Next generation EUV lithography: Challenges and opportunities, Dublin

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Public

Agenda

- Roadmap
- Challenges and opportunities
- Status
- Summary & conclusion

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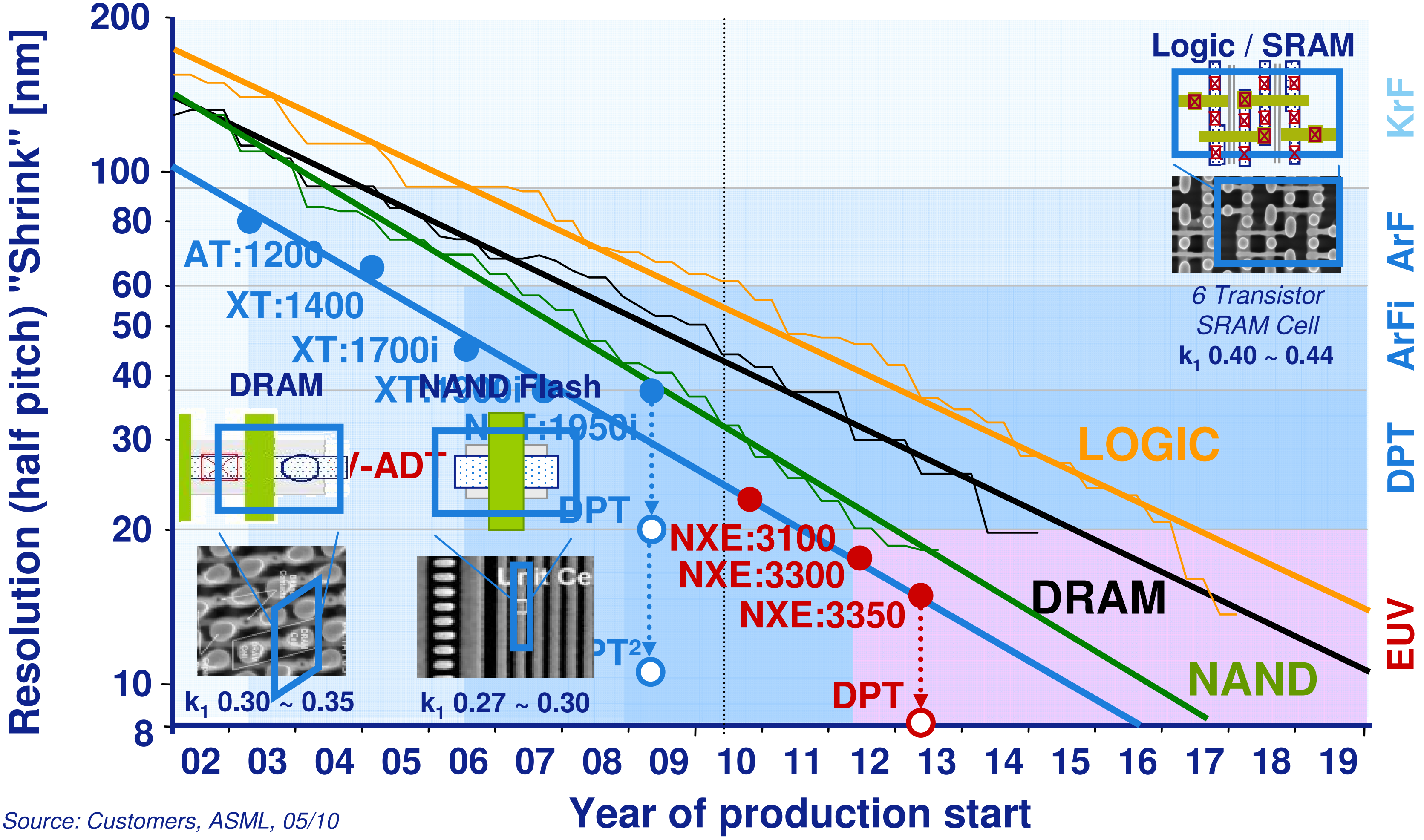
IC & Lithography roadmap towards <10nm

