Experimental Determination and Accurate Modeling of the EUV ADT flare

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Project goal

- Design correction for EUV requires a **flare map** of the design
- How can we calculate a flare map **accurately**?
  - Experimental flare levels have to be measured accurately and precisely
  - The experimental flare levels have to be translated into a point-spread function for flare map calculation
    - How do we optimize the point-spread function parameters to match the experimental flare tests?

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Outline

- Flare Metrology
  - Basic Issues
  - Dose Regimes
  - Contrast-Based Algorithm
    - Precision
    - Accuracy
- Generation of calibrated flare maps
  - Flare Measurement and Monitoring
  - Single Fractal PSF Approximation
  - Role and Optimization of the PSF parameters
  - Comparison of optimized PSF with experiments
  - DUV contribution
  - CD Modeling
- Conclusions

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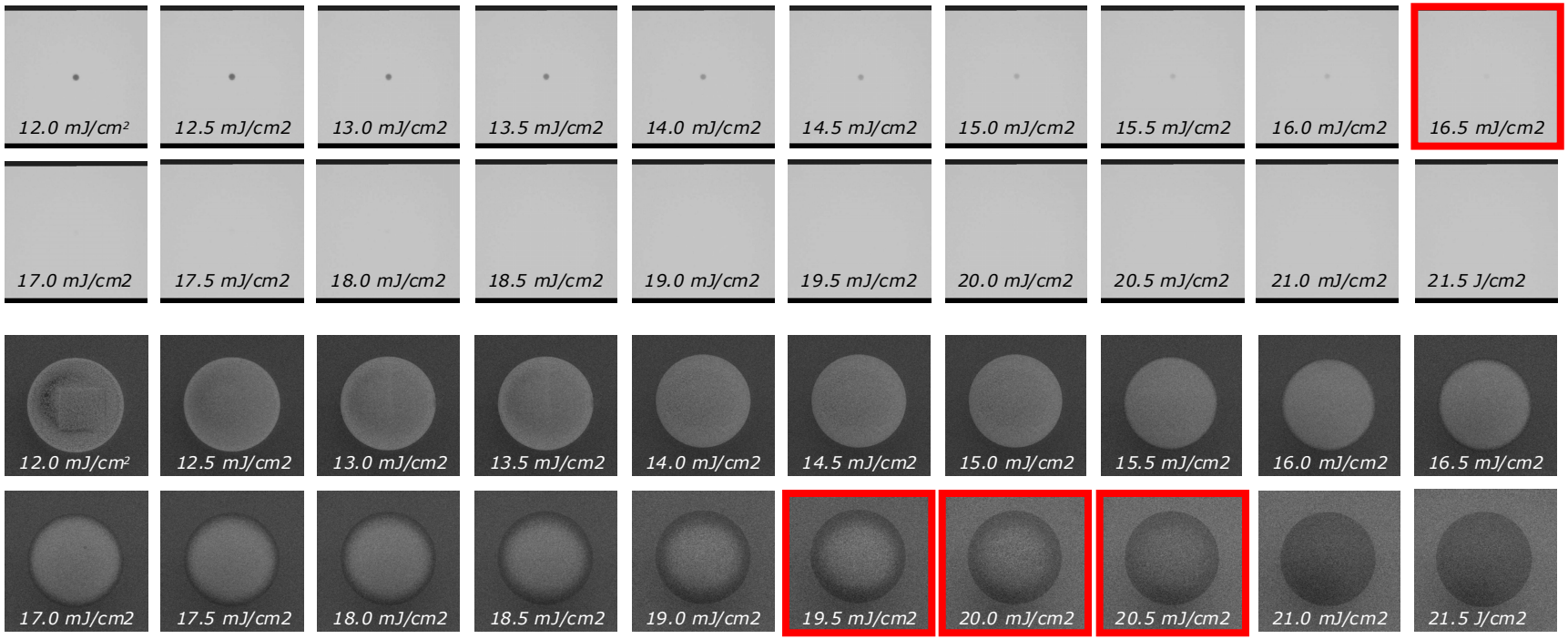
Flare Metrology: Basic Issues

- DEFINITION:
  - Flare is estimated by measuring the dose to clear of a 2μm line
- ACCURACY:
  - Different tools / operators will define the dose to disappear of a line differently
- PRECISION:
  - The flare estimate is usually not fully automated in terms of measurement and analysis



