EUV Resists: when more may be less

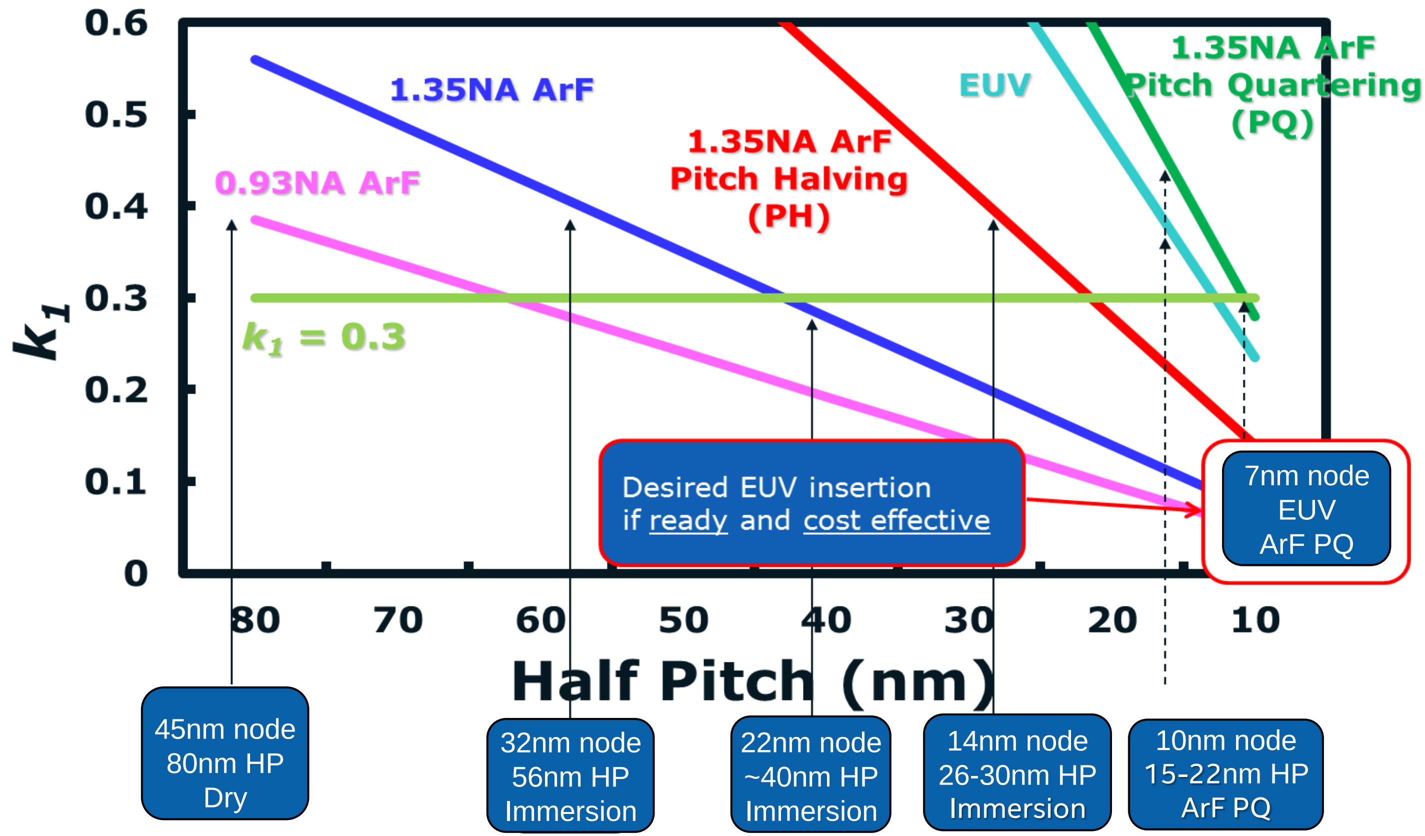
Anna Lio
Intel Corporation

Photo removed

It is one thing to decide to climb a mountain.
It is quite another to be on top of it.

