Readiness of Multiple E-Beam Maskless Lithography (MEB ML2)

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23 Oct 2009, 6th International Symposium on Immersion Lithography Extensions

Why Maskless?

- “The limit of lithography will not be in resolution but in economy.”

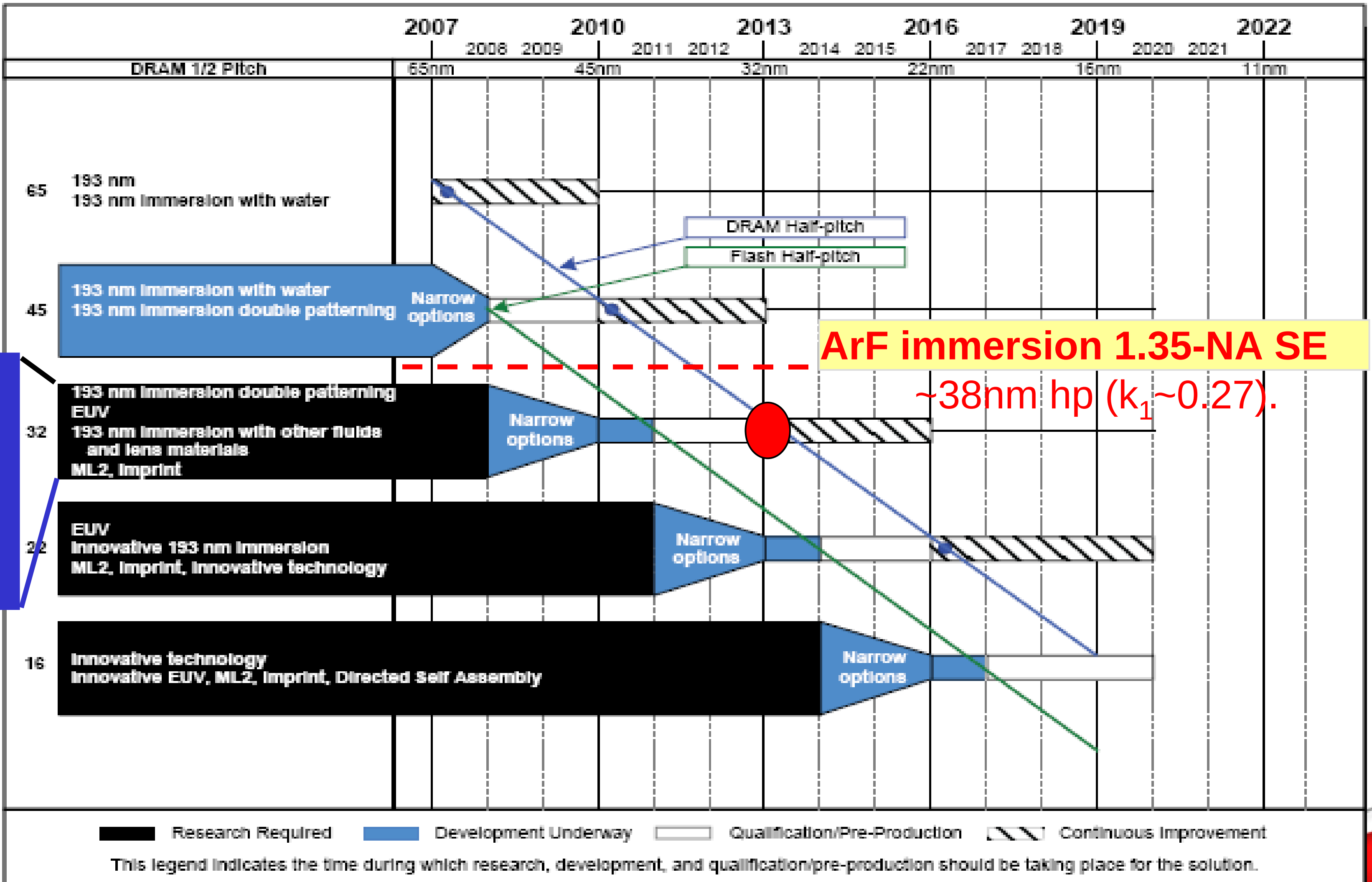
– Dr. Burn J. Lin, in 1987

- “The devil is in the mask!”

– Dr. Burn J. Lin, in 2007

Source from Proc. of
SPIE Vol. 6520-02, (2007)

ITRS Roadmap (2007)



NGL:
- **DP**
- **EUVL**
- **ML2**
- **Imprint**

ArF immersion 1.35-NA SE

~38nm hp (k_1~0.27).

