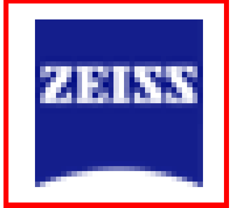

Excursion Prevention Strategy to increase Chip Performance by Photomask Tuning

Ofir Sharoni
Mask Tuning
Carl Zeiss SMT, Israel
ofir.Sharoni@zeiss.com

September 23-26, 2019

Outline

- Problem definition – patterning defects
- Litho parameters interaction effect
- Possible solutions – wafer intra field CDU improvement
- Potential yield improvement
- Summary and conclusions

Outline

- **Problem definition – patterning defects**
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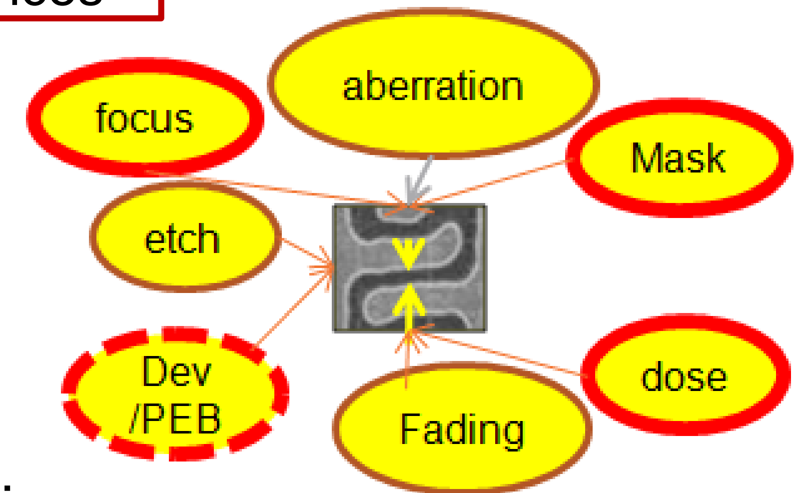
Patterning defects – Excursion root cause

Definition of an excursion:

„(Multiple) parameter deviation from normal with significant impact on either product yield, wafer scrap or electrical performance of devices"



*TSMC LinkedIn

TSMC technology conference guideline:

„Zero Excursion, zero defect"

Excursion prevention can reduce the Process defects Probability, even if all parameters are in SPEC

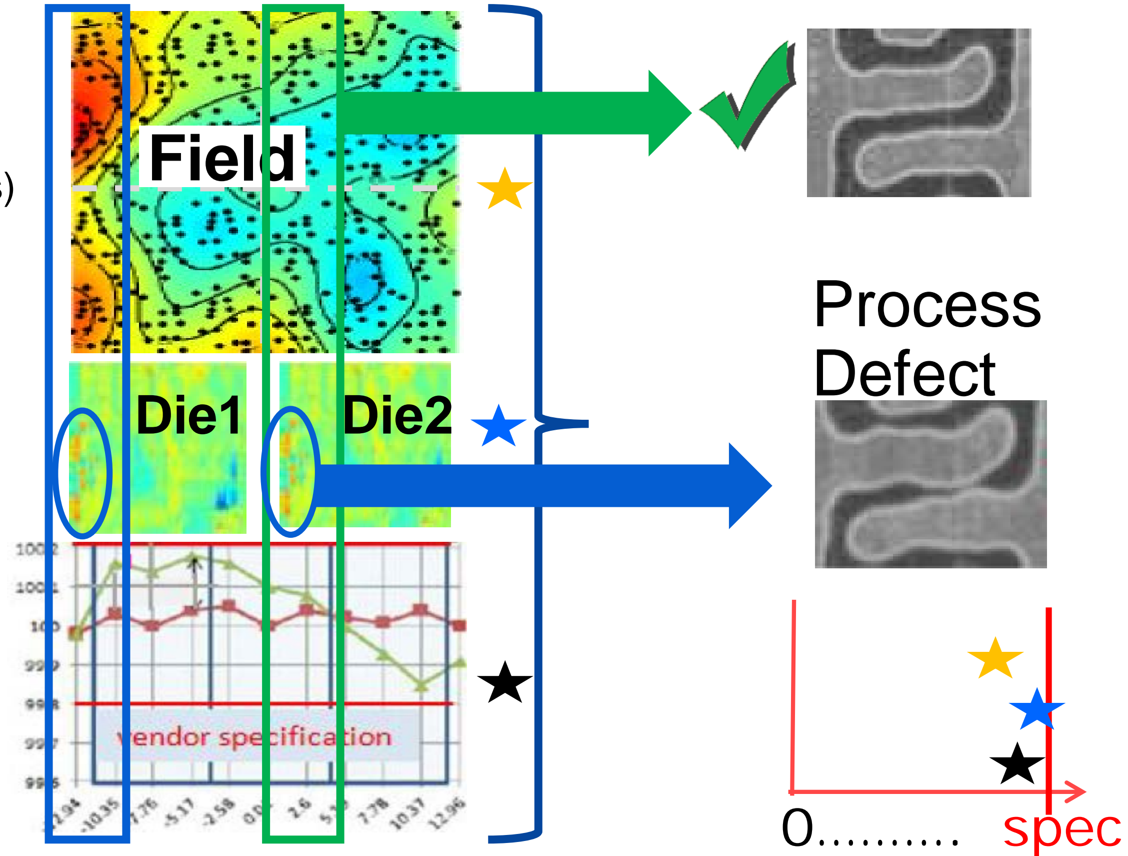
Problem statement:

