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*EUVL Symposium 2012*

# Enhancing Resolution of the Albany Alpha-Demo Tool (ADT) with Pupil Filtering

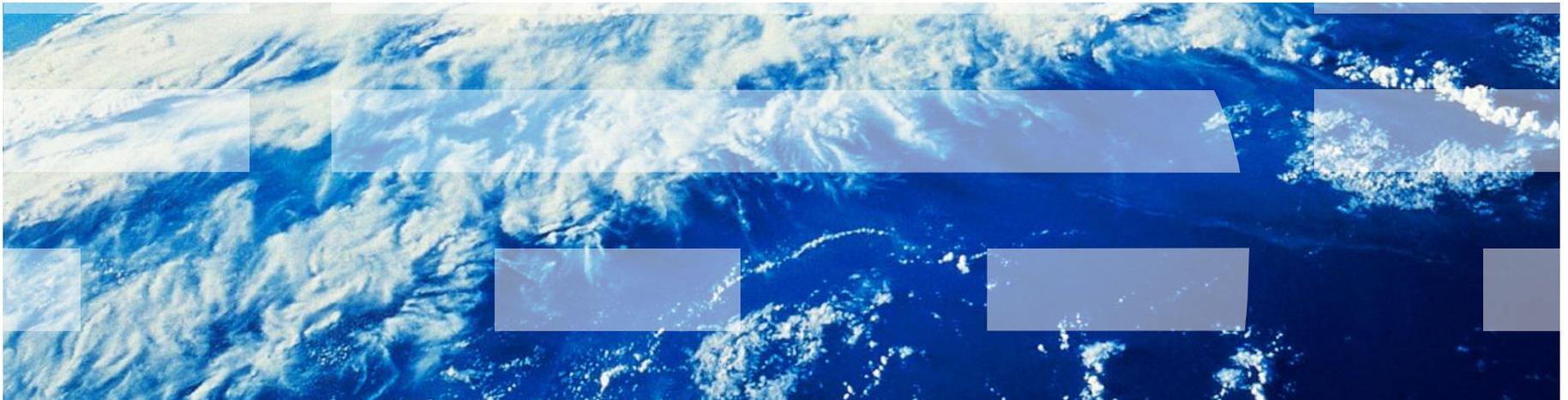
Gregory McIntyre<sup>a</sup>, Leon Teeuwen<sup>b</sup>, Obert Wood<sup>c</sup>, Erik Sohmen<sup>d</sup>, Daniel Corliss<sup>a</sup>, Theo van den Akker<sup>b</sup>, Sander Bouten<sup>b</sup>, Eelco van Setten<sup>b</sup>, Oleg Voznyi<sup>b</sup>, Sang-In Han<sup>b</sup>, Hermann Bieg<sup>d</sup>, Martin Burkhardt<sup>a</sup>, Karen Petrillo<sup>a</sup>, Alexander Friz<sup>a</sup>

<sup>a</sup> IBM Corporation, Albany Nanotech, Albany, NY 12203

<sup>b</sup> ASML, Albany Nanotech, Albany, NY 12203

<sup>c</sup> GLOBALFOUNDRIES, Albany Nanotech, Albany, NY 12203

<sup>d</sup> Carl Zeiss SMT GmbH, Oberkochen, Germany



# Motivation & Outline

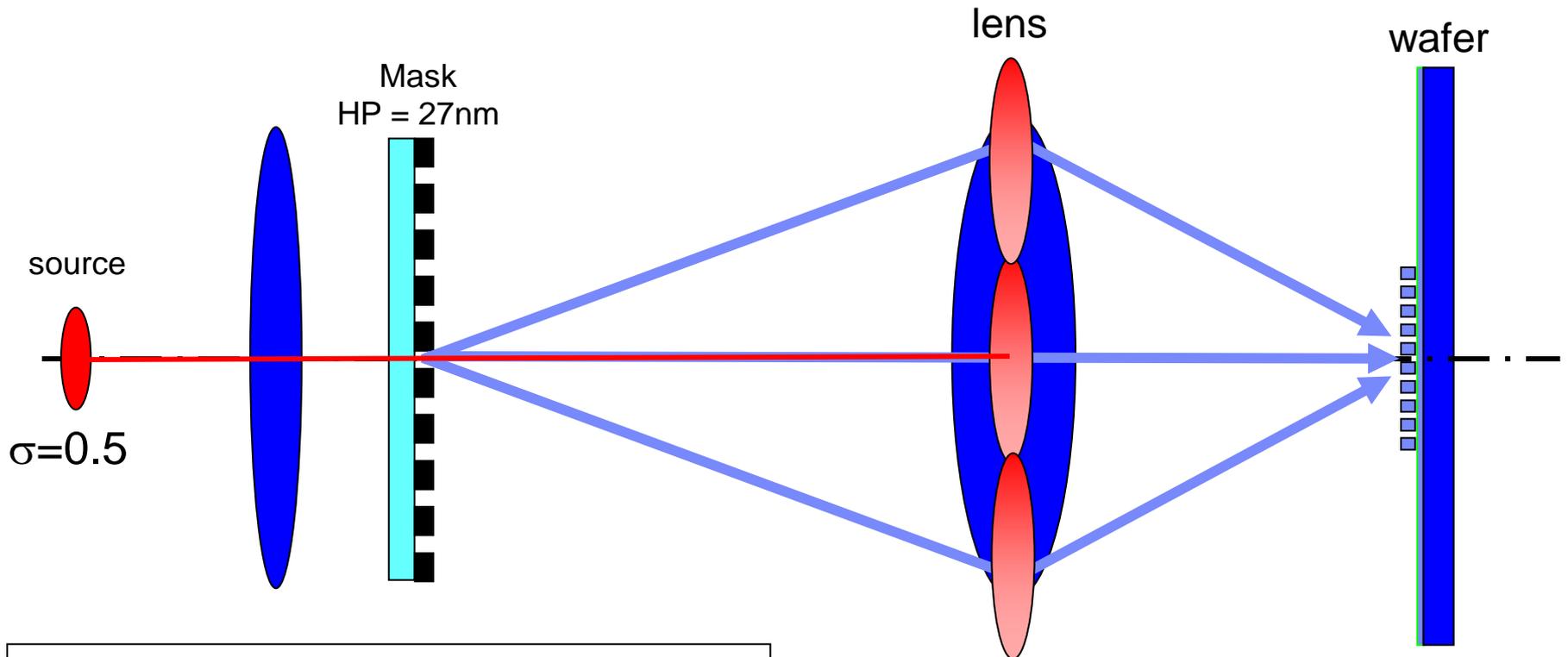
**Motivation:** Enable next-node process development at select features beyond the resolution limit of current tooling

## Outline:

- ❖ Theory
  - ❖ Pupil filter concept
  - ❖ Optimum pupil filter designs
    - Standard imaging filters
    - Frequency doubling filters
- ❖ Experimental results
  - ❖ 22nm HP line-space
  - ❖ 24nm HP contacts
  - ❖ Areas of development
- ❖ Summary

# Traditional imaging (ADT > 27nm HP)

- Source is fixed tophat with  $\sigma=0.5$
- All on-axis illumination rays contribute to imaging