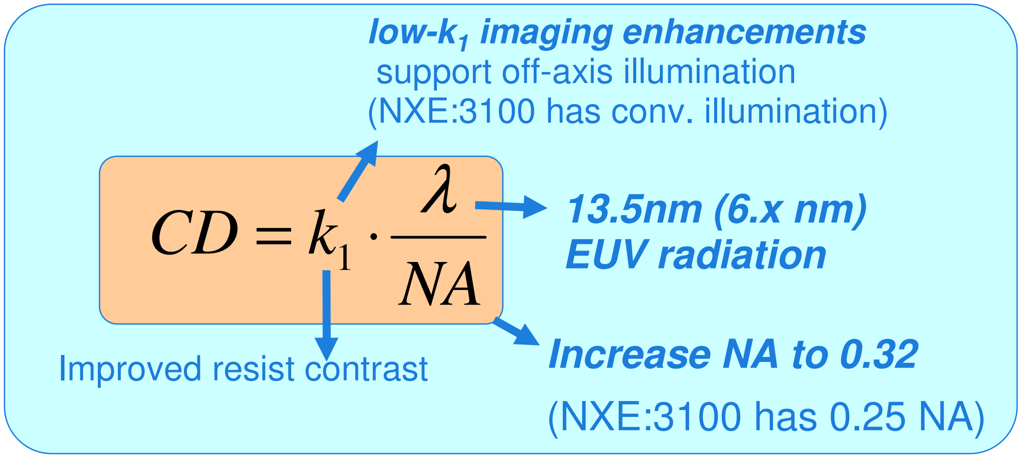


Source: Customers, ASML, 05/10

Notes:
1. R&D solution required 1.5~ 2 yrs ahead of Production
2. EUV resolution requires 7nm diffusion length resist
3. DPT = Double Patterning

EUV lithography is optical lithography…

- Resolution scales with aperture (starting at 0.25) and illumination wavelength (13.5nm → 14x leverage to 193nm, 6.x -> 2x leverage on 13.5 nm), and is extensible (beyond 8 nm).
- Throughput scales with source power and system transmission efficiency.



$$CD = k_1 \cdot \frac{\lambda}{NA}$$

low-k_1 imaging enhancements
support off-axis illumination
(NXE:3100 has conv. illumination)

13.5nm (6.x nm)
EUV radiation

Increase NA to 0.32
(NXE:3100 has 0.25 NA)