Herbert Simon

Lithography Options for Intel Technology Nodes



Source:
Mark Phillips

Outline

- Resists for HVM
- Edge Placement Control
- Stochastics
- Conclusions

Resists for HVM

- **Patterning Requirements**
  - CDU & Edge Placement Control/Stochastics - The Deal Breaker
  - Stable in-FAB performance
  - Sensitivity
    - Dose to target lower than 20 mJ/cm^2
  - Resolution
    - Good resolution is not sufficient
- **Quality Control**
  - Stable chemistry and shelf life
  - Defects
  - Manufacturability
- **Cost**

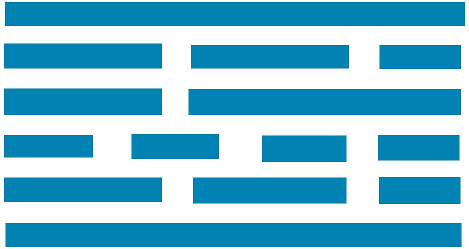
Resists for HVM – Quality Control and Cost

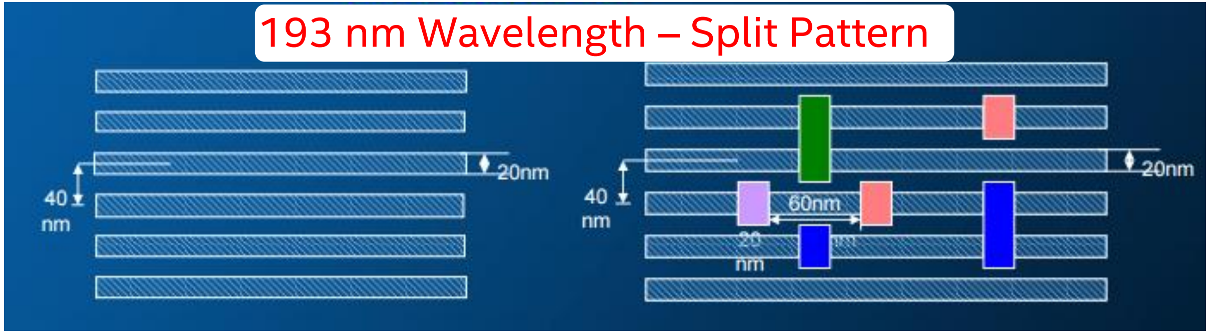
- Resist Batch Scalability, Quality Control are ESSENTIAL to EUV insertion in HVM
  - Raw materials quality control and shelf life are critical – only chemistries that are stable can be considered for HVM – Need to match immersion resists'
  - Metal contamination level in the resist must meet HVM SPECs
  - 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

Multiple Patterning and Edge Placement Control

Desired Pattern (MT)





1 mask + SDP

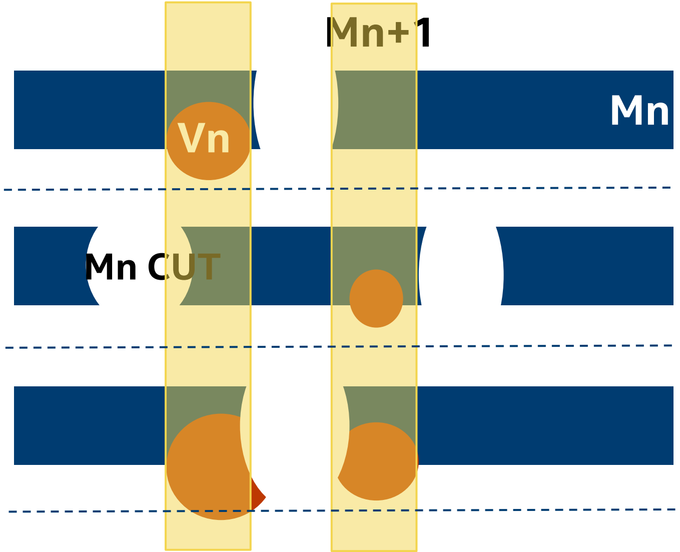
4 Cut masks

5 masks total

EUV to improve overlay and process variability

It is 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

How difficult is it? More difficult than we may think

- Today's microprocessors have ~1.3B 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

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

The Future will be ruled by Stochastics

AND

If we **always** do what we've **always** done,
we will **always** get what we've **always** got