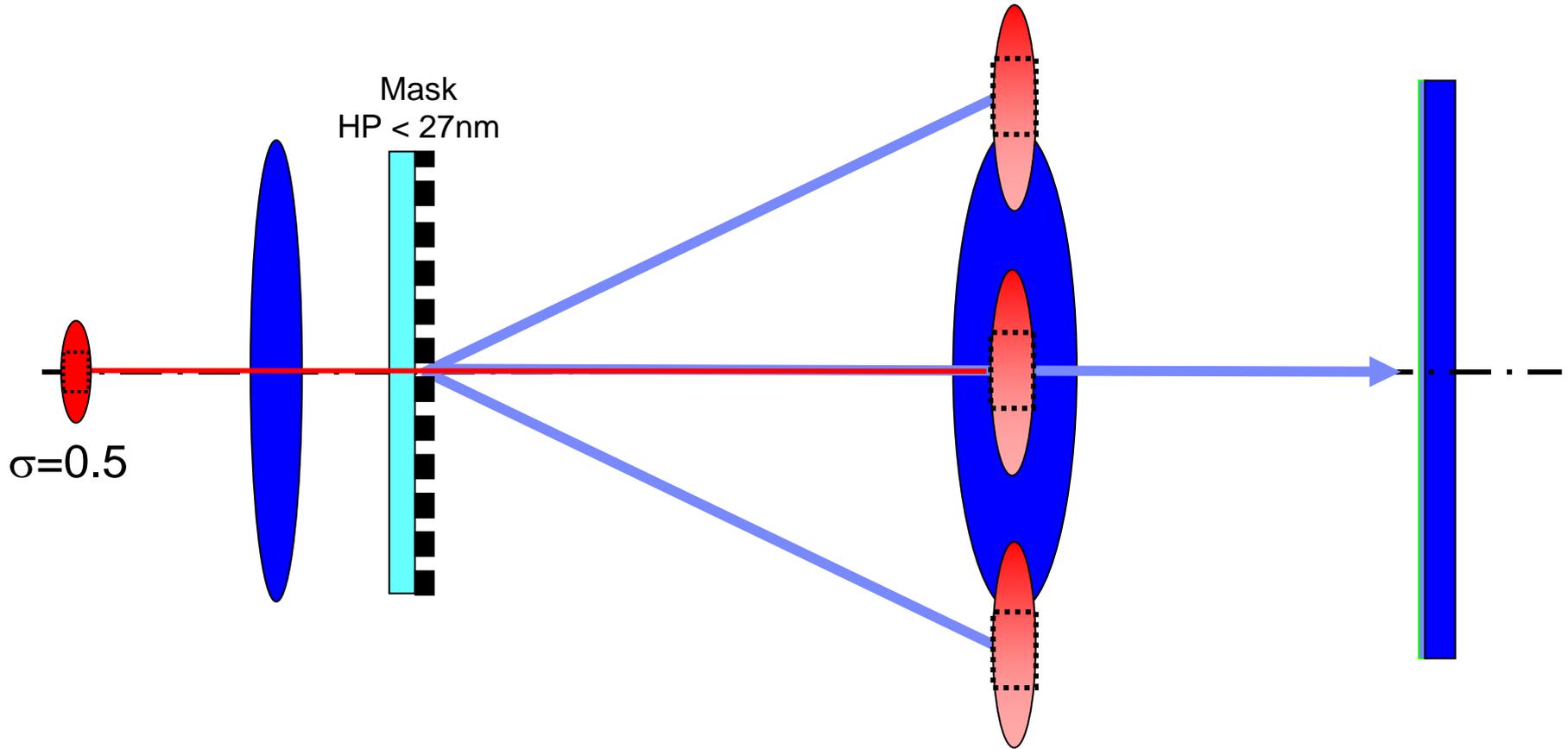


$$L_w(\text{min}) = 0.5 \frac{\lambda}{NA} = 27 \text{ nm}$$

**3 beam imaging**

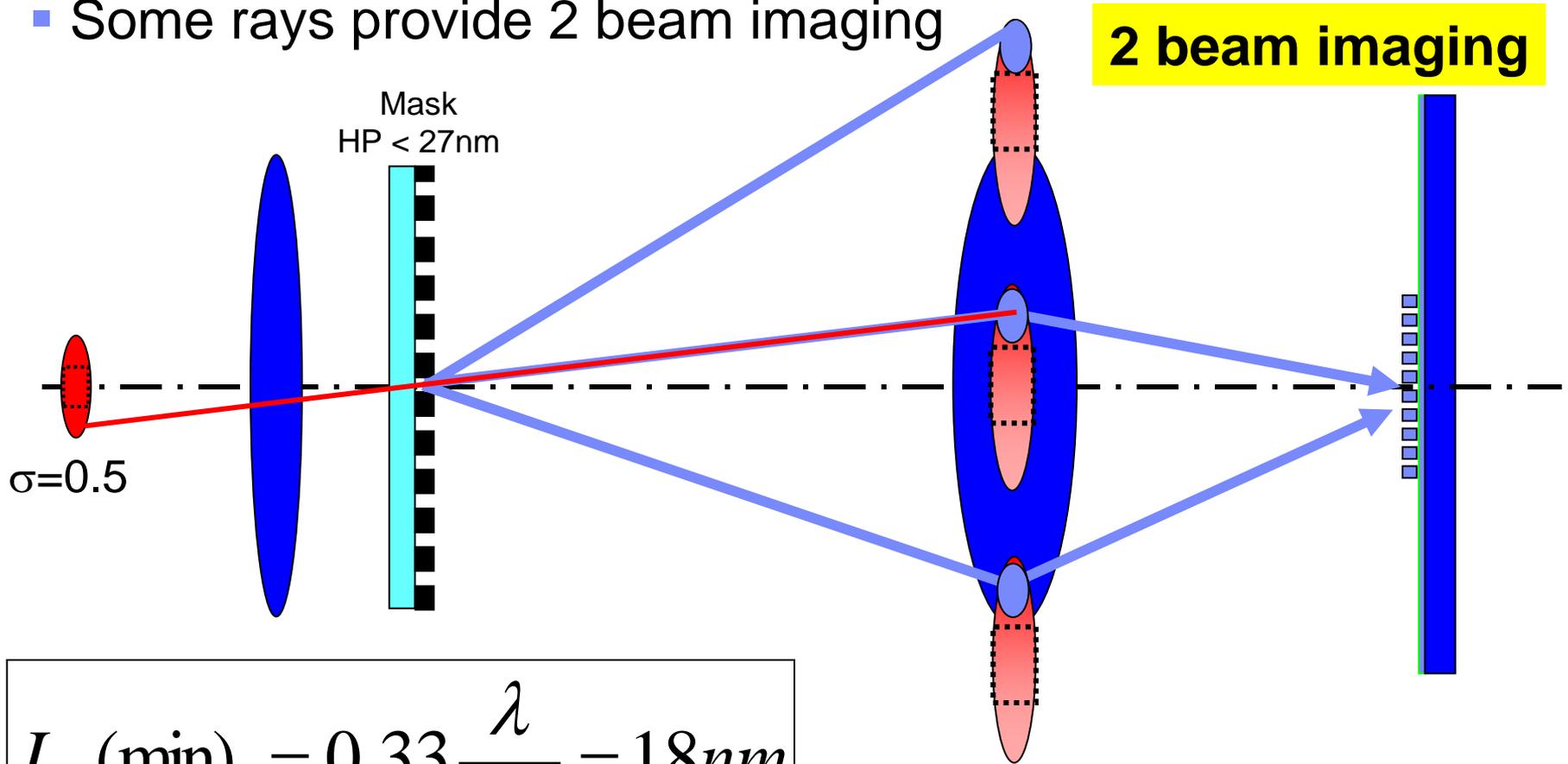
# Traditional imaging: Reduce HP below 27nm

- Central bundle of rays do not image
- They provide DC background & reduce image contrast



# Traditional imaging: Reduce HP below 27nm

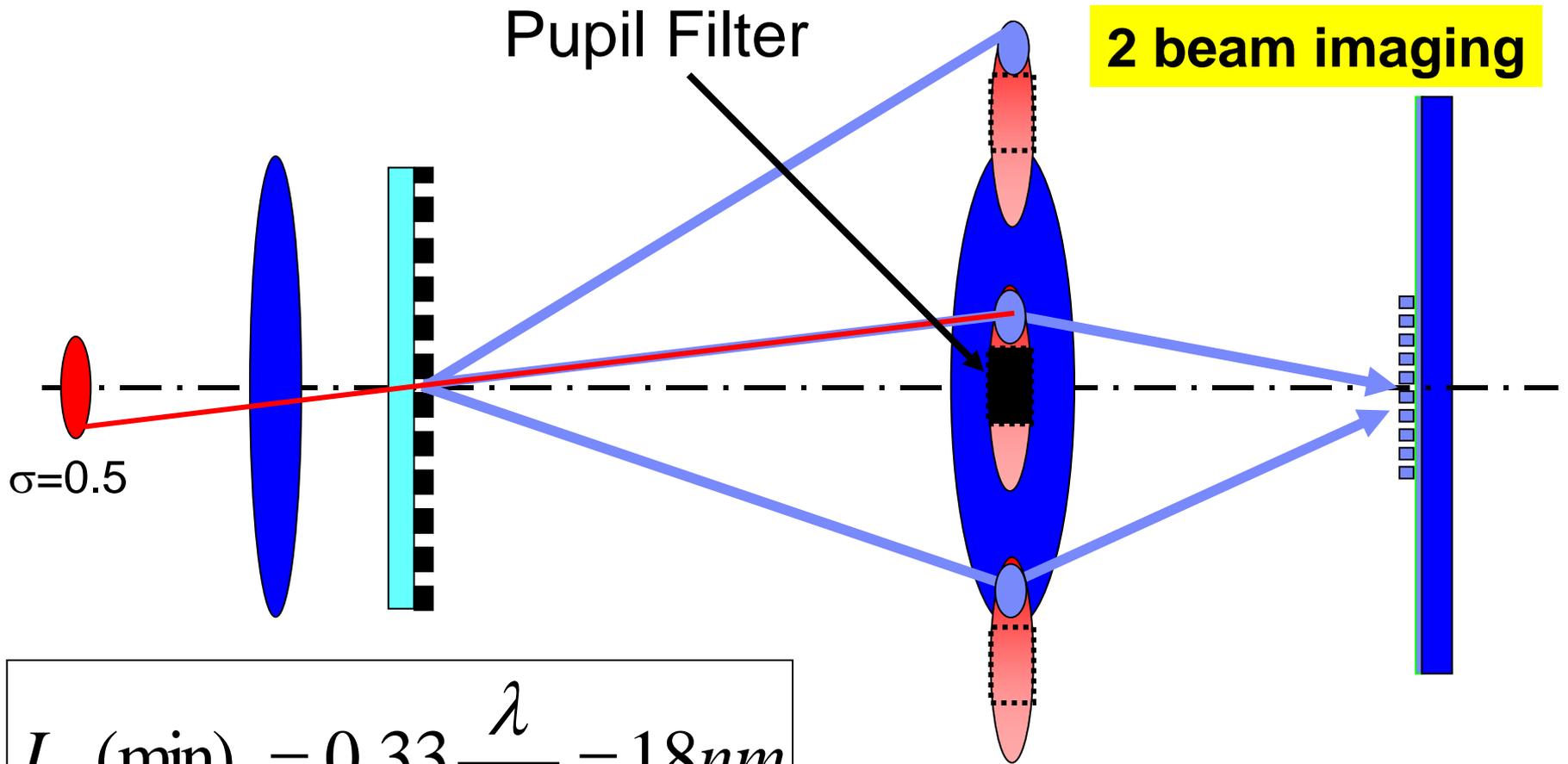
- Central bundle of rays do not image
- They provide DC background & reduce image contrast
- Some rays provide 2 beam imaging