Yield Loss caused by **Patterning defects**

Multiple parameter dependencies → patterning defect

Wafer Intra-Field main contributors:

- Mask CDU — Mask CDU (4 Dies)
- Litho PW
  - Across Wafer Focus — Die Topography
  - Across Wafer Dose — Intra-Field Slit Uniformity



Patterning defects can be caused by interaction of multiple parameters

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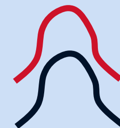
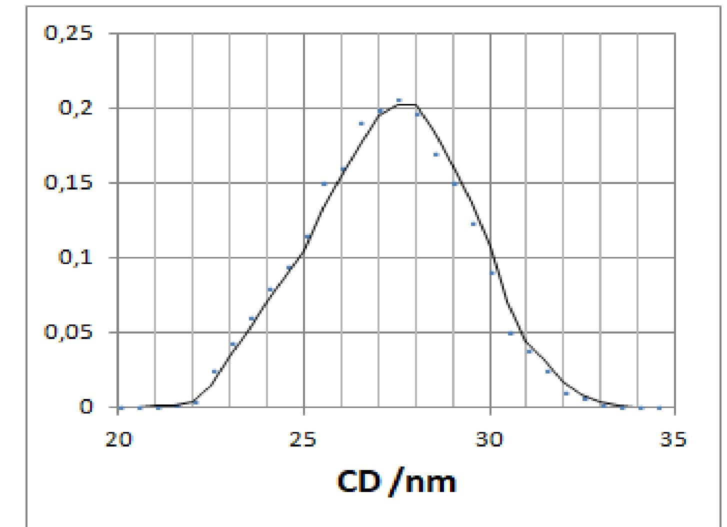
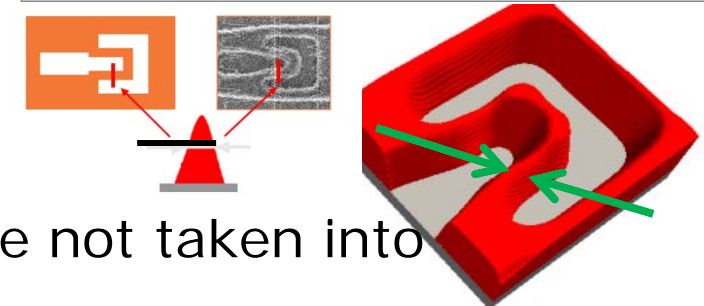
Litho Parameters – Simulation conditions

- Calibrated 3D resist model for an 28nm metal application (k1=0.32)
- Parameter variations (Gaussian) :

Case	Mask	Scanner
1	“Perfect”	Normal Noise (3σ): Dose Variation = 1.4% Focus Change = 30nm 
2	Systematic	Same as above
3	Systematic	Above + Dose offset
4	Systematic	Above + Dose & Focus offset



