MASK 3D EFFECTS FIRST EXPERIMENTAL MEASUREMENTS WITH NA 0.55 ANAMORPHIC IMAGING

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EUVL WORKSHOP. BERKELEY, JUNE 13th, 2018.

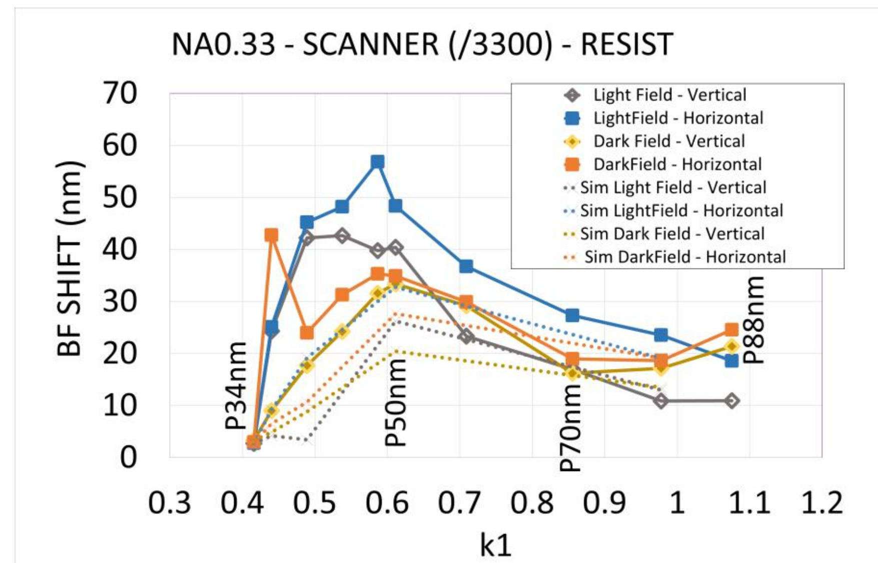
EUV MASK 3D EFFECTS
EXPERIMENTAL MEASUREMENTS WITH NA 0.55 ANAMORPHIC IMAGING

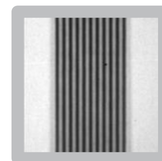
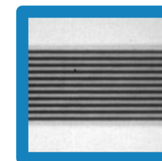
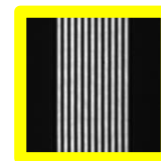
MASK 3D EFFECTS / NA 0.55 ANAMORPHIC / IMAGING WITH SHARP

- Mask 3D effects important to EUV imaging
  - important to understand
  - to develop mitigation strategies

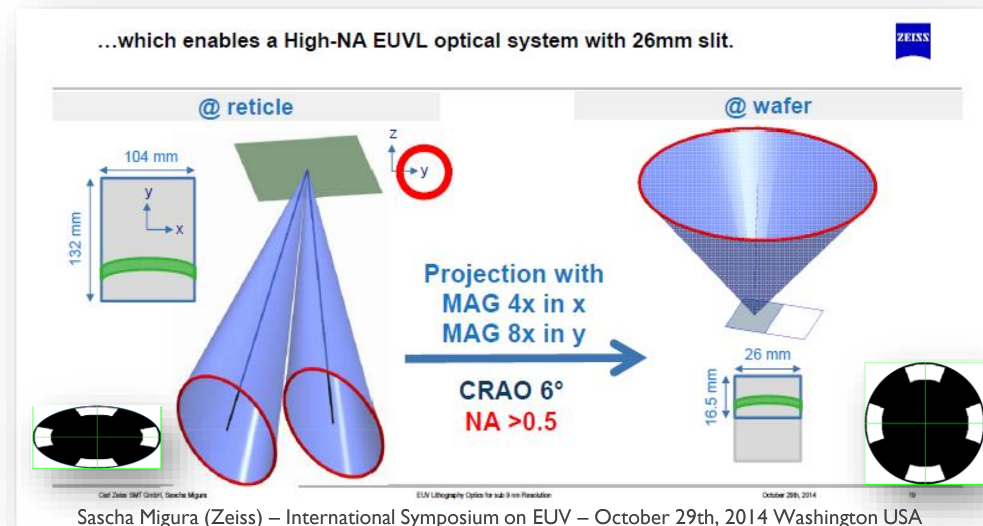
- At NA0.33, we measure on wafer BEST FOCUS SHIFT of the CENTRAL LINE in 11 bars THROUGH PITCH

- It is difficult to reach quantitative matching between the effects simulated with rigorous simulator and the ones measured in resist.
  - only matching trends…
  - let's compare aerial image experiment (SHARP) and sim !



- Moving to NA0.55 anamorphic imaging, the solid angles at mask level will change differently in X and Y
  - 4X8 magnification
  - CRA 5.355°
  - smaller pitches



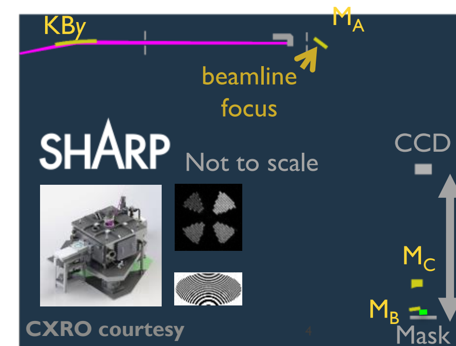
Sascha Migura (Zeiss) – International Symposium on EUV – October 29th, 2014 Washington USA

- How will mask 3D effects change at NA0.55?

