Oct. 4, 2012

A Comparison of Positive- and Negative-tone Contact Hole Process Flows Using the IMEC NXE:3100

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Outline

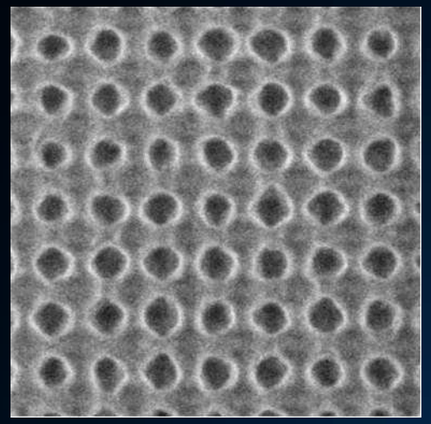
- **Introduction & Motivation**
  - Why NTD Resists for EUVL?
  - Graphoepitaxial Directed Self Assembly (DSA) for C/H Shrink Using a Blended Material
  - Process Flows We Are Comparing
    - 193i NTD + DSA Shrink Results at IMEC
- NTD Resist Performance on the IMEC NXE3100 :: **Recent Progress to 30P60.**
- DSA Blended Shrink for NTD :: **~10-35% Improvement vs. NTD Alone.**
- Best Results To Date :: **PTD Still the Champion, but Alternatives Quickly Maturing.**
- Conclusions & Next Steps
  - Acknowledgements
  - Personal Recommendation for Best Belgian Chocolate

Outline

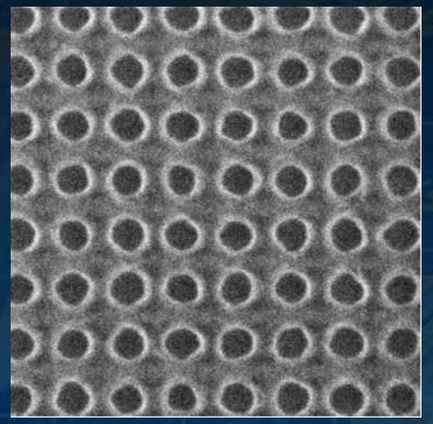
- ➢Introduction & Motivation
- NTD Resist Performance on the IMEC NXE3100
- DSA Blended Shrink for NTD
- Best Results To Date
- Conclusions & Next Steps

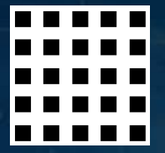
NTD Helped ArF Solve LCDU Issues

193i
45 nm hp



DF+PTD



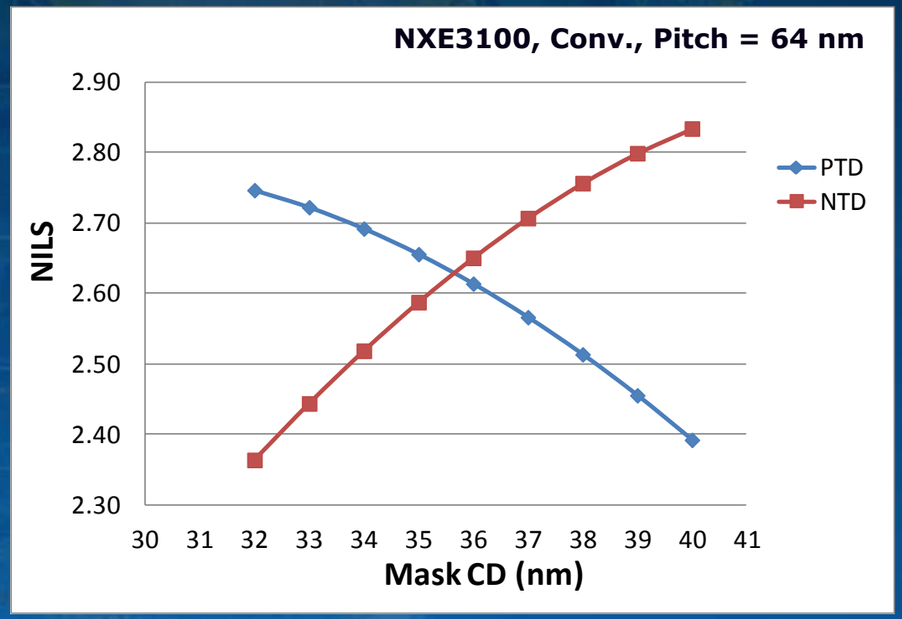


LF+NTD

- Over-exposing dots improves NILS in ArF, resulting in improved LCDU.

➢ **Can we over-expose dots in EUV to increase NILS? YES.**

- Potential benefit : Use more photons/hole; Improves shot noise.
- Absolute flare will be higher; But flare variation should decrease.
- Optimization yields material sets which are complementary to latest 193i NTD layers and are beneficial to several DSA flows.



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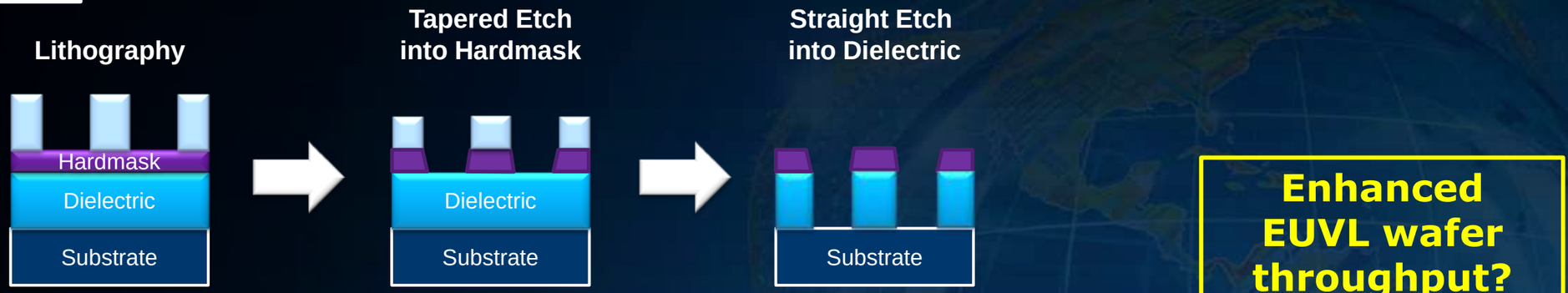
Process Flows Of Interest Here