- Most critical weak point (WP) in the whole patterning space (high MEEF, low NILS)
- The stochastic effects on top of parametric (LWR) were not taken into account in this presentation



Fail statistics / yield impact
Based on Wafer CD Distributions

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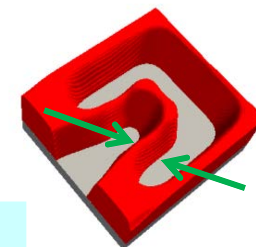
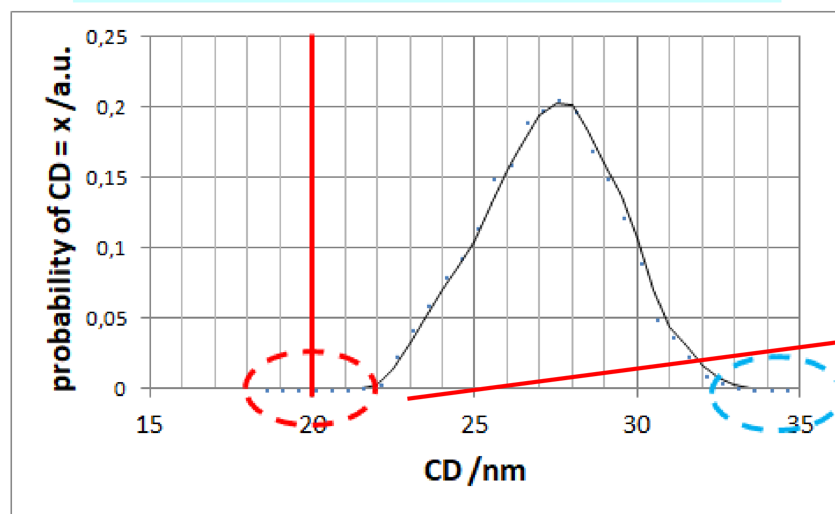
- Task: Calculate the probability of an excursion
- Success Criteria: WP top-CD >20nm. CD below threshold (20nm) → Fail

