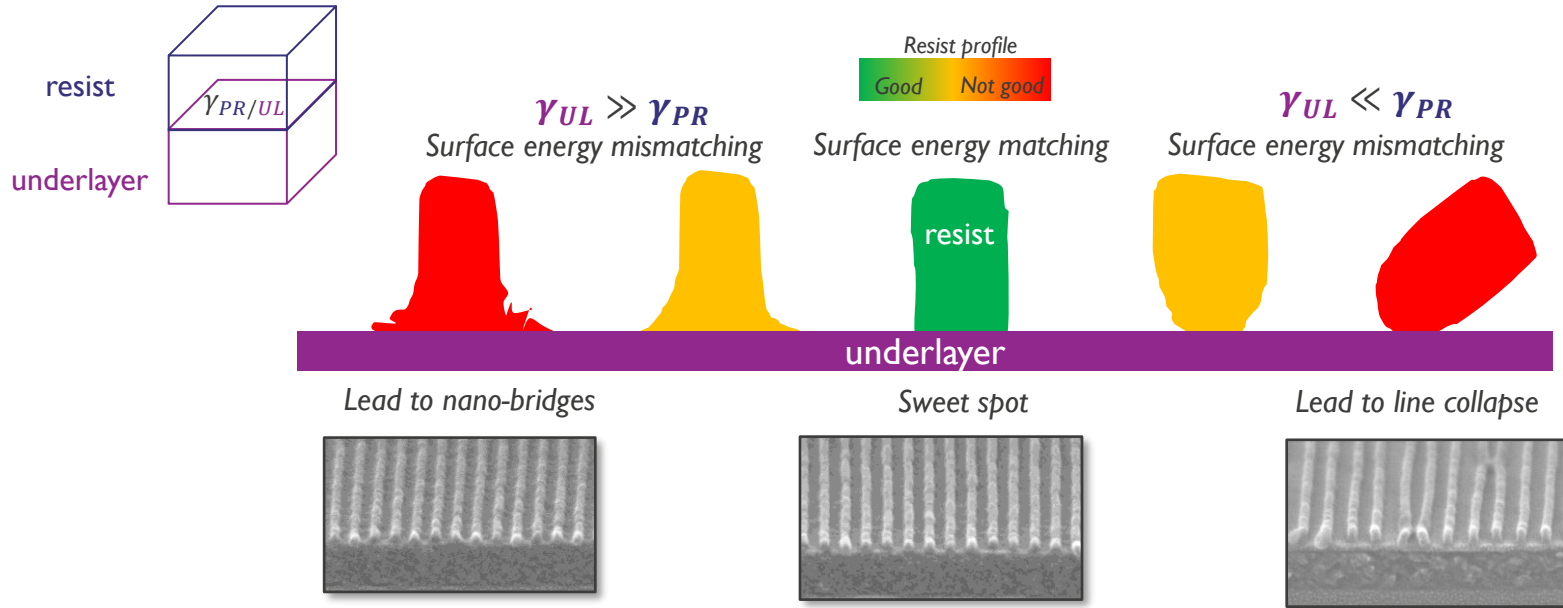
4. Resist performance becomes $\downarrow$ as films go thinner



- Resist roughness $\uparrow$ as film thickness $\downarrow$

Resists and underlayers are becoming more and more interdependent by pushing down the feature size. Mechanistic understanding, interface control and material engineering are key to enable disruptive efficient lithographic chemistry

Ultra-thin films: Interfaces and cross-layer interactions start to dominate. Proper layers matching is needed