EUV MASK 3D EFFECTS
EXPERIMENTAL MEASUREMENTS WITH NA 0.55 ANAMORPHIC IMAGING

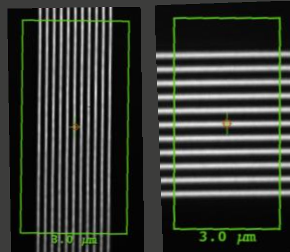
MASK 3D EFFECTS / NA 0.55 ANAMORPHIC / IMAGING WITH SHARP

- The SHARP EUV-actinic mask-imaging microscope at Lawrence Berkeley National Laboratory is today the only access to NA0.55 anamorphic imaging, emulating the relevant solid angles at an actual mask.
  - to measure an aerial image intensity map at sensor level

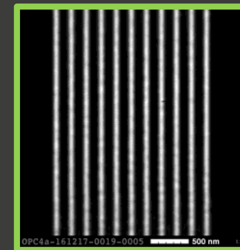


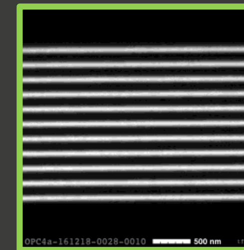
Example: NA0.55 imaging of L/S @ Pitch 50nm

MASK (4X8)
VERTICAL: PITCH 200 CD 74
HORIZONTAL: PITCH 400 CD 164



SHARP IMAGE CCD (4X8)
VERTICAL: PITCH 200
HORIZONTAL: PITCH 400





TF3 ANALYSIS SOFTWARE (1X1)
VERTICAL: PITCH 50 CD~16
HORIZONTAL: PITCH 50 CD~16

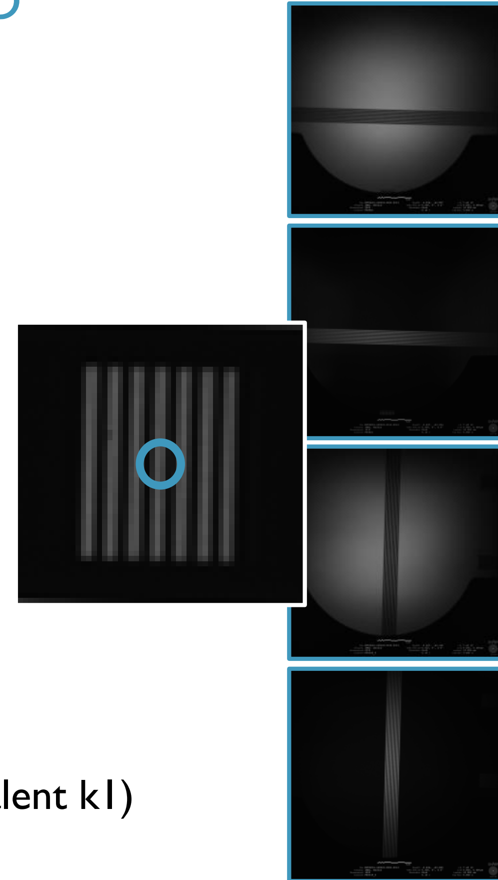
GOAL

- Enable the measurement of mask-3D-effects with NA0.55 anamorphic imaging using the SHARP microscope
  - seek to develop a measurement methodology which works with the limitations of the SHARP tool
  - model the SHARP tool accurately in a lithographic rigorous simulator to build confidence in the ability of the lithographic simulators to make predictions about lithographic scanners at higher NA.

EUV MASK 3D EFFECTS
BEST FOCUS SHIFT THROUGH PITCH – TO BE MEASURED
CENTRAL BAR OF 7 BARS @ NA0.33 (1X1) AND NA0.55 (4X8)

- 7 bars (LS)
- LF/DF , Vertical/Horizontal
- Quasar 35° - σ 0.381-0.885 to enhance BF shift range

- NA0.33 ISOMORPHIC: TO PROVE THE METHODOLOGY
  - target CD 17nm
  - pitches 32 – 34 – 36 – 40 – 46 – 50 – 54 – 58 – 62 – 70
- NA0.55 ANAMORPHIC: TO EXPLORE
  - target CD 10nm
  - pitches 19 – 20 – 22 – 24 – 28 – 30 – 32 – 34 – 38 – 42 (equivalent k1)
    - remark: smallest pitches below MRC for vertical bars