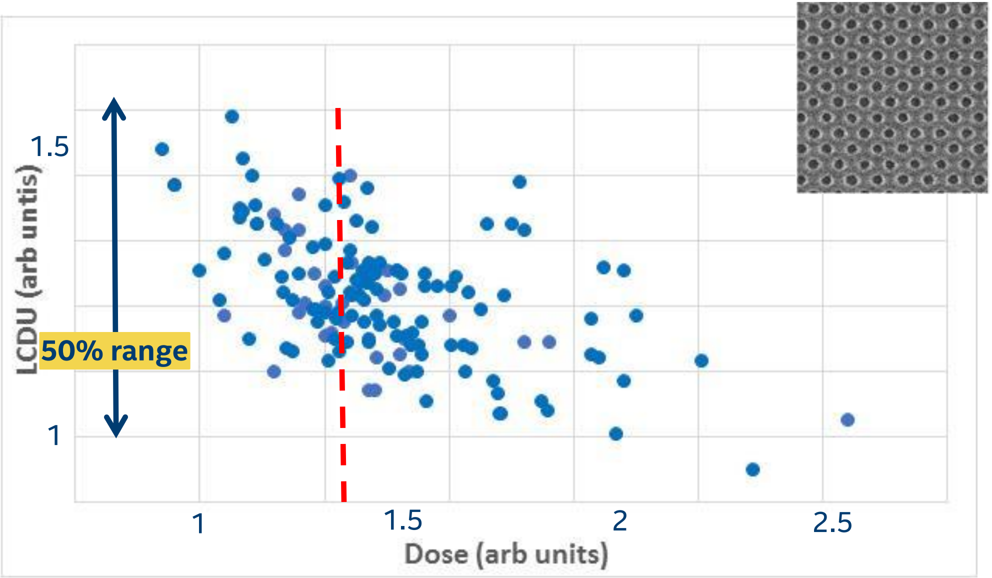
The Failure rate per VIA must be on the order of 1 part per Trillion!!!

The RLS Triangle

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

Enhanced Resolution can be realized only with variability control
What matters is performance at a given dose

CAR Resists today – LCDU for holes

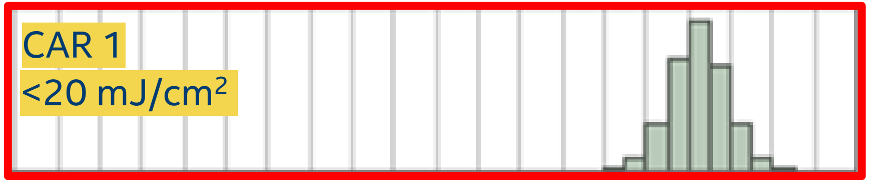


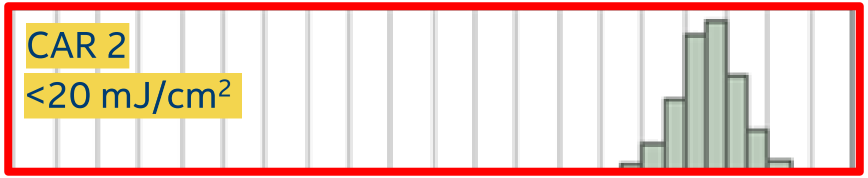
Clear evidence that LCDU depends on:

- Sensitivity/#photons
- Resist Chemistry
- Metals are not an easy fix
- No obvious correlation with absorption value

No strong evidence it is Photon Shot Noise limited

Can an increase in dose fix it all? Apparently not





NXE3300, 28 nm hole

72K measurements

Can an increase in dose fix it all? Apparently not

le

2.5X dose yields 10% CDU improvement
Is resist stochastics still largely dominating variability?
How does the quencher interacts with electrons?

You can't force chemistry to exist where it doesn't, in the same way you can't deny it when it does! Albert Einstein

If we could use dose of 40-50 mJ/cm^2 today, what for?

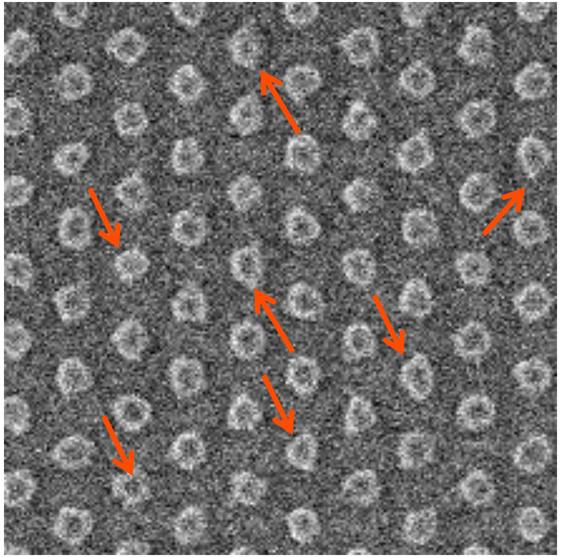
<u>This is the Deal Breaker</u>

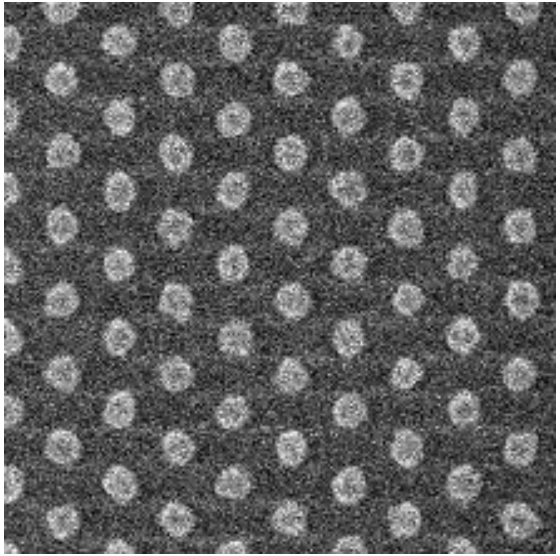
Can higher EUV Absorption do it all?Apparently not