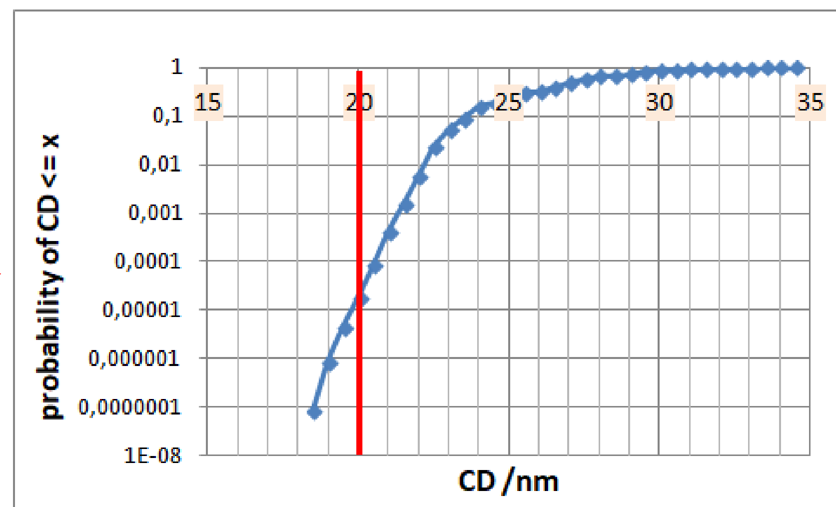


Wafer CD distribution



Cumulative plot

Integrated CD distribution



Based on the accumulative graph,
Process defects appearance can be predicted

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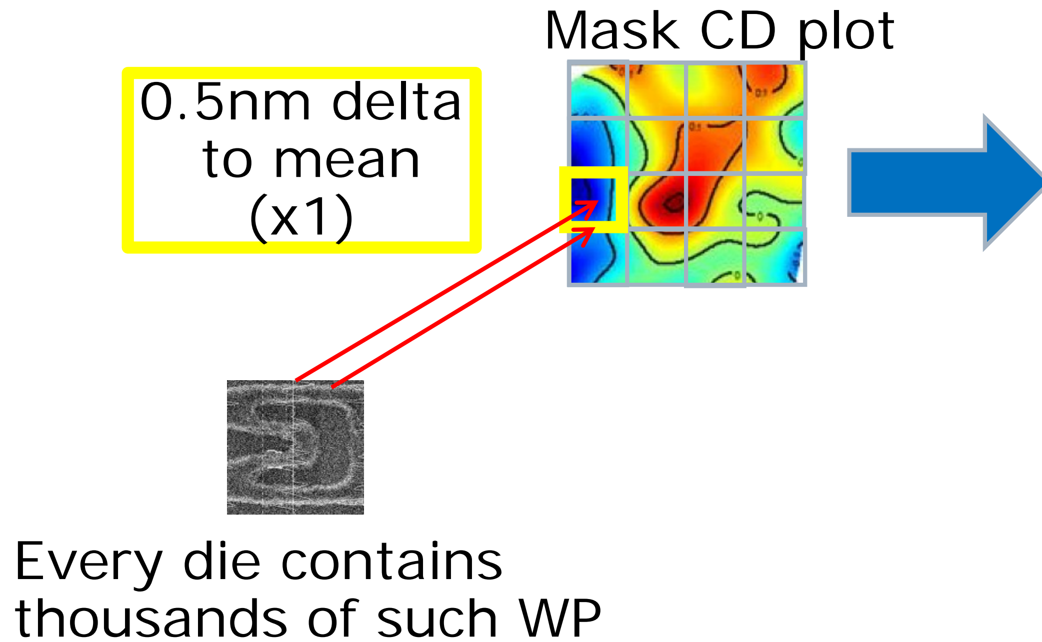
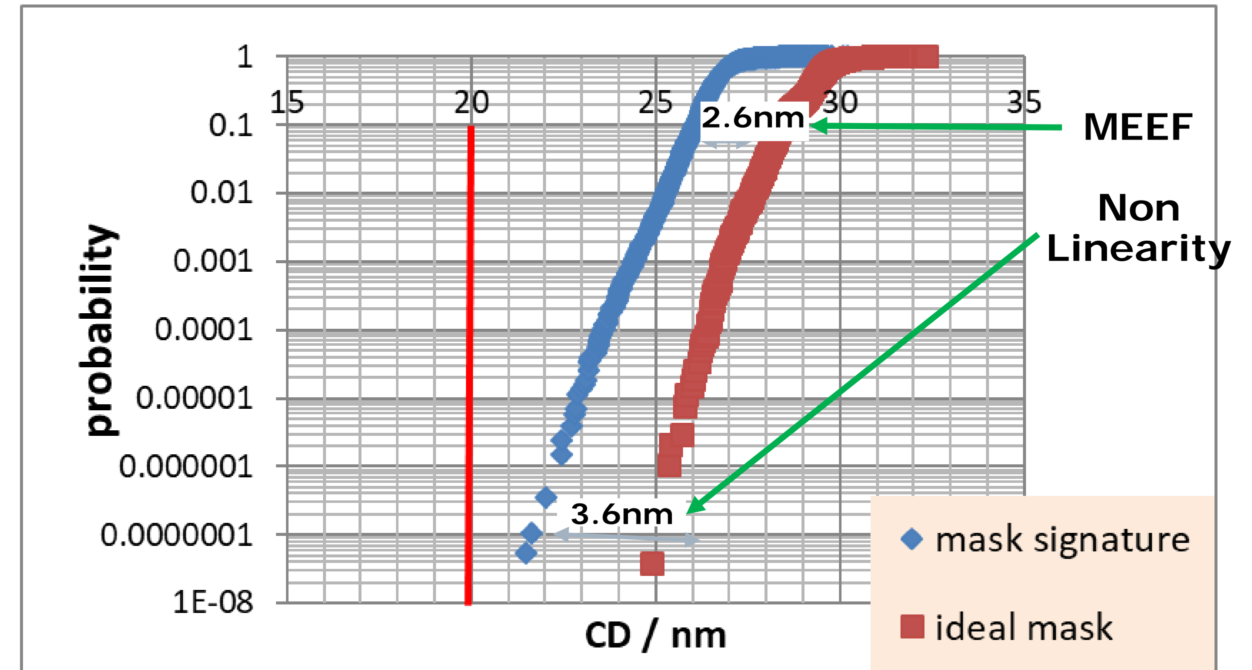
Simulated wafer CD distribution in the presence of a **systematic mask signature**