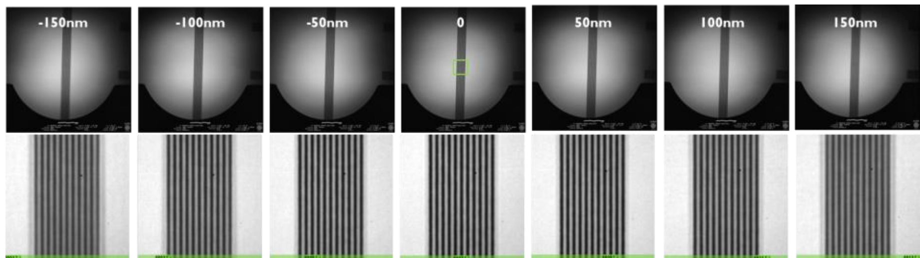
OUTLINE

MASK 3D EFFECTS FIRST EXPERIMENTAL MEASUREMENTS WITH NA 0.55 ANAMORPHIC IMAGING

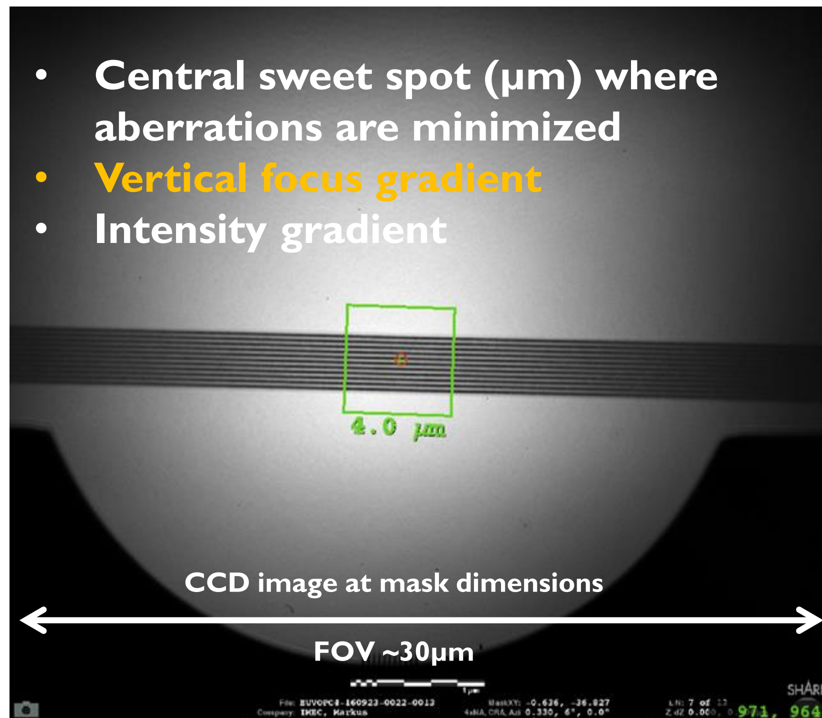
- EXPERIMENTAL MOTIVATION
- MEASUREMENT METHODOLOGY
- BEST FOCUS SHIFT : MEASUREMENTS VERSUS SIMULATIONS
- CONCLUSIONS

FOCUS RELATED MEASUREMENTS ON SHARP IMAGE CONSTRAINTS

… KNOWING WE ARE LOOKING FOR FOCUS-RELATED EFFECTS



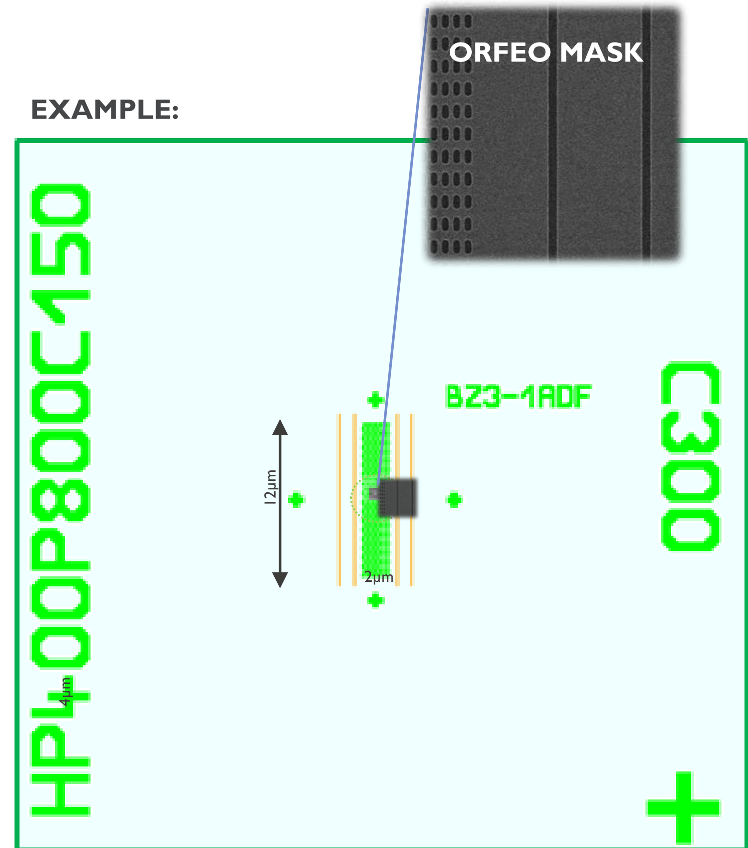
- Each test site is imaged through focus (through zoneplate or wavelength tuning)
- **There is no absolute focus plane in SHARP.** (the focus reference will change when moving to another test site on the mask)



FOCUS RELATED MEASUREMENTS ON SHARP DESIGN SOLUTION

ADEQUATE FRAME USING AN INSIDE-FOV ABSOLUTE FOCUS REFERENCE

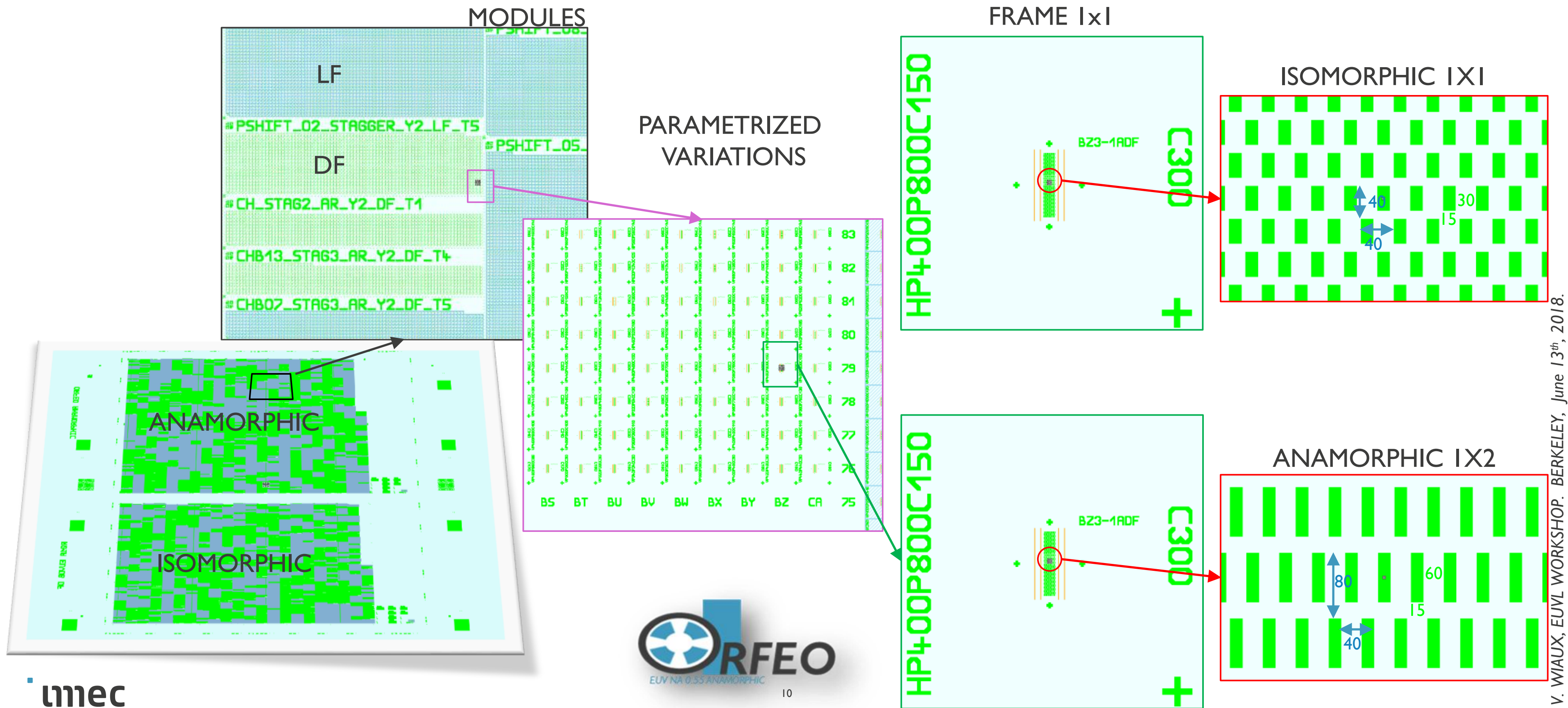
- “ORFEO”, a dedicated mask (60nm absorber)
  - as a work-around to no absolute focus plane : a vertical iso line as an inside-FOV absolute focus reference, repeated next to each test pattern all across the reticle.
  - including isomorphic and anamorphic patterns
- SHARP imaging using small focus steps
  - SHARP focus steps by tuning the wavelength instead of moving the zoneplate.