Improved resist contrast

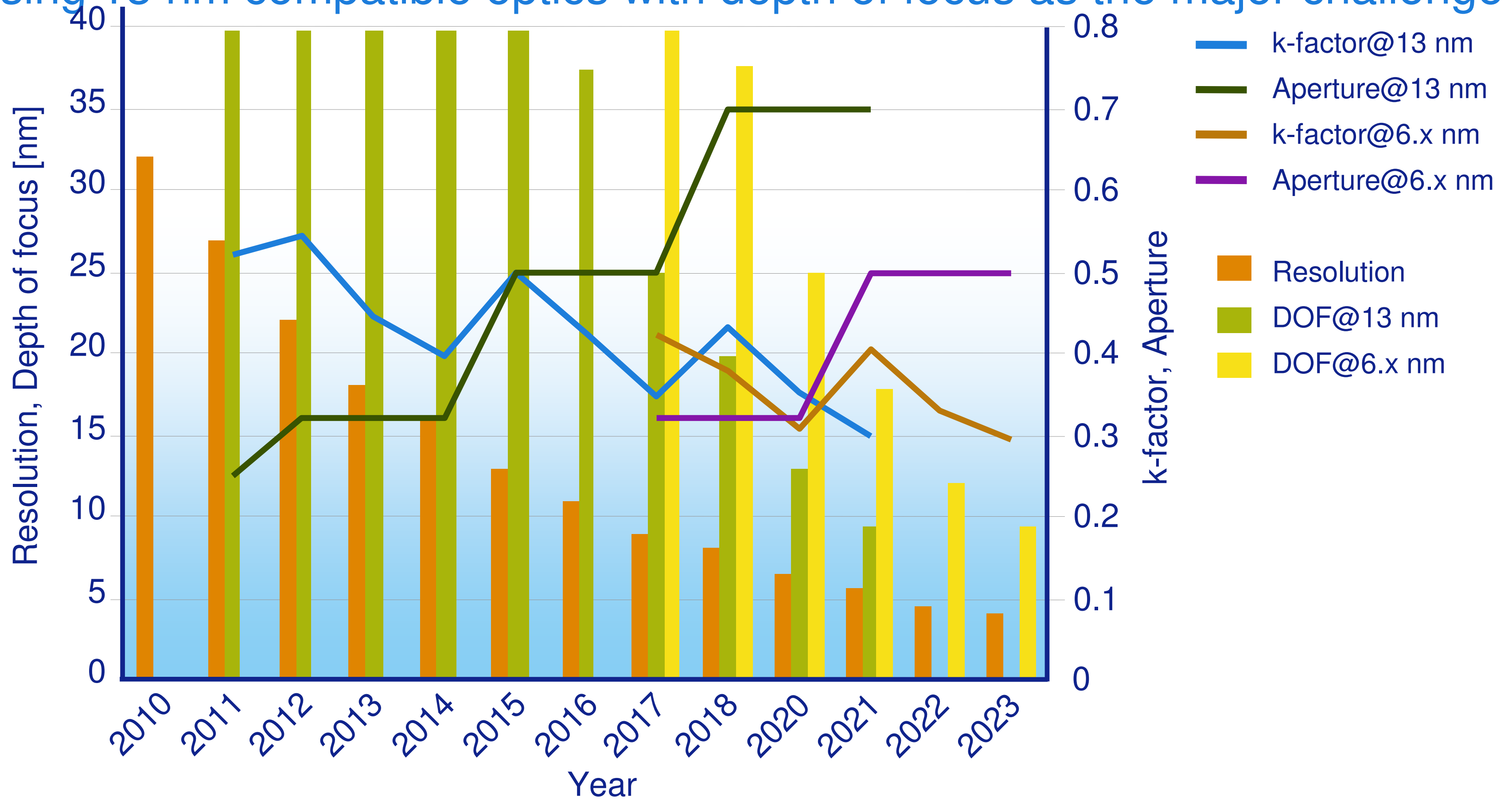
🟩 conventional illumination possible
🟨 off-axis illumination required
🟥 NA too small, even with off-axis illumination

k_1	0.25	0.32	0.35	0.40	0.45
27 nm	🟩 0.50	🟩 0.64	🟩 0.70	🟩 0.80	🟩 0.90
24 nm	🟨 0.44	🟩 0.57	🟩 0.62	🟩 0.71	🟩 0.80
22 nm	🟨 0.41	🟩 0.52	🟩 0.57	🟩 0.65	🟩 0.73
18 nm	🟥 0.33	🟨 0.43	🟨 0.47	🟩 0.53	🟩 0.60
16 nm	🟥 0.30	🟨 0.38	🟨 0.41	🟨 0.47	🟩 0.53

Example for 13.5 nm

Opportunity to extend of EUV down to sub 5 nm possible

increasing apertures up to 0.7, wavelength reduction down to 6.8 nm
using 13 nm compatible optics with depth of focus as the major challenge



EUV and BEUV product roadmap spans >10 years

						Under study	
	0.25 NA		**0.32 NA**			**>0.40 NA**	
Lens mirrors	6M	6M	6M	6M	6M	6/8M	6/8M
Wavelength	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	New λ
Product	**ADT**	**3100**	**3300B**	**3300C**	**3300D**	**3500**	**>3500**
Introduction year	**2006**	**2010**	**2012**	**2013**	**2014**	**2016**	**>2018**
Resolution (hp)	32 nm	27 nm	22 nm	18 nm	16 nm	11 nm	<8 nm
Sigma	0.5	0.8	0.2-0.9	OAI	flex OAI	flex OAI	flex OAI
Overlay (SMO)	7.0 nm	4.5 nm	3.5 nm	3.0 nm	2.5 nm		
Throughput (wph)	4 wph	60 wph	125 wph	150 wph	180 wph		
Dose (mJ/cm^2)	5	10	15	15	15		
Source (W)	3	105	250	350	500		