Considerations for NGL

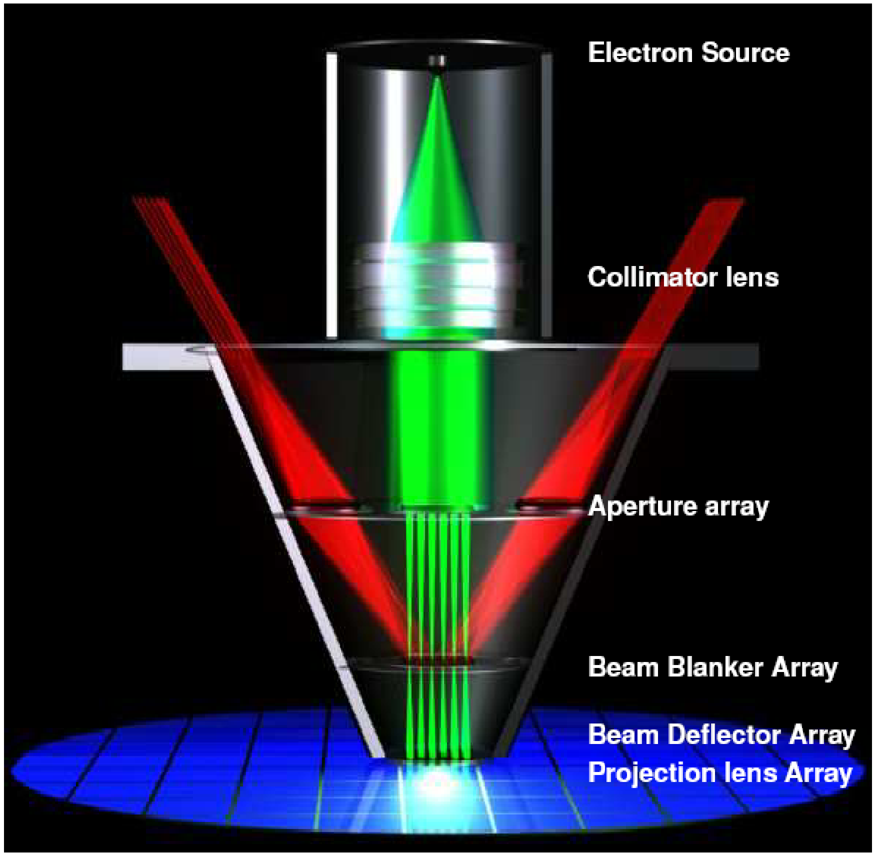
- **Cost**
  - Comparable to existing single exposure
  - >100WPH at similar or less than one scanner footprint
- **Extensibility**
  - Resolution & Throughput
  - Extensible from 22nm node and at least next two nodes
- **Mask**
  - Remove/Relax mask making challenges
- **Patterning performance**
  - CDU & LWR
  - SMO & MMO with existing optical lithography
- **Defectivity**
  - Low defect density
  - Inspection solution!

Major Challenges of NGLs

- Fundamentally, masks are too expensive and too difficult for <32nm-HP node and beyond
- **Double Patterning by ArFi**: Double masks/processes cost! Design rule restrictions!
- **EUV**: ML mask defect, inspection and source power.
- **Nanoimprint**: 1X, 3D template is too tough, defect and overlay
- **MEB ML2**: Throughput is a concern! However, it has a lot of advantages
  - No mask cost & mask induced troubles,
  - Remove design rule constraints,
  - Lowest cost if throughput can be > 10wph, or >100WPH by cluster
  - Cost (mainly from electronics) trend down by Moore’s law,
  - MEB column is much cheaper than optical lenses

The MAPPER Technology

- Single electron source split in 13,000 Gaussian beams
- V_{acc} = 5keV
- Apertures are imaged on substrate through 13,000 micro lenses
- MEMS-stacked static electric lenses
- Optical-switched CMOS-MEMS blanker array

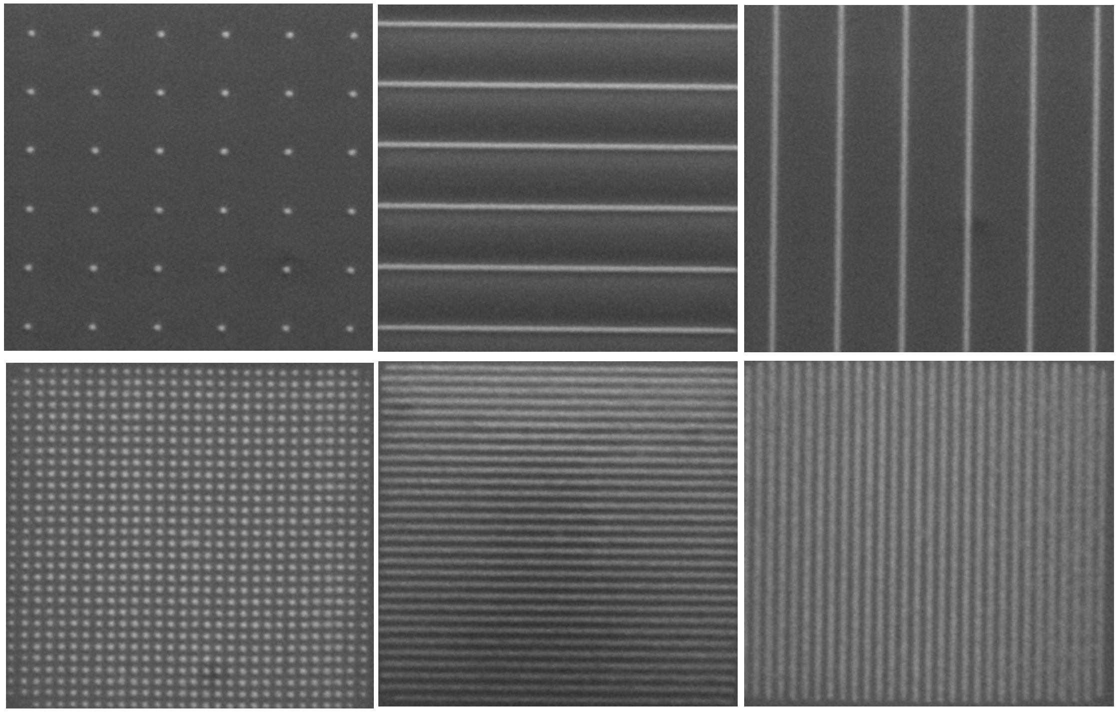


* Infomation from MAPPER Lithography.