PTD / NTD

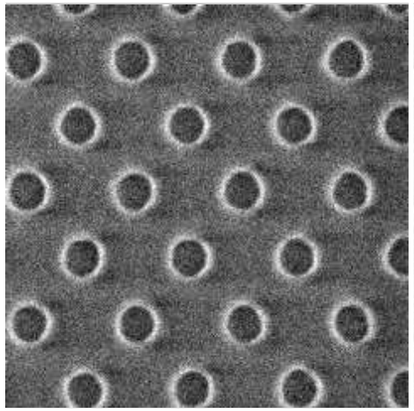
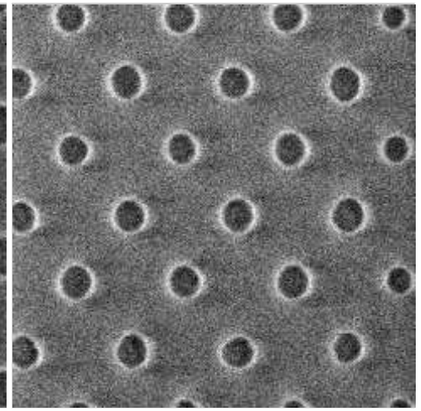
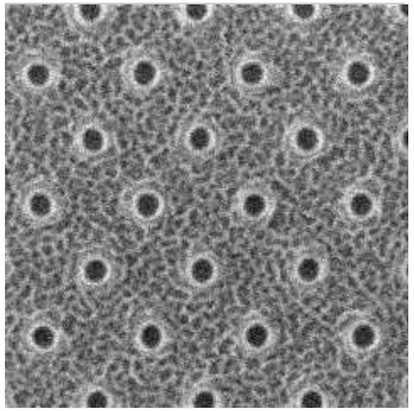
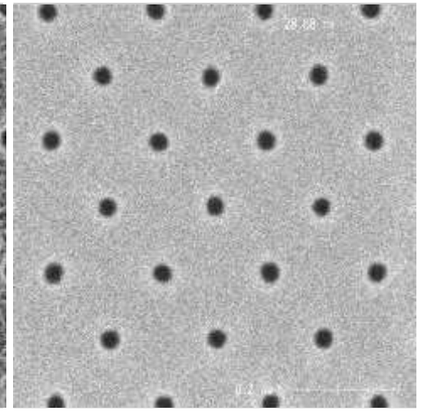
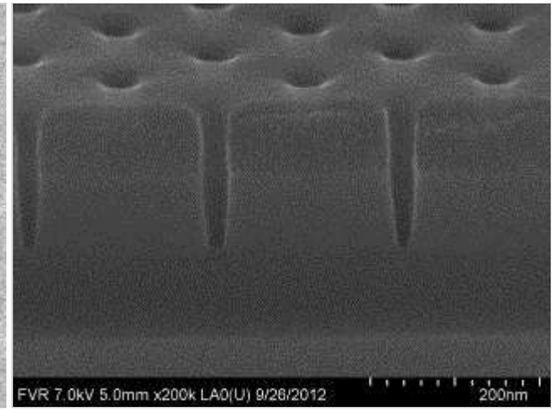


Enhanced EUVL wafer throughput?

NTD + DSA Shrink

- EUVL graphoepitaxy flow requires solvent-compatible pre-pattern. Primary path is an NTD EUVL resist with the appropriate thermal and chemical performance.

193i + DSA Blended Shrink :: IMEC Integrated Efforts

	Litho	+DSA Blend	Hardmask Etch	Dielectric Etch	XSEM Following Dielectric Etch
Image (Top-Down @ 200k)					
CD (nm)	~ 55	~ 35 (~36% ↓)	~ 35	~ 25 (~55% ↓)	

Lithography = ASML 1950i, NTD Resist + Develop
DSA = Blended Shrink, Anneal + Develop

- In parallel to the EUV work presented here, we are using a 193i NTD process to fabricate an IMEC electrical test vehicle for the direct comparison of standard patterning processes to variants which employ DSA.
- Results from our 193i NTD + DSA blended shrink flow (55% integrated shrink) are illustrated above.

➢ **Can we extend similar integration schemes to NXE-patterned wafers?**

➢ **If so, can we improve EUVL resolution, CDU, and / or wafer throughput?**

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- ➢NTD Resist Performance on the IMEC NXE3100
- DSA Blended Shrink for NTD
- Best Results To Date
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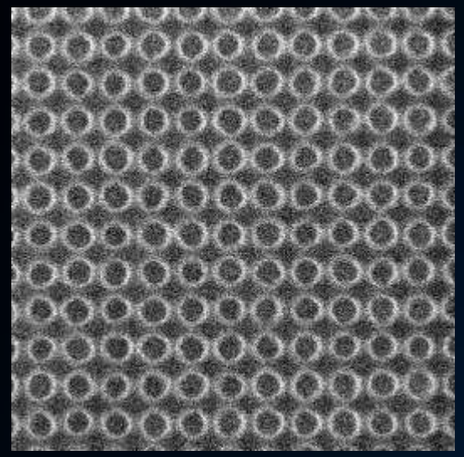
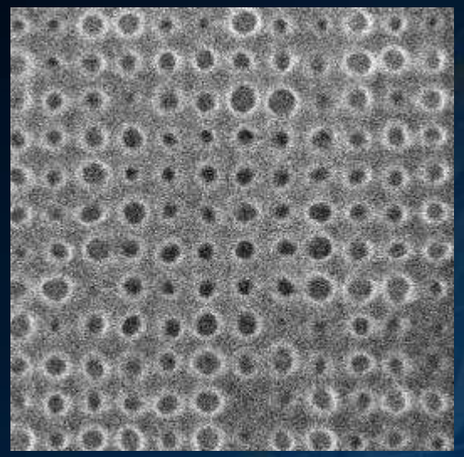
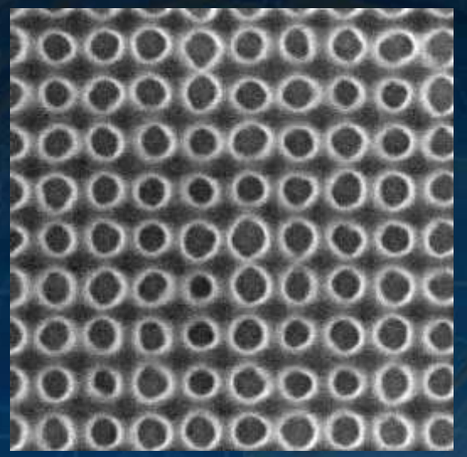
Feb'12 - NTD Performance on IMEC NXE3100



PTD
14.0 mJ/cm^2
Hole 36P64 @ mask



Gen-1
4.0 mJ/cm^2
Dot 36P64 @ mask



Gen-2
15.4 mJ/cm^2
Dot 44P64 @ mask

NXE3100
32 nm hp

- As material performance improves, we want to be cognizant of how the new material sets compare to positive-tone EUVL champion materials.
- ➢ In Feb'12, we expected further improvements via a combination of new material design as well as process improvements.
- NILS is meeting initial expectations. Further mask / modeling studies are required to refine our understanding.