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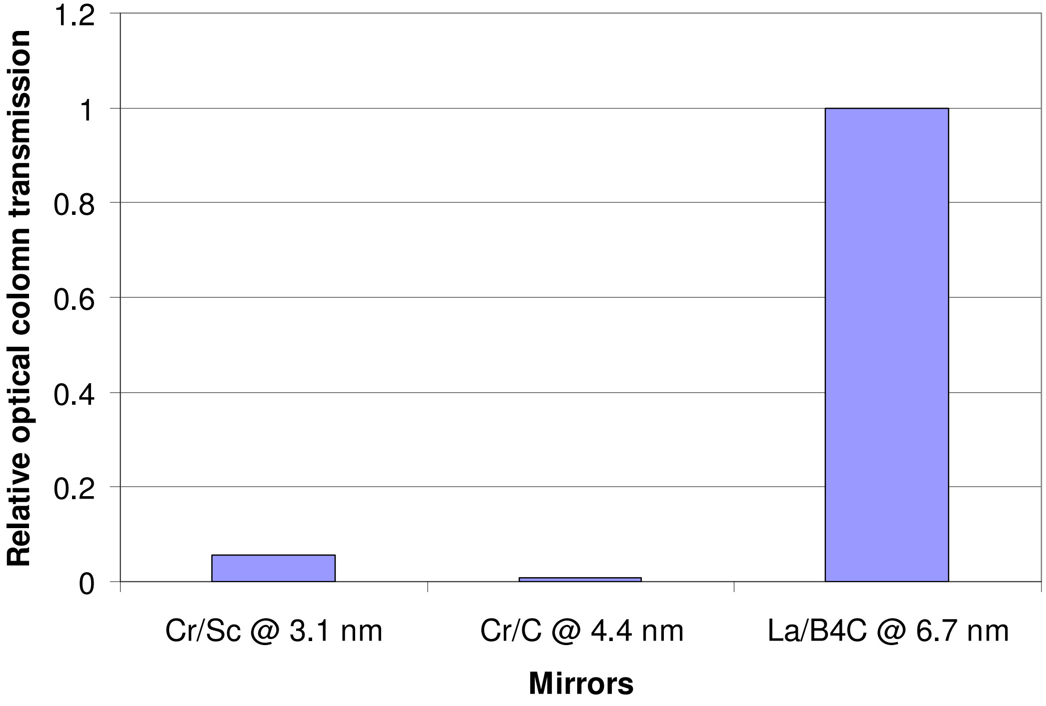
Possible mirrors and wavelengths

- Materials, Wavelengths, Theoretical transmission (TT) per mirror
  - Cr/Sc @ 3.1 nm -> TT= 60%
  - Cr/C @ 4.4 nm -> 50%
  - La/B4C and C/ B4C @ 6.x nm -> 80%
- Optical column transmission (10 mirrors)



6.x nm is the choice:

- Best transmission
- Easier manufacturing

Introduction to changing source wavelength: List of challenges

- **Imaging**
  - Flare level scales $\propto 1/\lambda^2$
  - Bandwidth of a single mirror $\Delta\lambda/\lambda(\mathrm{Mo/Si})=4\% \rightarrow \Delta\lambda/\lambda(\mathrm{La/B4C})<1\%$
  - Bandwidth of the optical column $\Delta\lambda_\Sigma/\lambda(\mathrm{Mo/Si})=2\% \rightarrow \Delta\lambda_\Sigma/\lambda(\mathrm{La/B4C})=0.6\%$
- **MLM Technology**
  - Smaller layer thickness $\propto \lambda$,
  - Requirements to interlayer diffusion $\propto \lambda$
  - Larger number of bi-layers per multilayer
- **Source**
  - New fuel is needed
- ***Resist (not discussed in this presentation)***
  - *Quantum efficiency of current EUV resist will decrease due to lower absorption of 6.7nm(186eV) photons vs 13.5nm(92eV) photons*
  - *Potential shot noise increase*
- **Currently transition from 13.5→6.x nm (6.6-6.8 nm) is considered**