It is critical to introduce an accurate and precise flare metrology

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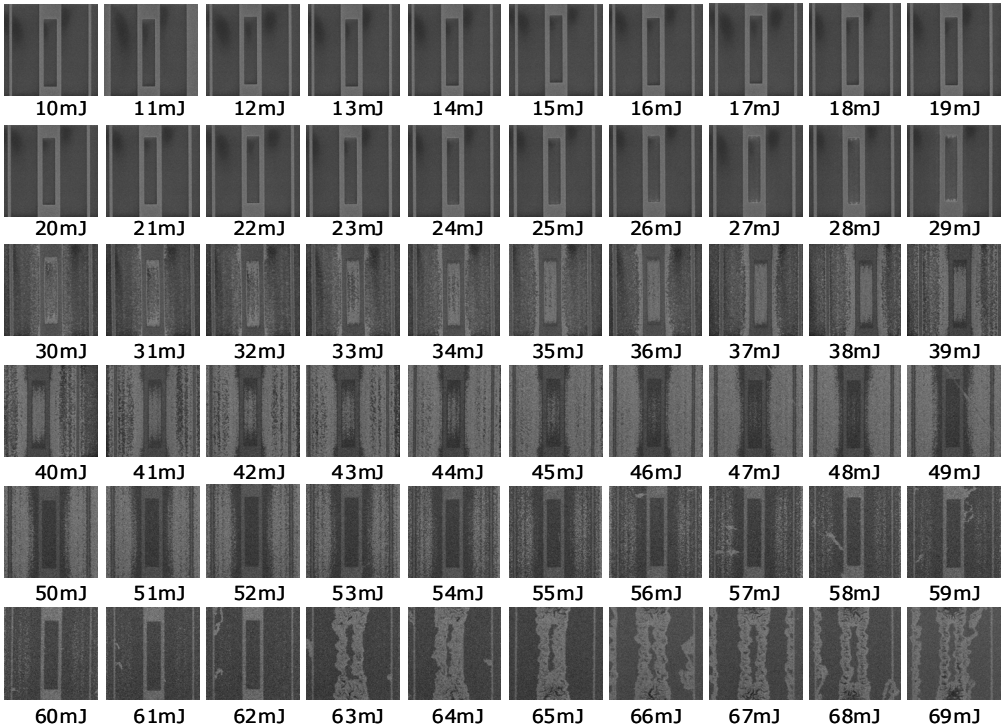
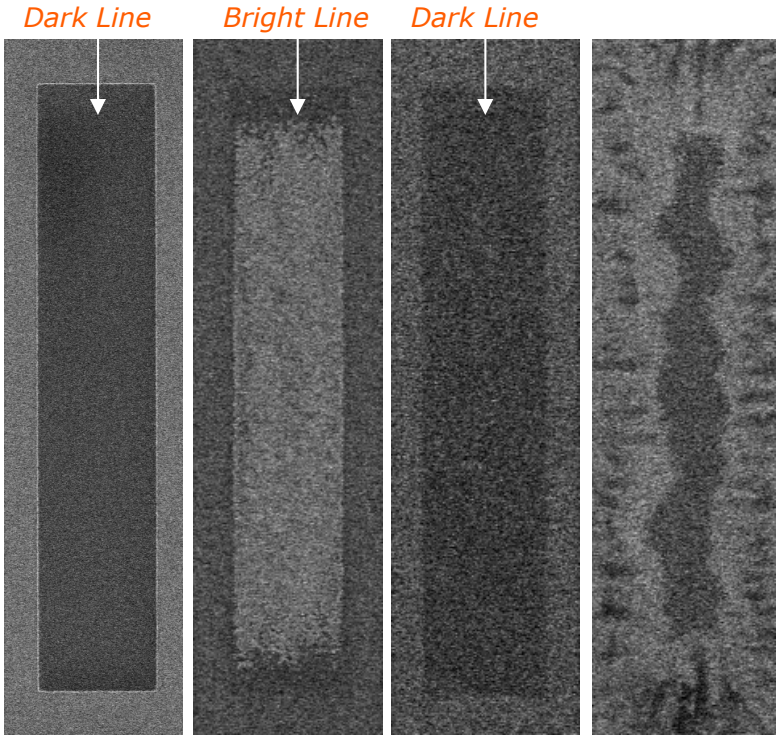
Flare Metrology: Dose Regimes

- Metrology Tool: CD SEM





Smooth surface *Rough surface* *Fully eroded* *Cross Linking*

- 4 different dose regimes can be identified by image analysis

The contrast change between resist and substrate can be exploited to develop an automated measurement algorithm

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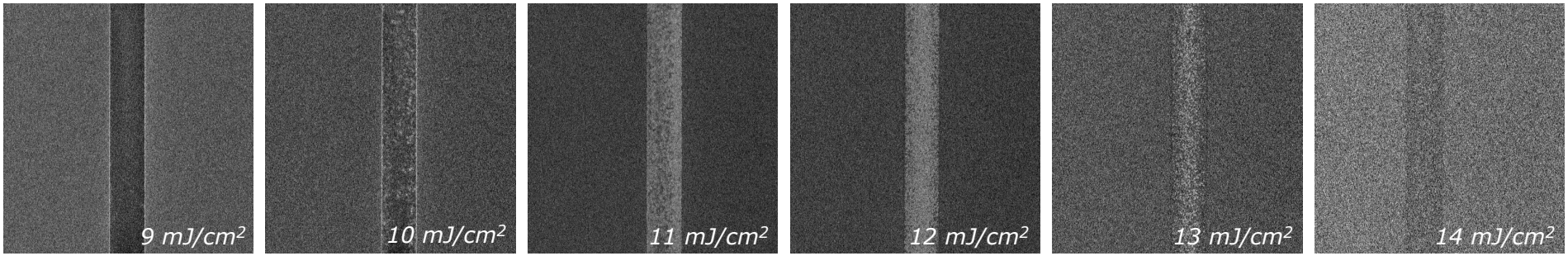
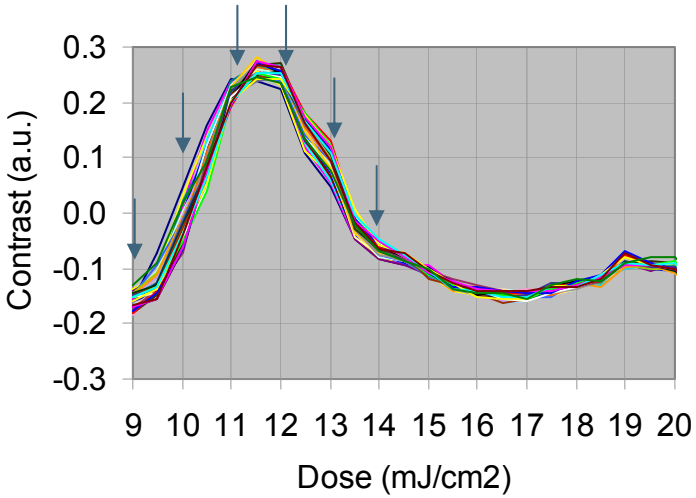
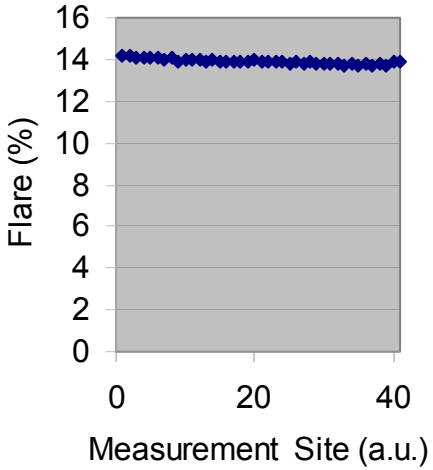
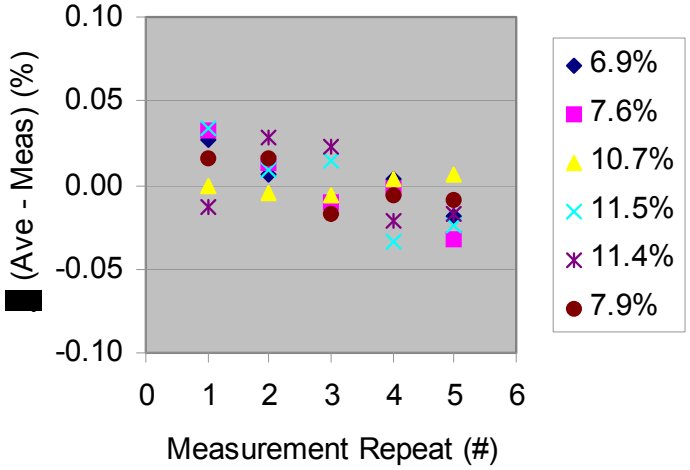
Flare Metrology: Contrast-based algorithm - Precision