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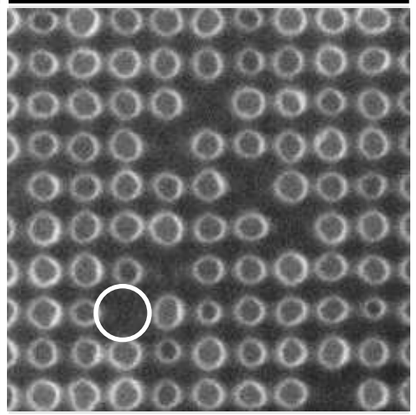
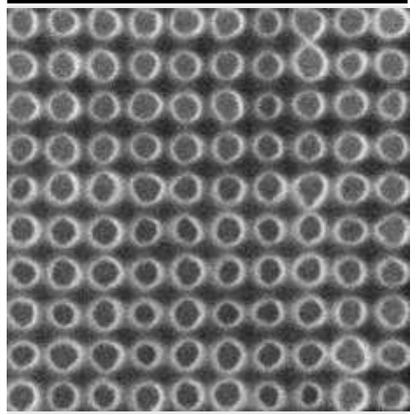
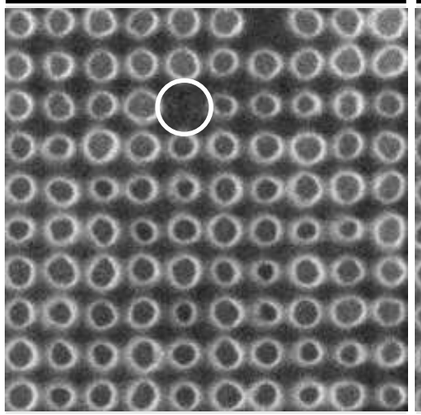
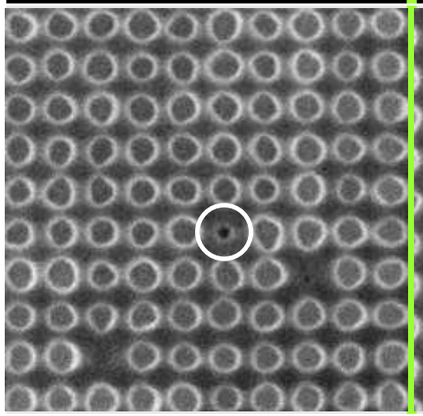
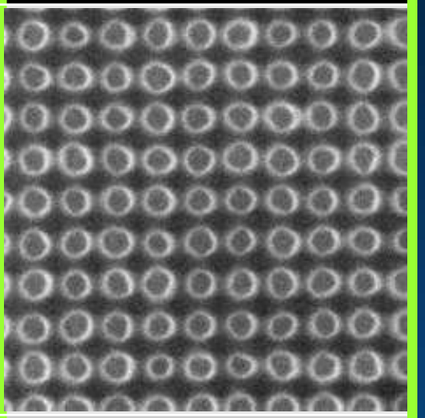
IMEC NXE Latest NTD Optimization

34P60 → 30hp

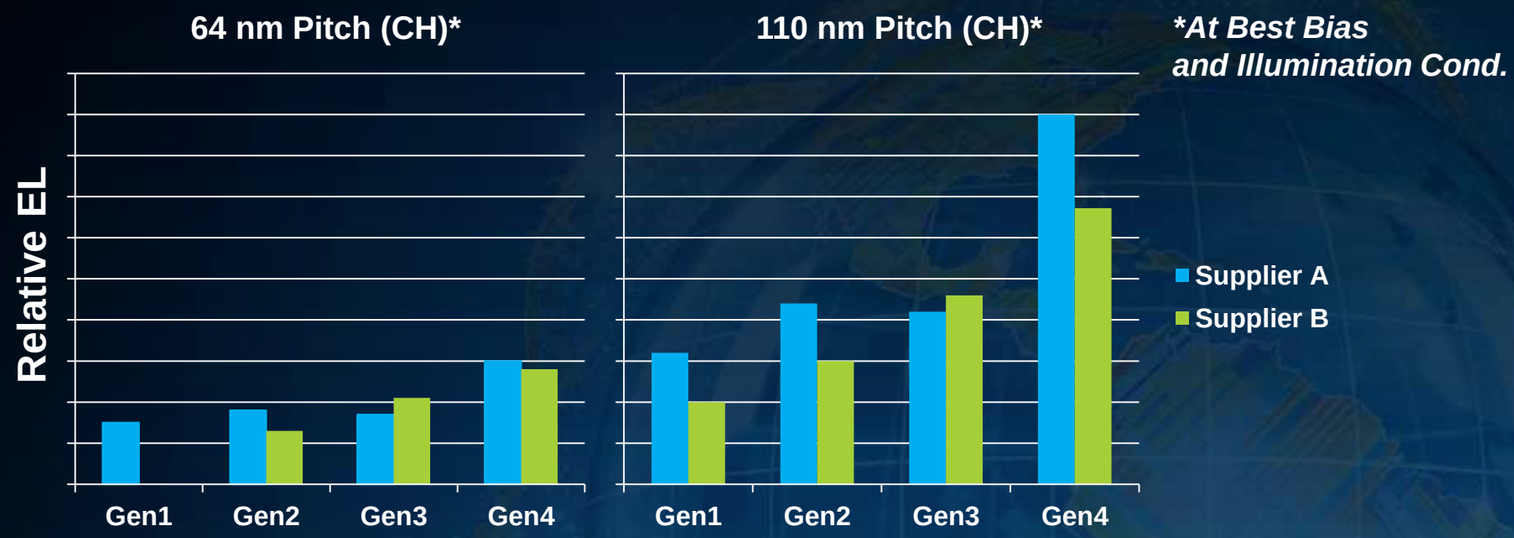
Resist	Gen-3	Gen-4	Gen-4	Gen-3	Gen-4
PAB/PEB	130/100	130/100	130/120	130/100	130/100
NTD Developer	Developer-1	Developer-2	Developer-2	Developer-1	Developer-2
NXE Illumination	Conventional	Conventional	Conventional	Quasar	Quasar
Image (Top-Down @ 230k)					
Esize (mJ/cm2)	17.0	20.8	10.8	15.8	20.8
CD (nm)	27.6	30.3	29.4	30.7	27.2
3 Sigma (nm)	4.9*	6.1	7.6*	5.3*	3.2

* Missing holes observed

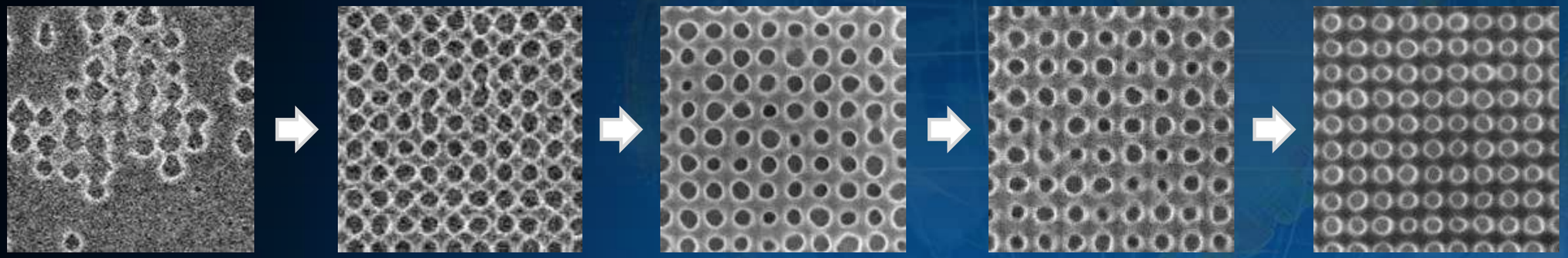
- Gen-4 platform showing reduced occurrence of missing contact holes.