$$L_w(\text{min}) = 0.33 \frac{\lambda}{NA} = 18\text{nm}$$

# Concept: standard filter

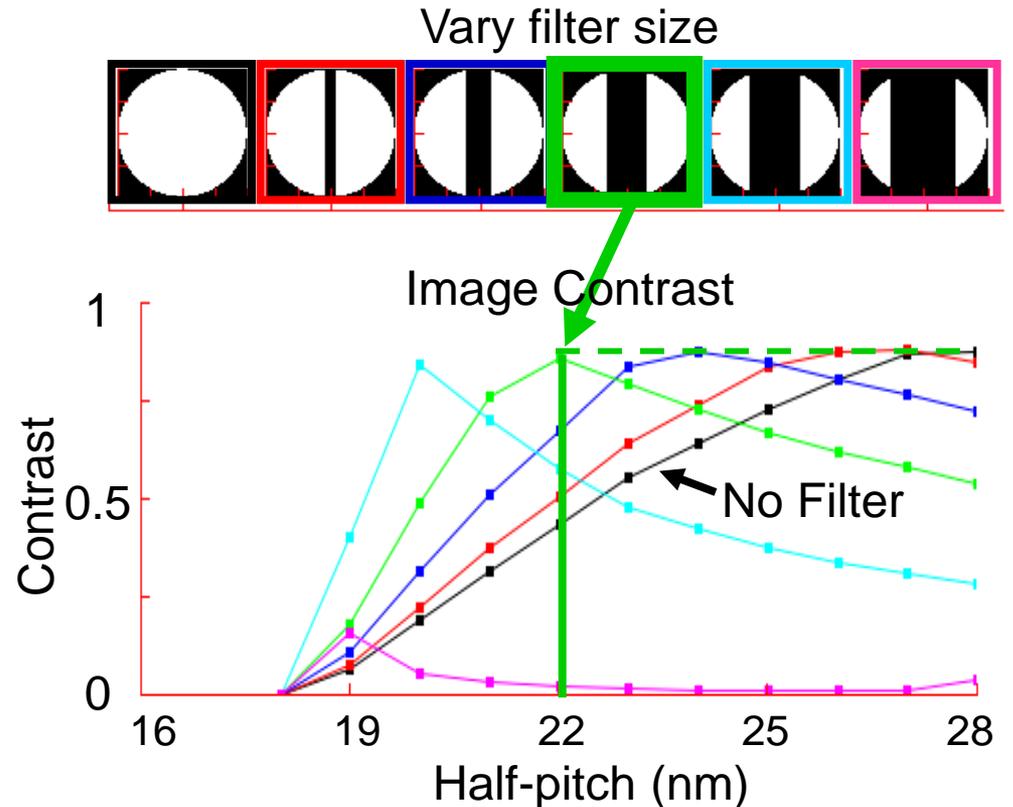
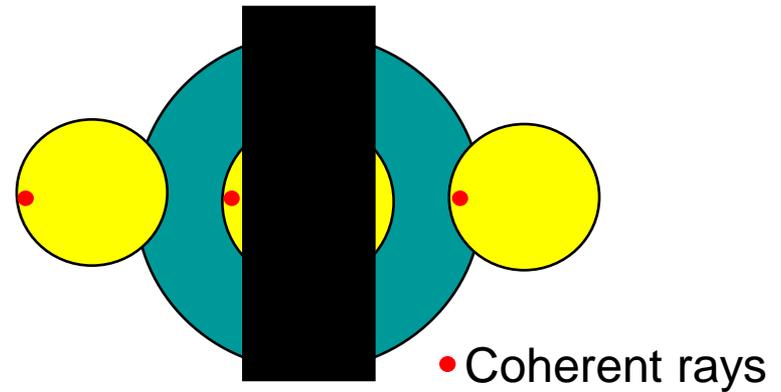
- Eliminate rays that do not contribute to imaging



$$L_w(\text{min}) = 0.33 \frac{\lambda}{NA} = 18\text{nm}$$

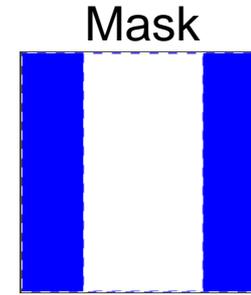
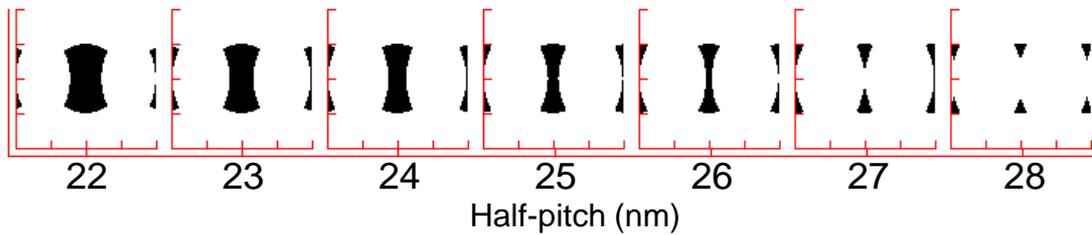
# Concept: standard filter

- Simple rectangular example
- Optimum filter size exists for each pitch
- 22nm HP with filter provides comparable contrast to 28nm HP without filter
- Exact benefit will depend on capabilities of resist

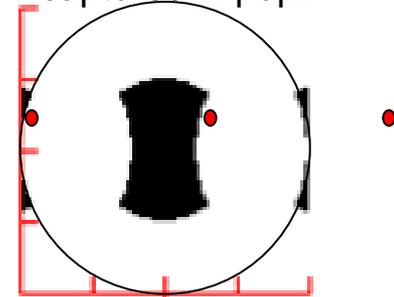


# Optimized line-space filter (standard imaging)

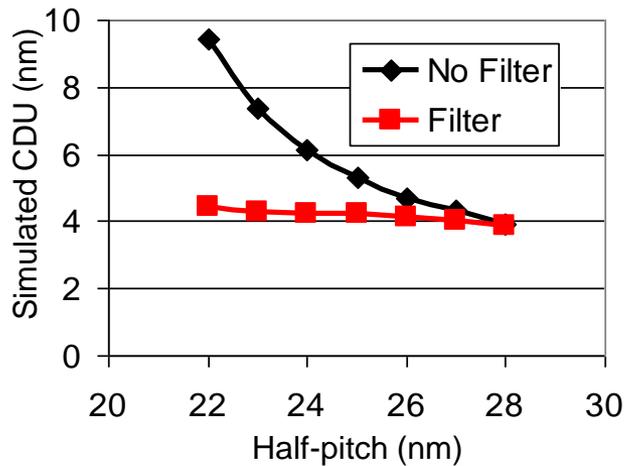
Filter design through pitch



Ensure 1<sup>st</sup> order captured in pupil

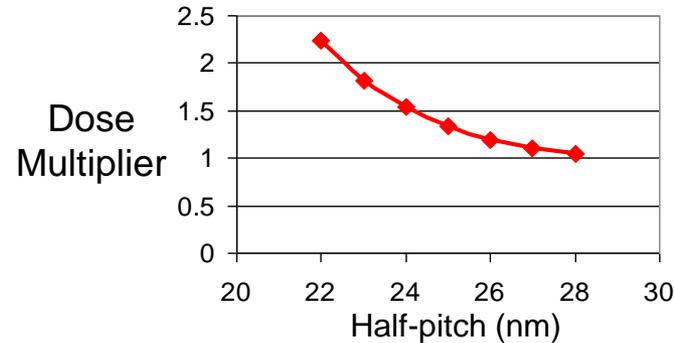


- Good resolution and good CD Uniformity to 22nm HP

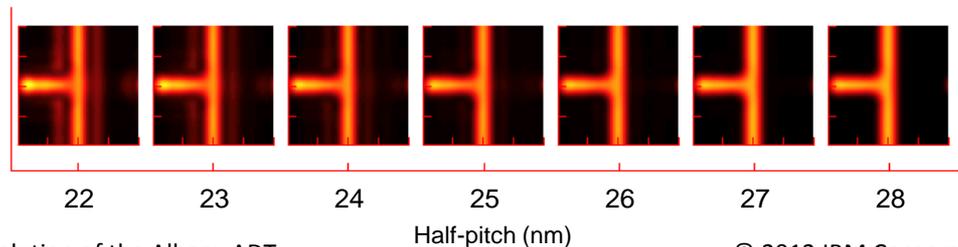


Dose +/- 5%  
Mask Error +/- 0.5nm  
Focus Error +/- 40nm

- Increase in dose required ~2.2x for 22nm HP

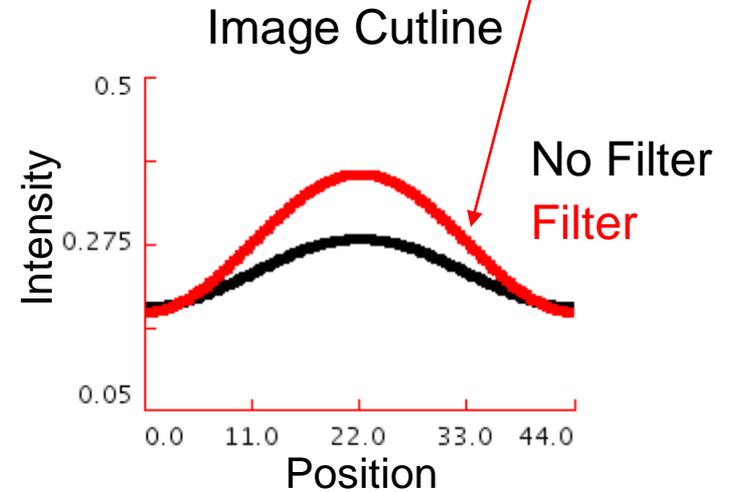
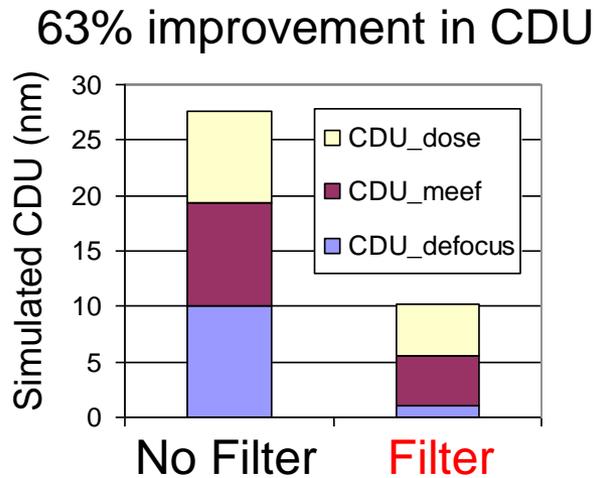
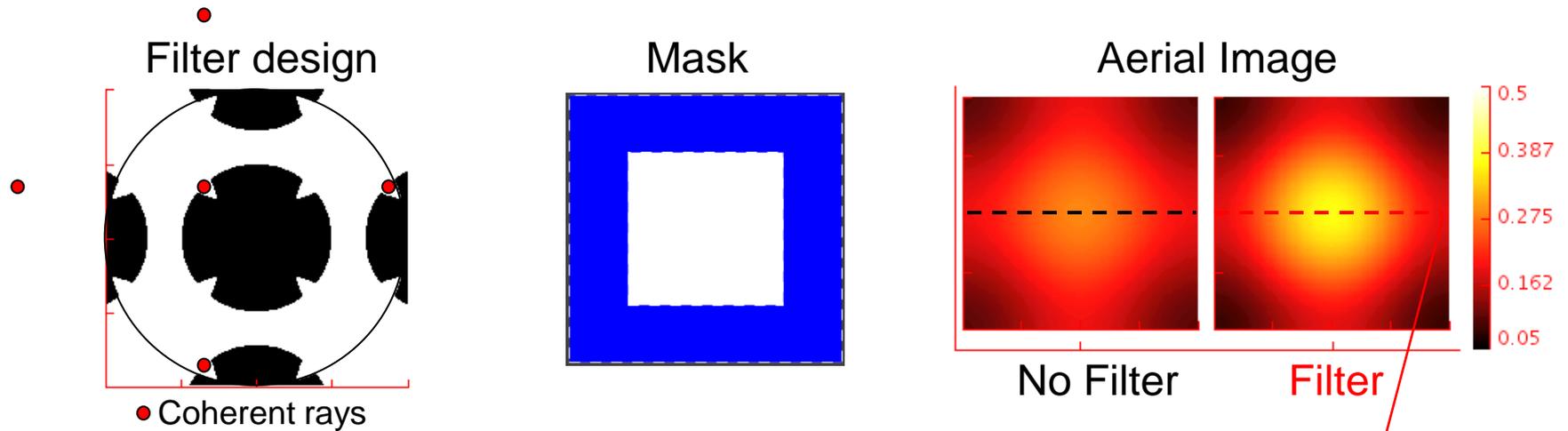


- Acceptable imaging of isolated features (i.e. SEM marks, Reticle align marks, etc.)