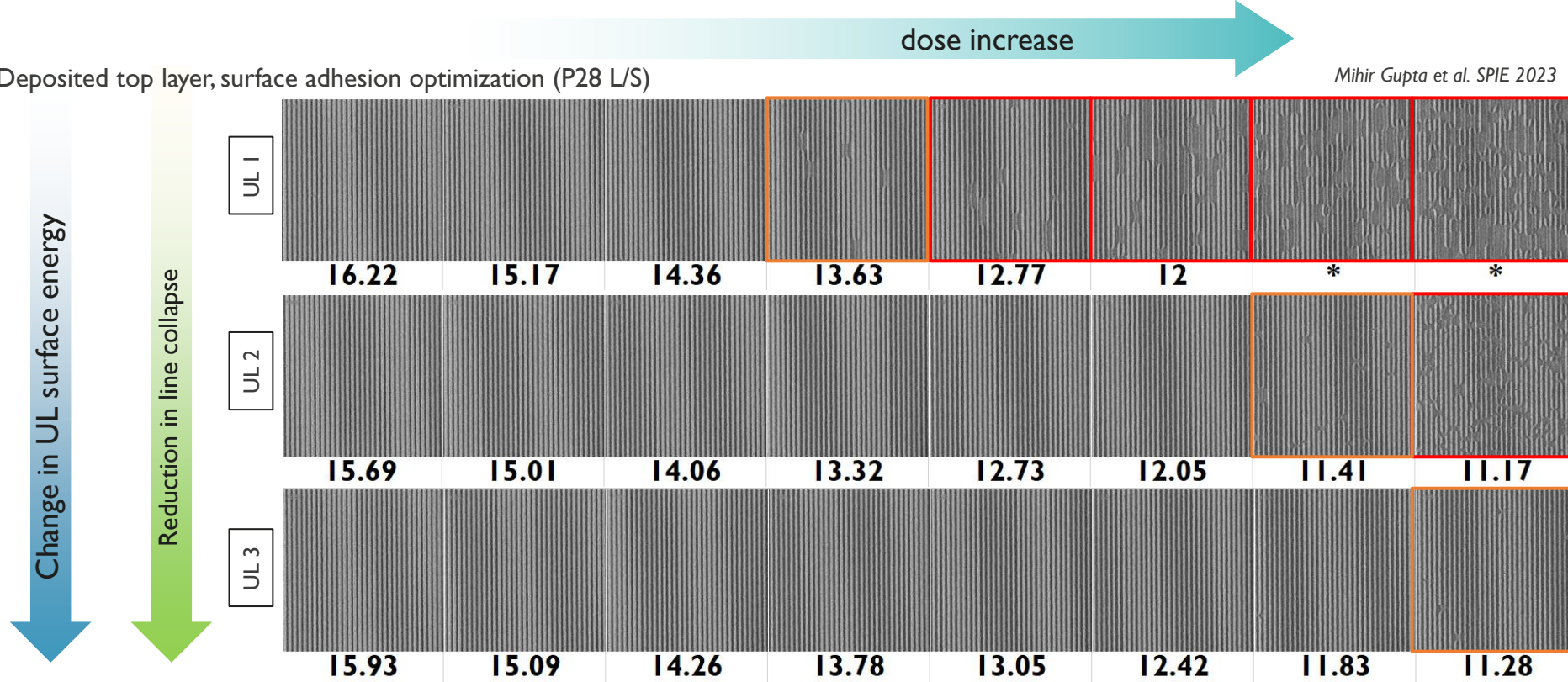
Surface energy matching of two the phases system, resist and UL, is a requisite.



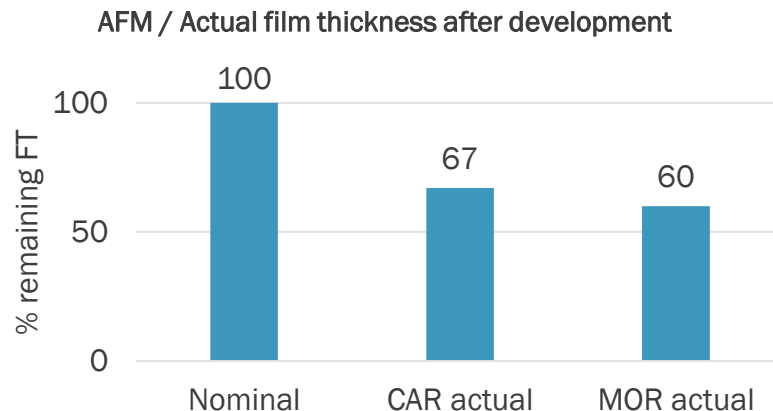
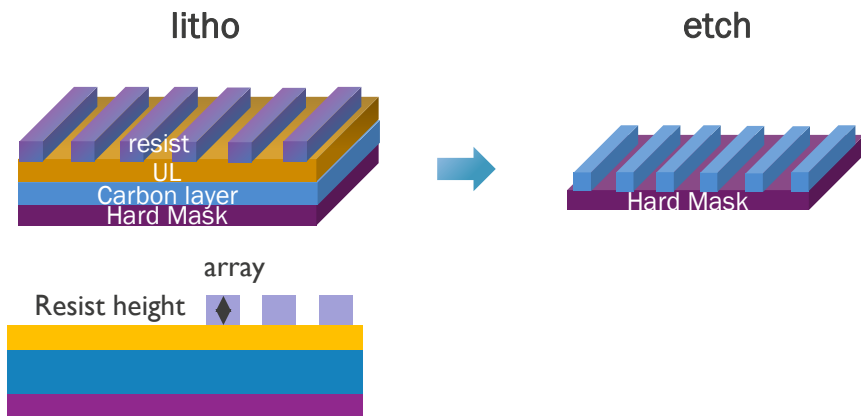
Proper matching with the EUV resist is needed