➢ **Best NTD Performance To Date Comes From Gen-4 Resist, Developer-2, & Quasar Illumination.**

Noteworthy Improvement Across Supplier Base



Q3 2011



Present Day

Prescreening | Gen-1 | Gen-2 | Gen-3 | Gen-4

- Seeing good improvement in a relatively short period of time.

➢ While NTD is not yet on par with PTD, it is starting to become competitive.

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- ➢DSA Blended Shrink for NTD
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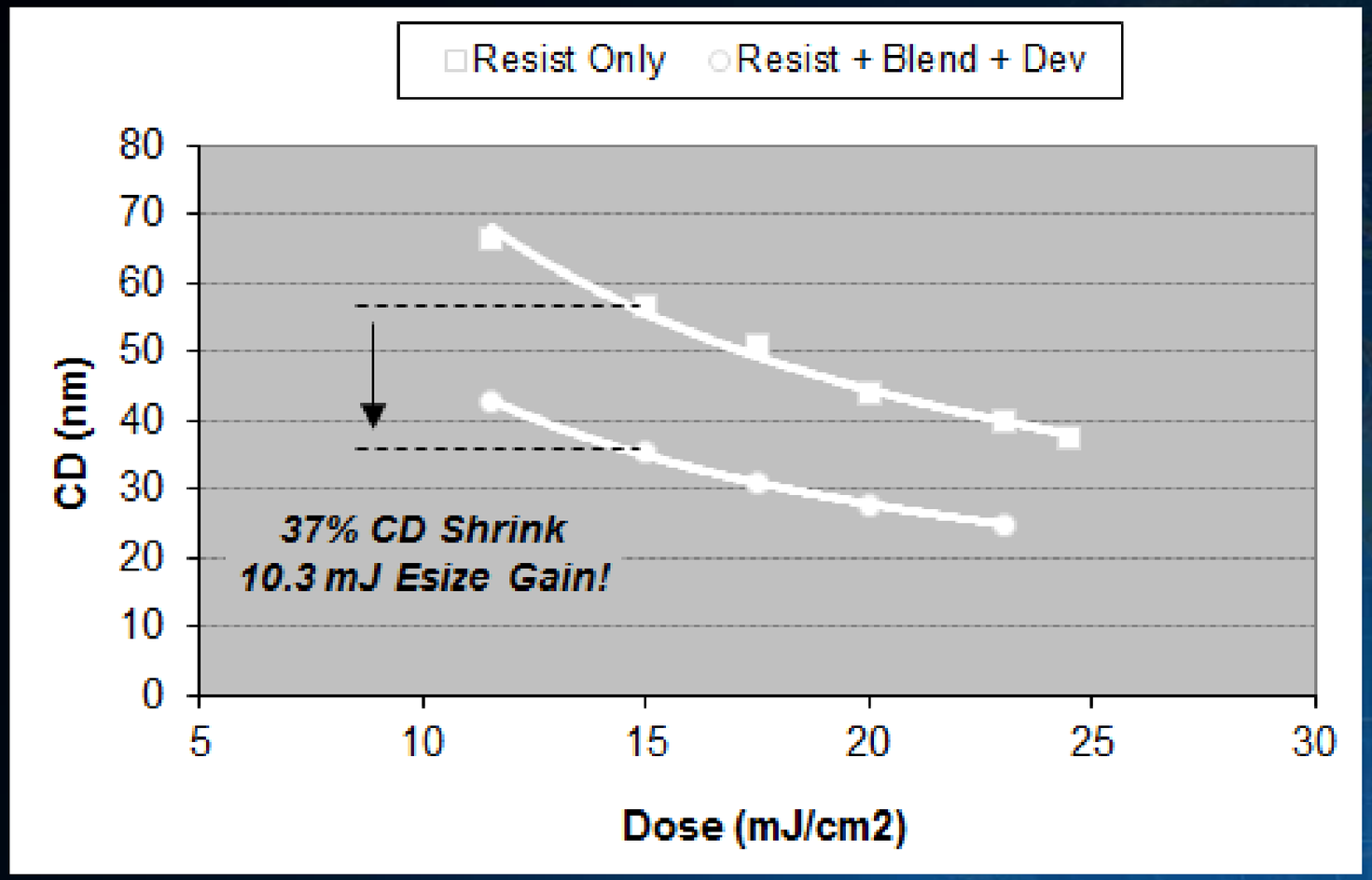
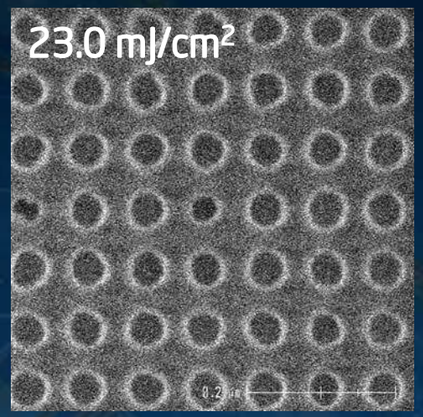
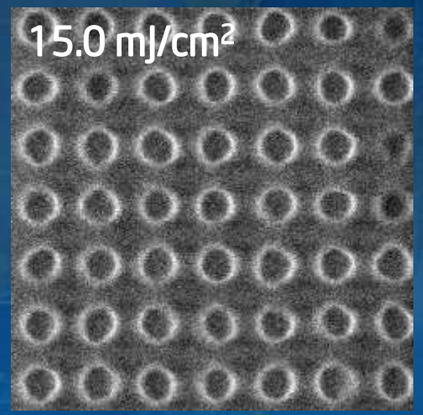
Use DSA Shrink As E-size Enhancement?