Increased absorption should help … BUT, high(er) absorption and use of metals do not necessarily imply higher sensitivity and better variability

NXE3100, conventional illumination – 32 nm, 20 mJ/cm2

Abs= 2X ref





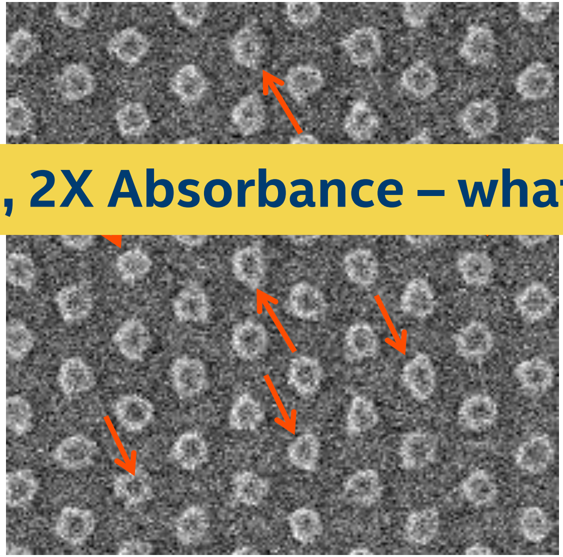
Abs= ref

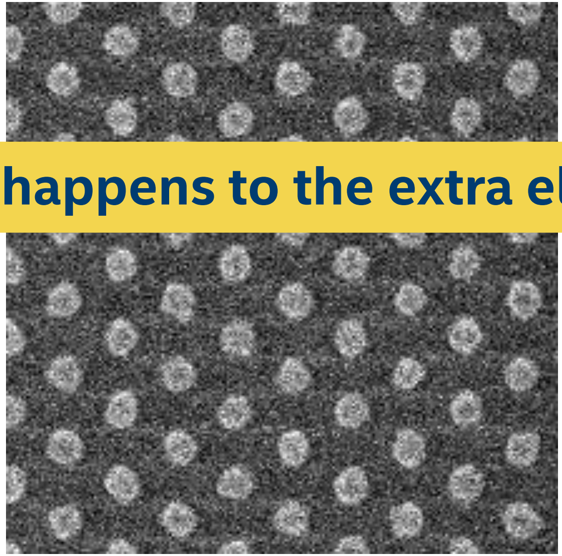
Can higher EUV Absorption do it all?Apparently not

Increased absorption should help … BUT, high(er) absorption and use of metals do not necessarily imply higher sensitivity and better variability

NXE3100, conventional illumination – 32 nm, 20 mJ/cm2

Abs= 2X ref





Abs= ref

Same dose, 2X Absorbance – what happens to the extra electrons?

Apparently chemistry makes all the difference and More can be Less

Resist Stochastics

- **Traditional CAR**
  - Photons
  - Electrons
  - Absorption
  - Acid
  - PAG
  - Quencher
  - Protecting groups
  - Development process
  - etc
- **Novel Chemistries**
  - Photons
  - Electrons
  - Absorption
  - Environment
  - Shelf Life components
  - Competing reactions
  - Multiple reaction paths
  - Dissolution process and mechanism
  - etc

We must understand the interaction of EUV radiation with resists, CAR and/or novel

A resist may have fewer discrete elements to start with
That alone does not make it better for stochastics

Summary and Conclusions

- **Variability is the Deal Breaker. The power is held by the resist chemistry**
  - Variability is high at moderate dose as well as high dose, with and without metals
- Can current resists take us into the **future**?
  - Current evidence suggests no
- Increase in **absorption** can reduce photon shot noise and improve sensitivity **if** the chemistry is right
  - Resists need to be compared at similar dose to target
- Use **Spectroscopy and modeling** to understand mechanisms in the resist
  - Think of current resists in new ways and innovate in new resists
- 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

Acknowledgements

Robert Bristol
Brent Busby
Dan Gardner
Marie Krysak
Ravi Narayanan
Charlie Wallace
Chihkai Yang

Sam Sivakumar
Britt Turkot

Thank – you very much for your attention!

experience
what's inside™