- 1mm long 2μm line was measured through dose (0.5mJ/cm^2 step) in 41 independent locations









- Average dose of ~ 13.42 mJ/cm^2, corresponding to flare level of ~13.89%
- Repeatability measured on 6 different flare locations on the same wafer by re-measuring 5 times

A contrast-based flare algorithm yields a precision of 3σ = 0.06%

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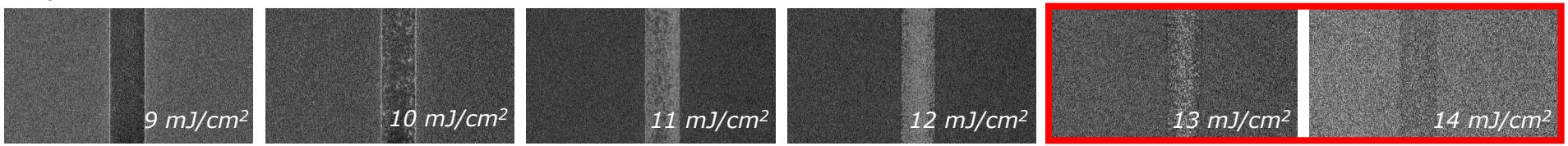
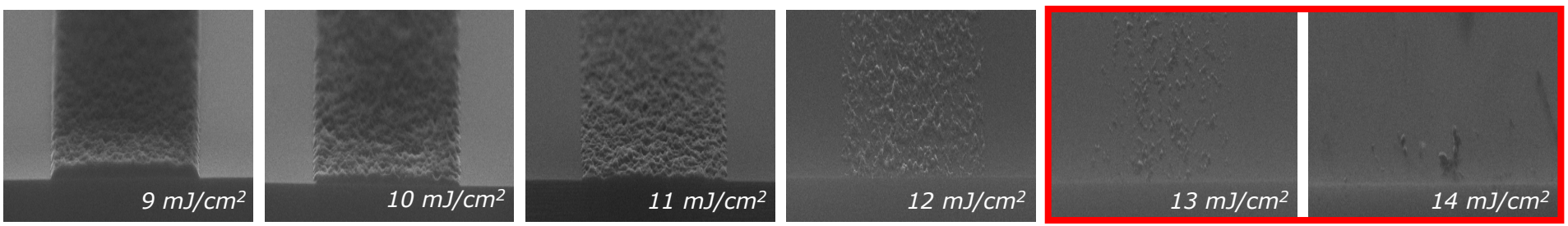
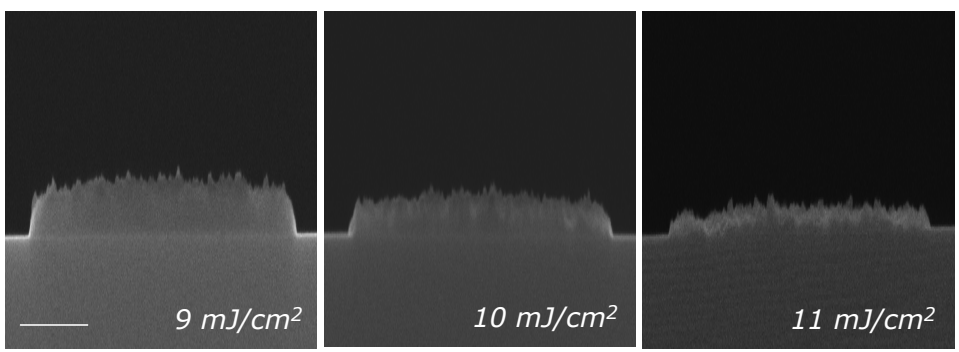
Flare Metrology: Contrast-based algorithm - Accuracy