48P80
→ 40hp





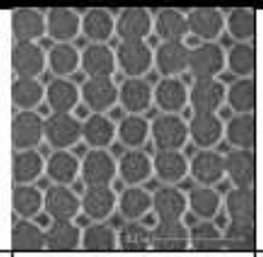
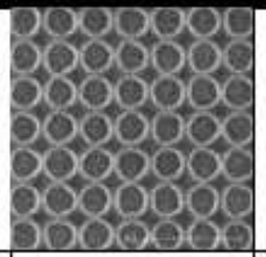
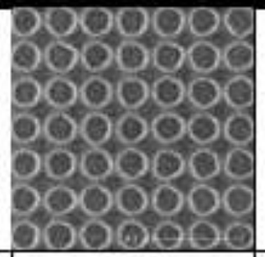
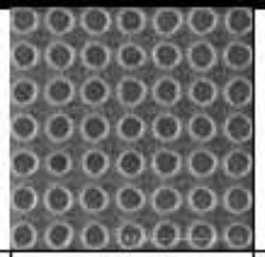
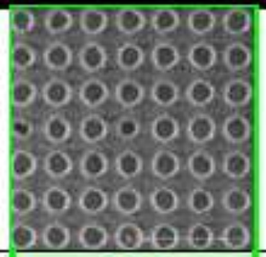
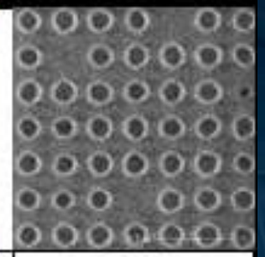
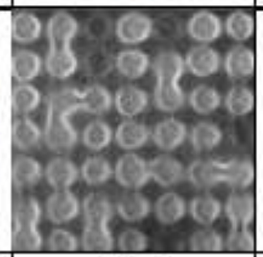
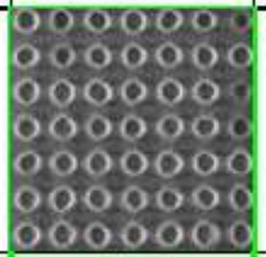
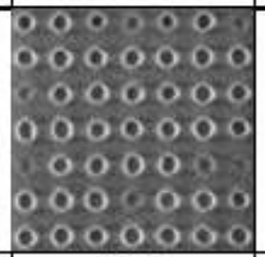
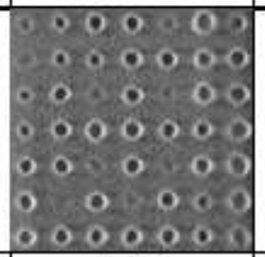
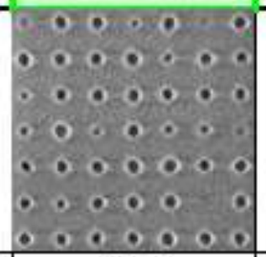
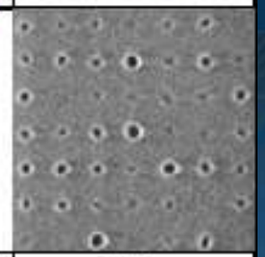
Gen-3 NTD
CD = 39.9 nm
CDU = 2.2 nm



Gen-3 NTD + Shrink-A
CD = 35.6 nm
CDU = 2.2 nm

- Rev0 proof of concept demonstrated.
- ➢ Possible throughput gain (~35% vs. NTD scheme).

DSA Shrink Behavior Through Dose / CD

Dose	11.5	15.0	17.5	20.0	23.0	24.5
EUVL NTD Resist Only						
CD	66.6	56.6	50.9	44.1	**39.9**	37.3
3Sig	3.98	3.53	2.94	2.52	**2.21**	2.04
+ DSA Blend and Dev						
CD	42.6	**35.6**	30.9	27.5	25.0	ND
3Sig	ND	**2.23**	1.70	1.26	0.94	ND
CD Δ (nm)	24.0	**21.0**	20.0	16.6	14.9	ND
CD Δ (%)	36%	**37%**	39%	38%	37%	ND
3s Δ (nm)	ND	1.3	1.2	1.3	1.3	ND
3s Δ (%)	ND	37%	42%	50%	57%	ND

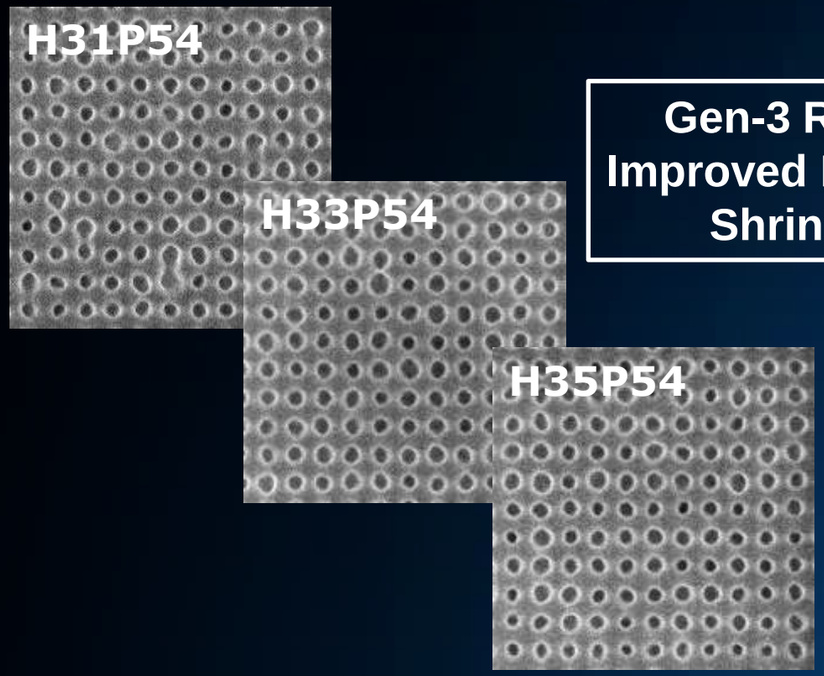
48P80 → 40hp Gen-3 Resist Shrink A

- DSA blended agent requires closed pre-pattern and saturates ~ 25-30 nm.

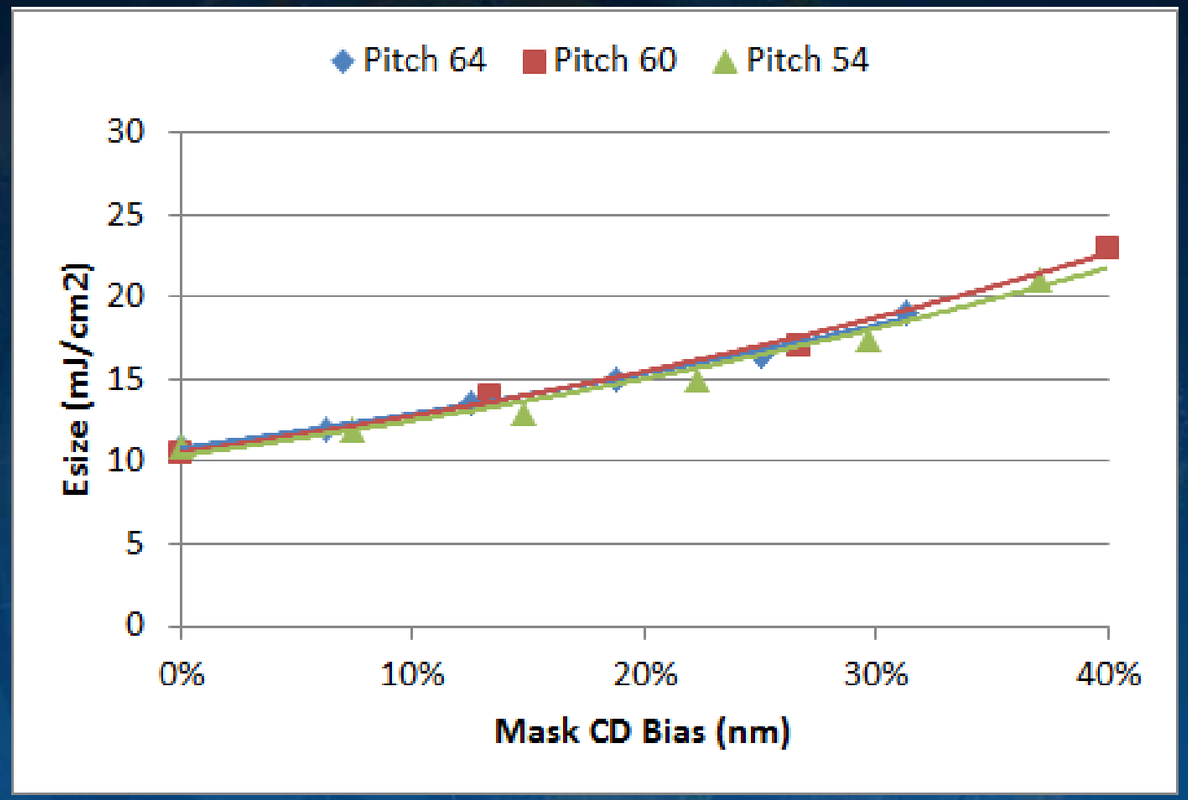
➢ May be used (instead) as CDU enhancement? Metrology / understanding = I/P