45nm images by Pre-Alpha Tool (Q4, '08)

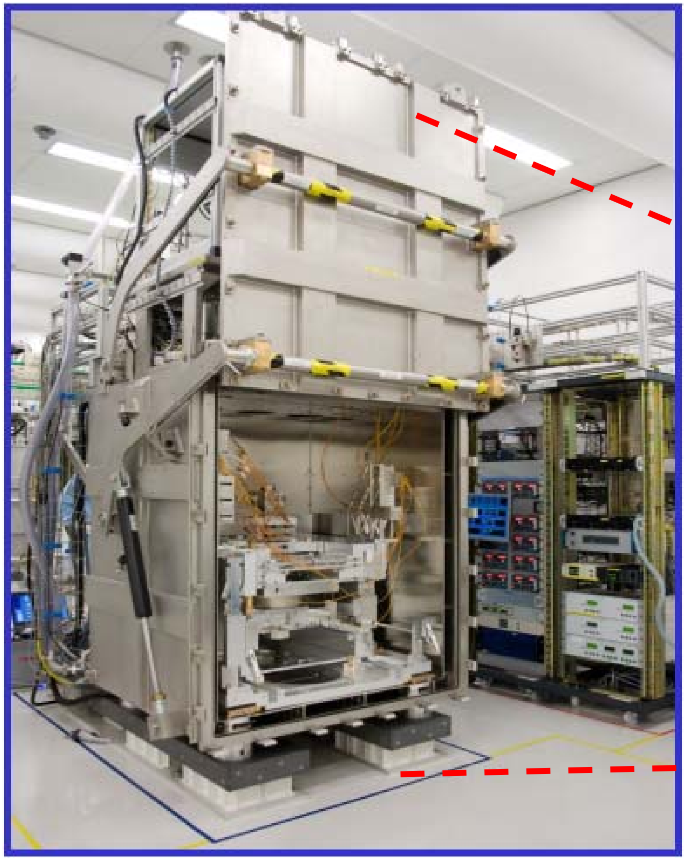
MAPPER Pre-Alpha Tool
110beams @ 5keV,

HSQ thickness = 40nm



pattern	CD [nm]		CD Mean-to-target [nm]		CDu [nm]	
	Measured	Required	Measured	Required	Measured	Required
Dots dense	43.4	45	1.6	3.2	2.5	4.5
Dots isolated	46.4	45	1.4	3.2	2.8	4.5
Lines_Horizontal dense	42.8	45	2.2	3.2	1.9	4.5
Lines_Horizontal isolated	42.1	45	2.9	3.2	3.0	4.5
Lines_Vertical dense	44.9	45	0.1	3.2	2.8	4.5
Lines_Vertical isolated	46.5	45	1.5	3.2	2.9	4.5

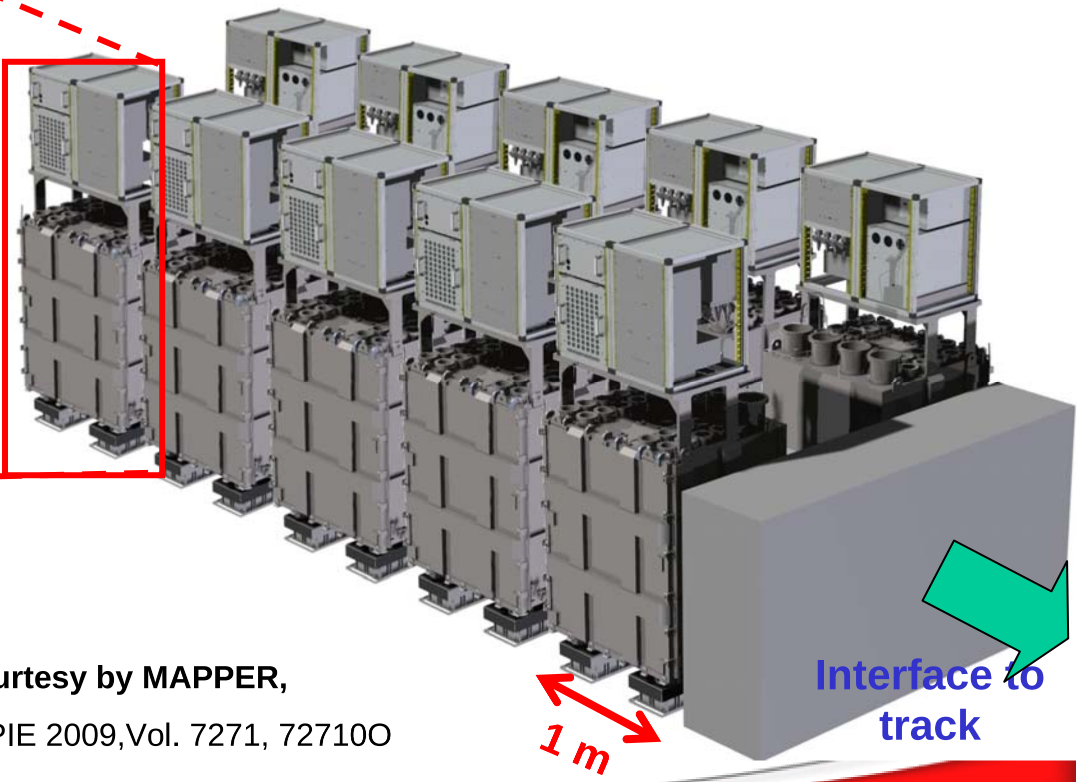
Cluster concept for 100WPH tool



MAPPER single column tool
Upgrade to 13,000 beams
for 10WPH

HVM clustered production tool:

- **>13,000 beams per chamber (10WPH)**
- **10WPH x 5 x 2 = 100WPH**
- **Footprint ~ArF scanner < 2/3 EUV scanner**
- **In-line to track**