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  - Surface roughness and Imaging evaluation
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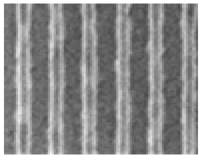
Mid-spatial frequency (MSFR) and flare level

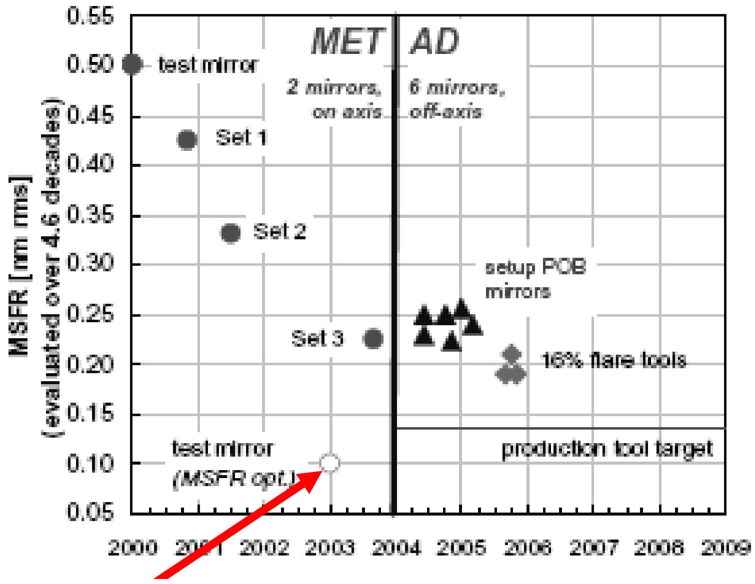
- Flare reduces contrast
- MSFR is linked to surface roughness



- Flare scales with wavelength as 1/λ^2 so by 13.5nm→6.x nm, flare increases 4x at the same MSFR

MSFR, nm	Flare, % 13.5nm	Flare, % 6.7nm
0.2	16	65
0.14	8	32
0.12	6	23
0.1	4	16
0.05	1	4

Achieved for NXE3100

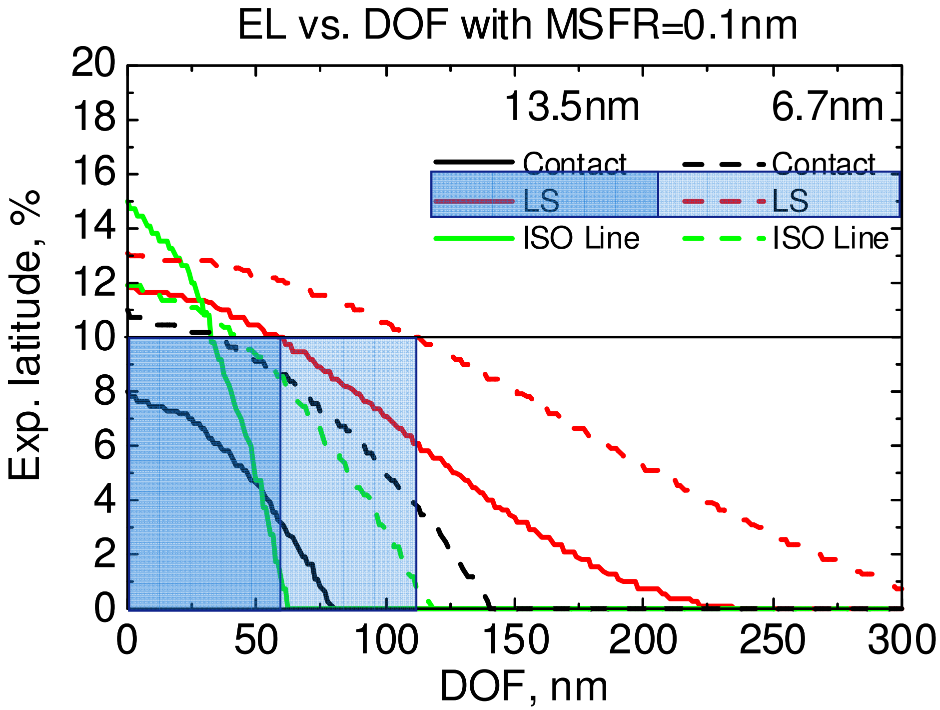


Demonstrated roughness (MSFR optimized)