FOCUS RELATED MEASUREMENTS ON SHARP

"ORFEO": IMEC'S MASK FOR ANAMORPHIC IMAGING AT SHARP

VERTICAL 20NM ISO LINE AN IN-FOV FOCUS REFERENCE IN A DEDICATED FRAME.



FOCUS SHIFT MEASUREMENT METHODOLOGY

17 STEPS THROUGH FOCUS WITH SHARP

EXAMPLE: 7 BARS P30NM HORIZONTAL DF NA0.55, 17 FOCUS STEPS BY λ TUNING

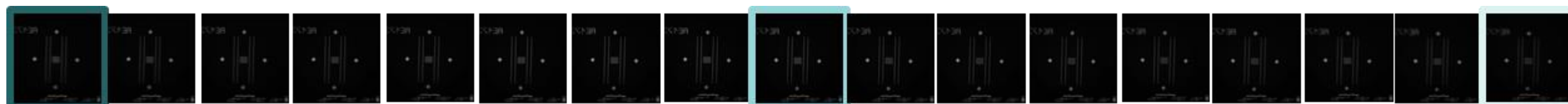
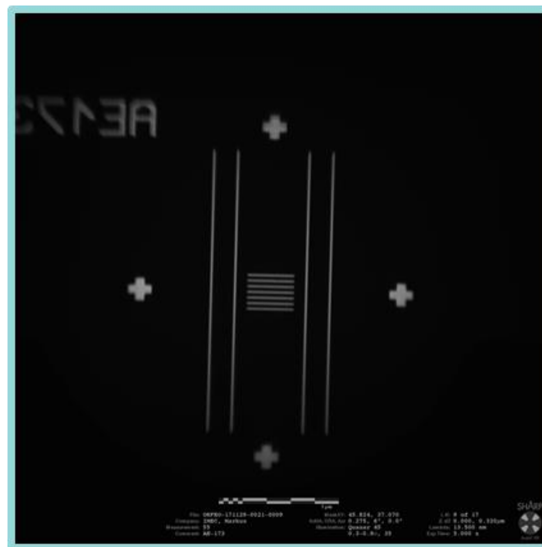
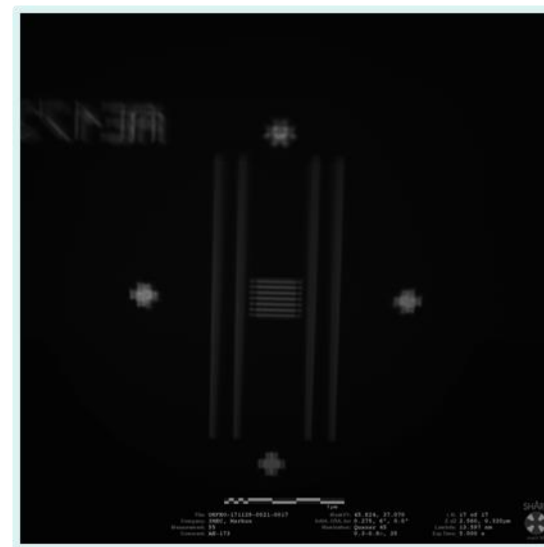


image 1…

…image 17



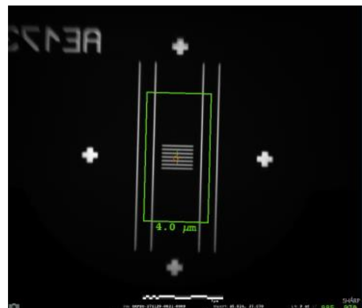


FOCUS SHIFT MEASUREMENT METHODOLOGY
BEST FOCUS AS MAX OF FITTED ILS

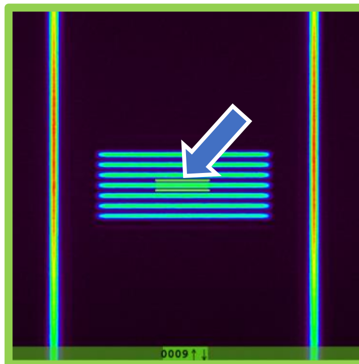
BEST FOCUS SHIFT = FITTED BF OF ISO – FITTED BF OF CENTRAL LINE IN LS