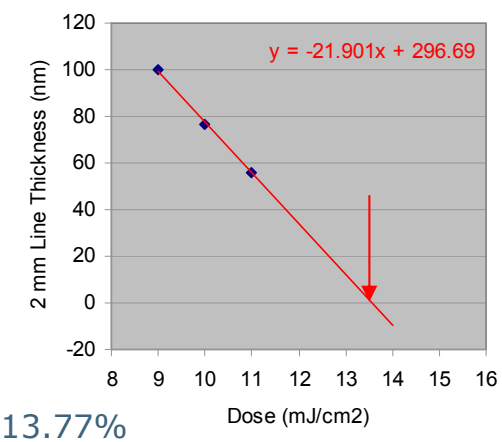
Top Down SEM



Cross Section SEM







–Average dose of ~ 13.54 mJ/cm², corresponding to flare level of ~13.77%

A contrast-based flare algorithm yields an accuracy of Δ = 0.12%

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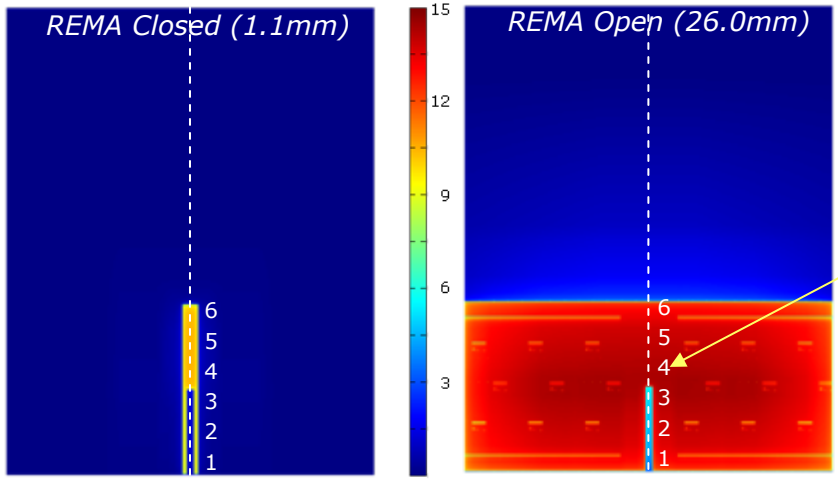
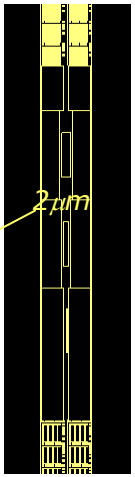
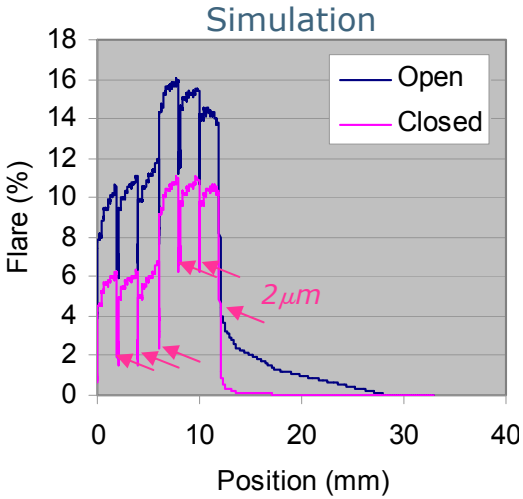
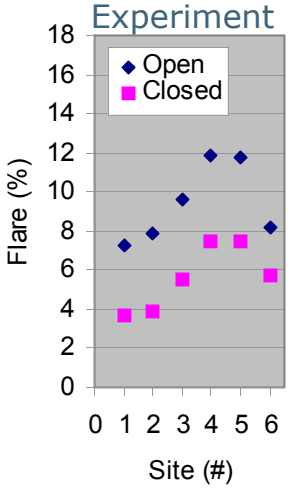
Generation of calibrated flare maps: Flare Measurement and Monitoring

- *2 micrometer Kirk testpads on 6 sites on mask with different local tiling*
- *6 flare sites were measured with REMA blades closed and open on 2μm targets*
- *The 6 flare sites with REMA open were used as flare monitoring*









Flare was not observed to change over 10 months period (~6000 MPulse)

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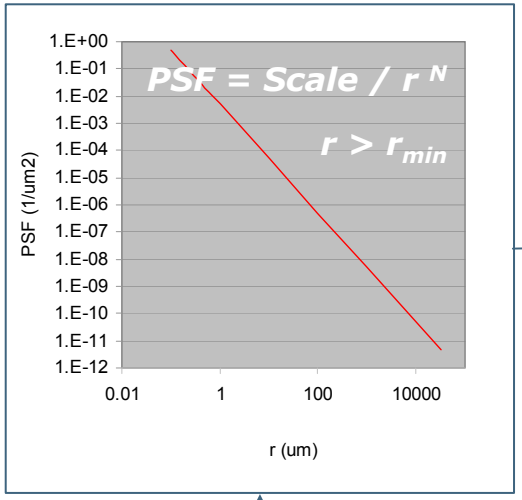
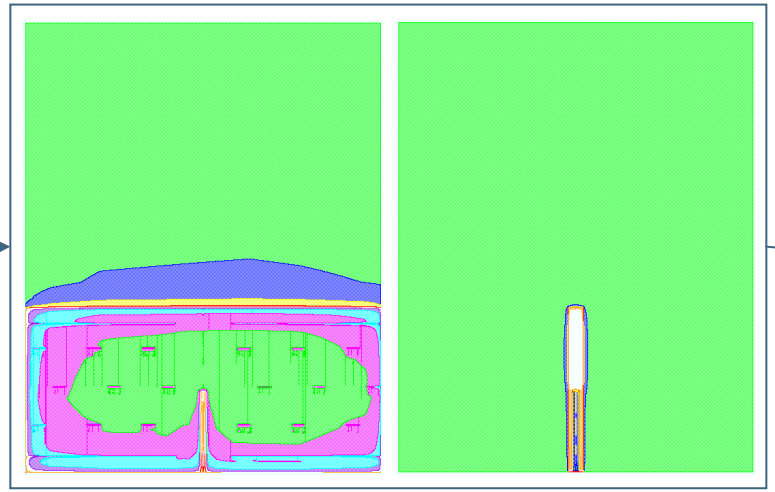
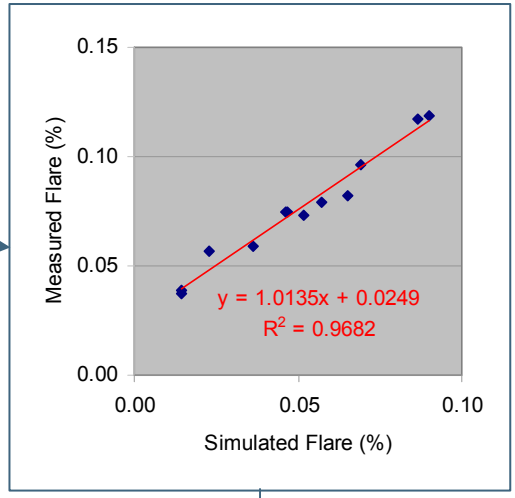
Generation of calibrated flare maps: Single fractal approximation

- ***Simulation Input***: Single fractal approximation of PSF with 3 adjustable parameters
- ***Simulation Output***: Flare maps of with REMA closed and open
- ***Comparison with experiment***: Accuracy plot of experimental vs. simulated flare
- ***DOE***: optimization of r min, Scale and N requiring 400 flare maps







Goal: Understand and optimize the parameters r min Scale and N to provide the best match with experimental flare measurements on the ADT