Courtesy by MAPPER,

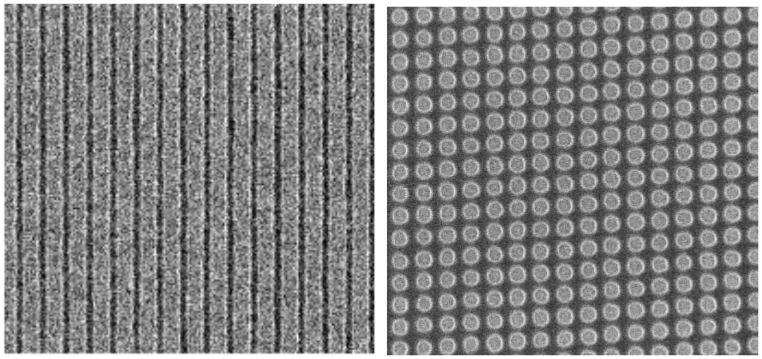
Proc. of SPIE 2009,Vol. 7271, 72710O

MAPPER Pre-Alpha Tool @ TSMC

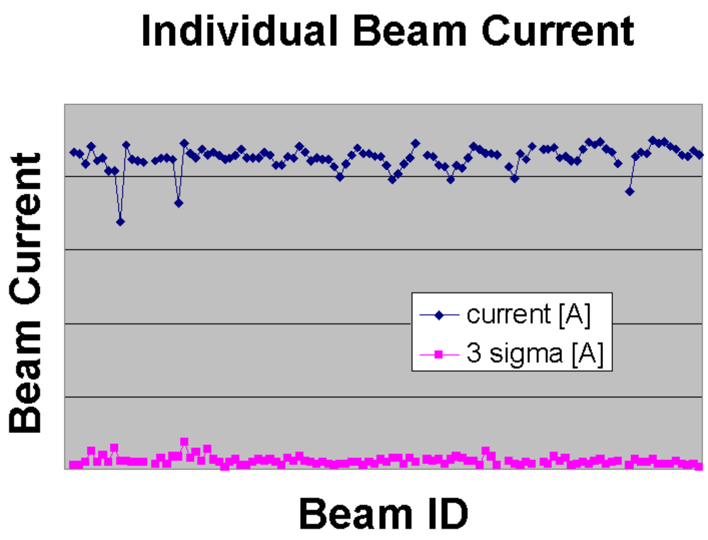
- Tool configuration
  - 110x Gaussian beams @ 5keV
  - Raster scan by individual beam, with MEMS blanker array controlled by 110x optical data channels
  - 300mm wafer stage & loadlock interface
  - Resolution start from 45nm HP, will upgrade to 32nm HP.
- Possibly upgrade to 10WPH on the same platform

45nm HP resolution & CDU correction

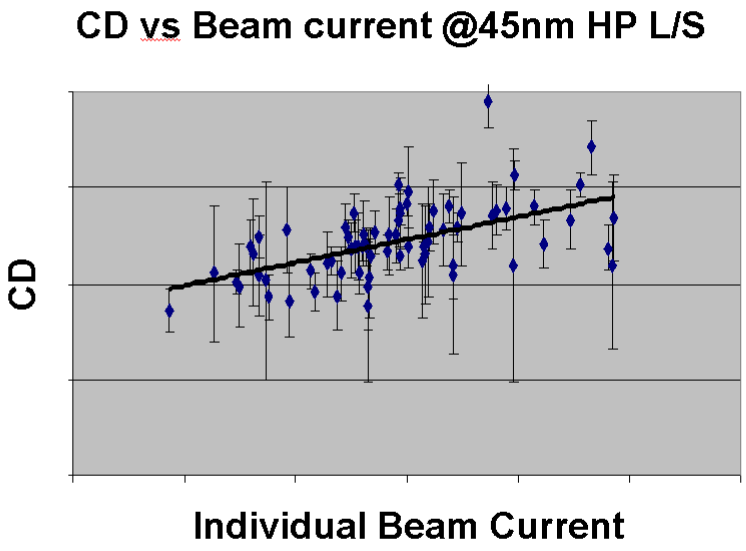
- Individual beam current can be measured by using Faraday cup,
- Correlation of CD vs beam current shows the possibility of correction CDU by apply different dosage offset



45nm HP L/S & C/H @ PMMA



Individual Beam Current

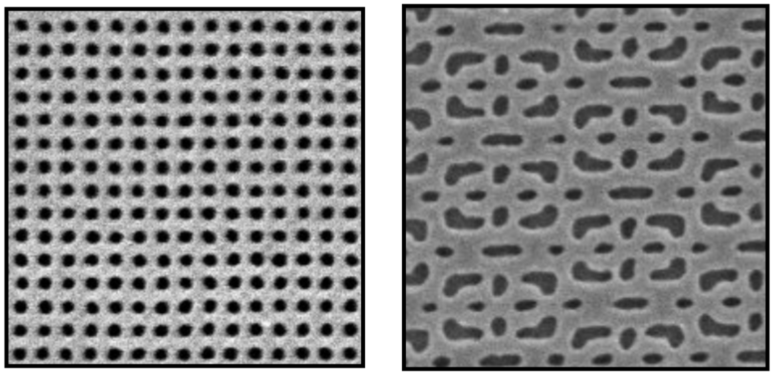


CD vs Beam current @45nm HP L/S

30nm HP resolution @5keV

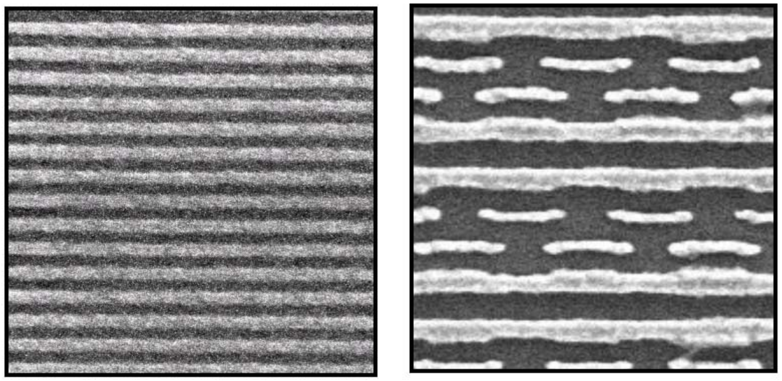
- Mimic 5keV writing experiments at spot size ~ 25nm were done by a SEM-converted writer in NTU IRND Lab.
- Manual processes, in poor environmental control.