- The mask systematic signature addition to the ideal mask case
- Simulation only for the yellow marked die:



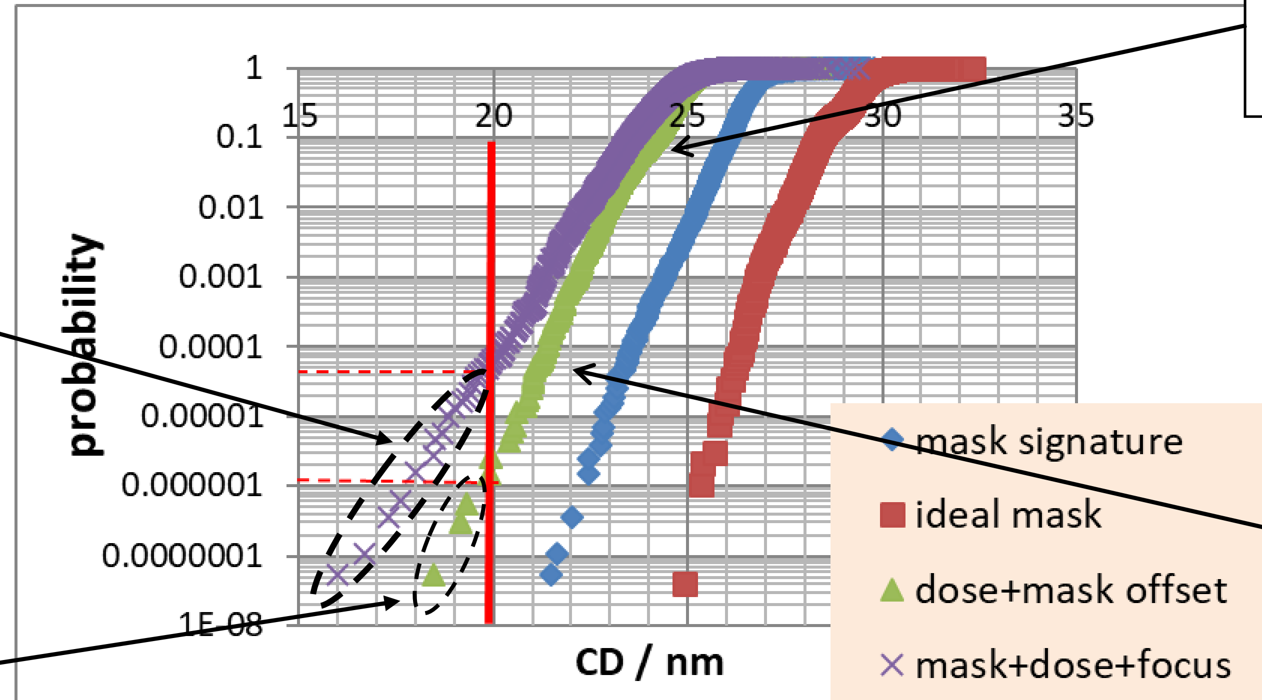


Mask systematic signature just by itself (perfect Dose & Focus condition) can bring critical CD close to SPEC Limit

Simulated wafer CD distribution
Full case (Mask + Dose + Focus)

Simulation Conditions (on top of the mask signature):

- 1.2% systematic dose error
- 15nm systematic focus error



Full case: Relatively high failure probability

Dose case: The CD slightly goes below the critical value

To reduce the high failure probability, the wafer CD distribution must be improved significantly

Outline

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Wafer intra field CDU improvement

Using ZEISS ForTune CDC Application

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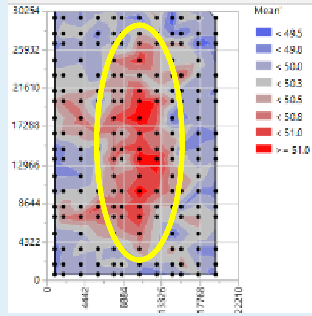
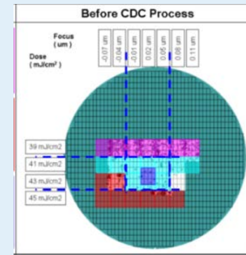
Intrafield CDU