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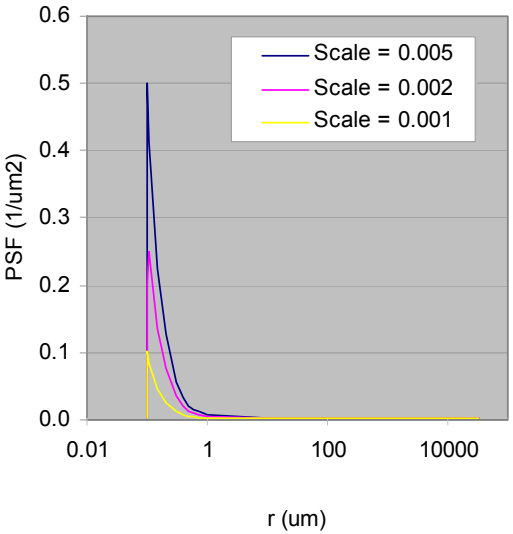
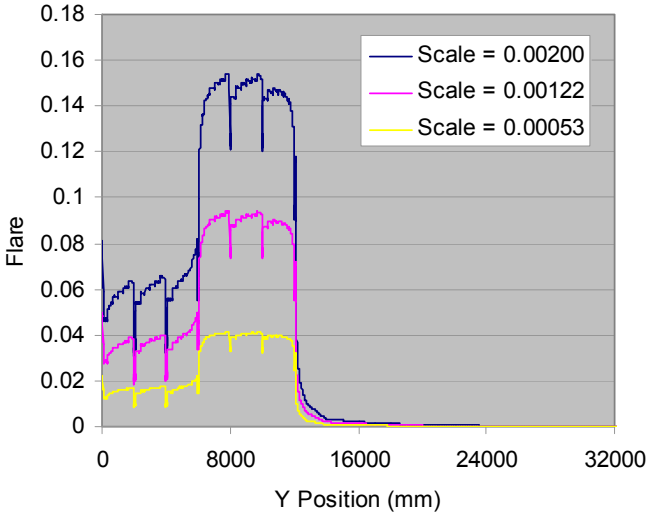
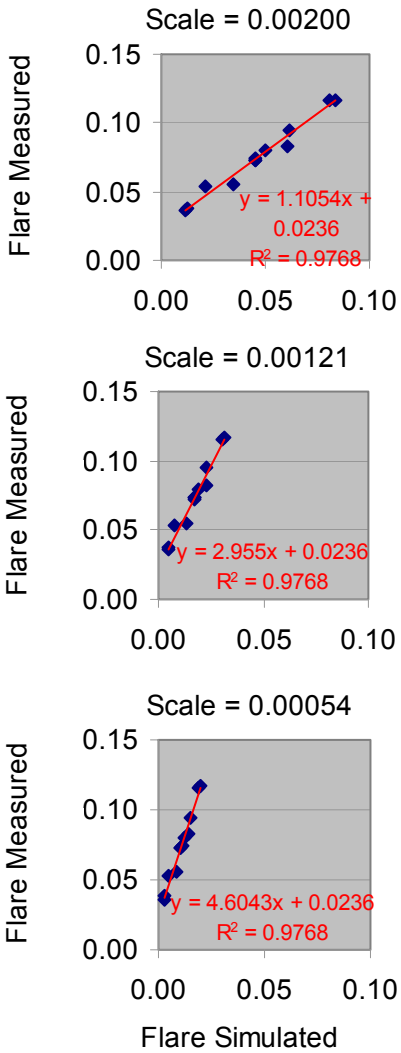
Generation of calibrated flare maps: Role of the parameters - Scale







- *Scale acts by introducing a multiplicative factor in the flare map*
- *By tuning Scale it is possible to ensure that the accuracy plots are linear with slope 1*
- *Scale does not affect R^2 and offset*

Scale modulates the accuracy linearity

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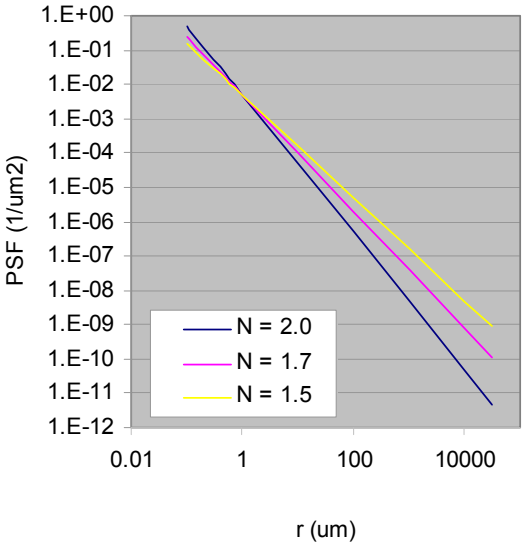
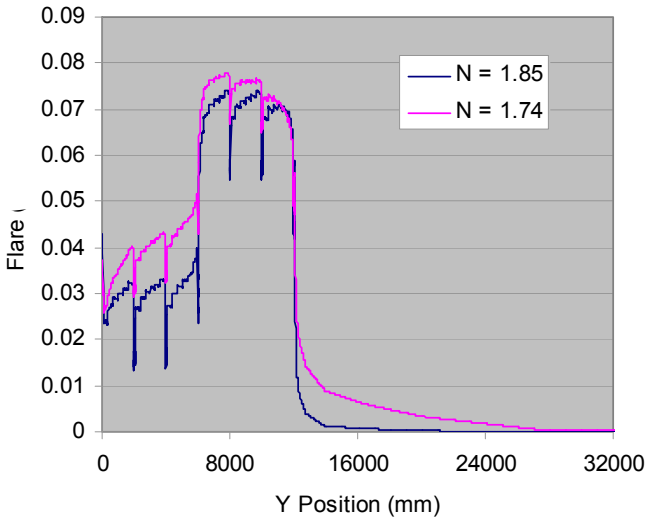
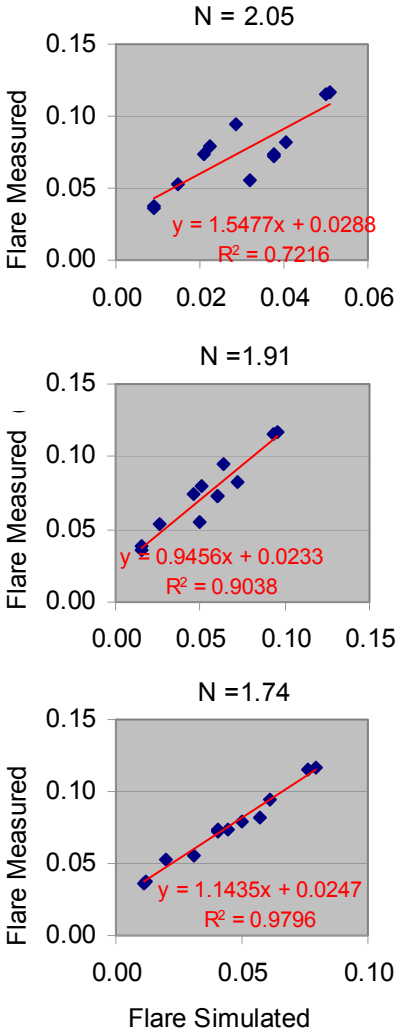
Generation of calibrated flare maps: Role of the parameters - N







- *The N parameter acts modifying the relative weight of short and long range flare*
- *By tuning N it is possible improve the fit quality of the fit R^2 to flare data*
- *N impacts linearity as well, so it has to be optimized before Scale*