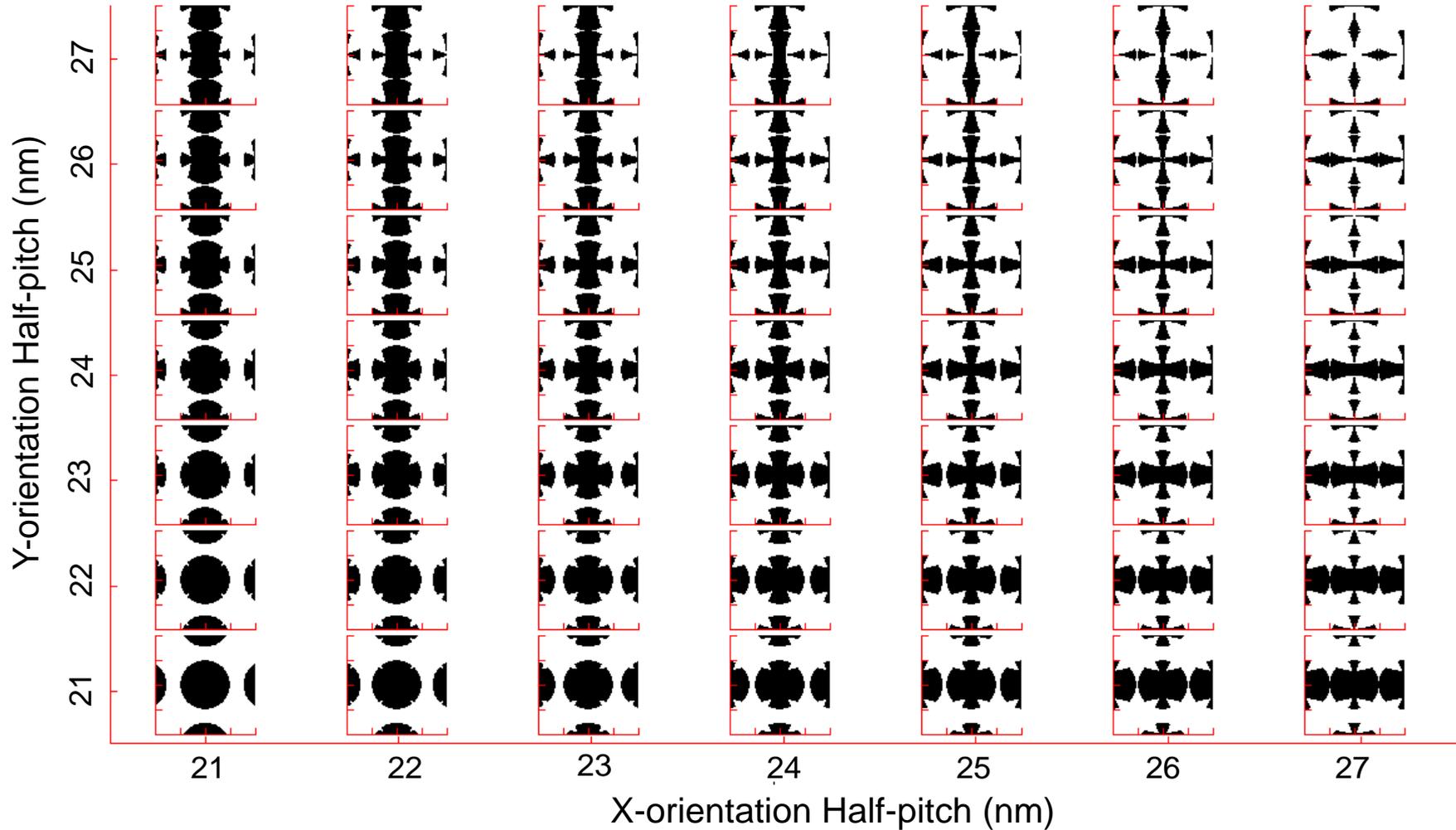
# Optimized contact filter (standard imaging)

- 22x22HP Contact, capture minimum 1 order in each X and Y orientation



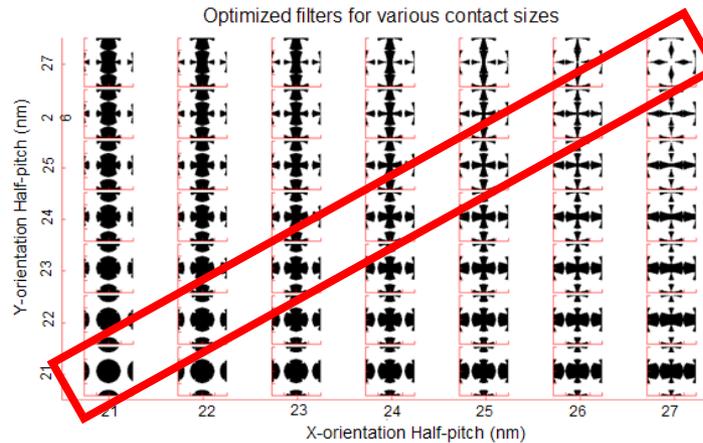
# Optimized contact filter (standard imaging)

Optimized filters for various contact sizes



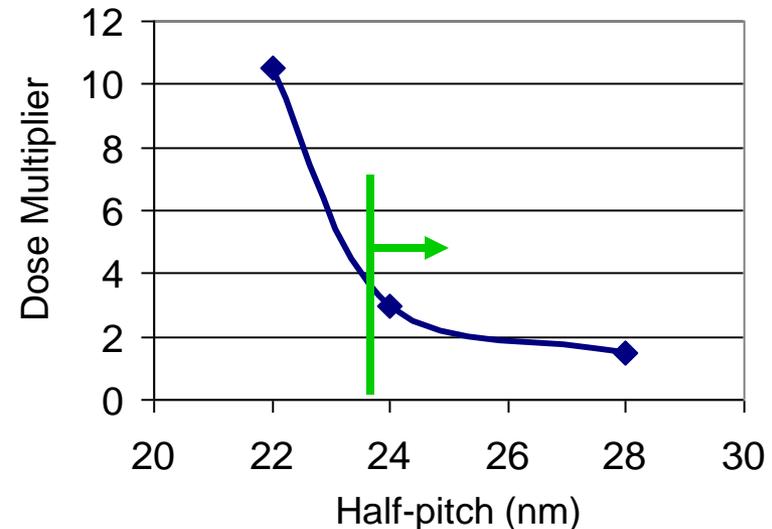
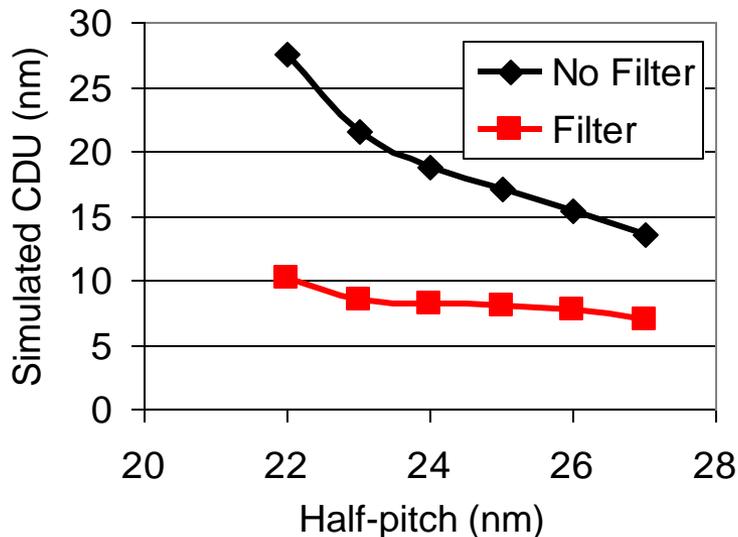
# Optimized contact filter (standard imaging)

## Square Contact Filters



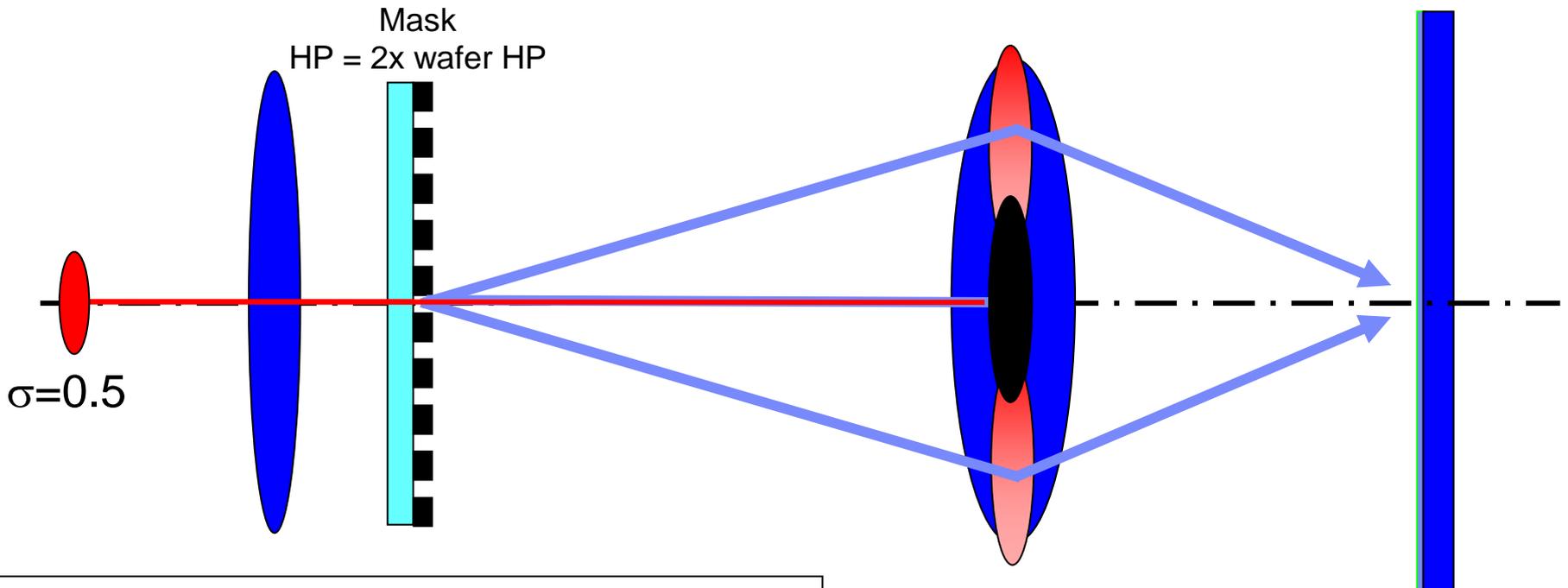
- Good resolution and good CDU to ~22nm HP

