Blue – X: The New Frontier

Vivek Bakshi, *EUV Litho, Inc.*

2019 EUVL Workshop

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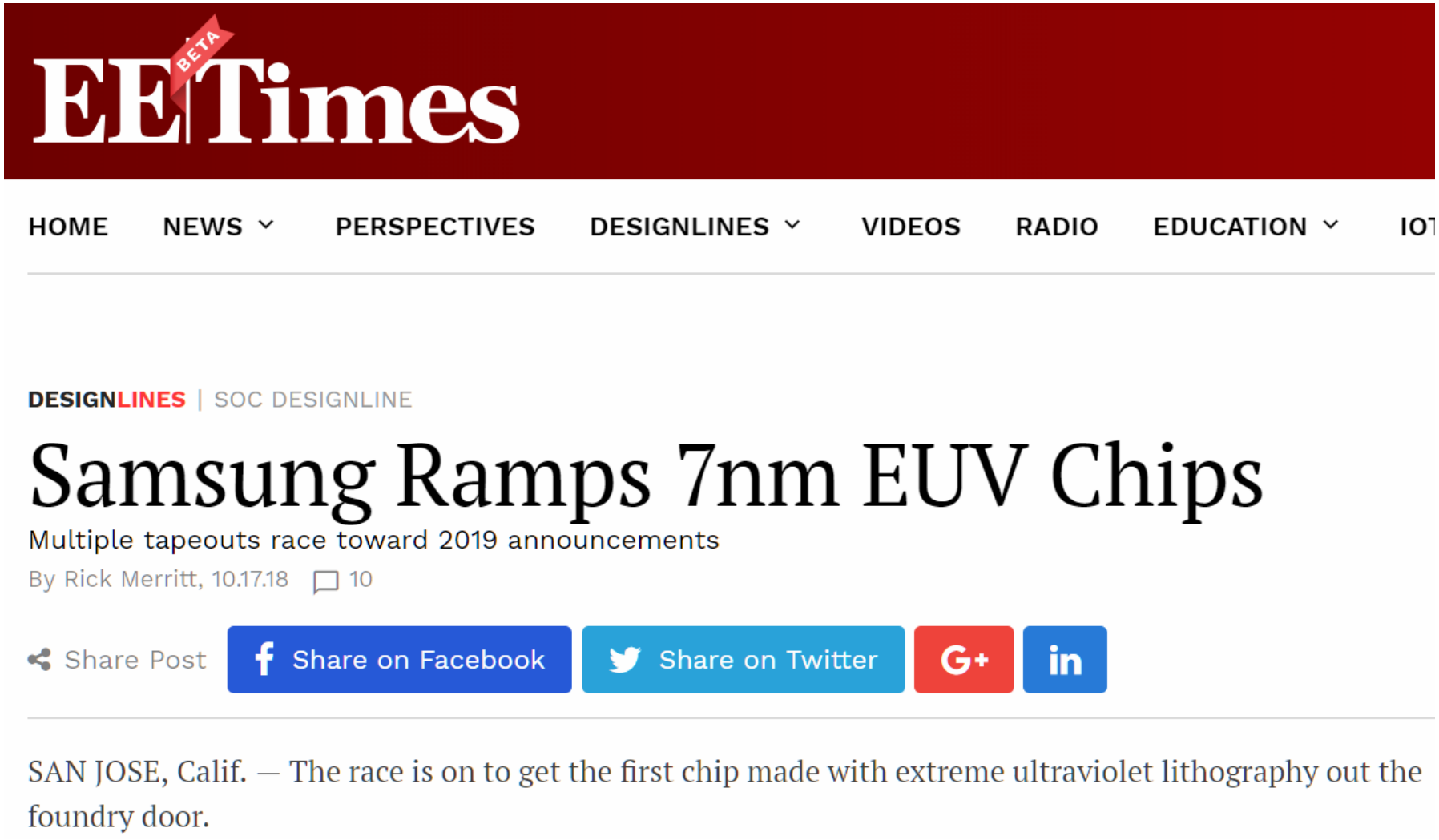
Outline

- EUVL Status – Today, History and Lessons Learned
- Continuation of Moore's Law - Where we go from here?
- Blue – X : Further Scaling via Wavelength Reduction
- Summary – List of Open Questions
- Progress so far

EUVL Status Today - EUVL is finally in HVM!