N influences the R^2 of the accuracy plots

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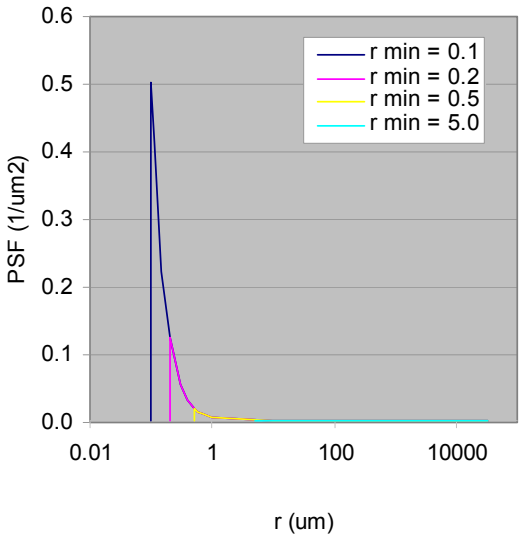
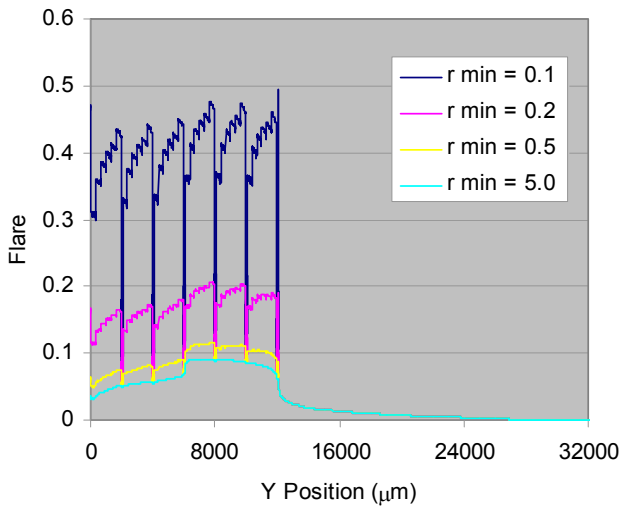
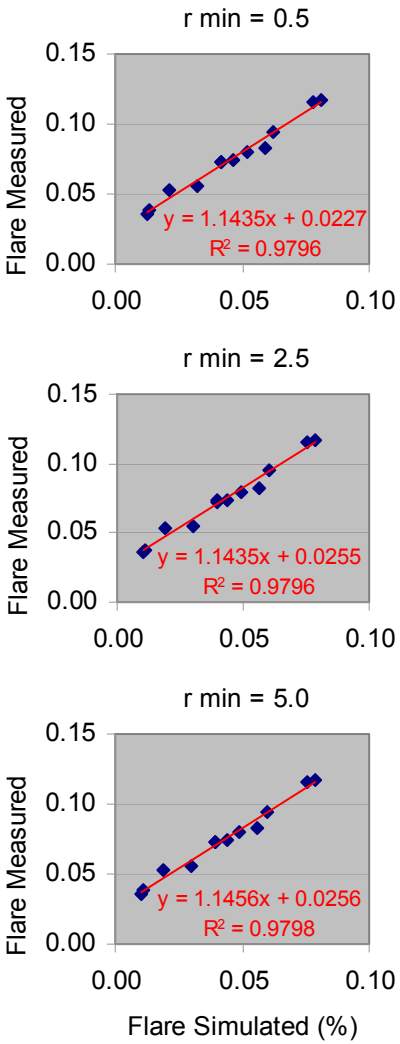
Generation of calibrated flare maps: Role of the parameters - r min







- *r min alters difference in flare between different targets*
- *r min does not alter the comparison with 2μm pads*

- ***Although r min clearly influence the scaling properties of flare, its effect is not quantifiable by comparison with 2μm lines measurements***

- ***A different approach is required to calibrate r min***

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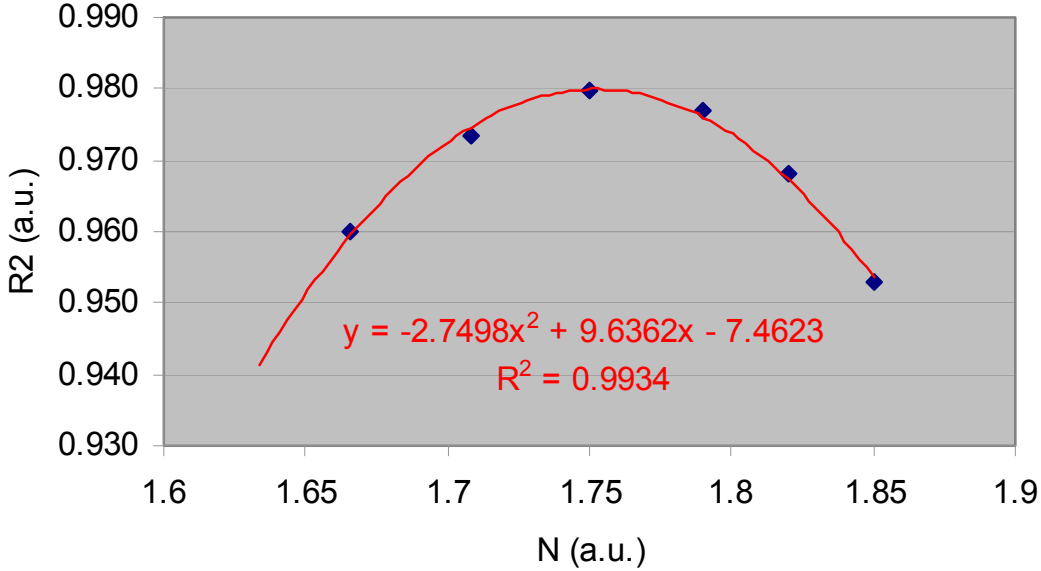
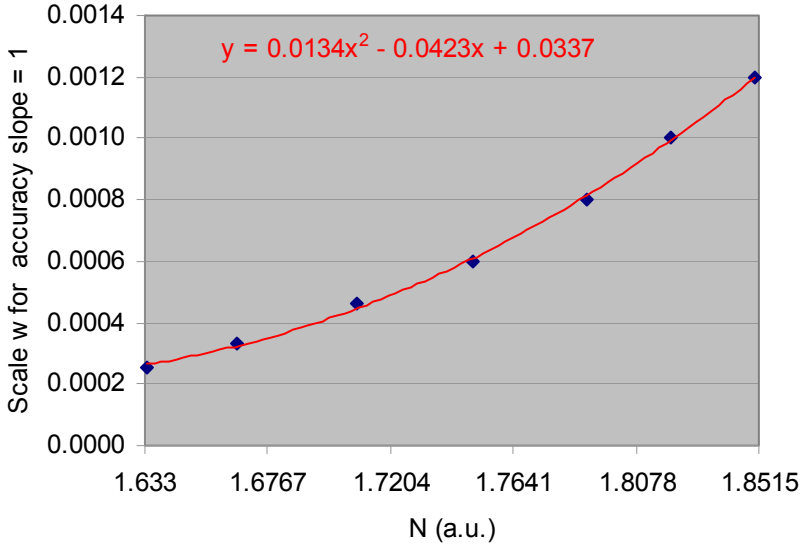
Generation of calibrated flare maps: Optimization of the parameters - N and Scale