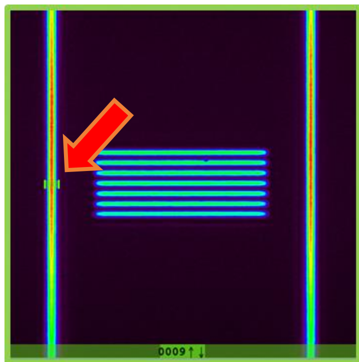
- EXAMPLE:
  NA0.55 7LS
  Horizontal DF
  P30nm

SHARP A.I.
(1:2 @ SENSOR)

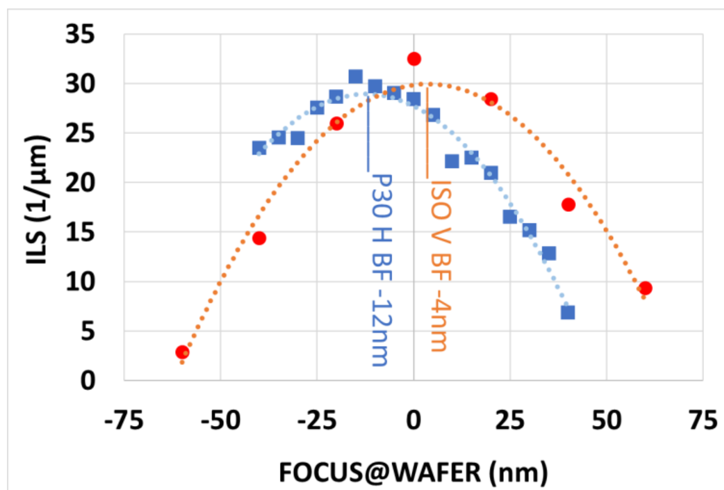


TF3 SOFTWARE
(1:1 @ WAFER)

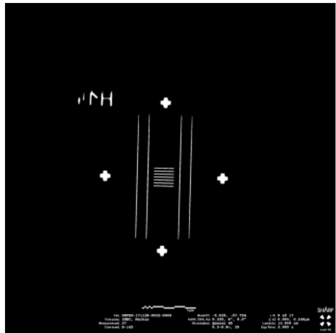


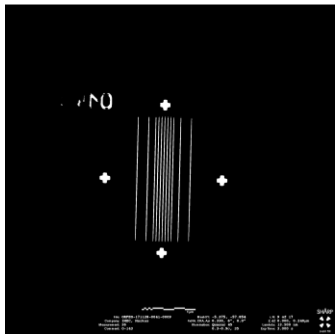


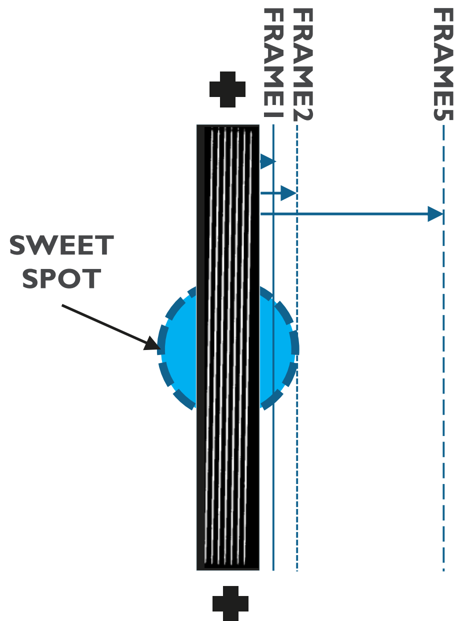
ILS-BASED FITTED BEST FOCUS



FOCUS SHIFT MEASUREMENT METHODOLOGY
VARY THE FRAME BY MOVING THE ISO LINE OUTWARDS
VERSUS THE SWEET SPOT EDGE







NA0.33 DF P70nm	FRAME 1	FRAME 2	FRAME 5
distance V_iso to center	375nm iso inside the sweet spot	450nm iso at the edge of the sweet spot	950nm iso far outside of the sweet spot
BF SHIFT Horiz.	27.0nm	27.4nm	
BF SHIFT Vert.	20.4nm	19.6nm	16.7nm

OUTLINE

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- EXPERIMENTAL MOTIVATION
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- BEST FOCUS SHIFT : MEASUREMENTS VERSUS SIMULATIONS
- CONCLUSIONS

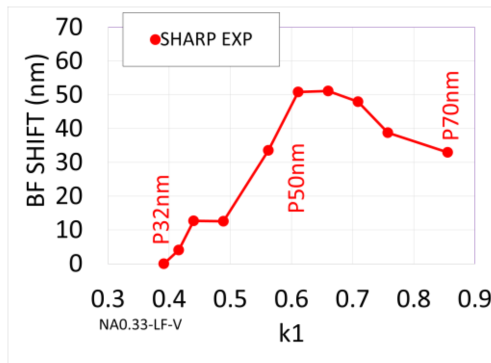
ORFEO&SHARP BEST FOCUS SHIFT AT NA0.33

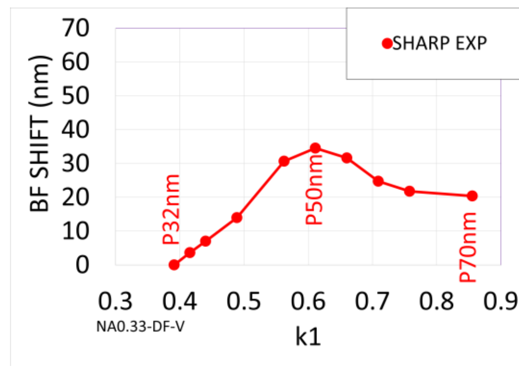
CENTRAL OF 7 BARS: SHARP EXP AERIAL IMAGE