EUVL History – Status 20 years ago

- EUVL in HVM was planned for ~ 2007
  - No one thought, including critics, that it will take us this long to bring EUVL to HVM
- Optics contamination was perceived to be the main hurdle to HVM
- Next challenge was 100 W of EUV power at 13.5 or 11 nm
  - There were at least 12-14 potential source suppliers.
  - Most had claims of few W to 10 W
  - Several claims of even “100 W” were appearing regularly

History - Status ~ 10 Years ago

Many Litho experts declared technology dead.

- Nikon exited the market while ASML and some others increased investment.
- Number of source suppliers dwindled – about a dozen to just three or four
- Bakshi placed his bet with Mack and got his famous license plate in ~ 2008

EUVL Status today – High level lessons

- We knew the physics of EUV but modeling does not always tell us the right engineering solution
- Even more difficult is to estimate level of engineering and cost to solve them (it takes 3x more cost and money than best estimate)
- Not a good idea to solve many difficult problems at the same time – source, mask, contamination, resist
- Moore's law said – scaling will happen and consumers will enjoy the fruit – cheaper computing power every year
- BUT….Moore's Law did not say that the technology development will be cheap

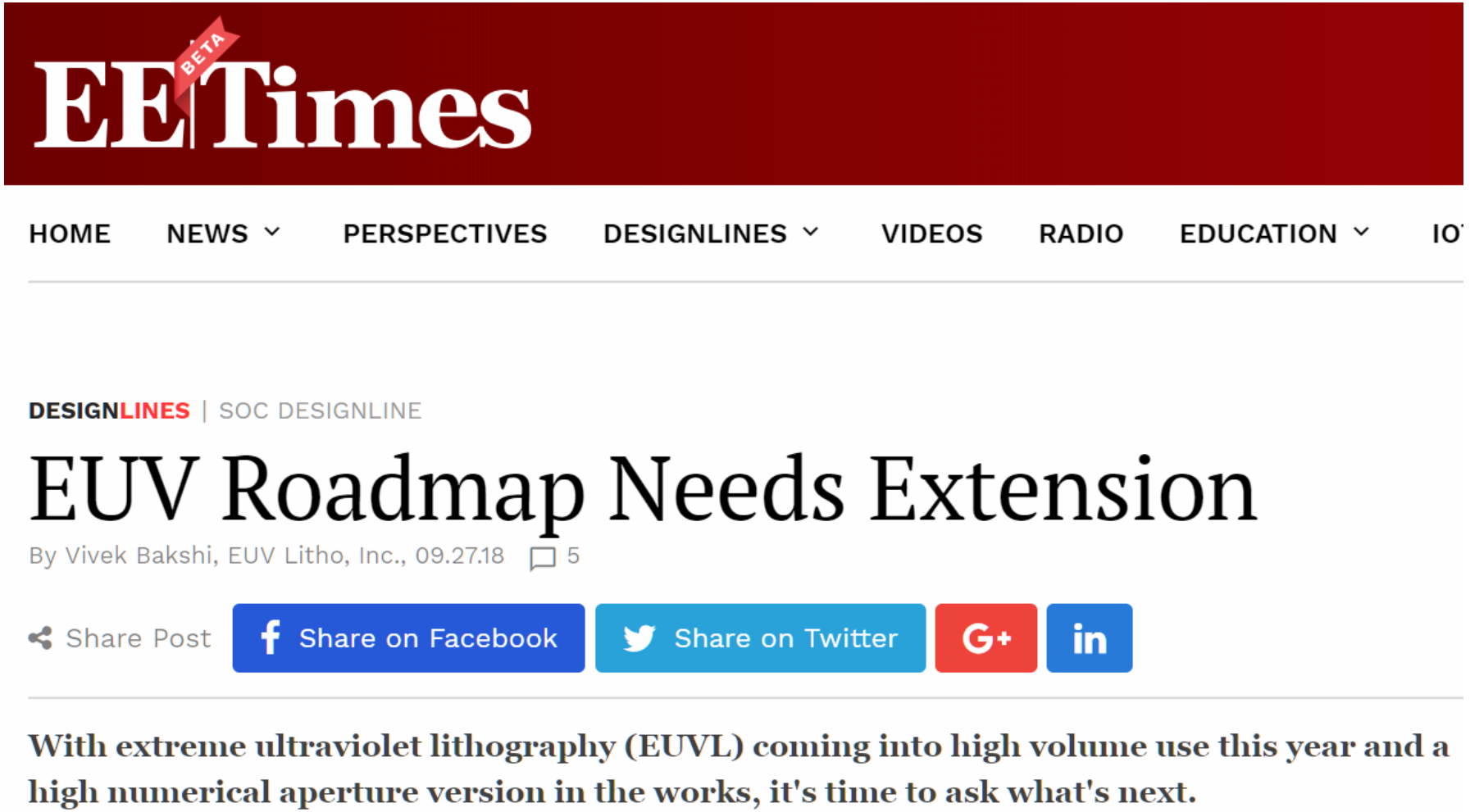
EUVL Status today

Horizon is clear for next 10 years

- **Current version of EUVL is for 250 W at 0.33 NA**
  - Double pattering is already needed at 0.33 NA
- Increase in resolution using 0.33 scanner is driven by source power
  - At lower k1 we need more power
- **Roadmap is clear for 500 W, OK for 600-750 but not so much beyond that**
- Scanner design can help with power requirements
  - Stage speed, optical transmission to improve but what more could be done?
- **Next version of EUVL scanner is 0.55 NA**
  - 2 x more expensive and bigger tools, mask will contain only half die – require stitching

Where we go from here? Quest for Blue-X

Horizon is clear for next 10 years for EUVL. What is next?



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EUV Roadmap Needs Extension

By Vivek Bakshi, EUV Litho, Inc., 09.27.18 5