- Required dose increase likely limits minimum HP to ~24nm



# Concept: frequency doubling filter

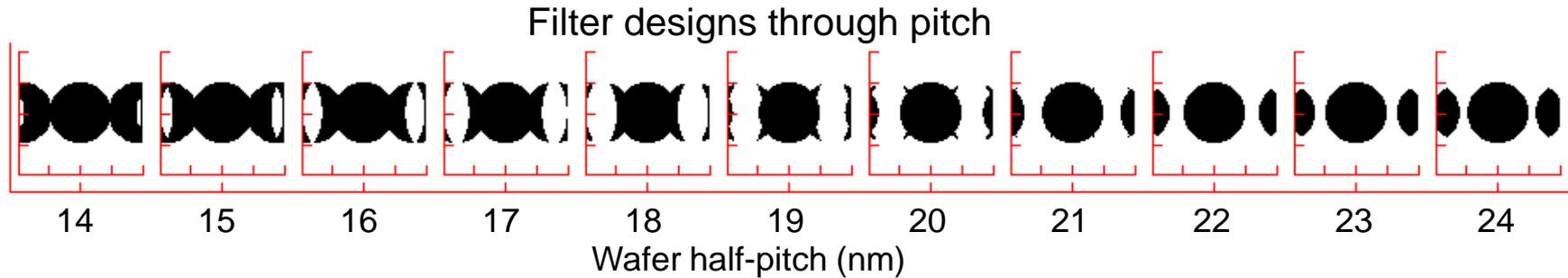
- Increase mask pitch, block all of 0<sup>th</sup> order
- Wafer pitch is frequency doubled (similar to ALT-PSM imaging)



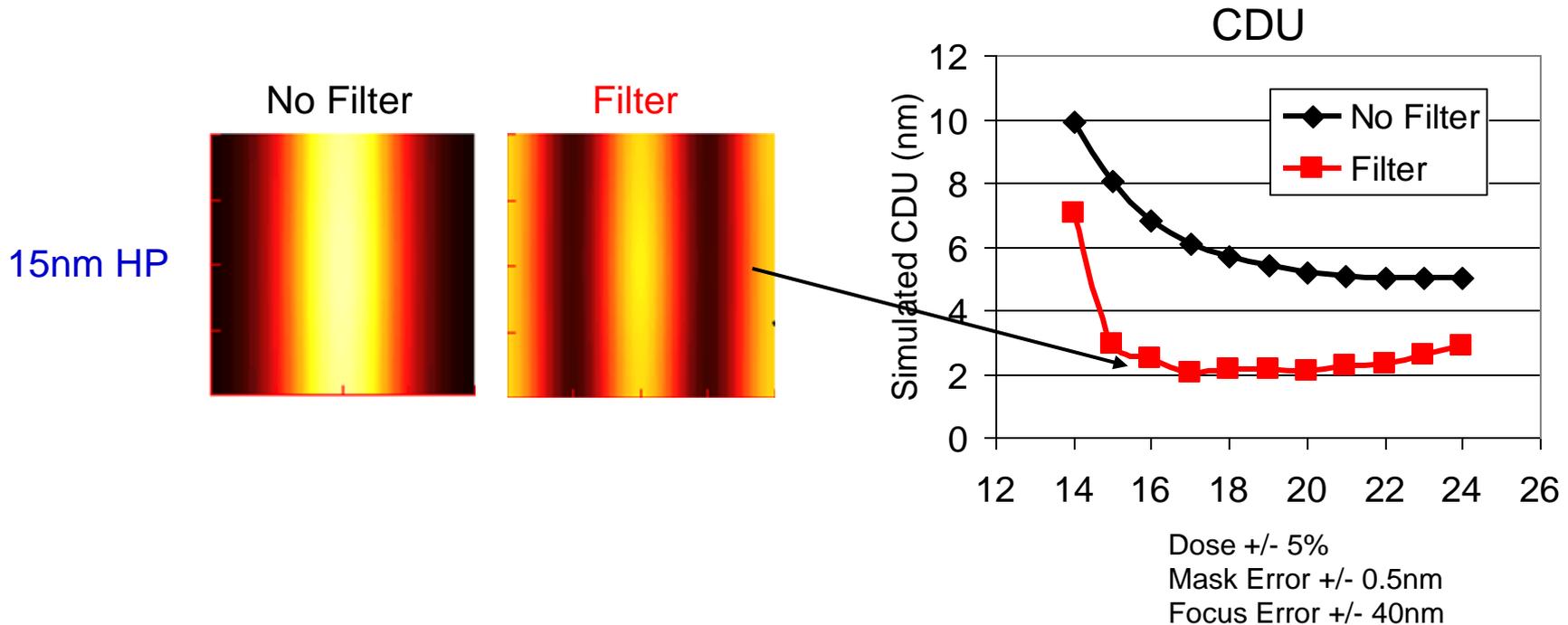
$$L_w (\text{min}) = 0.25 \frac{\lambda}{NA} = 13.5 \text{nm}$$

**Freq. Doubled  
2 beam imaging**

# Frequency doubling filter (1D line-space)

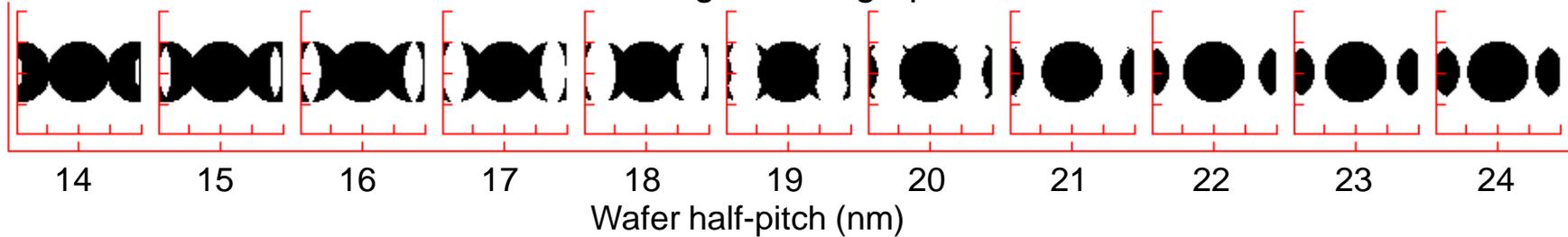


- Very small resolution and great CDU to ~15nm HP

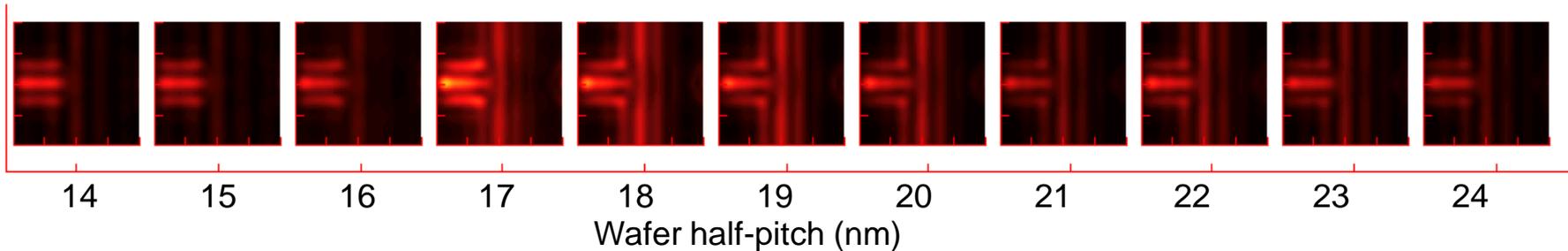


# Frequency doubling filter (1D line-space)

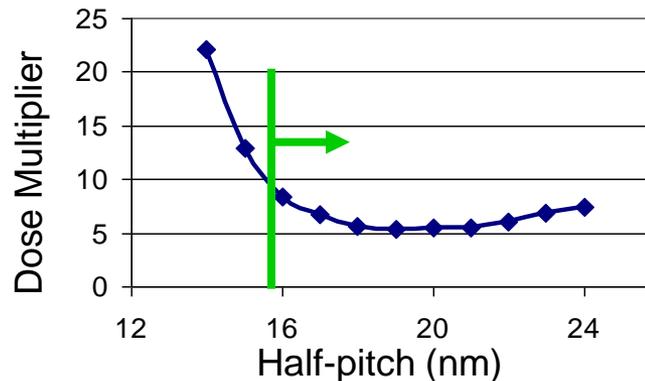
Filter designs through pitch



- Poor printing of isolated features (requires alternate strategies for reticle alignment, SEM navigation, etc.)