LIGHT FIELD

DARK FIELD

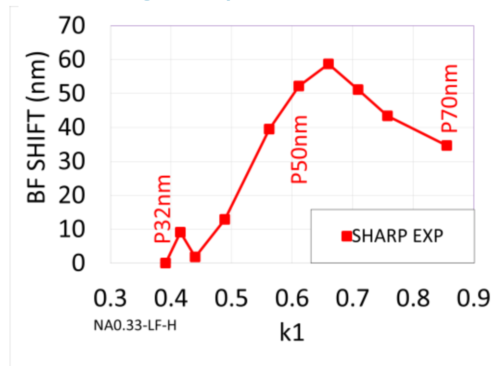
VERTICAL

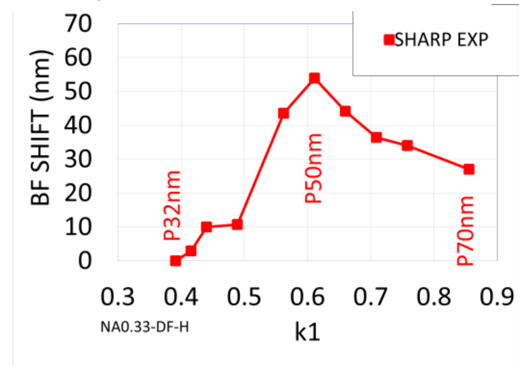




Meaningful experimental trends in aerial image. Let's compare to the trends in resist?

HORIZONTAL





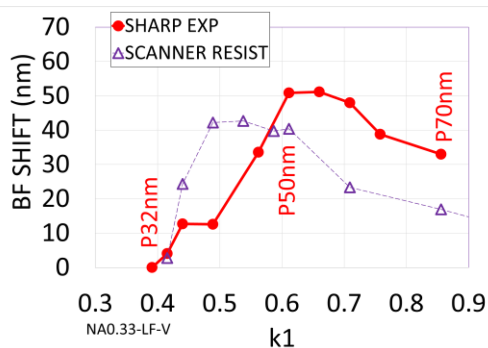
ORFEO&SHARP BEST FOCUS SHIFT AT NA0.33

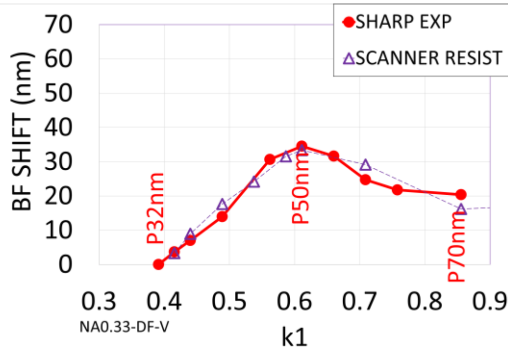
CENTRAL OF 7 BARS: SHARP EXP AERIAL IMAGE VERSUS SCANNER EXP IN RESIST

LIGHT FIELD

DARK FIELD

VERTICAL

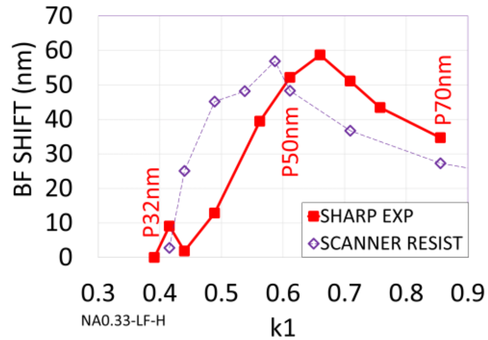


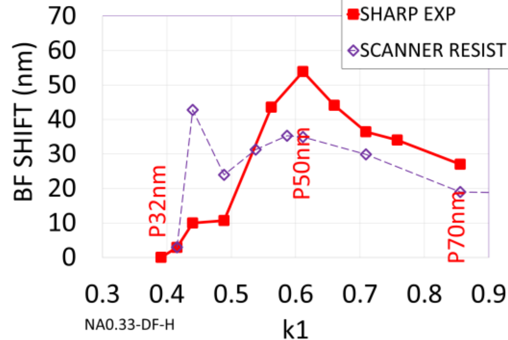


	SHARP	SCANNER
RESIST	NO	YES
QUASAR	35º	45º
MASK	ORFEO	other
ABSORBER	60nm	70nm
SYSTEM	ENLARGING	REDUCING

Similar trends/ranges. Peak positions differ. But different exp conditions...

HORIZONTAL





	SHARP	RIG SIM
RESIST	NO	NO
QUASAR	45°	45°
MASK	ORFEO	MEAS CD
ABSORBER	60nm	60nm
SYSTEM	ENLARG.	ENLARG.

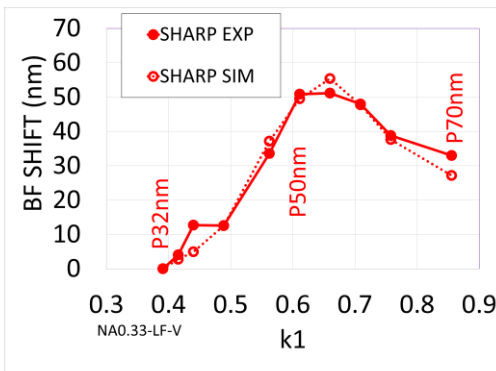
ORFEO&SHARP BEST FOCUS SHIFT AT NA0.33

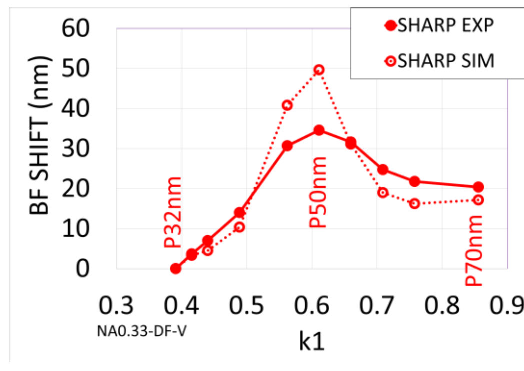
CENTRAL OF 7 BARS: SHARP EXPERIMENT VERSUS SIMULATION