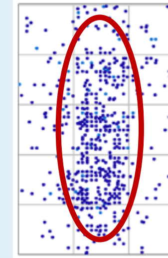
Litho PW

Process defects

Pre CDC







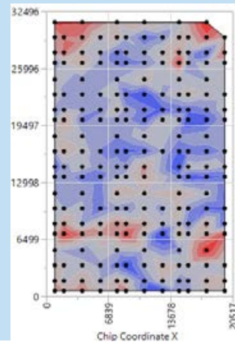
Increase the IC functionality

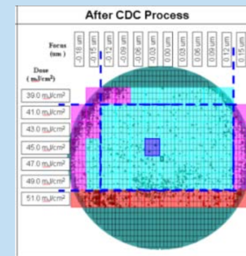
CDC proces

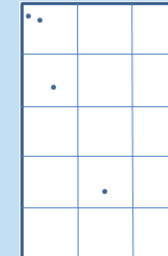
Expand Litho PW

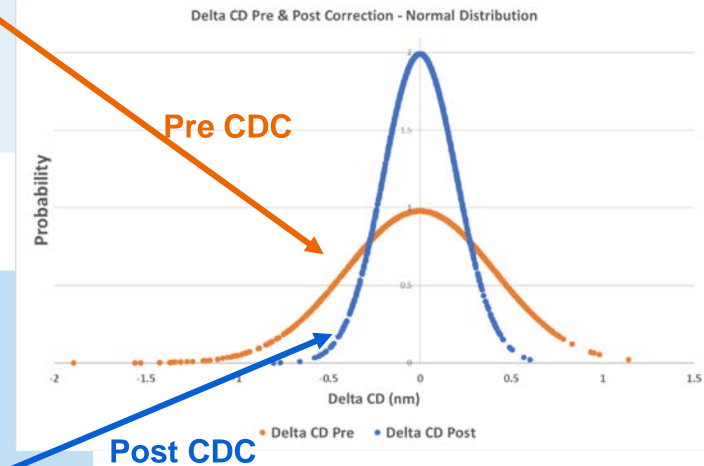
Reduce Process defects

Post CDC









Process Defects Probability reduce when using CDC process (even if the wafer intra-field CDU is in SPEC)

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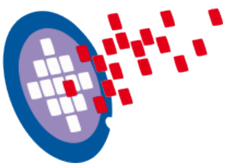
CDU Improvement (CDC tool Concept)



Controlling intra-field CD by locally attenuating the light transmitted through the mask

The CDC solution improves Range, 3Sigma and Mean To Target CD

The **ultimate control concept**: Intra field CDU improvement by ZEISS CDC

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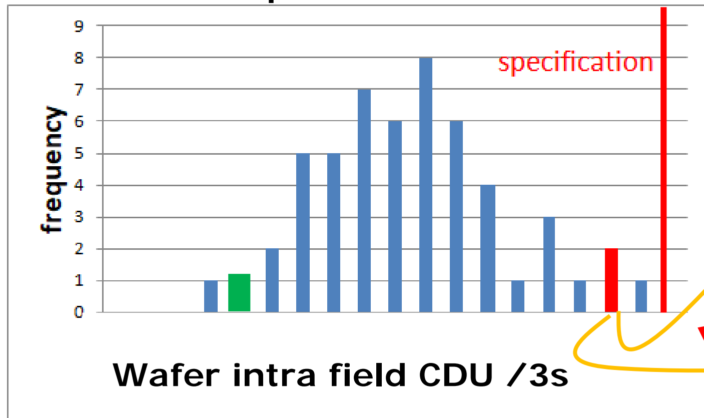
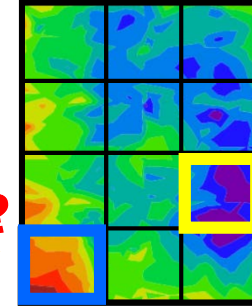
Wafer intra field CDU performance, for different products /metal layers



