Current status, challenges, and outlook of EUV Lithography for High Volume Manufacturing

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Intel Corporation
• Milestone Progress
  • Exposure Tool
  • Reticle
  • Pellicle
  • Infrastructure
• HVM Considerations
• Looking Ahead
  • Materials
  • High NA
• Conclusion
NXE:33x0 combined scanner/source availability

- Improvement from NXE:33X0 to NXE:3400 platform
- Top contributor is exposure source
- Need continued focus on availability
NXE:3400 combined scanner/source availability

- Best data on 3400 comes from dedicated effort on small number of systems – little bit of luck and lots of focus
- Need to scale to install fleet
Exposure source power meeting roadmap

- Meeting 250W exposure source power established for NXE:3400
- Proliferation to field systems
- Continued emphasis ensuring sufficient power overhead for predictable quality and output
Collector lifetime improvement continues

- Collector degradation follows continuous, roughly linear trend – predictable lifetime
- Recent breakthrough advances in reflectivity as f(GP)
- Bottom Line: expect significant correlation to system availability and OpEx
Intel’s Pilot Line: CD trend

- Unfiltered data
- Timeline > 1 year
- Multiple masks
- Multiple features
- Multiple tools
- CD control within tight distribution
- Stable CD performance trend
Scanner cleanliness: Intel reticle defectivity

- Variability in defect level after ‘burn-in’; many tools showing no adders/reticle load for several weeks
- Every tool has shown adders after many weeks with no adders
- NXE:3400 cleaner overall
- Unpredictability of adder events drives need for pellicle
ASML two-fold approach: one element is to improve cleanliness → avoid particle generation in scanner

- Investigation continues into origin of defects
- Improved understanding of nature of defects introduced by scanner
Pellicle membrane progress and infrastructure

- Steady progress in pellicle membrane defect levels since Q3'16
- Multiple membranes with zero defects >10um
- Continued focus expected to deliver volumes for HVM
Intel EUV mask manufacturing is capable of volume production with full specification product requirements.
EUV infrastructure readiness snapshot

EUV infrastructure has 8 key programs
7 are ready or near-ready now; 1 has significant gaps

- **E-beam Mask Inspection**: In use for low volume production. Need TPT increase.
- **Actinic Blank Inspection (ABI)**: Ready for qualification of HVM quality blanks
- **AIMS Mask Inspection**: Systems installed in field; NXE:3400 illumination emulation underway
- **Pellicle**: ASML commercializing
- **EUV blank quality**: Process and yield improvements continue
- **Blank multi-layer deposition tool**: Improving defect results
- **EUV resist QC**: RMQC center at IMEC online
- **Actinic Patterned Mask Inspection (APMI)**: High resolution PWI for fab. Still need actinic inspection in mask shop.

★ Significant progress in EUV infrastructure

From 2017 SPIE

Judged as of Today
Overall milestone progress messages

- Combined scanner/source availability improving
  - Exposure source remains largest contributor to tool downtime
  - NXE:3400 availability encouraging; need to scale to install fleet
- Exposure source power meeting 250W roadmap, field upgrades in process
- Scanner defectivity levels improving with introduction of NXE:3400
  - Every tool has shown defects after weeks of clean performance
  - Underscores need for pellicle and associated infrastructure / support
- Significant progress in pellicle program over past year
  - Pellicle membranes manufactured with zero defects >10um; lifetime and power resiliency continue to increase
- Progress has been made in pellicle membrane material development, but continued improvement necessary for increasing transmission, withstanding increased source power, and extending lifetime (OpEx)
  - Pellicle membrane power resiliency needs to keep pace with increasing source power (300W, 500W, …)
- Manufacturing increasing number of defect-free 7nm EUV masks
- Inspection of pelliclized reticles is needed to ensure predictable yield. APMI is not a show-stopper, but without it yield and cost may be an issue – no change
Outline

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HVM insertion considerations ➔ Predictability

• Capability demonstrated:
  ✓ Exposure source power meeting HVM roadmap
  ✓ Pilot line imaging performance

• What is impact on fleet predictability of availability vs. power?

• Simulate HVM conditions – how do these parameters affect reliable TPT?
  • Simulation methodology assumptions:
    • Acceptable level of collector degradation (50%-100% RR)
    • Fixed exposure source power (300W)
    • Vary availability 65%-95%
    • 10,000 runs with comparable results for tool count N=25 and N=100
Impact of Availability is critical

65% availability

• Wide spread in productivity
Impact of Availability is critical

- Fleet productivity distribution improves with increasing availability.
Impact of Availability is critical

- 65% availability
- 75% availability
- 85% availability
Impact of Availability is critical

Best-case productivity of fleet with 65% average system availability is less than the worst-case productivity of a fleet with 95% average availability.
Availability vs. Source Power

10% availability equivalent to ~50W power in terms of fleet productivity

Cannot overlook importance of availability
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EUV Materials

https://geoffpark.files.wordpress.com/2015/04/swans3.jpg

EUV materials and resolution

- EUV enables 2D design features, e.g. corner segments
- Need materials that can take advantage of improved EUV resolution
- Adequate for EUV introduction
- Need materials that are tunable for desired properties
- Materials development constrained by photon availability (BL, MET, NXE)

For continued material development, suppliers need an understanding of fundamental properties of materials
Looking ahead: More than photon shot noise

NXE3300, 28 nm hole
72K measurements

CAR 1
<20 mJ/cm²

CAR 2
<20 mJ/cm²

CAR 3
>2.5X dose vs resist 1 and 2
~ 10% CDU improvement

- 2.5x higher dose provides <10% LCDU improvement
- Not consistent with photon shot noise alone
- There must be a chemical effect
- We must gain a deeper understanding of how EUV radiation interacts with resist and design resist for stochastics
- Next generation EUV requires materials innovation

Materials suppliers must have the means to study fundamental properties of materials
EUV materials

- EUV material interaction processes are complex
  - Photon absorption
  - Photoelectron gen.
  - Secondary electron gen.
  - Radical generation
- Electron-stimulated process induce chemical reactions
- Dissolution mechanism varies for different material systems
- Not one-size-fits-all

Resist is progressing
Exposures at PSI, SEM at ASML

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<table>
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Mask and process optimization will improve line quality. <10nm hp is expected with suitable mask.

J. Van Schoot, ASML, February 2018

Must consider multiple options / material systems
High NA EUV: The next step

- Next logical step

**Business as usual: increase NA as far as possible**

Relative improvement: 5X over ArFi, 40% over 0.33 NA EUV

![Diagram showing NA increase timeline]

- Major technology step (e.g. source, mirror)
- Optimization of NA

Year of introduction:
- EUV 0.25
- EUV 0.33
- EUV 0.55

Slide courtesy ASML February 2018
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Conclusion: Preparation for HVM and beyond

• Exposure source → First field system meeting source power roadmap: power improvements proliferating to install fleet
• Availability → NXE:3400 platform demonstrating improved capability – keep focus
• Pellicle → Needed to ensure EOL yield; pellicle program continues to make significant progress
• Infrastructure → demonstrating increased maturity; single gap remains
• HVM requires predictability
  – Output impact of 1% improvement in availability > 4% improvement in source power
  – OpEx (mostly source consumables) – Collector lifetime improvements encouraging – need to translate to field systems
• Materials
  – Materials performance – Won’t gate introduction of EUV, but need to consider stochastics for decreasing feature sizes and high NA: need to understand the interaction of EUV radiation with resist and design resist materials for stochastics
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