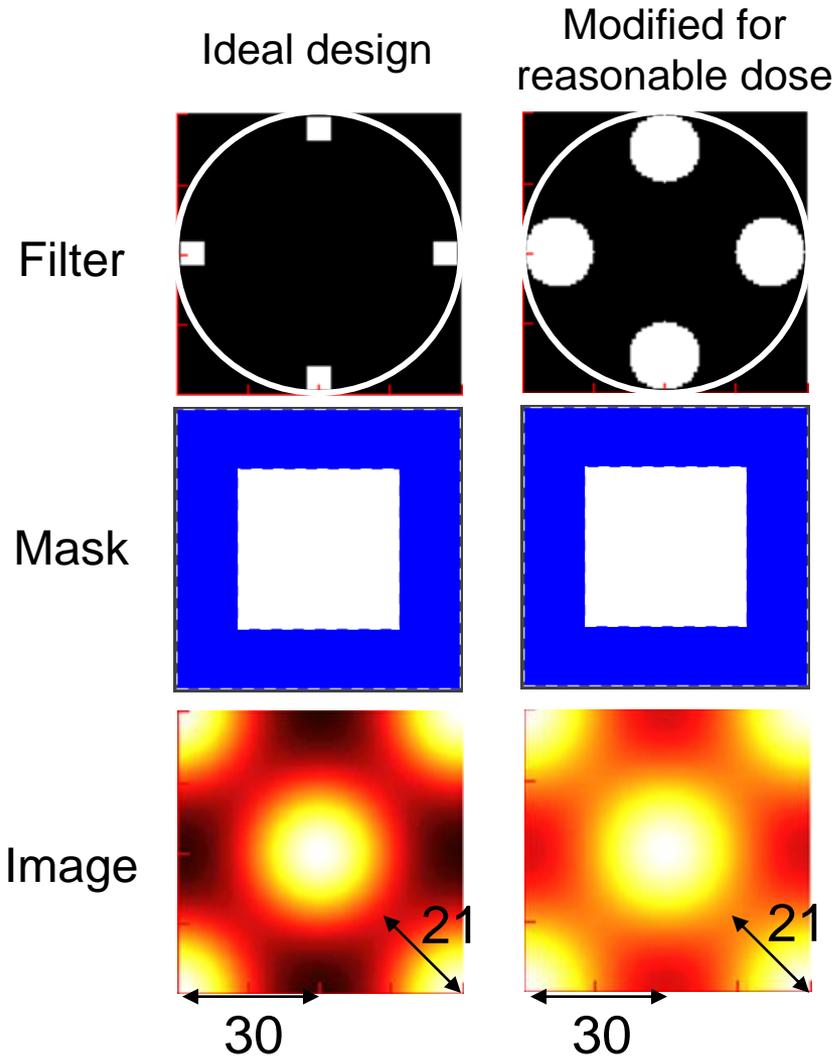


- Reasonable dose multiplier down to ~16nm HP



# Frequency doubling filter (contacts)

- 30nm HP square array on mask produces 21nm HP staggered array



Through pitch with modified filter

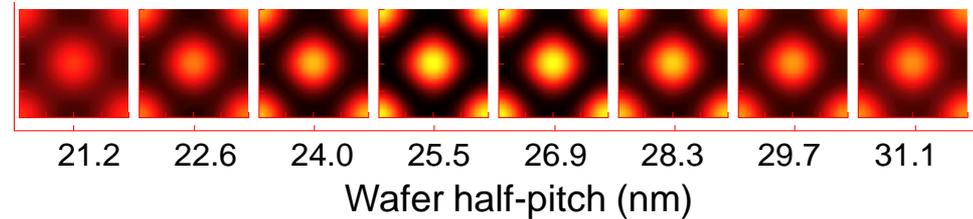
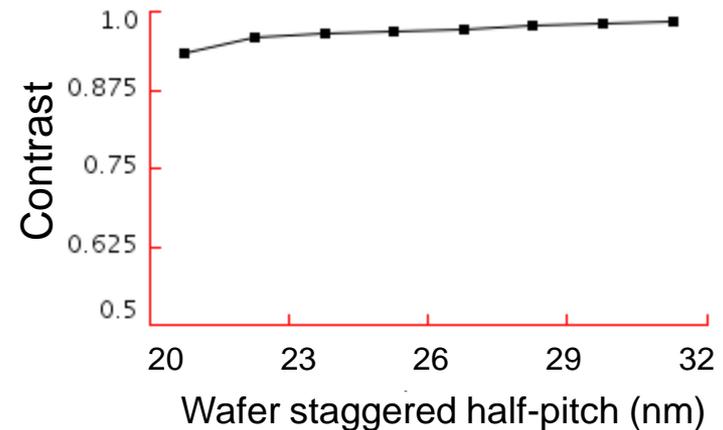


Image Contrast



# Motivation & Outline

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# 6 Filter designs being tested experimentally

Filter #	1	2	3	4	5	6
Half-pitch	22LS	24CH	22LS	27x22CH	19LS	21CH
Filter Design						
Feature	line-space	contact	line-space	contact	line-space	line-space
Type filter	standard	standard	standard	standard	freq double	freq double
Status	installed	installed	<p>In final processing, expected Oct '12</p>			

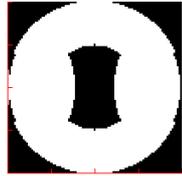
# Hardware enablement on ADT

- Development and installation of hardware solution (NA Handler) complete
- Modified hardware originally designed to allow multiple NA settings
- ADT-specific hardware solution

NA handler

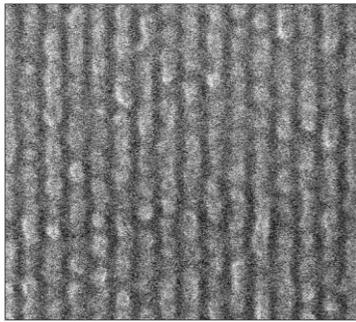


# Pupil filter validation (22nm HP Line-space)

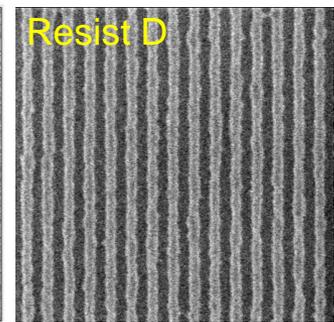
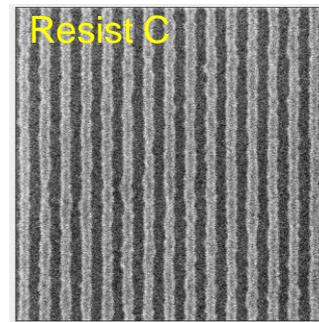
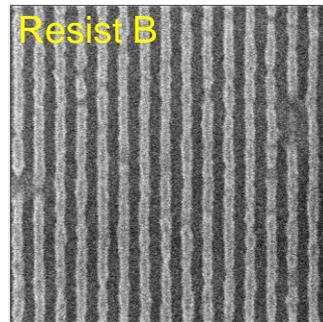
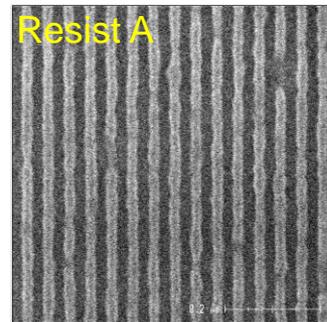


- Concept validated, showing ~20% improvement in ADT resolution
- Resist process evaluation and development has begun

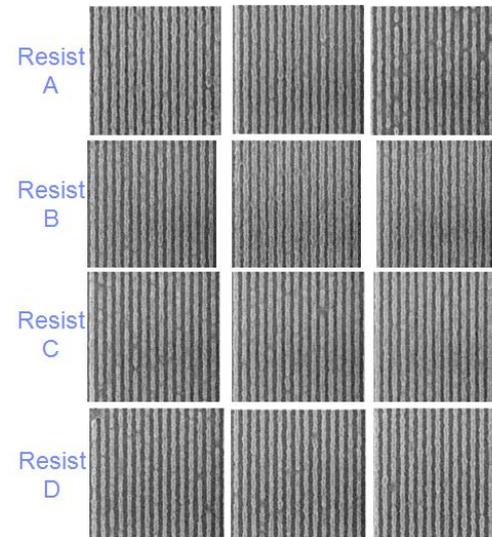
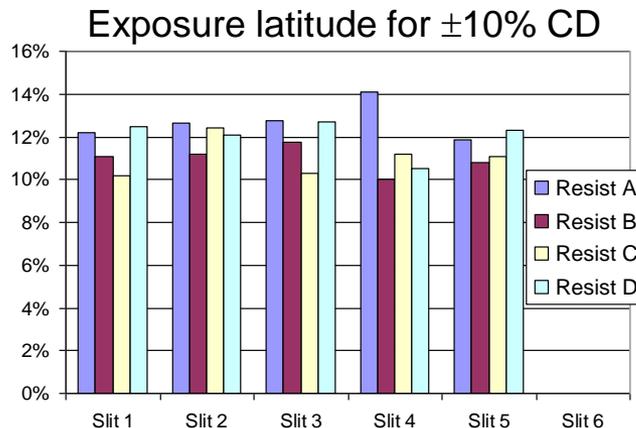
No Filter