Elionix ESM9000



- **ZEP520A – Positive resist**

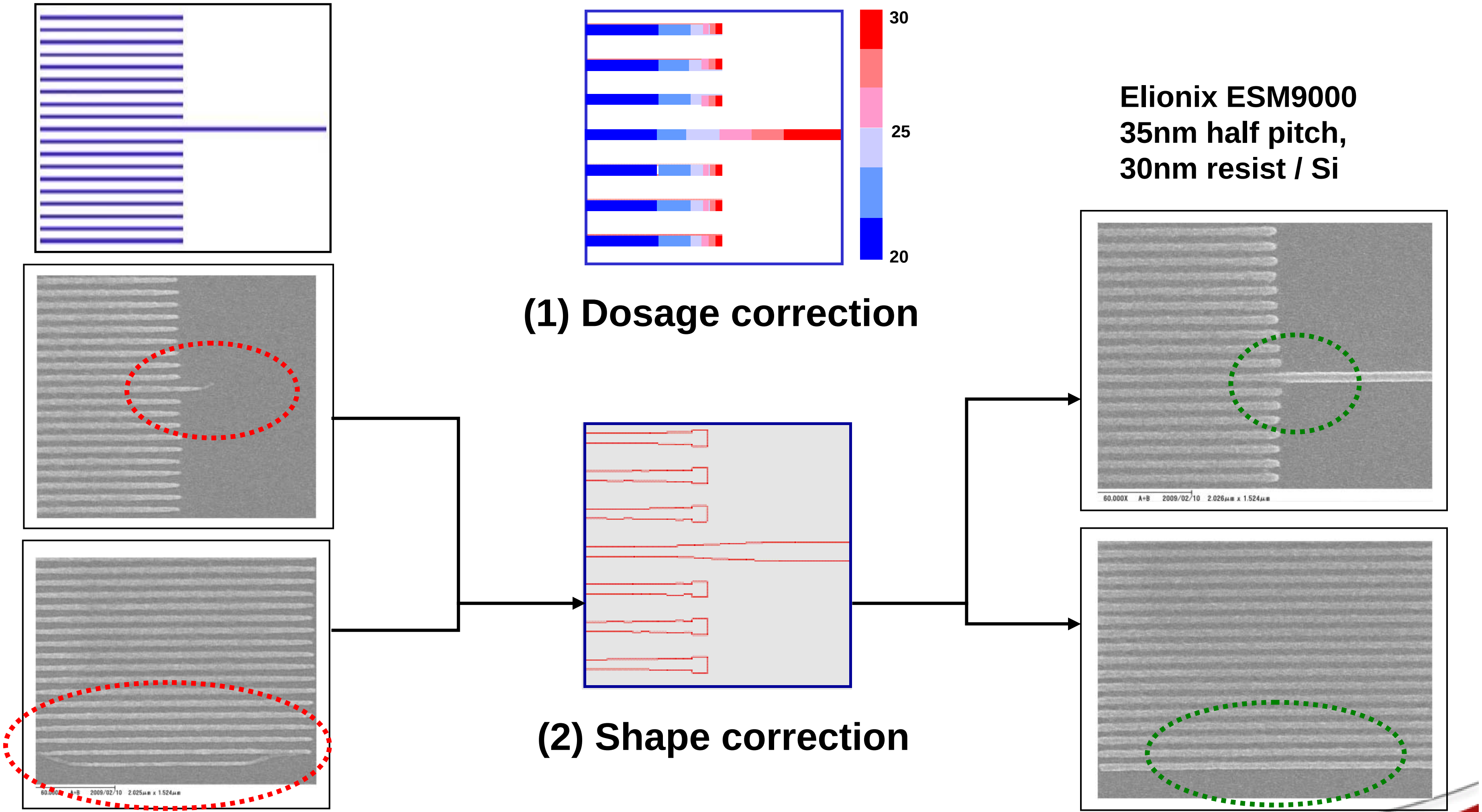
  @40nm thickness



- **HSQ – Negative resist**

  @40nm thickness

E-Beam Proximity Correction Verification



(1) Dosage correction

(2) Shape correction

Elionix ESM9000
35nm half pitch,
30nm resist / Si

Before EPC

After EPC

Proximity Effect Correction

Test Clip:

