Blue – X (EUVL Extension): Status and Update

Vivek Bakshi, EUV Litho, Inc.

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Presentation Outline

- EUVL – Past, Present, Near Future (next 10 yrs) and Future (10-20 yrs)
- Case for EUVL extension
- Blue-x (Change of wavelength of emitter and drivers) – Progress so far
- Options for EUVL extension
- Need for consensus
- List of Open Questions and proposed subgroups
- Summary

EUVL – Lessons from Its History: Last 35 years

- 1980s: Early concepts with soft x-rays (4-40 nm) – patterning can be done in wide range of soft X-ray wavelengths
- 1989: EUVL at 13.5 nm was formally agreed upon, mostly because of ML – ML is a key deciding factor although source determines its success
- 1997: EUV-LLC was formed for EUVL commercialization – Consensus is needed for start development of new technology
- ~ 35 years to get EUVL from labs to fabs – Long time to develop a new technology
- However, we have learned how to address many key challenges. So this time it will be a shorter cycle time than 35 years!
    - High power sources in soft X-ray, Optics, contamination and still learning about resist

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EUVL Status Today and Expectations for Next 10 Years

- 30 EUVL scanners of 0.33 NA will be delivered in 2019
  - Multiple patterning EUVL is already here
- High NA scanners will be ready in 2023-2025
  - End users are ready for them now and will prefer them over 0.33 NA MP today
- High NA scanners will be very quickly used in multi-patterning mode
- Extension of Moore’s Law in 2025-2030 will be enabled by High NA MP EUVL

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Long term Future for EUVL: 2030 - 2040

- Google last week showed a proof for “Quantum Supremacy”
  - Quantum computers will gain more traction in practical application
  - Quantum computer will start working together with classical computers
  - Focus will shift to “Information Processing” from adherence to “Moore’s Law”
- Extension of Moore’s law will become very expensive and Challenging
  - High NA MP EUVL will face increasing challenge and will become lot more difficult
  - We will face yield issues similar to 5x 193iMP
  - **We will need “Higher Octane” version of EUVL**
- **This will be the time period where Blue-X – Extension of EUVL will be very much needed**
- **Now is the time to start looking into the feasibility of Blue-X**

Basic Case for EUVL Extension:
We have already tried two out of three knobs

$$\text{Resolution} = k1 \frac{\lambda}{NA}$$

- Path of k1 – need more power – we will always use this until k1~ 0.3 and we have to go to multiple patterning.
- Path of NA - Results in a much larger tool
- **Path of λ (Sources and drive lasers) – Blue –X!**

Path of k1, λ or NA – future choices

Res (nm)	Δ (nm)	Δ (%)	k1	λ (nm)	NA
8	4	34%	0.3	13.5	0.5
6	2	25%	0.3	6.7	0.33
4	2	34%	0.3	6.7	0.5
1.32	4.77	78%	0.3	2.2	0.5
1.00	0.32	24%	0.3	1.1	0.33

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Progress So far in Blue –X in one year…..

- **Community Response has been <u>very positive</u>**
  - Two sessions each in 2018 Source Workshop, 2019 EUVL Workshop and Source workshop
- **BAT (2 micron Thulium) laser from LLNL**, shared with community first time during 2018 EUVL workshop, has emerged as a potential new key component - may allow us two key benefits:
  - More Intensity (similar CE) and much better COO
  - Power scaling beyond CO_2 lasers
- **Due to work for last few years, 6.x ML peak reflectivity can be >70% (Univ. Twente).**
- **Combining 6.x nm ML with BAT lasers, we already have a potential Blue-X solution for extension of EUVL! We want to know what else is possible.**
  - Previously 6.x nm was reviewed and abandoned – due to ~ 50% reflectivity, need for > 100 kW drive lasers and attention needed on 13.5 nm to address remaining issues

Progress So far in Blue –X in one year …..