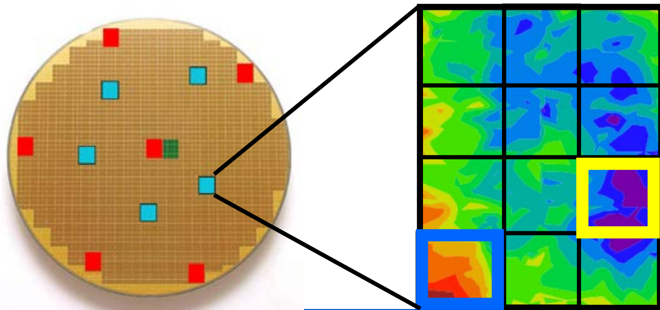
"I am fine, I am in specification"

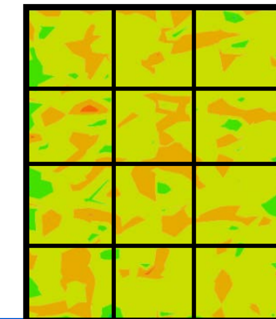
Really? With dose & focus variations, still?

Intra field CD fingerprint



The systematic CD difference (between the two dies) is printed **on every field, at every wafer**





High CD variations solution

Wafer intra field fingerprints can be improved at low effort and low cost with ZEISS CDC tool to reduce the process defect probability

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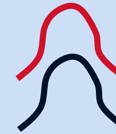
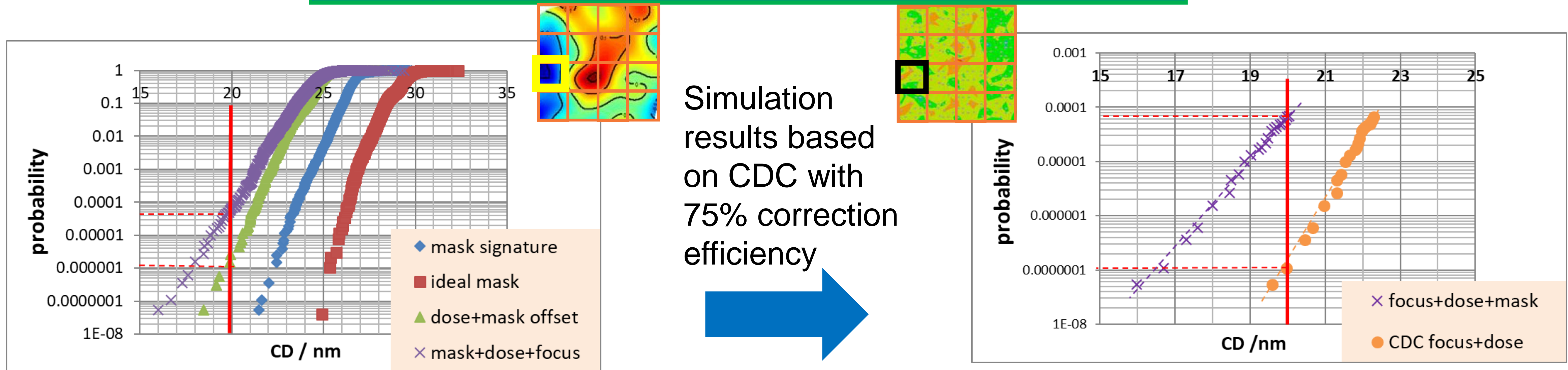
CDC correction simulation for the mask/focus/dose case

Case	Mask	Scanner
1	"Perfect"	Normal Noise (3s): Dose Variation = 1.4% Focus Change = 30nm 
2	Systematic	Same as above
3	Systematic	Above + Dose offset
4	Systematic	Above + Dose & Focus offset



The CDC solution for the combined focus & dose offset case reduces the fail rate significantly

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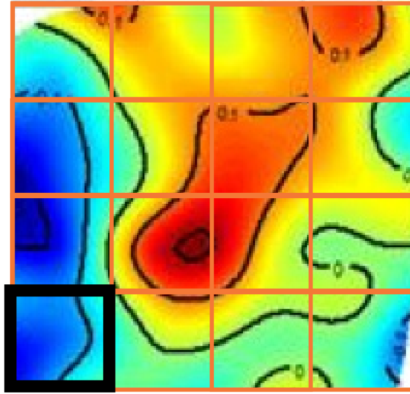
Full field **Yield impact estimation**; Pre and post CDC process