- *N and Scale are optimized by comparing simulated and experimental flare on 2μm targets*
- *N is optimized by using R^2 as cost function*
- *Scale is optimized by imposing accuracy slope = 1 <u>and</u> the optimized value of N*



OPTIMAL N
1.75216379373045



OPTIMAL Scale
0.00061251619

Optimization of N and Scale provides good R^2 and linearity

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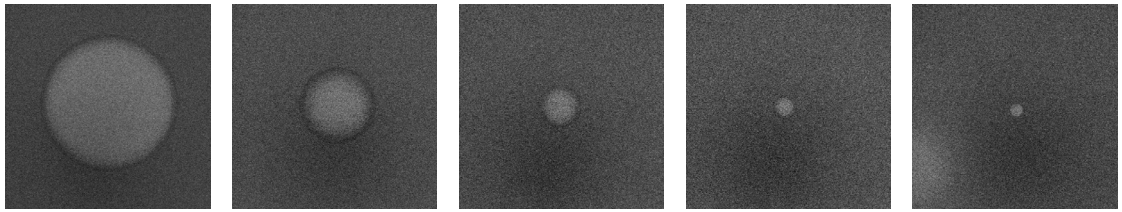
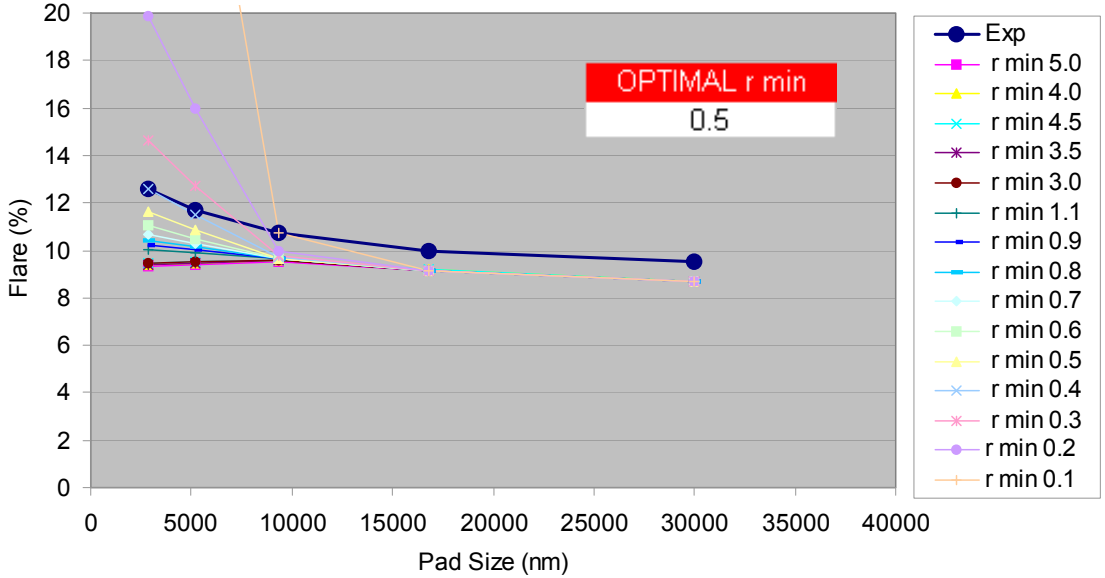
Generation of calibrated flare maps: Optimization of the parameters - r min

- *2μm pads are not sufficient to calibrate r min flare scaling properties*
- *Pads of different size up to 30μm are used instead*





Optimization of r min using pads of different size ensures correct flare scaling

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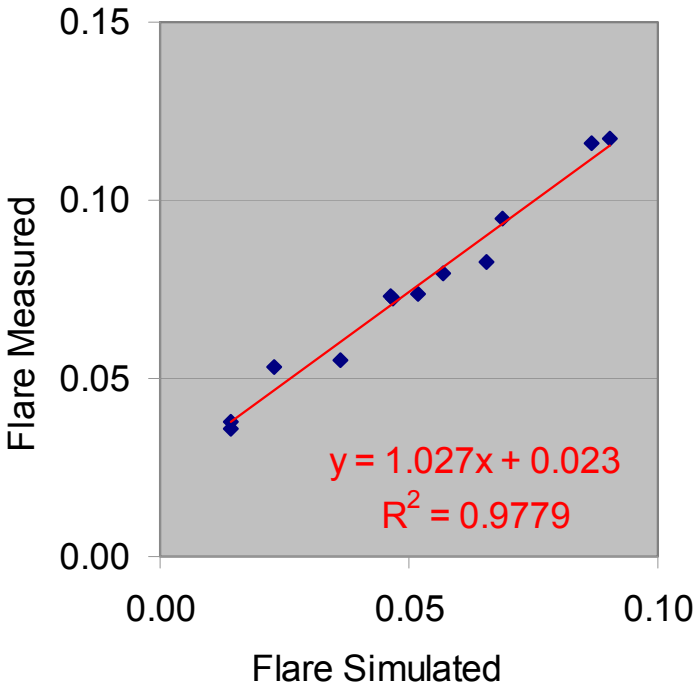
Generation of calibrated flare maps: Comparison of optimized PSF with experiments

- *Comparison of simulation and experiment for 2 μm pads*



- ***Very good match of experiment and simulation***
- ***The offset of ~ 2.5% was observed with different PSF /Methodology***