LIGHT FIELD

DARK FIELD

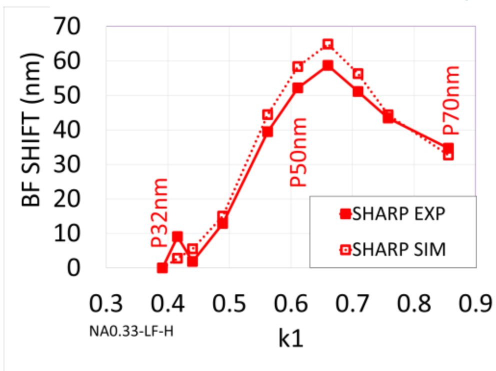
VERTICAL

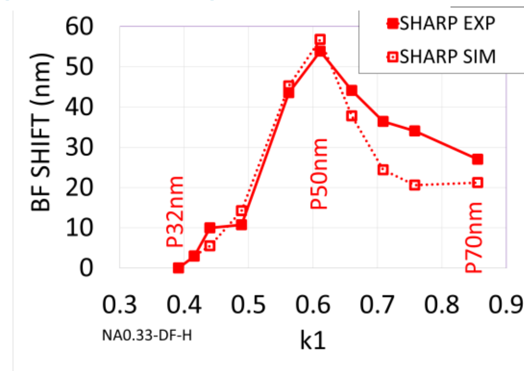




Good confidence @NA0.33: quantitative matching @LF, matching of trends @DF

HORIZONTAL





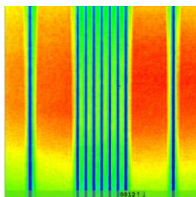
ORFEO&SHARP BEST FOCUS SHIFT AT NA0.55

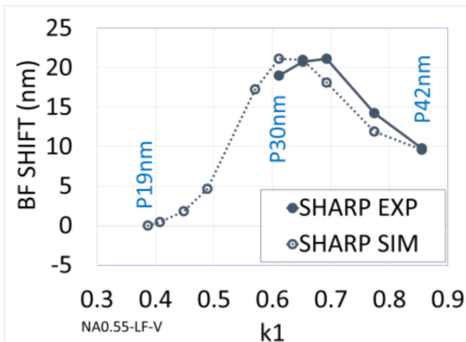
CENTRAL OF 7 BARS: SHARP EXPERIMENT VERSUS SIMULATION

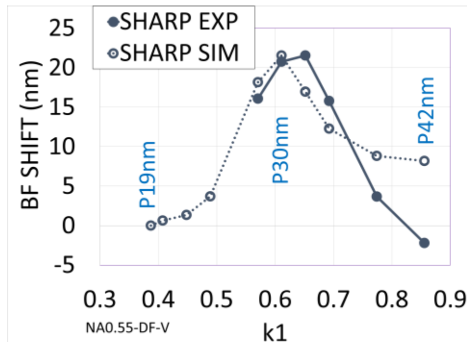
LIGHT FIELD

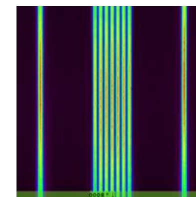
DARK FIELD

VERTICAL



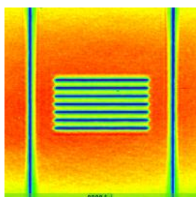


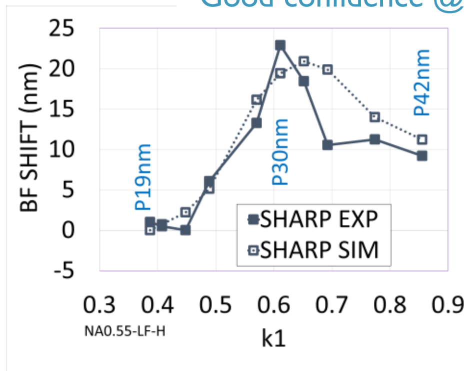


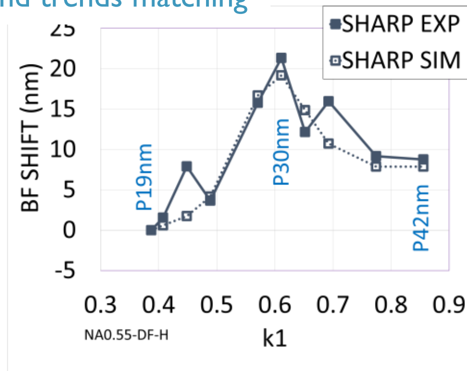


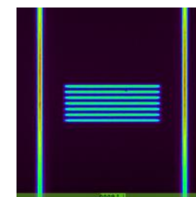
Good confidence @NA0.55: ranges and trends matching

HORIZONTAL









imec

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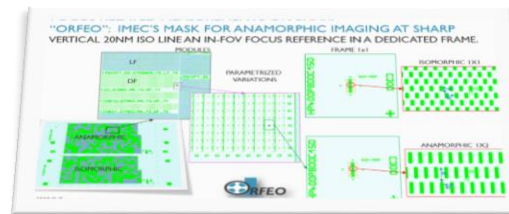
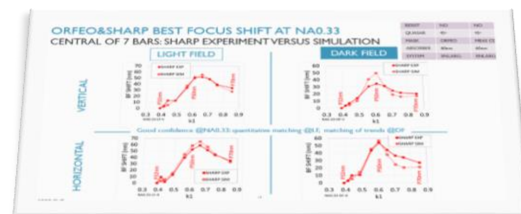
- EXPERIMENTAL MOTIVATION
- MEASUREMENT METHODOLOGY
- BEST FOCUS SHIFT : MEASUREMENTS VERSUS SIMULATIONS
- CONCLUSIONS

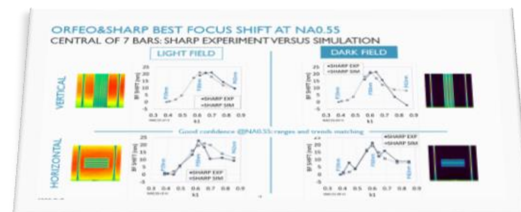
CONCLUSIONS

- We have reported
  FIRST NA0.55 EXPERIMENTAL BF-shift measurements
  using ANAMORPHIC SHARP imaging system
  and ORFEO, a dedicated mask.