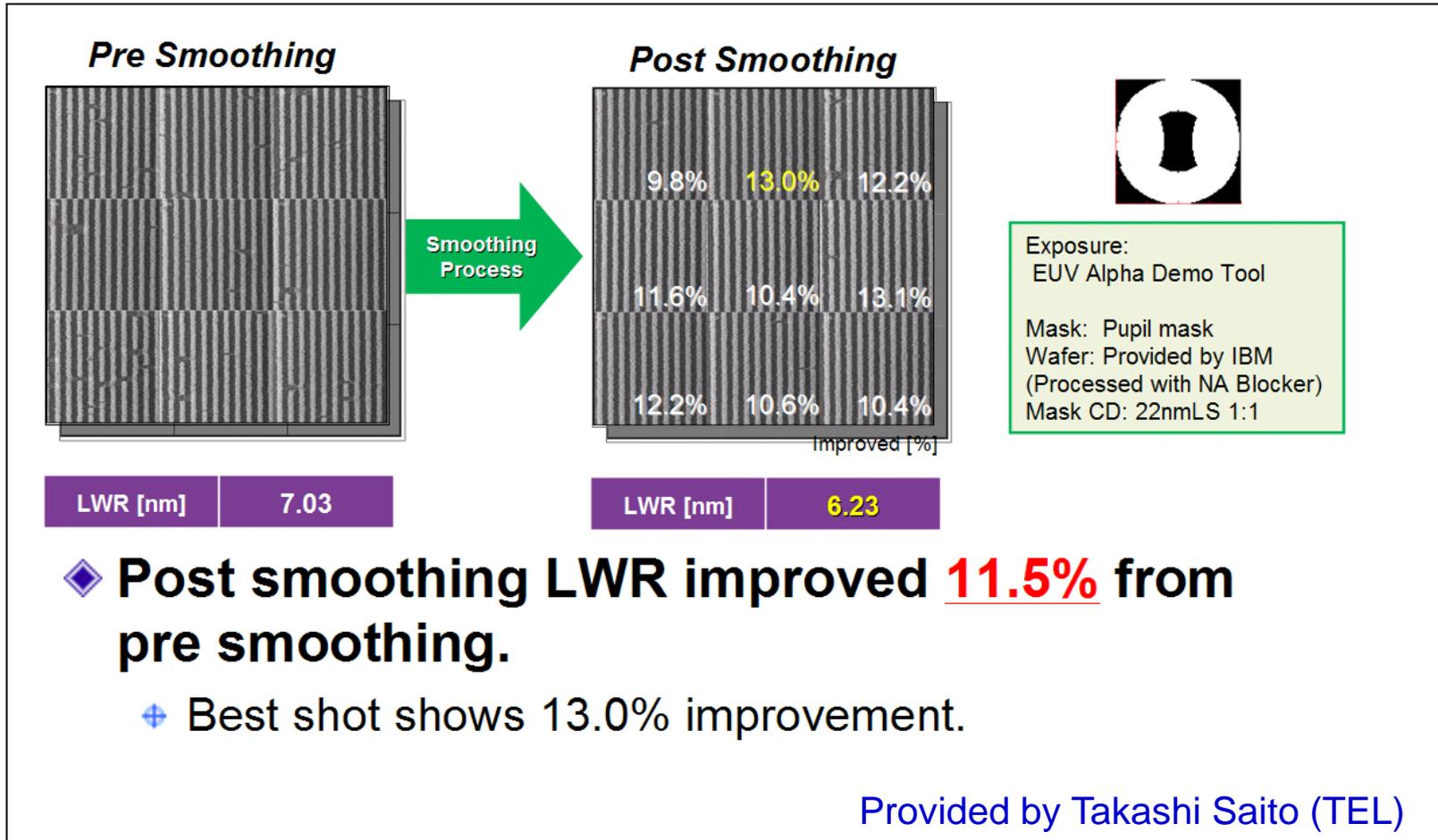
With Filter



- >10% Exposure latitude for  $\pm 10\%$  CD



# Resist process optimization ongoing



See also: Jun Hatakeyama, et al., "Reduction of LWR by Advanced Polymer bound PAG based EUV resist" EUVL Symposium, 2012

# Mask LER transfer study with pupil filters

## Impact of EUV photomask line edge roughness on wafer prints

Zhengqing John Qi\*<sup>a</sup>, Emily Gallagher <sup>a</sup>, Amy Zweber <sup>a</sup>, Yoshiyuki Negishi <sup>b</sup>, Tasuku Senna <sup>b</sup>,

Satoshi Akutagawa <sup>b</sup>, Toshio Konishi <sup>b</sup>, Gregory McIntyre <sup>c</sup>

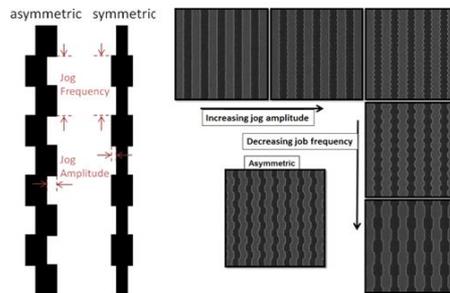
<sup>a</sup> IBM Microelectronics, 1000 River St., Essex Junction, VT 05452

<sup>b</sup> Toppan Photomasks Inc., 1000 River St., Essex Junction, VT 05452

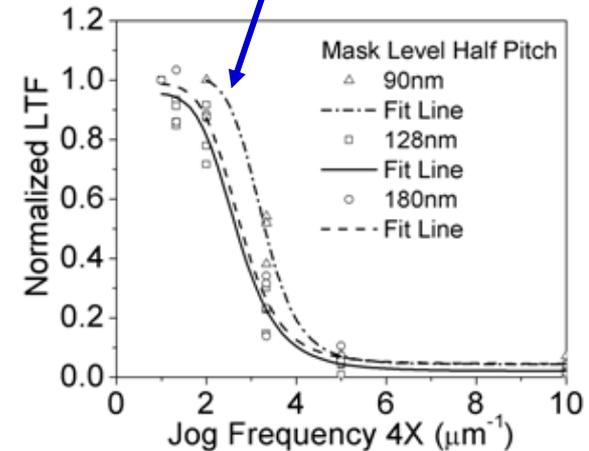
<sup>c</sup> IBM Microelectronics, 255 Fuller Road, Albany Nanotech, Albany, NY 12203



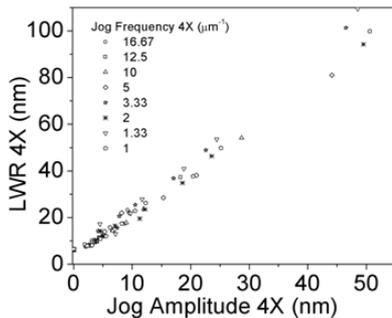
### Programmed LER Mask



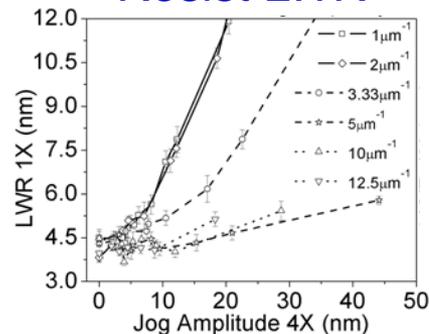
### Photomask LER Transfer Function with Pupil Filter (22HP)



### Mask LWR



### Resist LWR

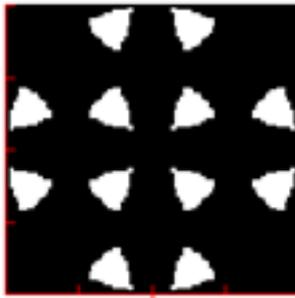


SPIE Photomask 2012

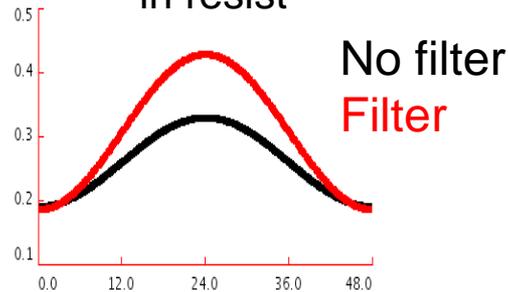
# 24nm HP contacts

- 24nm HP contact filter (15% improvement in ADT resolution)