- We are now also looking at water window ML to get higher wavelength reduction but ML reflectivity is only ~ 35%
- Progress on 6.x and others ML will be reported in this session
- **Newer optical designs are possible for scanner (fewer reflections) but they will allow LIMITED patterning options. What are the new possibilities?**
  - **Reduction of peak reflectivity from 0.7 to 0.4 will require reflections to go from 11 to 5 for the same throughput.**

Options on EUVL Extension: Traditional (1A/B) or Blue-X (1C-3B)

Option	Name	λ (nm)	NA	Laser	Open Questions		
					Source	Laser	Optics
1A	Traditional	13.5	0.5	CO_2		Laser Feasibility	
1B	Traditional	13.5	>0.5	CO_2		Laser Feasibility	Size
1C	Blue-X	13.5	0.5	BAT		Laser Feasibility	
2A	Blue-X	6.x	<=0.5	CO_2		Laser Feasibility	
2B	Blue-X	6.x	<=0.5	BAT		Laser Feasibility	
3A	Blue-X	<6.x	<=0.5	CO_2	Source Choices	Laser Feasibility	ML
3B	Blue-X	<6.x	<=0.5	BAT	Source Choices	Laser Feasibility	ML

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Lots of Choices and We Need consensus: Proposal for Creating Community Consensus

- Define initial questions in the area of sources, drive lasers, optics, optical design and resist
- Form sub-groups that will answer those questions and deliver answer in 2020 Source Workshop (some answers may be ready sooner in June EUVL Workshop)
- Assign a moderator (s) for each group who will collect responses and report in the next meeting.

Questions for Sources

- What are three potential sources that community needs to focus on: Higher Z UTA and or low z single transitions?
- Criterion for selection:
  - Conversion efficiency and Power scaling
  - Power requirements for drive lasers
  - Wavelength
- What are the questions that modeling can help us answer?
- **Members:** ARCNL, UCD, Utsunomia University, Osaka University, ASML, Gigaphoton, ISAN, Fraunhofer and others

Questions for Drive Lasers

- What are the potential drive laser technologies for >100 kW range?
- Criterion
  - Power scaling
  - Cost of Ownership
  - Commercial Availability
  - CE and plasma properties of LPP produced by these lasers
    - Modeling will be needed to support this study
- Members: <u>LLNL</u>, Trumpf, Northup Grumman, Mitsubishi

Questions for ML Optics

- What are potential best choices for ML at various wavelengths?
- What projects do we need to pursue to investigate significant improvements?
- Members: optiXfab, Univ Twente, LLNL, Universite Paris-Saclay

Questions for Optical Design and Resist

- **Optical Design**
  - What can we do with a design with fewer reflection?
  - Members: Zeiss, K&M Innovation and others
- **Resist**
  - Interaction of lower wavelength / higher energy photon with resists – Stochastics and other challenges need to be studied.
  - Members: PSI, IM, TBD

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Summary

- EUVL extension beyond “High NA MP” will be needed in ~ 10 years.
- We need to start evaluating various options now
- Need community consensus on options so that we can focus on few options and evaluate them in depth
- List of questions (source, drive lasers, optics, optical design, resist) have been proposed together with groups for evaluating
- Community consensus will be reported in coming workshops

One last item - Progress so far…

My action item has been completed……Get the Blue-X license Plate

Backup

Scaling via Wavelength reduction

Source

- Unidentified transition arrays (UTA) give us way to scale wavelength with high conversion efficiency
- We move to higher Z element with reduced wavelength
  - How do lighter elements compare?
- + Established infrastructure and suppliers
  - Cymer and Gigaphoton for HVM
  - Many others suppliers for metrology sources
- (-) Higher drive laser power 100- 300 kW. May need to move away from CO_2 lasers