Deposited top layer, surface adhesion optimization (P28 L/S)

Mihir Gupta et al. SPIE 2023

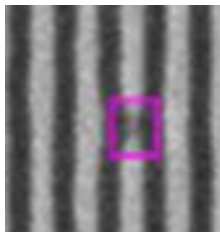


Ultra-thin resist requires novel patterning solution



Resist budget is very limited (10÷20nm thickness)

- ❖ Pattern transfer is prone to deliver nano-failures (i.e., breaks)

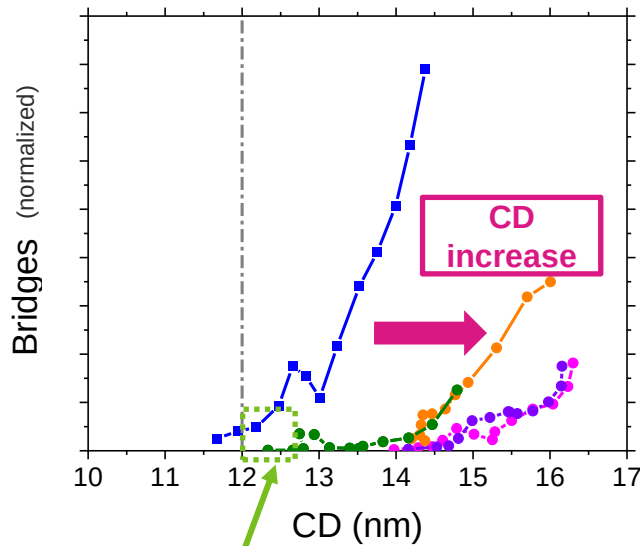
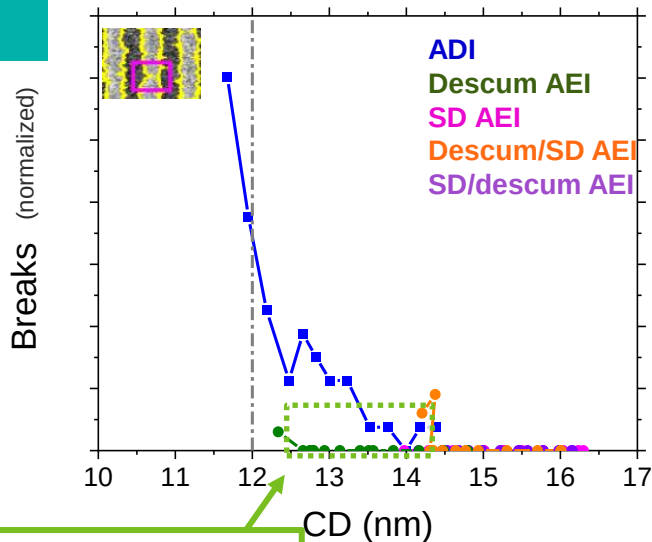


To prevent nano-failures the following are required:

- ❖ Resist with high etch resistance
- ❖ Selective deposition-etch
- ❖ Thin and fast etch underlayers
- ❖ Higher etch selectivity

Defect Reduction Using Selective Deposition (SD)