Filter design



Simulated image in resist

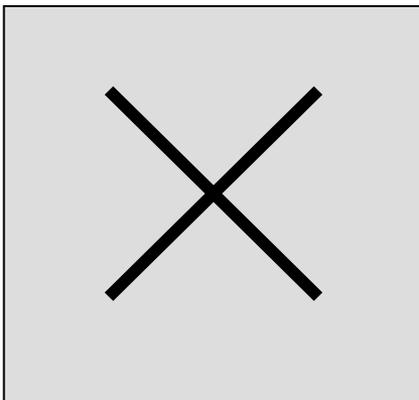


Fabricated filter

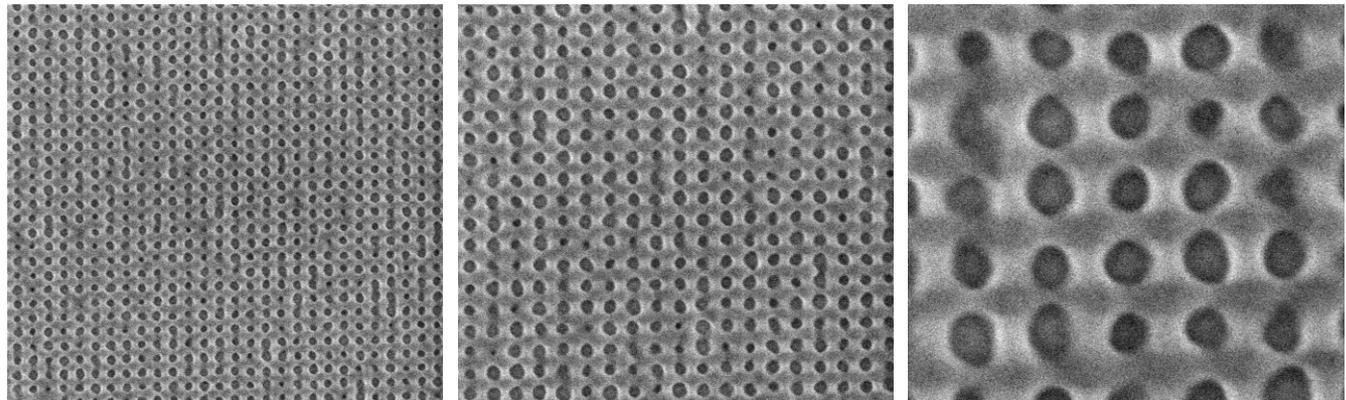


- Successful printing in resist; beginning process development

No Filter



With Filter

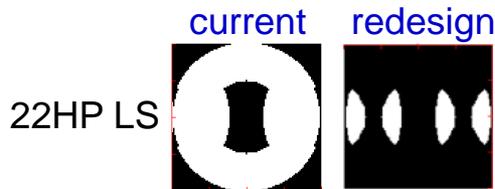


# Pupil filtering: Areas of development

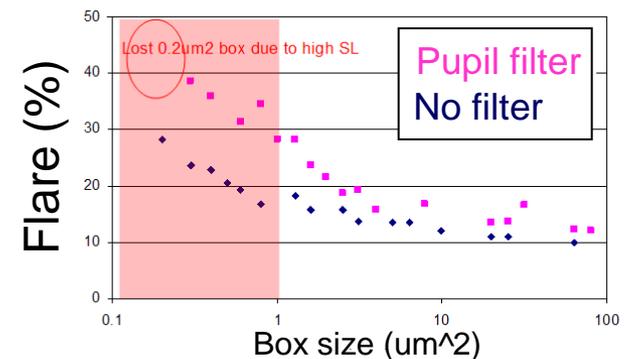
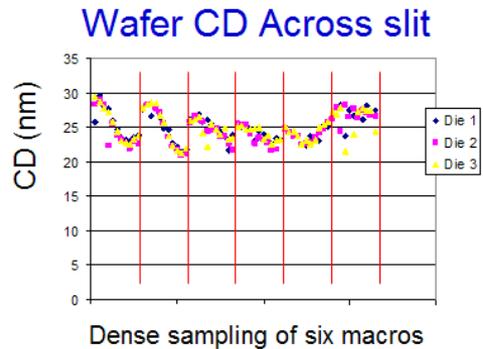
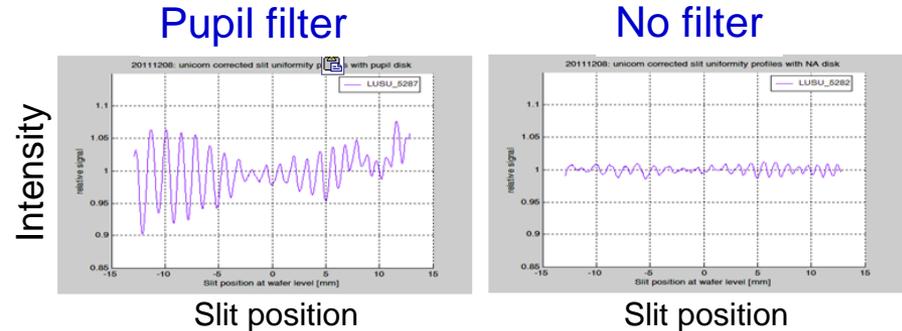
- **Slit uniformity:** Presence of pupil filter is impacting across slit intensity uniformity optimization with unicom blades.

- Out of Band **stray light** suspected to be large with current filter. Measurements show stray light in  $\sim 1\mu\text{m}$  range  $\sim 2\text{x}$  larger with filter installed.

- Developed coating to minimize OoB reflections
- Some filters redesigned to minimize stray light

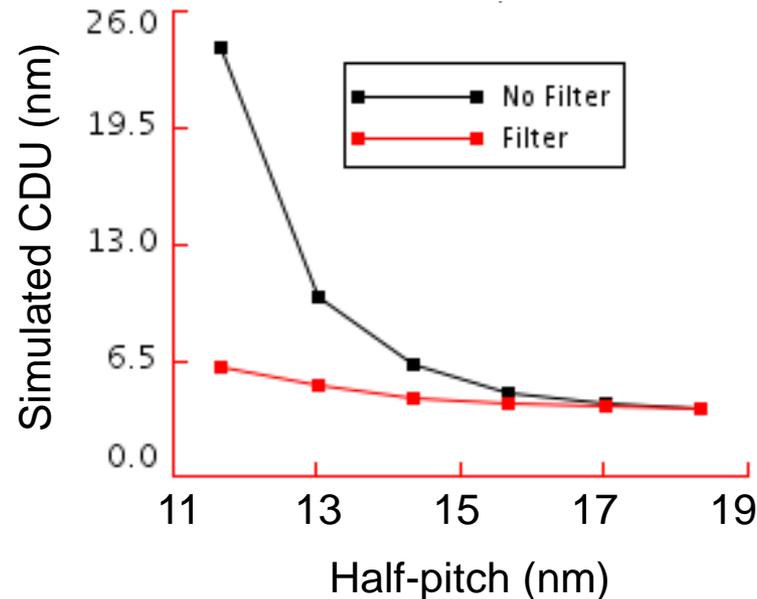
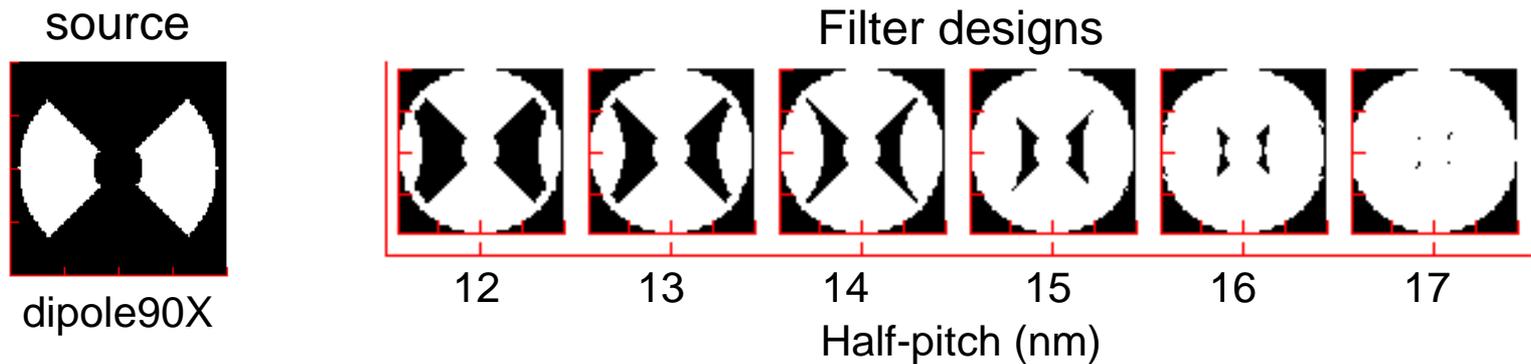


- Optimized **reticle alignment procedure** to improve reticle align repro and enable alignment of frequency doubling filters



# Theory: Filters could enable ~12nm HP w/ NXE3300B

- Concept could apply to any projection printing system with fixed illumination
- Note: Hardware for filter exchange does not exist on NXE

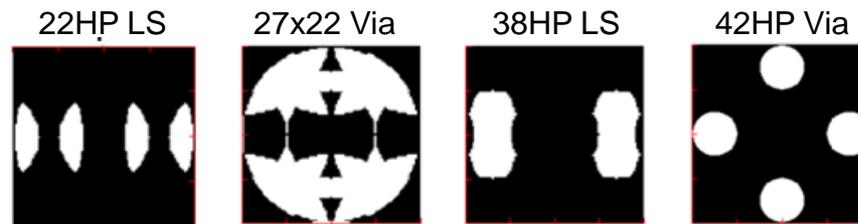


# Summary: Resolution enhancement with pupil filtering

- Demonstrated 20% improvement in resolution limit of ADT
- Purpose is to enable process development at feature sizes beyond the resolution limit of current tooling
- Filters designed for optimum imaging performance of a specific feature
- Hardware developed and installed on ADT for filter exchange
- Experimental verification with 22HP line-space and 24HP contact filters



- Additional four filters in final fabrication



- Concept extendable to any projection printing system with fixed illumination

# Acknowledgements

- The authors would like to thank the following individuals and companies for their assistance:
  - Brian Lee, Jerry Woods, Brian Niekrewicz, James Waddell (ASML)
  - Takashi Saito & Lior Huli (TEL)
  - Luke Orsini (IBM)
  - Matt Colburn, Cecilia Smolinski & David Mederios for management support (IBM)
- This work was performed by the Research Alliance Teams at various IBM Research and Development Facilities

**ASML**

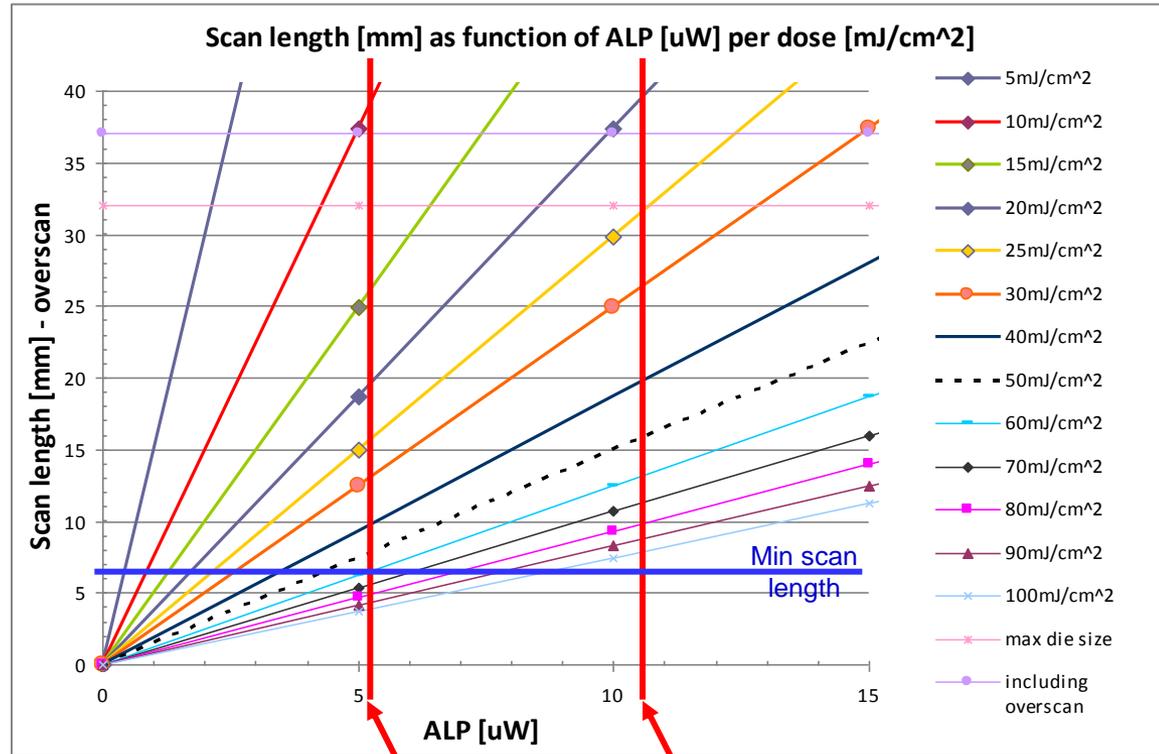
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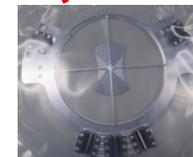
# Backup

# Dose requirements

- High dose values required depending on amount of light blocked by filter
- ADT maximum exposure time per die is 830 seconds, which can limit scan length
- Current collector near end of life; new collector expected soon and should increase power by >100%



48CA



44LS