0.1 nm MSFR can be taken for image simulation

Exp. latitude vs DOF as calculated for 11nm (conventional illumination σ=0.8)

Comparison 13.5nm@NA0.45 vs 6.7nm@NA0.25



MSFR 0.1nm corresponds:
13.5nm - 4%
6.7nm -16%

Depth of Focus 2x larger with 6.7nm

ASML

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    - Multilayer mirrors
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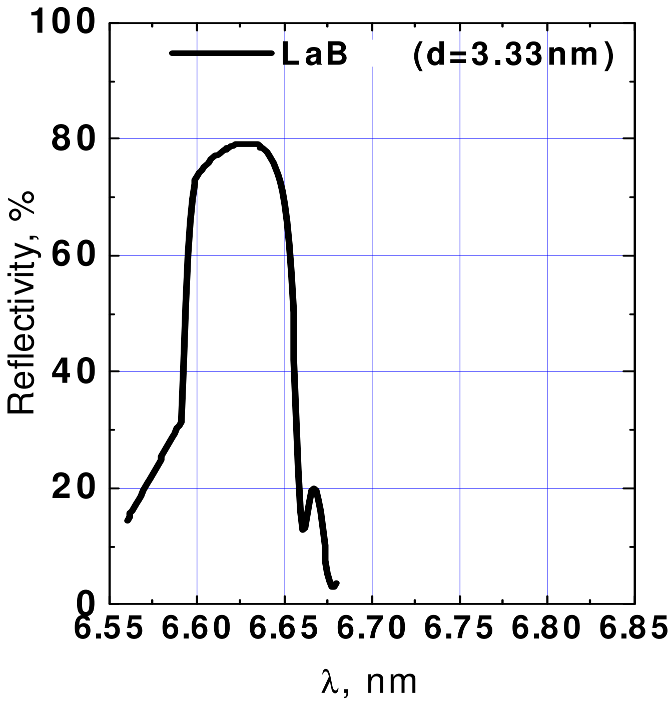
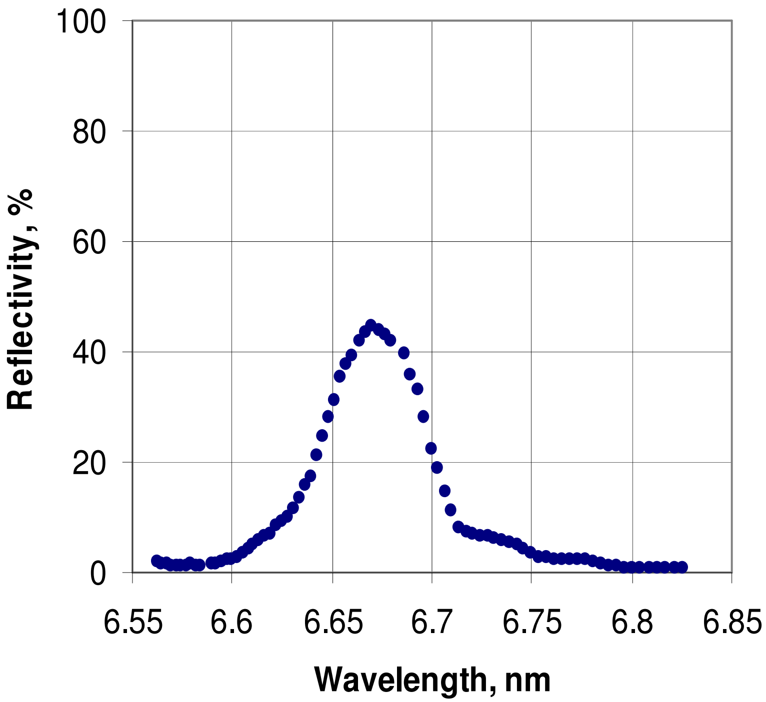
1^{st} Pilot MLM coating La/B_4C for the range 6.6-7.0 nm