Performance of DSA Shrink vs. Mask Bias

27 hp Conv. = Not Yet Resolved



Gen-3 Resist
Improved Process
Shrink A

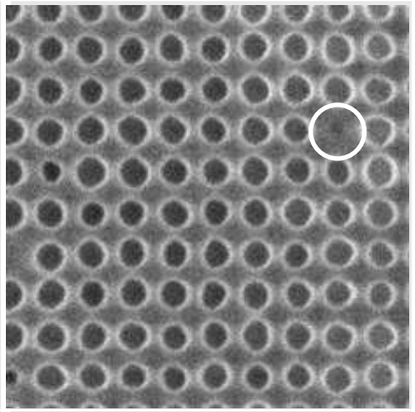
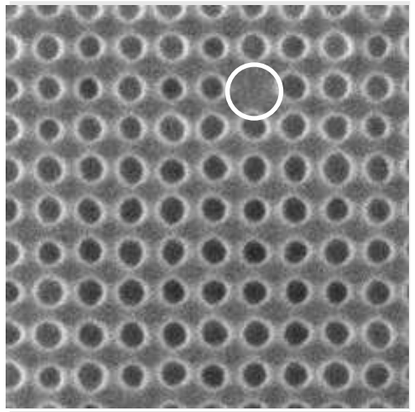
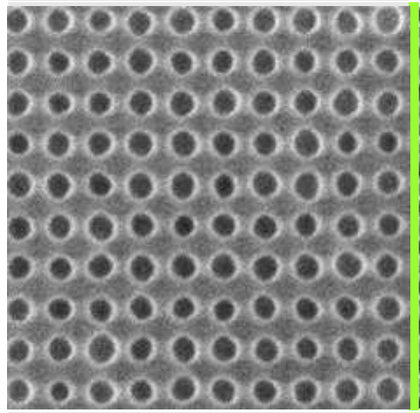
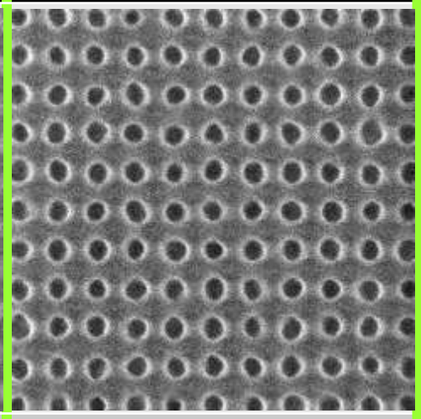


- Today, target features are 34P60 – 38P60 by conventional or quasar illumination.
  - Continued optimization will likely yield 27 hp resolution with Esize < 20 mJ/cm^2

➢ Ideal bias for NTD and NTD+DSA process is ~13 - 30 %

Key Parameter = DSA Shrink Agent FT

38P60 → 30hp

NTD Resist	Gen-3	Gen-3	Gen-3	Gen-3
Shrink	None	Shrink A, Std FT	Shrink A, FT+	Shrink A, FT++
Image				
Esize (mJ/cm2)	23.5	20.8 (11 %)	20.4 (13 %)	17.0 (27 %)
CD (nm)	32.5	30.2	29.2	27.3
CDU (nm)	1.4*	1.3*	1.3	1.0

* Missing holes observed; Believed to arise from NTD pre-pattern

- Optimization = Shrink FT > Resist FT >> Resist Anneal > Shrink Anneal
  - ➢ Process optimization yielded ~10-25% Esize Gain at 30 hp vs. NTD

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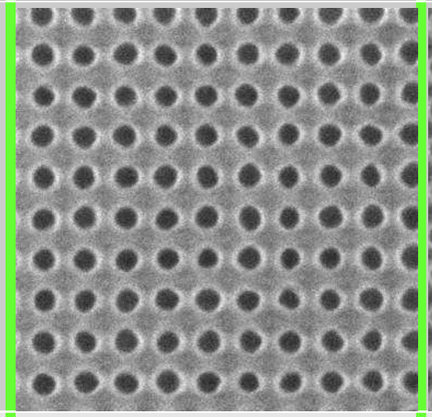
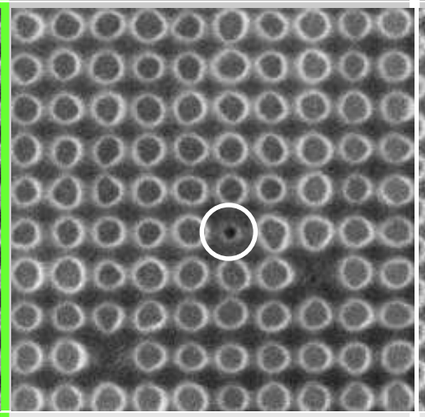
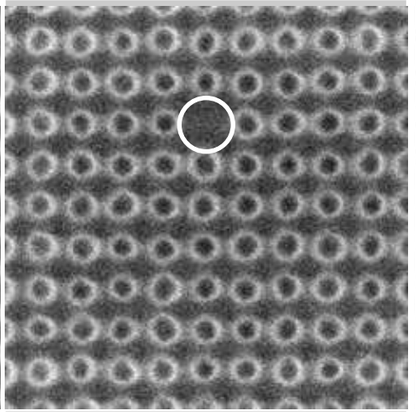
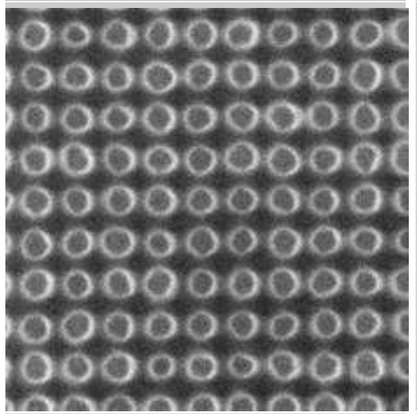
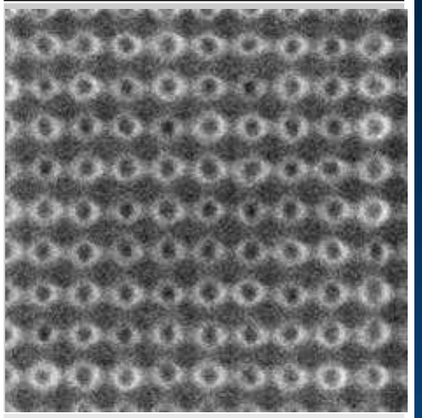
- ➢Conclusions & Next Steps