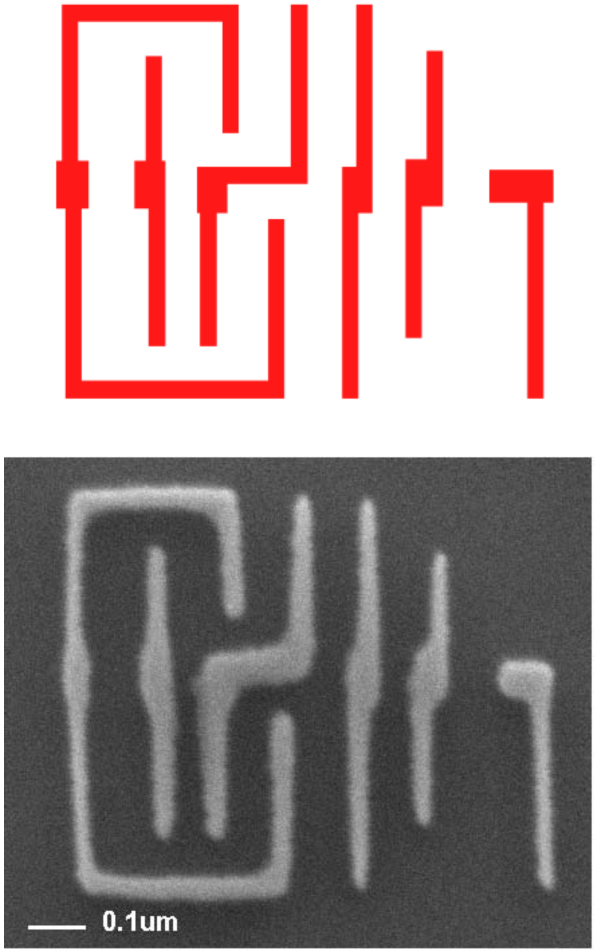
32nm Logic clips

Conditions:

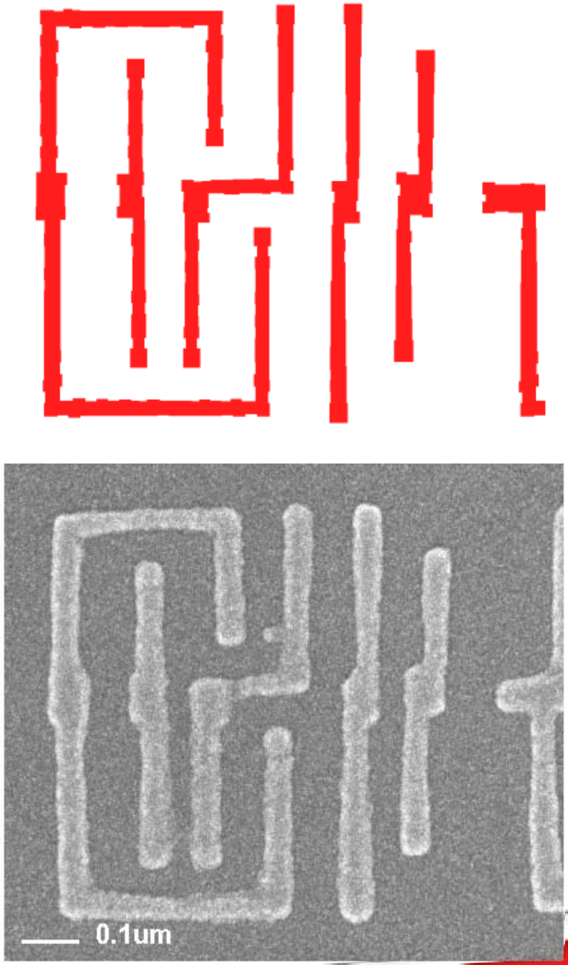
HSQ thickness 40nm
Beam size = 35 nm
Scanning pixel = 2.25 nm

Reference: SPIE 7271_54 (2009)