CD signature



CD signature separated into 4 sub-fields per die

ΔCD - Pre CDC

0,21	0,70	0,70	-0,14	-0,28	0,70	1,12	0,35
-1	-0,49	0	0,56	0,56	0,77	0,49	-0,14
-1,7	-1,6	-0,28	0,63	0,91	0,63	0,49	-0,56
-1,9	-1,19	-0,35	0,84	1,05	0,56	0,35	0
-2,2	-1,6	-0,07	1,26	1,05	0,28	0,07	0,21
-2	-0,7	0,35	1,4	0,84	-0,14	-0,07	-0,35
-0,84	-0,7	-0,42	0,35	0,7	0,3	0	-0,35
-1,8	-0,63	-0,21	-0,21	-0,21	-0,07	0,07	0,49

Yield loss per die [%]

1,6	0,0	0,1	0,0
36	0,1	0,0	0,0
47	0,0	0,0	0,1
13	0,1	0,0	0,1

Mean Yield Loss **5.4%**

CDC **Process**

ΔCD - Post CDC

0,053	0,175	0,175	-0,04	-0,07	0,175	0,28	0,088
-0,25	-0,12	0	0,14	0,14	0,193	0,123	-0,04
-0,43	-0,4	-0,07	0,158	0,228	0,158	0,123	-0,14
-0,48	-0,3	-0,09	0,21	0,263	0,14	0,088	0
-0,55	-0,4	-0,02	0,315	0,263	0,07	0,018	0,053
-0,5	-0,18	0,088	0,35	0,21	-0,04	-0,02	-0,09
-0,21	-0,18	-0,11	0,088	0,175	0,075	0	-0,09
-0,45	-0,16	-0,05	-0,05	-0,05	-0,02	0,018	0,123

Yield loss per die [%]

0,1	0,0	0,0	0,0
0,5	0,0	0,0	0,0
0,3	0,0	0,0	0,0
0,2	0,1	0,0	0,0

Mean Yield Loss **0.12%**

Yield loss = #Failing WP per wafer (86 exposure fields)

ZEISS CDC solution improves the yield dramatically

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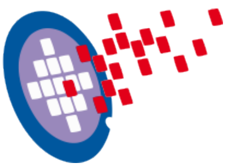
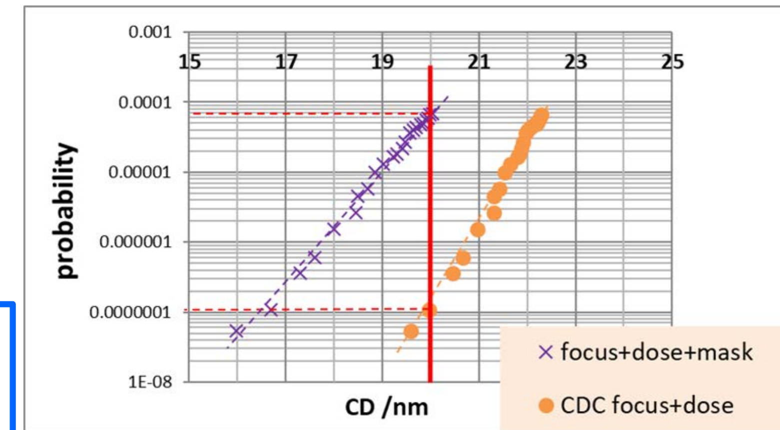
Summary / conclusions



- **Yield Loss** caused by Patterning defects due to process excursions even if all parameters are in spec
- **Excursion prevention**, by controlling wafer CD distribution, reduce the Process defects Probability
- **Wafer intra field CD** distribution will be improved at low effort and low cost by mask modification using CDC Application of ZEISS ForTune System
- **The yield will be improved** dramatically using the excursion prevention strategy



Thank you!
Questions??

Acknowledgement

This work is funded by the German Bundesministerium für Wirtschaft und Energie (BMWi) in the frame of the "Important Project of Common European Interest (IPCEI) on Microelectronics

I also would like to acknowledge AMTC for their collaboration in this presentation with the shared data and their knowledge on this subject:

Aravind Narayana, Thomas Thamm