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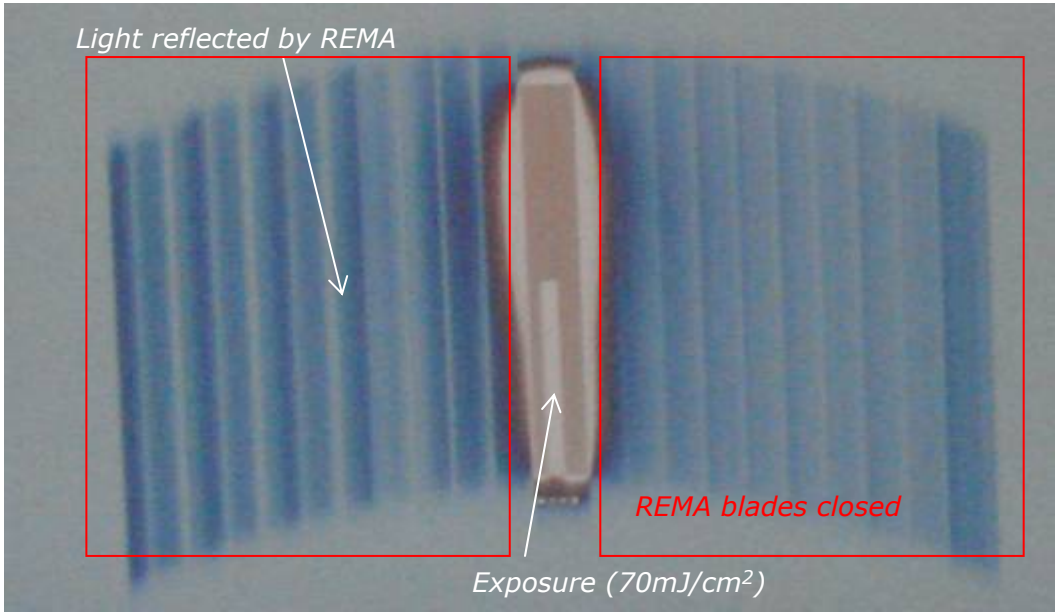
Generation of calibrated flare maps: DUV Contribution

- *High dose exposure with REMA closed (70 mJ/cm²)*
- *REMA can only reflect DUV and visible*
- *This results indicates ~ 2-3% DUV content (Eo = 2 mJ/cm²)*



- ***The offset of ~ 2.5% can be interpreted as DUV contribution***

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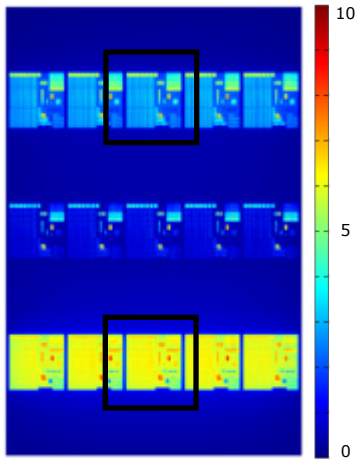
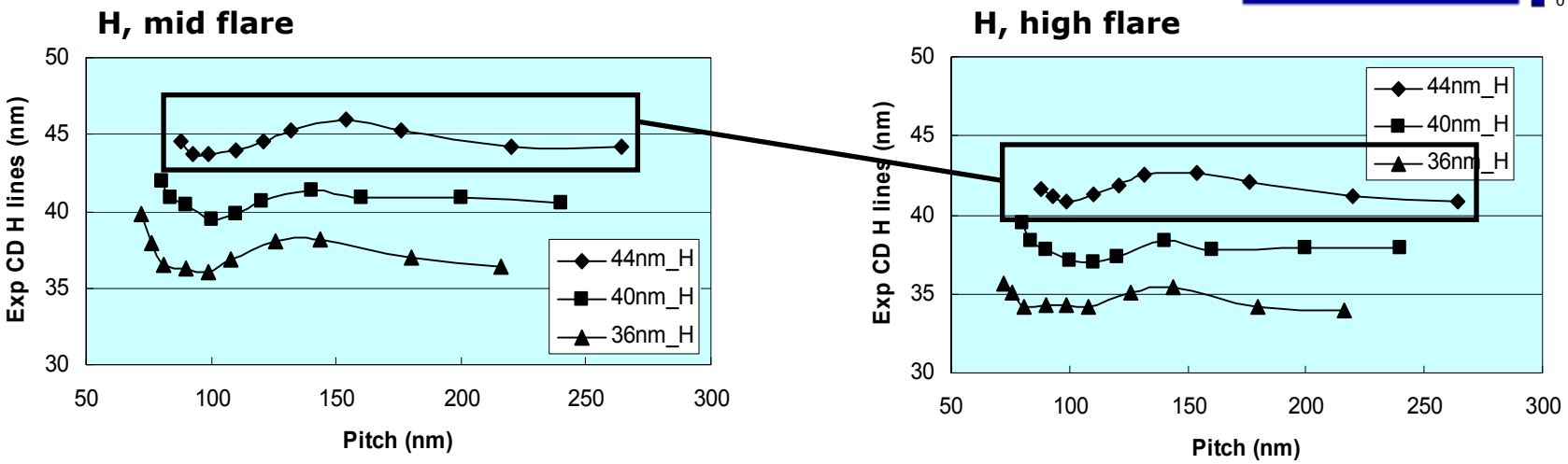
Outlook: CD Modeling

- ***CD modeling through flare and orientation***
  - *ShinEtsu SEVR59*
  - *Proximity data at 3 flare levels*
  - *Vertical and Horizontal orientation*
  - *600 datapoints total*





- ***Accurate flare modeling absolute requirement for CD modeling***
- ***First models with background flare show rms error around 1nm can be obtained***

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Conclusions

- Flare Metrology
  - The automated flare metrology we implemented is both accurate and precise
- Generation of calibrated flare maps
  - Flare has been monitored for 10 months and no change was observed
  - We reported on flare map calibration using single fractal PSF
  - More than 400 flare maps were generated and compared to experiments
  - After optimization, the single fractal model reproduces accurately the experimental flare results
  - An offset is observed and attributed to DUV contribution
  - CD data have been measured to verify the impact of flare compensation and develop full scale EUV OPC
  - Initial CD modeling over a broad range of flare shows an rms error of ~1nm

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Acknowledgements

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  - IMEC: Jan Hermans and Bart Baudemprez
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  - Resist vendors for providing resists
  - IMEC colleagues and IIAP partners for their contributions

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