Impact of an etched EUV mask Black Border on imaging and overlay[a]

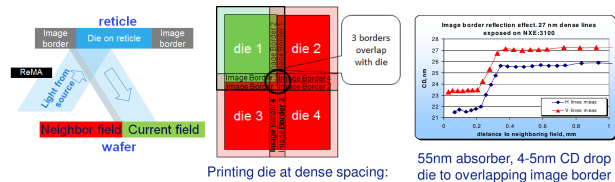
Robert de Kruif[1], Natalia Davydova[1], Brid Connolly[3], Norihito Fukugami[4], Ad Lammers[1], Vicky Philipsen[5], Shinpei Kondo[4], Eelco van Setten[1], Vidya Vaenkatesan[1], John Zimmerman[2], Noreen Harned[2]

[1] ASML Netherlands B.V., Development Imaging Reticles & Imaging, De Run 6501, 5504 DR Veldhoven, The Netherlands
[2] ASML Wilton, EUV Product Marketing USA, 77 Danbury Road, Wilton, CT 06897, USA
[3] Toppan Photomasks inc., Rähnitzer Allee 9, 01109 Dresden, Germany
[4] Toppan Printing Co., Ltd. Nobidome 7-21-33, Niiza, Saitama, 352-8562 Japan
[5] Imec, Kapeldreef 75, B-3001 Leuven, Belgium

IMAGE BORDER REFLECTIVITY[b,c]

Multiple mask parameters to optimize lithographic performance EUV photo mask, for example absorber height. **Reduction absorber height → higher resolution** patterning on mask, **reduction of OPC** needed for shadowing correction, but also **increased reflectivity** in image field (contrast loss) and image border

- Printing die at **dense spacing** → image border will **overlap** part of the neighboring die → EUV and DUV light **affect CD and contrast at the edges of the dies**



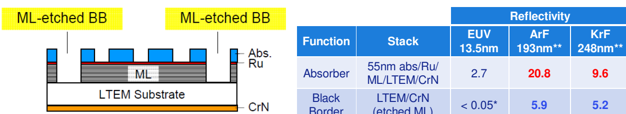
Printing die at dense spacing: overlapping image borders

55nm absorber, 4-5nm CD drop die to overlapping image border

Possible solutions:

1) Optical **Proximity Correction** (OPC) using ASML Brion's Tachyon NXE model,
2) create a so called **Black Border**: reduce reflectivity in the image border, by for example
   a) increase the **absorber thickness**,
   b) add **special coating or replace the absorber** with a low reflective material or
   c) removal of absorber and underlying multilayer down to the low reflective substrate: **multilayer etching**

We used the later solution and studied the impact on imaging and pattern placement.



Function	Stack	Reflectivity EUV 13.5nm	Reflectivity ArF 193nm**	Reflectivity KrF 248nm**
Absorber	55nm abs/Ru/ ML/LTEM/CrN	2.7	20.8	9.6
Black Border	LTEM/CrN (etched ML)	< 0.05*	5.9	5.2

* Less than lower measurement limit, ** DUV light

Image border: pattern free, absorber covered, area around die. Transition area between die and part of mask that is shielded from exposure light by Reticle Masking (REMA) blades.

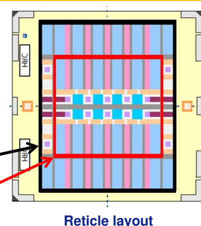
TEST MASK LAYOUT

State of the art commercial EUV blank

- LTEM substrate, Mo/Si multilayer
- **Thin absorber 55nm** (14nm top absorber/ARC, 41nm bottom absorber) → reflectivity @ 13.5nm ~ 2.7%
- Main repeating test block: **27nm horizontal and vertical dense lines** gratings for ASML Yieldstar metrology
- **250 pattern placement crosses** in- and outside the image field, near and away from image/black border

- Image borders
  - Etched Black Border around full field
  - Standard absorber image border around reduced field

Image borders measure 3mm in scan (or Y) and 2mm in slit (or X-direction). Black Border was etched after creation of the image field features using an laser writer



Reticle layout

TRENCH AND PATTERN PLACEMENT

Trench placement

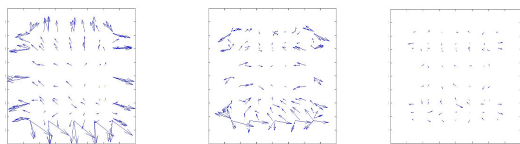
- Trench width: X: 2000.11 ± 0.13 µm (2000 µm by design); Y: 3000.14 ± 0.11 µm (3000 µm by design)
- Trench placement accuracy: within 200nm
- **Trench placement and width control are sufficient**

Pattern placement

Deposition of EUV multilayer and absorber → stress. **Etching** of ML and absorber: relaxation part of the stress → **pattern displacement**

Experiment: Measurement pattern placement crosses at various distances from image/black border before and after multi-layer etch

- Corrected for translation, symmetrical rotation and symmetrical magnifcation
- Applied ASML on tool **intrafield High Order Process Corrections:** iHOPC, 18 of 20 parameters of 3rd order polynomial



[nm]	Before iHOPC correction, full field	After iHOPC correction, full field	After iHOPC correction, without outer tens µm
|max(X)|	3.53	**3.0**	**1.0**
|max(Y)|	4.00	1.9	0.6

- Reduced field: exclude first 15µm from trench (part of 'scribe lane' with pattern placement and process features), next data point at 100µm from trench: 1.0nm displacement residuals (4x)
- NXE3300 overlay requirements < 3nm (1x) → **observed displacement is an issue**