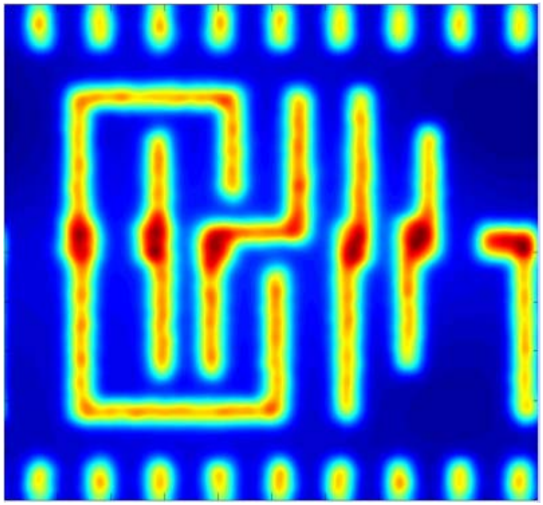
W/O EPC



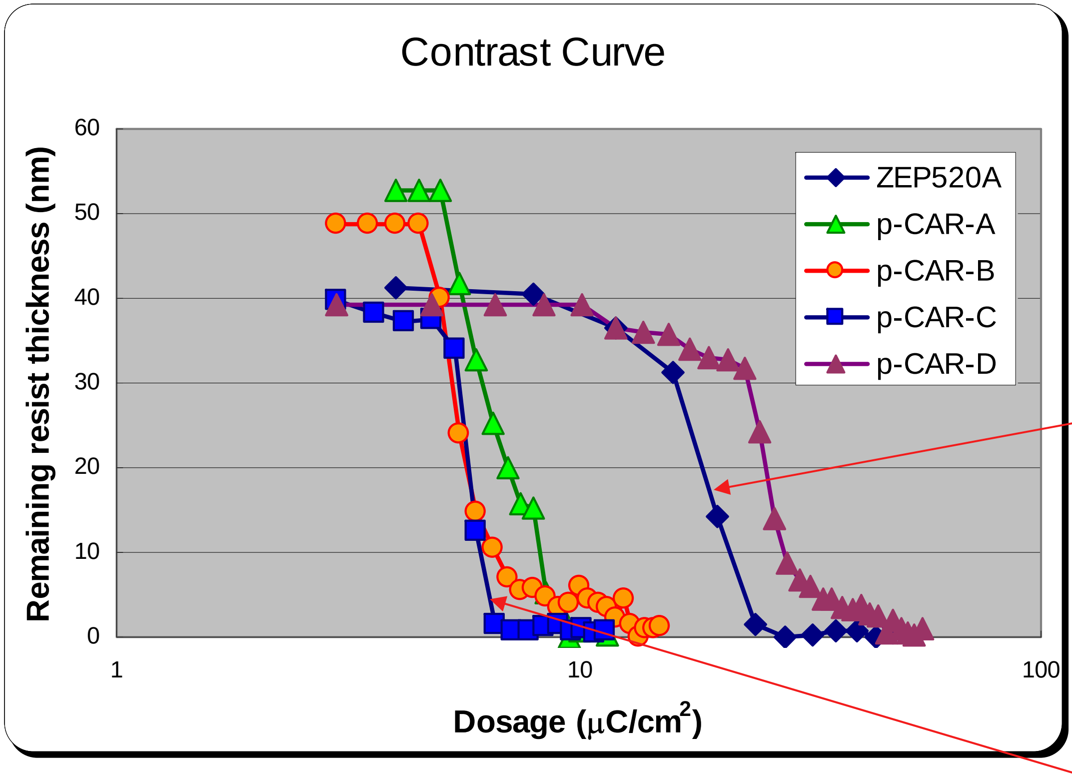
W/ EPC

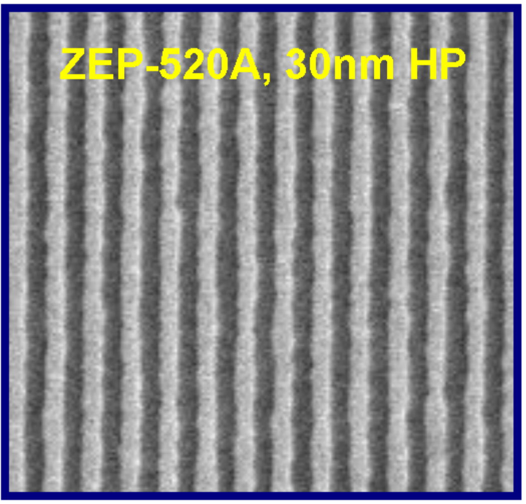


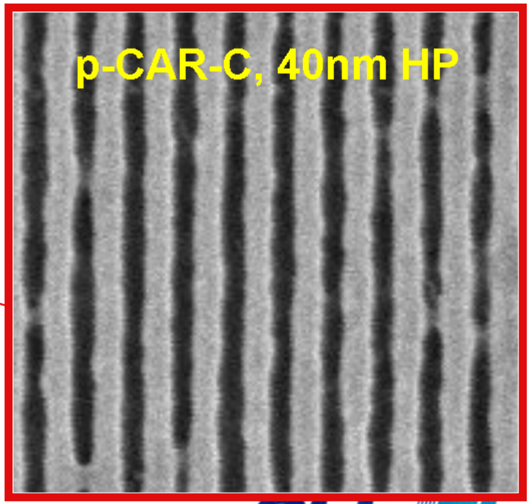
by MOSES



Chemical Amplified Resist @ 5keV







- **ZEP-520A proved high resolution of EBL tool.**
- **P-CAR-C, with polymer bound PAG, showed highest contrast at 5 keV.**
- **Severe T-topping due to airborne contamination.**

Throughput Challenge – 1: Source

$$WPH = \frac{3600}{t}$$

$$t = t_w + t_m + t_o$$

$$= \boxed{\frac{QA}{n \cdot I}} + \sum t_m \times r_m + t_o$$

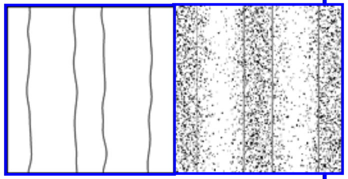
t_w: time for writing all features on a wafer

t_m: time for movements between shots, including over-scans, turnovers of changing scanning direction, and so on

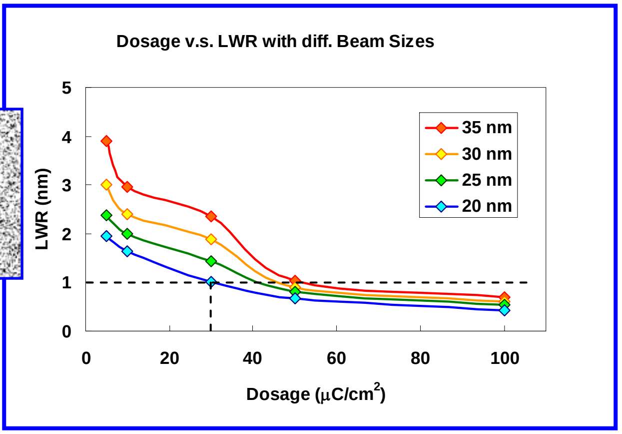
t_o: overhead time between wafers

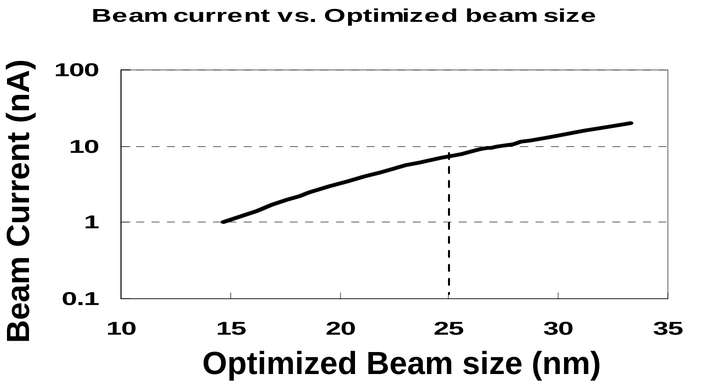
Monte-Carlo simulation by MOSES:

However, $I = \frac{\pi^2}{4} B_r V \alpha^2 d_I^2$



Refer to SPIE 6921-19 & 20 (2008)