Comparison of Champion Results

34P60 → 30hp

Resist	PTD	Gen-3 NTD	Gen-3 NTD	Gen-4 NTD	Gen-4 NTD
Shrink	NO	NO	YES , Shrink A, Std FT	NO	YES , Shrink B, Std FT
NXE Illumination	Conventional	Quasar	Quasar	Quasar	Quasar
Image (Top-Down @ 230k; 2nd Image @ 300k)					
Esize (mJ/cm2)	17.0	15.8	14.4 (9 % ↓)	20.8	18.3 (12% ↓)
CD (nm)	30.4	30.7	24.7	27.2	27.6
Normalized Exposure Time	1.00	1.65	1.55 (6 % ↓)	1.90	1.75 (8 % ↓)

- Move from Gen-3 to Gen-4 resist platform decreased missing C/H rate (but increased Esize).
  - DSA Blend agent does not increase missing hole rate when target CD > 20-25 nm.

➢Champion EUVL Process Remains Positive Tone Resist.

Summary

- NTD resists have recently realized good progress to 30P60.
- Ideal bias for NTD (as well as NTD+DSA process) is ~13 - 30 %

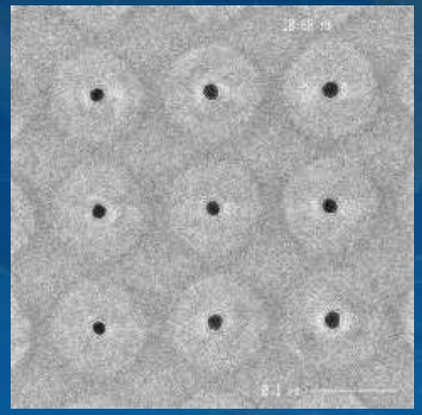
➢ Best NTD performance to date comes from Gen-4 resist, developer-2, and NXE3100 Quasar illumination.

- Novel DSA blended shrink agents can provide ~10-35% improvement vs. NTD alone.
- DSA optimization = Shrink FT > Resist FT >> Resist Anneal > Shrink Anneal.
- Using 193i, we have illustrated a 55% integrated shrink following dielectric etch using a similar blended DSA shrink agent.

➢ While our best results to date show that PTD is still the primary EUVL solution, alternative options are quickly maturing.

Next Steps

- **NTD Resist**
  - Understand NTD outgassing & WP contamination rate. (& Improve…)
  - Correlate mask measurements to design and wafer level observations.
  - Use stochastic resist model to understand potential areas for material and / or process improvement.
  - Once resolution of NTD resist(s) warrants it, use OAI to push patterning limits.
- **DSA Shrink Agent**
  - Validate pattern transfer for EUVL-patterned + DSA blended shrink wafers.
  - Understand how material or process optimization can push to CDs < 20-25 nm or 2-5 beard seconds[#].
- **IMEC DSA Electrical Test Vehicle**
  - SPIE'13 :: Use IMEC e-test vehicle to evaluate process flows having blended DSA agent to those using a block copolymer (BCP).



1900i
Graphoepitaxy
71P130 → 18P130
or 1.8 beard seconds

[#] *http://en.wikipedia.org/wiki/List_of_humorous_units_of_measurement#Beard-second*

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AZ Electronic Materials

Brewer Science, Inc.

Fujifilm Holdings Corporation

JSR Corporation

Nissan Chemical

TOK (Tokyo Ohka Kogyo Col, LTD)

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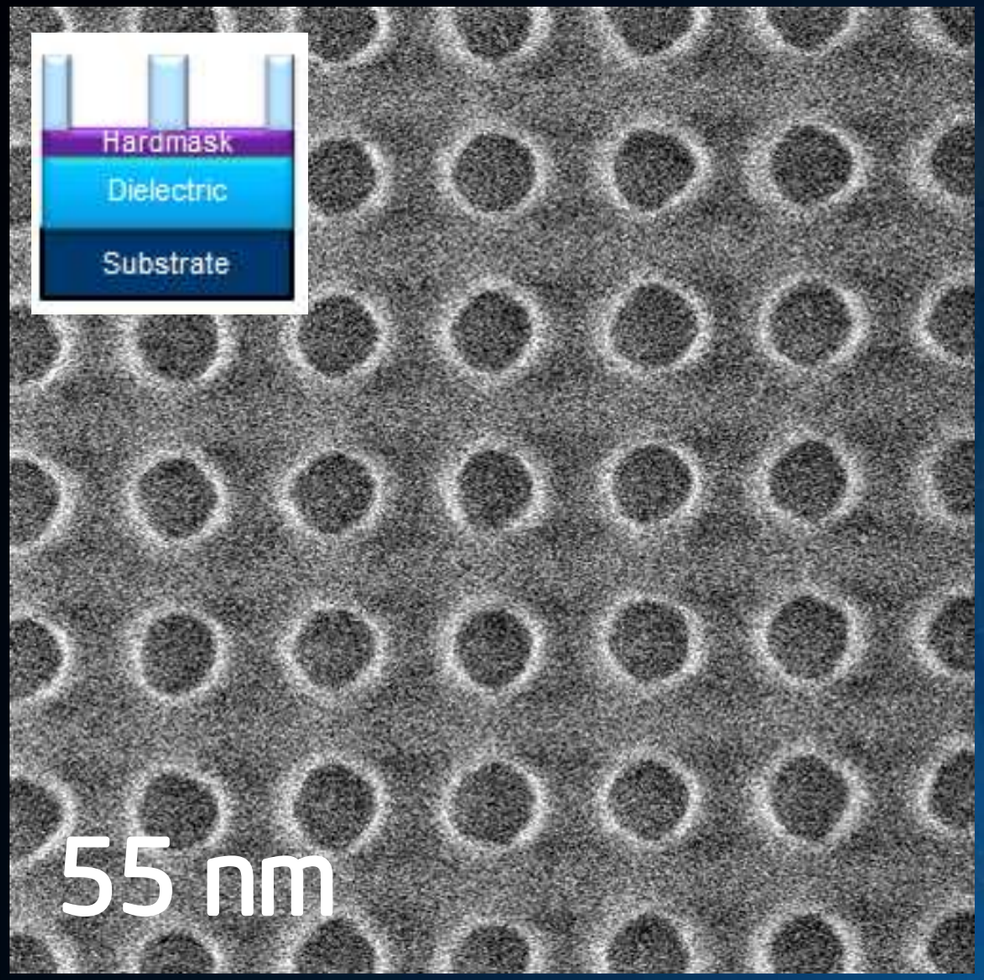
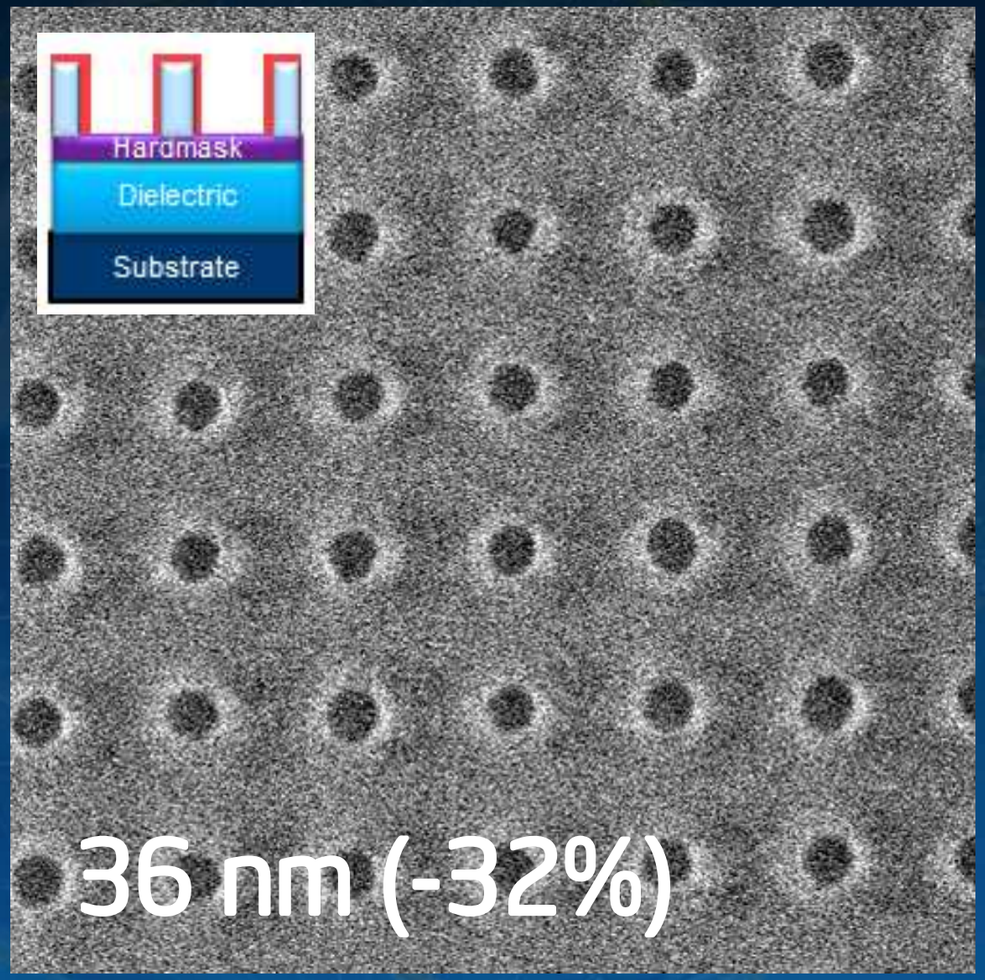
- **Mary's Furtive!**
  - Fresh vanilla cream dusted with speculoos