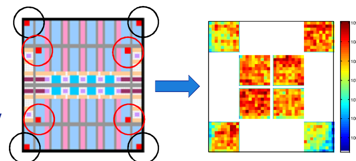
Possible **mitigation methods** for etch induced displacement:

- Reduce ML film stress
- Etch Black Border prior to patterning of the die
- Compensate Black Border induced displacement by the mask writer

MASK METROLOGY: RETICLE CD

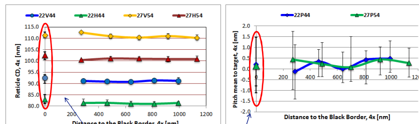
CD uniformity

- Measure corners of the image borders, Black Border (black) and the standard absorber image border (red) over 4x4 mm² square, 27nm node L/S
- Mean to target CD = 0.007 nm (4x)
- CDU = 1.5 nm (4x), 3s → **Good quality**



Impact of Black Border placement on CD and Pitch

- 22nm and 27nm node L/S
- At 280 - 1200nm and 100µm (reference) from Black Border
- **No trends observed**
- Offset w.r.t. the reference measurements is within normal intra-grating CDU ~ 2.5 nm

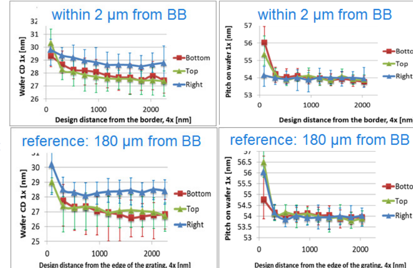


Reference measurement results (placed at 0nm to limit graph size)

WAFER RESULTS

Impact of Black Border on imaging at border: wafer CD and Pitch

- 27nm node L/S
- At 280-2000nm and 180µm (reference) from Black Border
- Wafer CD and pitch increase same on the Black Border and at the reference → OPC effect or flare, correctable
- **No impact Black Border**



Field to field experiment: Expose reticle Full Field for Black Border testing & reduced field for standard absorber image border testing, printing the fields dense packed isolated. Measure the corners

Image border type	Overall [nm] CDU, 3s	Overall [nm] CD range	Average Field [nm] CDU, 3s	Average Field [nm] CD range	Impact CD change
Standard absorber (here Small Field 20.9x19.3 mm²)	7.9	> 10	8.6	> 10	5nm at edge; no imaging in corner
Black Border (here Full Field 26x33 mm²)	2.4	7.3	1.1	2.3	1nm at edge; 2nm in corner

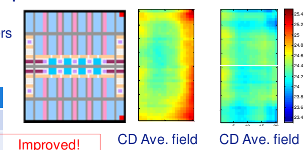
- EUV reflectivity in the image border < 0.05% (removal of multilayer and absorber)
- CD drop reduced from 5nm to 1nm at edge→ **major improvement!**

Study remaining CD range corner of 2 ± 0.4nm → *Budget breakdown* using data from two right hand corners

1) Correction for **reticle fingerprint** (smoothen reticle data, Mask Error factor (MEEF) of 1.7) →

	CDU [nm] 3s	CD range [nm]
Isolated	0.7	1.2
3 borders overlap	0.4	0.8

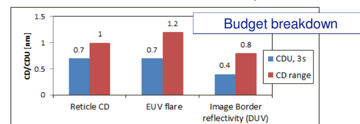
Improved!



CD Ave. field isolated fields

CD Ave. field borders overlap

2) 1.2nm CD increase at edges of corners of isolated field may be related **to EUV flare** drop at those locations. Impact of flare on isolated fields is supported by **resist height measurements;**
3) 0.8nm due to **DUV Out Of Band light reflections** (5-6%) at Black Border. Possible mitigation: DUV anti-reflective coating in trench after etch or between the substrate and the multilayer.



Resist height Ave. field isolated fields

Resist height Ave. field borders overlap

SUMMARY, CONCLUSIONS

- Used laser writer for Black Border. Trench is placed with sufficient accuracy and CD control
- Impact trench etch on in die pattern displacement:
  - After ASML scanner (iHOPC) correction ≤ 3.0 nm
  - Excluding first tens of µm from the edge ≤ 1.0 nm
  - Possible mitigation methods are given
- No impact trench etch on reticle CD & pitch within 1.2 µm of Black Border nor in corners 4 mm² from the Black Border and no impact of the Black Border on imaging within 2 µm of Black Border
- Reduction of edge effect from 5 nm to 1 nm. No imaging to 2nm in corner
  - Possible contributors 2nm in corner: EUV field to field flare & DUV Black Border reflection
  - Possible mitigation methods for DUV Black Border reflection are given.
- **Main conclusion: Feasibility of ML etched Black Border for imaging is proven**

REFERENCES

[a] "Impact of an etched EUV mask black border on imaging, overlay and defectivity," N.Davydova et.al, BACUS 2012, Proc. of SPIE (2012); [b] "Mask aspects of EUVL imaging at 27nm node and below, " N.Davydova et.al. Proc. SPIE. 8166 (2011), [c] "Black Border with Etched Multilayer on EUV Mask", N.Fukugami et.al. Proc. of SPIE Vol. 8441 (2012)

ACKNOWLEDGEMENTS

ASML: Dorothe Oorschot, Wendy Liebregts, Bert Vleeming, Kees Feenstra, Joep van Dijk, Andre van Dijk; **Toppan:** Hiroaki Morimoto, Yo Sakata, Franklin Kalk, Romy Wende; **IMEC:** Eric Hendrickx, Rik Jonckheere