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With extreme ultraviolet lithography (EUVL) coming into high volume use this year and a high numerical aperture version in the works, it's time to ask what's next.

Where we go from here? Quest for Blue-X

What we do next in about 10 years

- Scaling can continue beyond 8 nm via Optical projection lithography
- **We can continue scaling via following options:**
  - Path of lower k1 – more power and then continue with Multiple patterning
  - Or Increase NA once again
  - Or Reduce Wavelength
- **Wavelength reduction option is somewhere between the deep EUV region and X- ray region.**
- **This technology option – I have named “BLUE- X”**
- **Blue – X may go together with other options for scaling (NA, k1, MP)**

Where we go from here?

Let us look at +/ - for our options

- **Resolution = k1* wavelength / numerical aperture**
- Path of k1 – approach 0.25 as close to as possible
  - (+) Same technology and tools
  - (-) Lower k1 needs complex exposure schemes and higher power
  - (-) k1 limit of 0.25 – 0.3 for one exposure and then need multiple pattering
- Path of k1 beyond 0.25 via Path of MP
  - (+) Same litho tools
  - (-) more tools, cycle time, edge placement error
  - **(-) Cost**
- **Path of NA**
  - (+) Same technology and tools
  - (-) Cost and size beyond 0.55 may be difficult to increase
  - **(-) Can we afford multiple $350M high NA scanners for High NA MP?**

Where we go from here?

+ / - for our options

- **Path of Wavelength reduction – new sources and new ML optics**
  - (+) We have learned a lot: LPP source, mask, optics, contamination
  - (-) We do not know the best wavelength choice, based on source and optics
  - (-) Flare, Stochastics

Where we go from here?
Path of k1, λ or NA – historical path

Res (nm)	Δ (nm)	Δ (%)	k1	λ (nm)	NA	
145			0.3	436	0.9	
122	23	16%	0.3	365	0.9	
83	39	32%	0.3	248	0.9	
64	19	22%	0.3	193	0.9	
45	**19**	**31%**	**0.3**	**193**	**1.3**	193 SP
36	8	19%	0.3	157	1.3	
16	20	64%	0.3	13.5	0.25	
12	**4**	**24%**	**0.3**	**13.5**	**0.33**	**EUV HVM SP**

Where we go from here?
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

Where we go from here?
Path of k1, λ or NA – future choices

Gain from wavelength reduction can be shared over higher k1 (lower power) and lower NA (smaller tool size)