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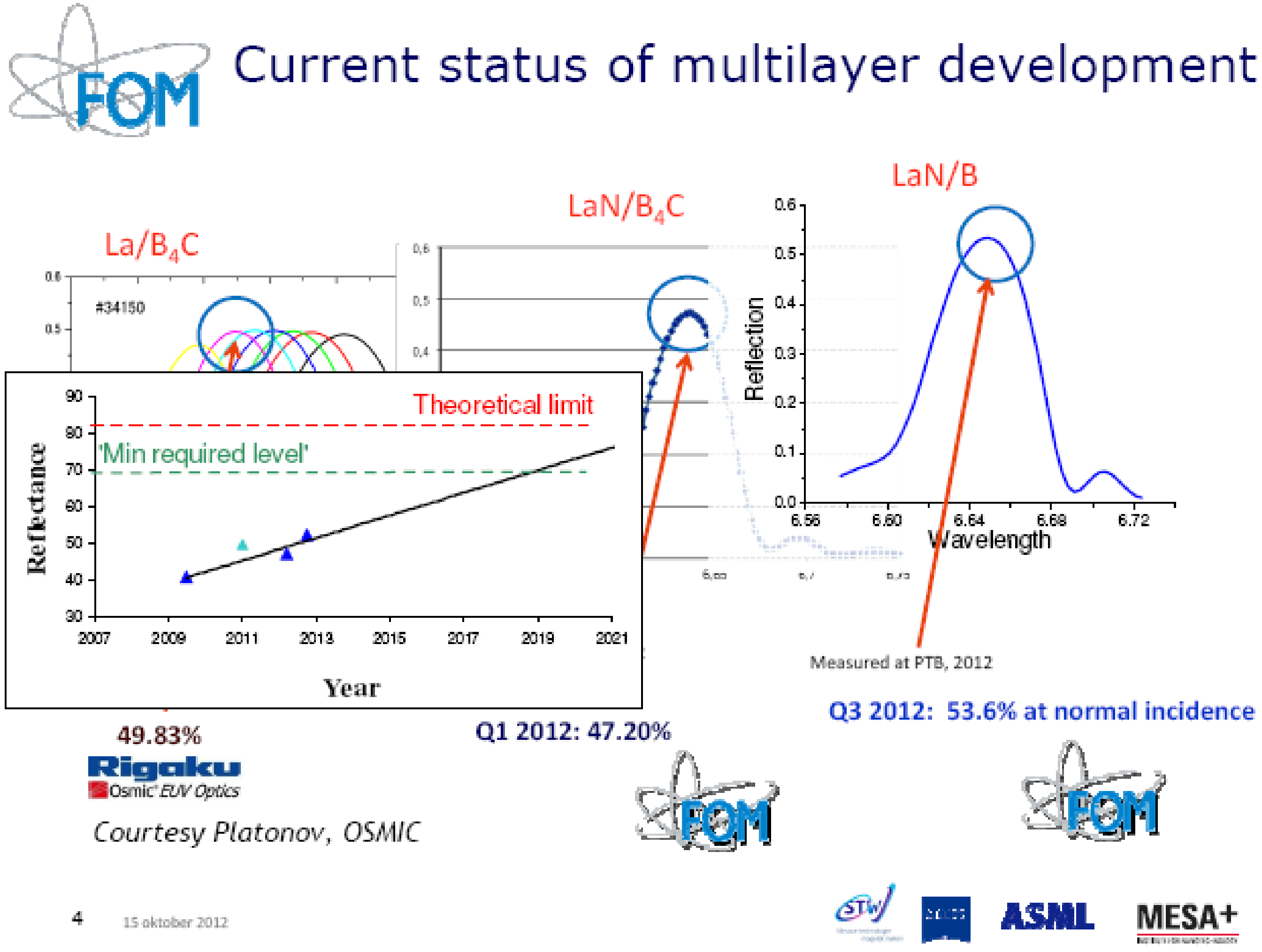
Scaling via Wavelength reduction:

Summary of Challenges for sources

- Source - LPP
  - **Need to define CE for various UTA vs drive laser requirements**
  - Drive lasers
    - CO_2 lasers – 40 kW + modules for current version. 100 kW for optically pumped
    - BAT - New drive laser technology from LLNL
- Sources - FEL
  - **Advantage due to tunability of required wavelength**
  - Size (large for proven versions and unproven for smaller version)
  - Radiation, peak power (ML damage), band width
  - Technology demonstration

Scaling via Wavelength reduction: Optics

At 6.7 nm, 54% reflectivity Obtained (2012), 80% possible.
What about other wavelengths?



Eric Louis, Source Workshop, 2011

Scaling via Wavelength reduction: Optics
Current Status for ML optics at shorter wavelengths

- Main challenges for short wavelength optics:
  - Peak reflectivity
  - Bandwidth
  - Interface roughness

λ, nm	1.4	2.4	2.7	4.4	6.7	9.0	12.0	13.5
R, %	0.02	18.1	26.2	16.8	61.0	36.0	49.2	70.1
FWHM, nm	0.002	0.005	0.008	0.02	0.05	0.11	0.32	0.52

Torsten Feigl, 2018 Source Workshop

Next Steps for the community: Questions for us to answer

- ML Optics
  - What are the best reflectivity and bandwidth we can get in the 1-13.5 nm region?
  - New ML deposition technologies for reducing interface roughness?
  - What other innovations are possible?
- **Key obstacle is ML (> 70% peak reflectivity) or optical design (11 reflections)? What can we do with tool with fewer reflections but with lower ?**
- Source
  - Is UTA the option the best – which one? Lighter elements?
  - CE vs wavelength?
  - Drive lasers for 100- 300 kW – which technology offers best CoO?
  - FEL – can we deliver 500- 1000 W, while addressing current concerns about FEL
- Any other challenges?