16nm
PR

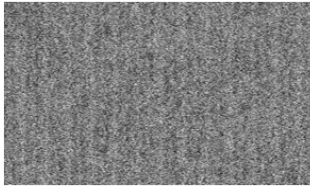


Source: TEL

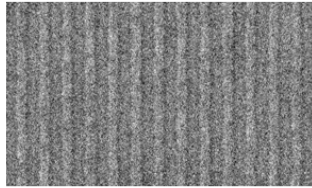
MOR (16nm) SD is critical to defect reduction. Co-optimization of descum and SD shows that descum + SD does not provide improvement over SD alone. SD increases CD and needs to be tuned with ML over etch

Metrology for film resist scaling to ultra-thin

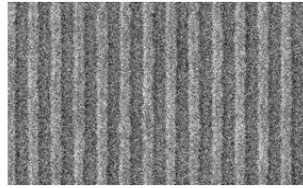
*CAR on spin-on-glass



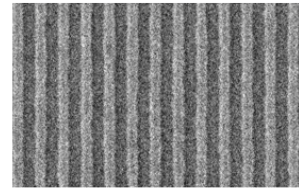
Target FT = 10nm



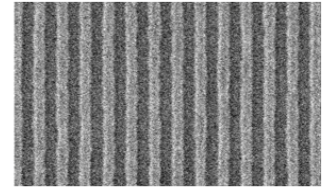
Target FT = 15nm



Target FT = 20nm



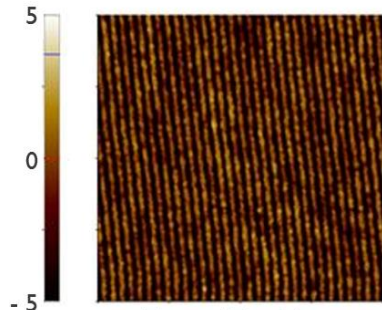
Target FT = 25nm



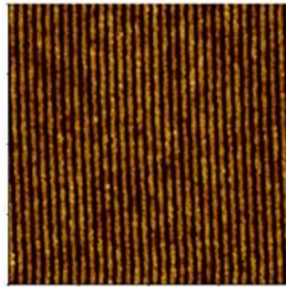
Target FT = 30nm

*imec BKM's for After Development Inspection (ADI) wafers. The images are acquired at 500eV, 8pA, 16 frames, using a Hitachi CG6300 – P32LS