- Mary's (www.mary.be) is located in the Galerie de la Reine (Glass Gallery near the Grand Place) ::
  - 36 Galerie de la Reine, 1000 Brussels

Thank You,
Merci, &
Dank U!

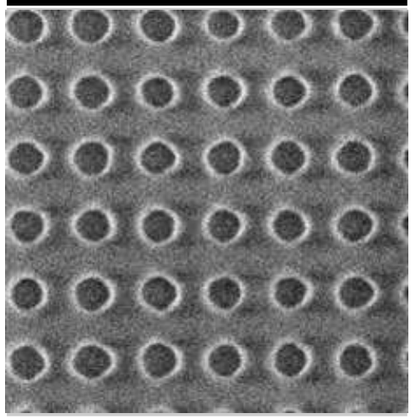
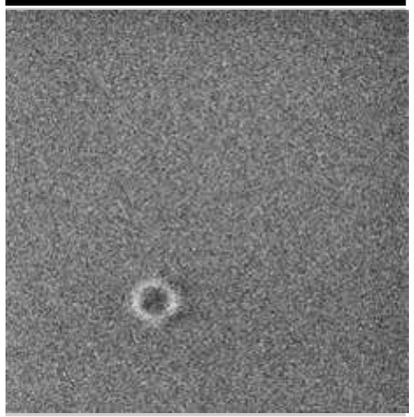
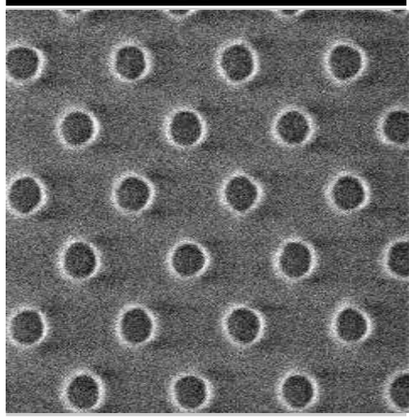
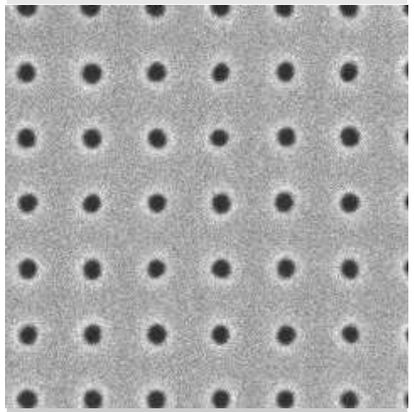
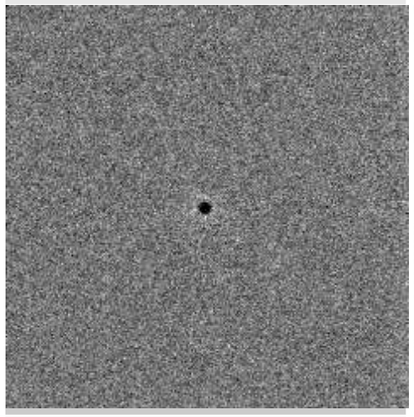
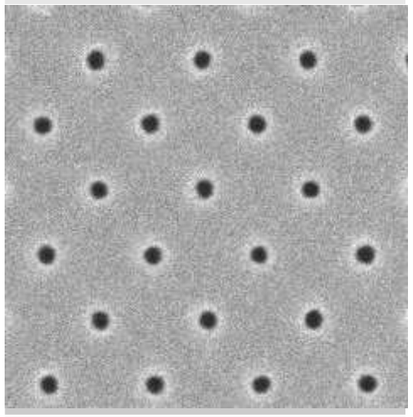
193i + DSA Shrink :: IMEC Integrated Efforts





- Representative performance of DSA shrink agent for 55P110 on IMEC 1950i.

193i + DSA Shrink :: IMEC Integrated Efforts

Feature	Dense	Isolated	Staggered
After Litho (Pre-DSA Shrink)			
CD (nm)	50.4	41.9	51.5
After Dielectric Etch			
CDU (nm)	29.1	20.2	26.9
Shrink (%)	42%	52%	48%

➢ Characterizing a variety of features to understand iso-nested performance for DSA blended shrink process.