- We have validated the measurement methodology using ORFEO&SHARP by comparison to rigorous simulations.
  - we have built confidence in our ability to measure best focus shift thru pitch with the ORFEO & SHARP as well as in our rigorous simulator ability to predict these curves.
    - we will keep investigating the differences.
    - we report matching trends
      both at NA0.33 isomorphic and at NA0.55 anamorphic
    - strong agreement for the location of the maximum best focus shift and best focus range over pitch.







ACKNOWLEDGEMENTS

- Jack Liddle (Zeiss) for simulation input
- Markus Benk, Kenneth Goldberg (LBNL)
- Luc Rynders, Rudi De Ruyter (imec, Design and Tape out)
- Rik Jonckheere, Emily Gallagher, Kurt Ronse (imec)

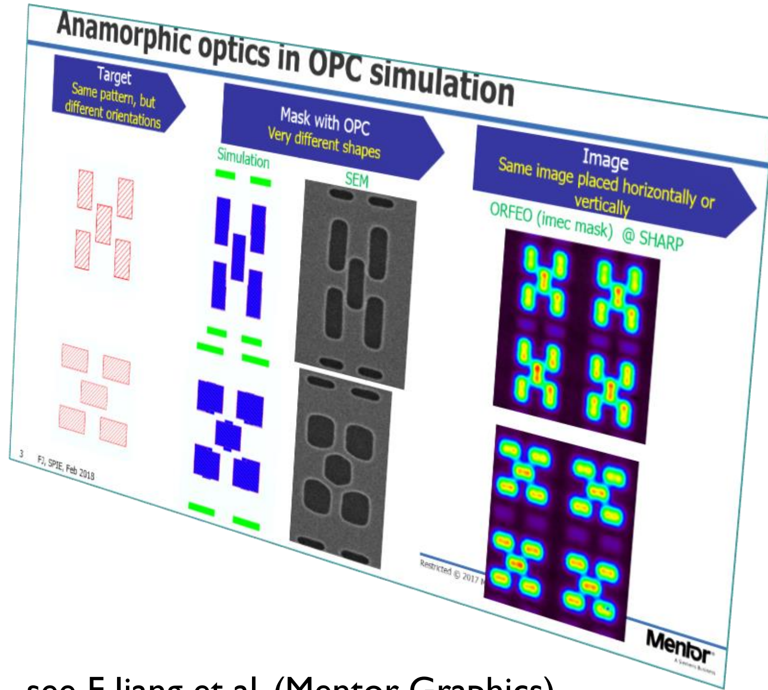
"L'Orfeo" (1607) – Claudio Monteverdi (1567)

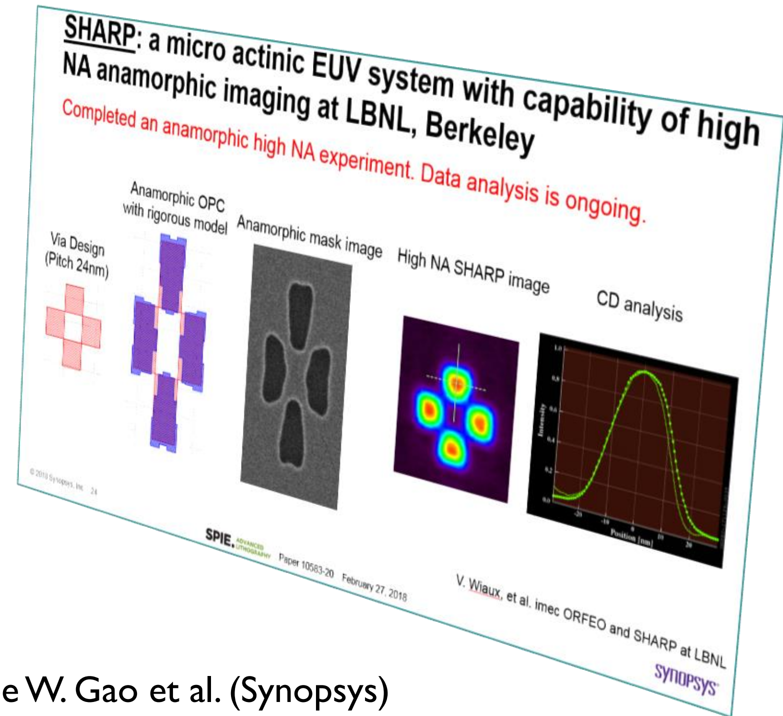
"L'Orfeo wasn't quite the first opera, but the consensus seems to be that it was the first that was any good." – The Guardian, January10th, 2015.

embracing a better life

OPC ON ORFEO AND SHARP IMAGING

FROM HIGH NA ANAMORPHIC OPC FLOW TO HIGH NA EXPERIMENTAL AERIAL IMAGE.





- see F. Jiang et al. (Mentor Graphics)
  SPIE Proceedings Volume 10583,
  Extreme Ultraviolet (EUV) Lithograph IX; 105830P (2018)

- see W. Gao et al. (Synopsys)
  SPIE Proceedings Volume 10583,
  Extreme Ultraviolet (EUV) Lithography IX; 105830O (2018)