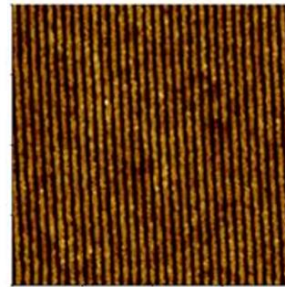
AFM on CAR and spin-on-glass



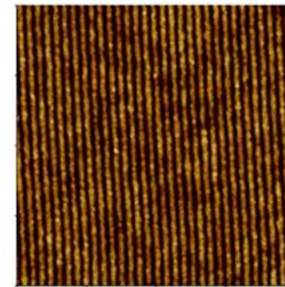
Target FT = 10nm



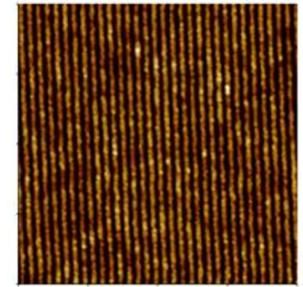
Target FT = 15nm



Target FT = 20nm



Target FT = 25nm

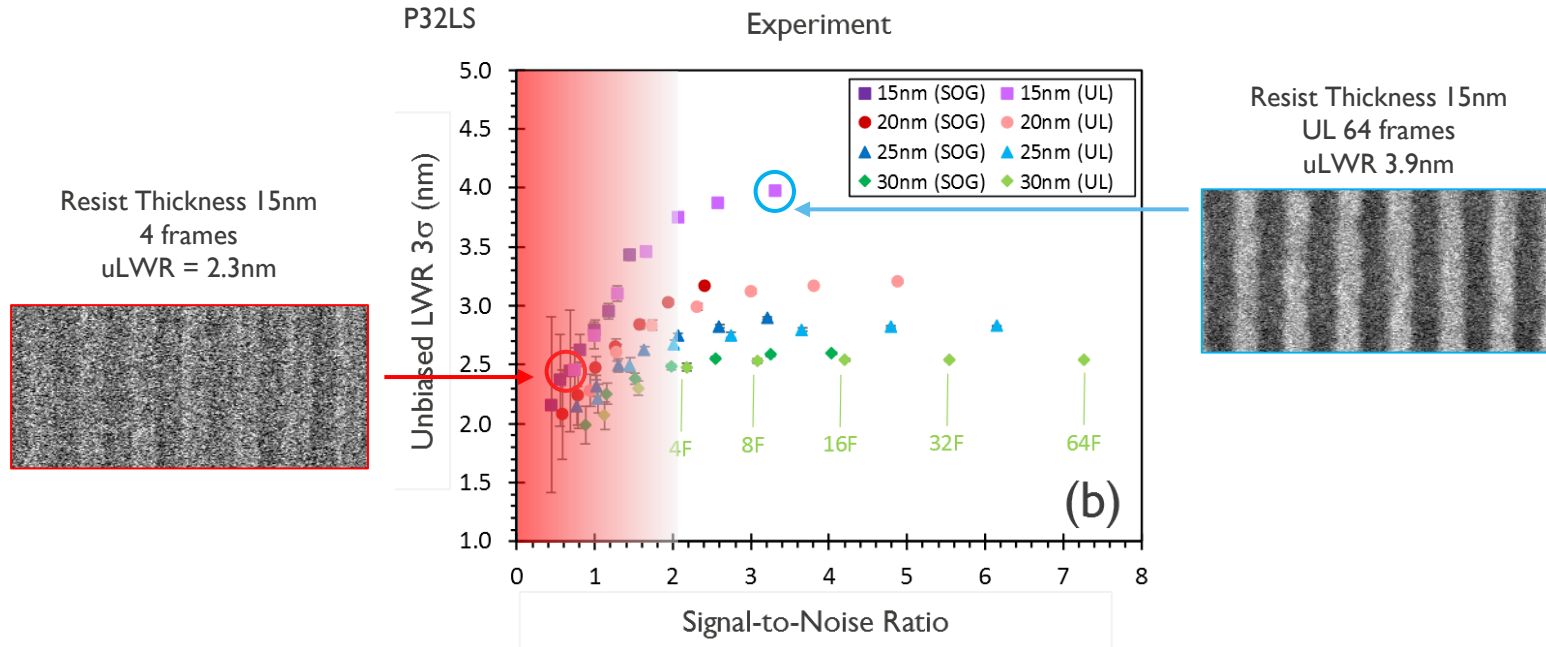


Target FT = 30nm

The AFM analysis shows that LS patterns are printed down to 10nm film thickness, thus indicating that the limitations observed in the SEM images at 10nm target FT are related to metrology rather than patterning.

Metrology for patterning roughness of ultra-thin resists

Impact of Signal-to-Noise Ratio (SNR) on unbiased roughness metrology



SNR < 2: values of unbiased LWR strongly suggest a measurement artifact

SNR > 2 the roughness values are lower with the following resist thickness order: 30nm < 25nm < 20nm < 15nm

Summary

- **Moore's law will continue**
 - The lithography roadmap enables the device scaling and high-NA EUV is the next step
- Sub-10nm technology nodes show new challenges strictly connected to the feature scaling and the **material film thicknesses** (3÷30nm).
 - **Resists and underlayers** are becoming more and more **interdependent**
 - **Mechanistic understanding, interface control** and **material engineering** are key to enable disruptive efficient patterning chemistry.
- The scaling of feature sizes is further challenging the **metrology** equipment performance to maintain the pace of their own “resolution”.
- A **comprehensive approach** is needed to tackle all challenges at fundamental and patterning level.
- Enabling the **high NA eco-system** and address all high NA patterning challenges is the number one priority of the imec Advanced Patterning Process Program in the next years

A low-angle, night-time photograph of a modern glass skyscraper, the IMEC building, with its interior lights glowing. The sky is dark blue with some clouds. The building's facade is composed of many rectangular glass panels, some of which are illuminated from within, creating a pattern of light and dark rectangles. The building is angled towards the right side of the frame.

Thank you for your attention

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imec

embracing a better life