Theoretical



1^{st} experimental MLM



λ=6.63nm, δλ=0.06nm, R=80%

λ=6.67nm, R=44.3%, δλ=0.06nm

Reason for low R: interlayer diffusion → Reflectivity can be improved

Bandwidth of the optical column (11 mirrors):
ΔλΣ/λ(La/B4C)=0.6% (vs 2% for 13.5 nm)

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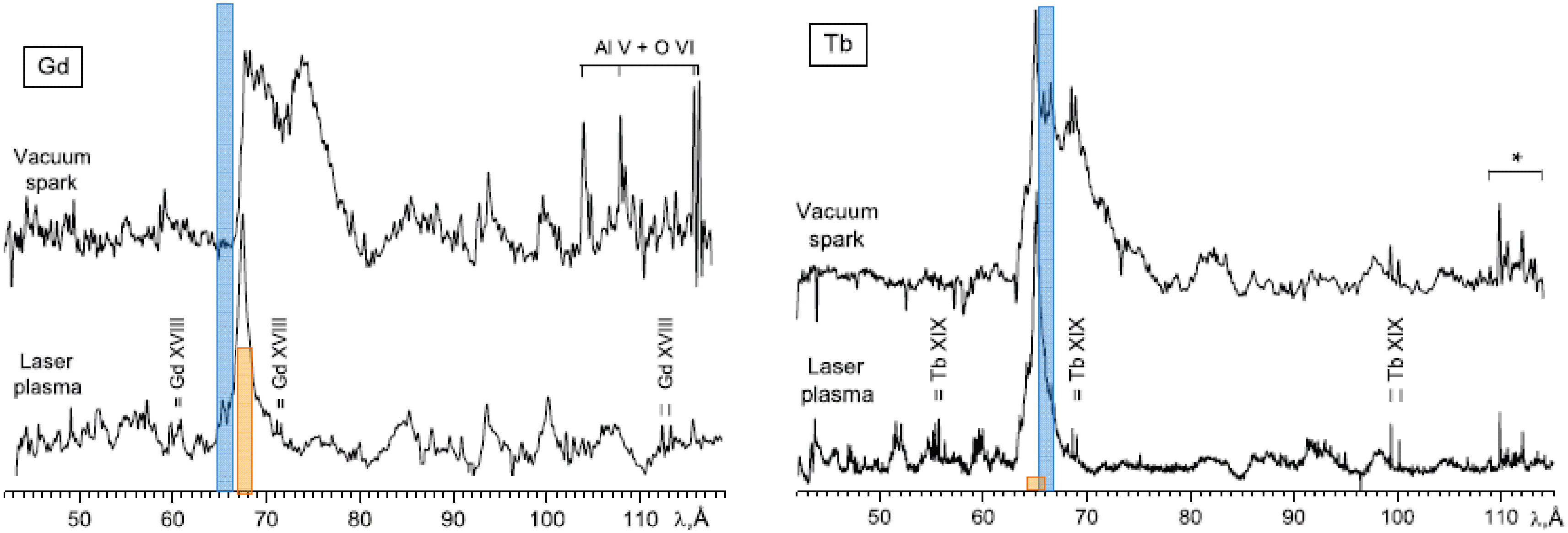
Source: materials and spectra