Res (nm)	k1	λ (nm)	NA
8	0.4	6.7	0.33
6	0.3	6.7	0.33
5	0.4	6.7	0.5
4	0.3	6.7	0.5

Scaling via Wavelength reduction

Source

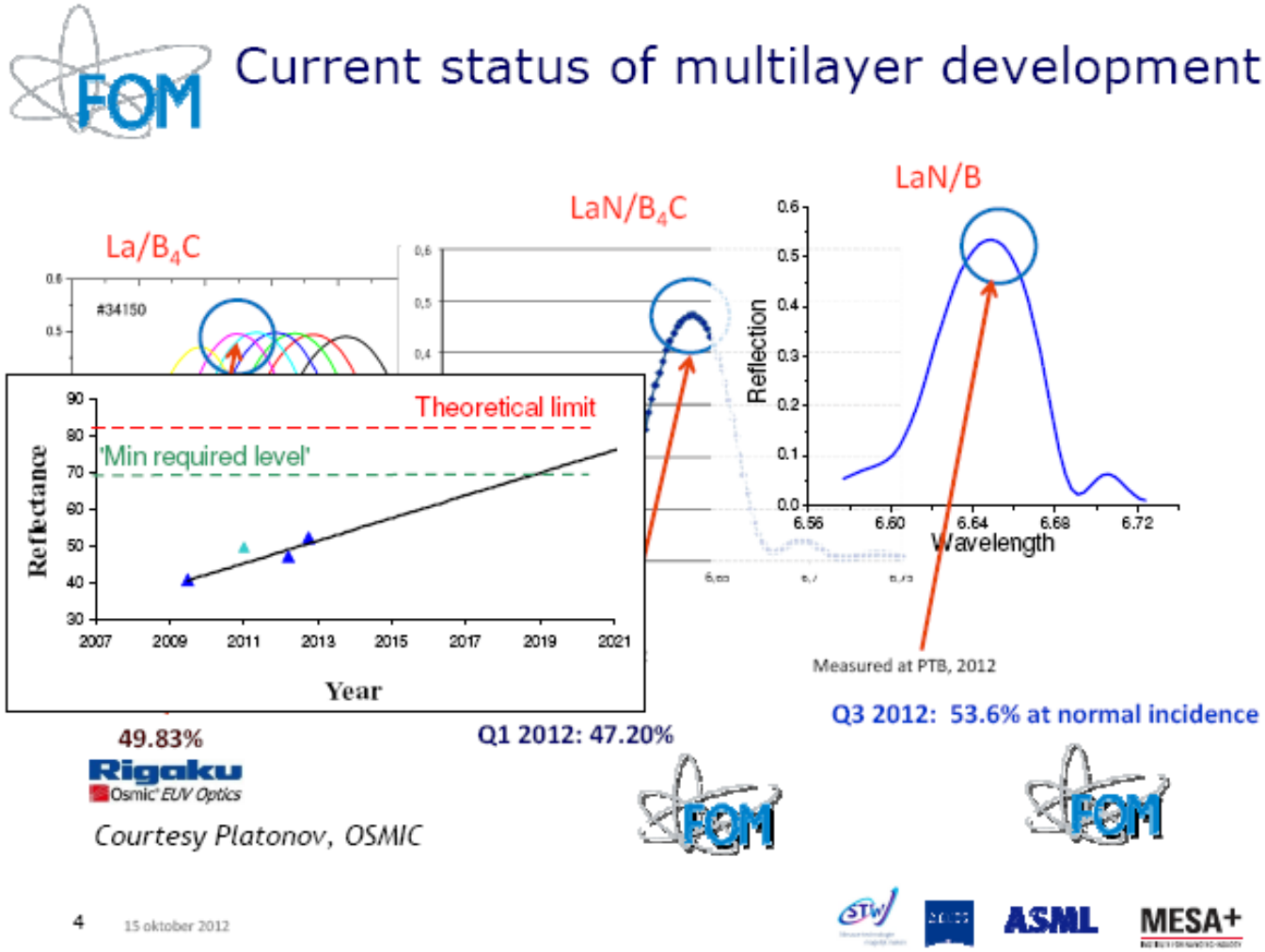
- Unidentified transition arrays (UTA) give us way to scale wavelength with high conversion efficiency
- We move to higher Z element with reduced wavelength
  - How do lighter elements compare?
- + Established infrastructure and suppliers
  - Cymer and Gigaphoton for HVM
  - Many others suppliers for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

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

Summary

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)?**
- 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?

Progress So far…..

- Community Response has been very positive
  - Two sessions each in 2018 Source Workshop and 2019 EUVL 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:
  - Improve CE via switching to mid- IR for drive lasers and
  - 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!**
  - 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…..

- We are now seriously looking at water window ML. As we need to get as much wavelength reduction as possible for the next generation NGL
- Progress on 6.x and others ML will be reported in the 2019 Source Workshop
- **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.**
- **Good to note that some of these new developments will also can be applicable at 13.5 nm – BAT lasers, ML improvement and new optical designs**
- One day / half day Workshop focused on “Blue-X” is being planned
  - Maui or Europe in 1-2 years

Progress so far…

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

Still a very long and steep way to go … but good to start now

- Torsten Feigl (optiXfab, 2018 Source Workshop)

Q&A