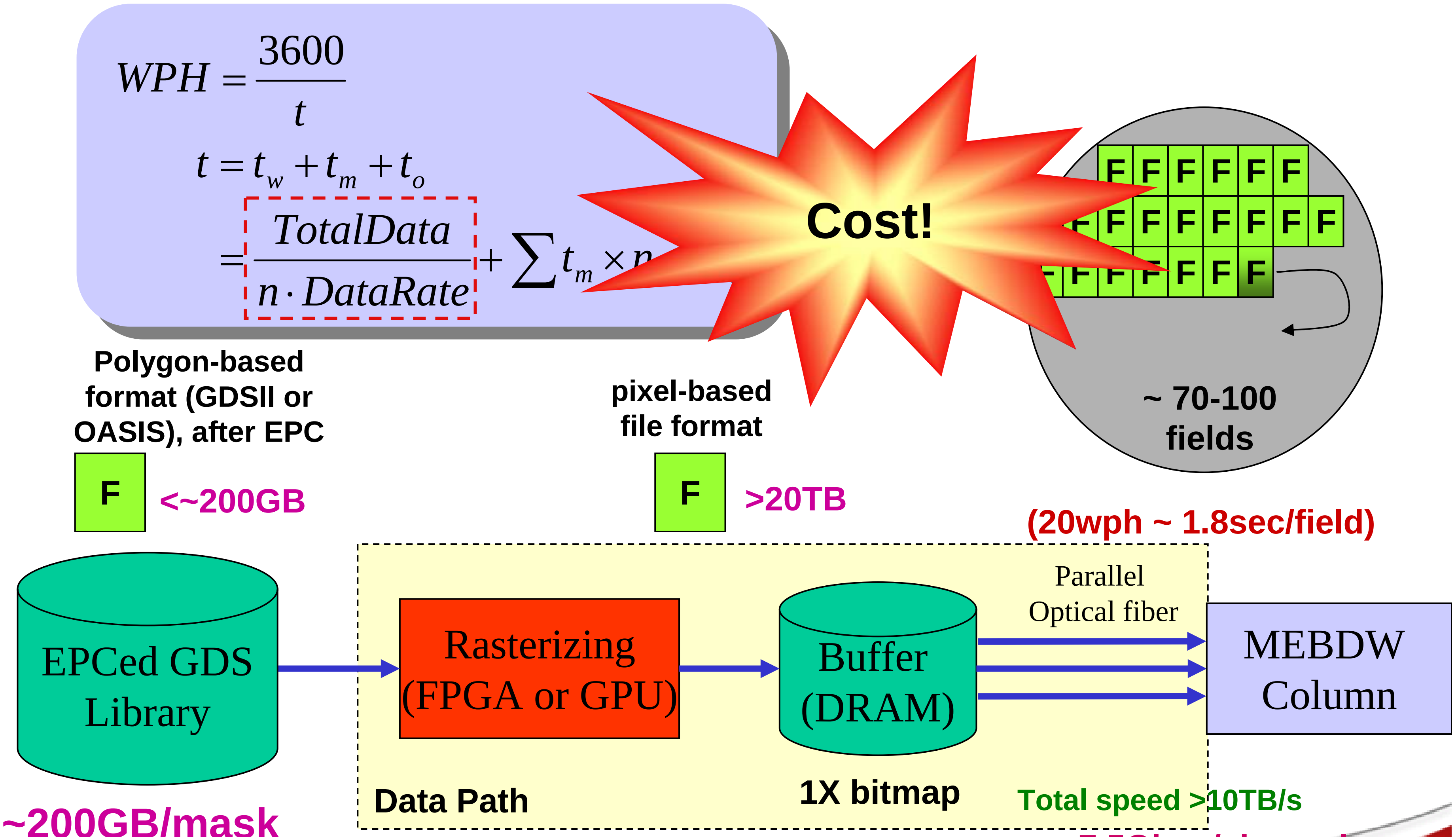
- ➔ **Required source Brightness ~ 10^7 A/m^{2}Sr^{2}V!**
- ➔ **Or need a solution for ~50x increment on writing area for a normal source brightness!**

Throughput Challenge – 2: Data Rate

$$WPH = \frac{3600}{t}$$

$$t = t_w + t_m + t_o$$

$$= \boxed{\frac{TotalData}{n \cdot DataRate}} + \sum t_m \times n$$



Cost!

~ 70-100 fields

Polygon-based format (GDSII or OASIS), after EPC

<~200GB

pixel-based file format

>20TB

(20wph ~ 1.8sec/field)

EPCed GDS Library

Rasterizing (FPGA or GPU)

Buffer (DRAM)

Parallel Optical fiber

MEBDW Column

Data Path

1X bitmap

Total speed >10TB/s

~7.5Gbps/channel

~200GB/mask X1,000 masks

Conclusions

- MAPPER Pre-Alpha tool has been installed in manufacturing environment, and 45-nm HP resolution by 110 beams has been successfully proven.
- High resolution down to 30nm HP at 5keV has been demonstrated, and EPC by shape modulation has been proven.
- Clustered MEB can achieve 100WPH at scanner footprint, and thus in-line to track. CAR is also feasible. So the existing single patterning lithography concept and operation can continue.
- Ebeam maskless lithography is the most desirable NGL if succeeds! Since maskless, as long as the MEB tool is ready, the technology is ready!

Acknowledgement

- Mr. Hill Liao and Mr. Te-Wei Tsai from TSMC, Hsinchu, for their support on tool installation and resist testing.
- Prof. J.Y. Yen, Prof. K.Y. Tsai, Prof. C.H. Kuan and their group from National Taiwan University for providing EBL tool and lab facility.
- Dr. Yoshio Kawai, from ShinEtsu, Japan, for providing CAR resist sample.
- Mr. Maurits Weeda, Mr. Tijs Teepen, Mr. Abdi Farah, and other colleagues from MAPPER Lithography, Delft, who contributed to the pre-alpha tool.

The End

Questions?