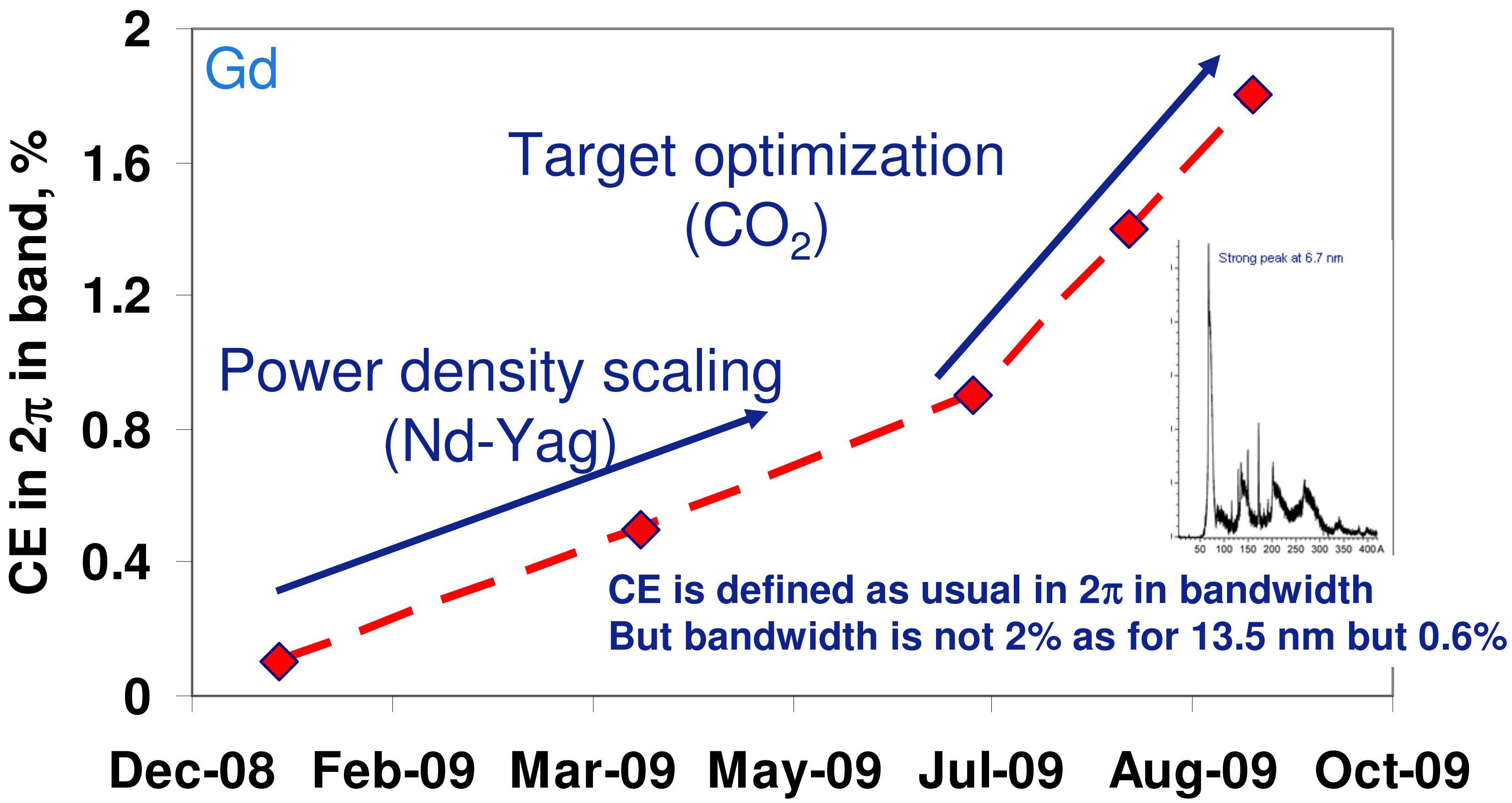


Source: Churilov etc Phys. Scr. 80 (2009)

🟦 Optical throughput optimized for the coating (10 mirrors)
🟧 Optical throughput optimized for the maximum emission spectrum

- Gd and Tb are the main potential materials of choice for 6.x lithography
- Simultaneous optimization of ML band and emission spectral power is required

Investigating Conversion efficiency (CE) for 6.77 nm with LPP



CE is defined as usual in 2π in bandwidth
But bandwidth is not 2% as for 13.5 nm but 0.6%

In-band CE for 6.x nm (1.8% vs theoretical 3-5%) is already comparable with that of 13.5 nm Sn

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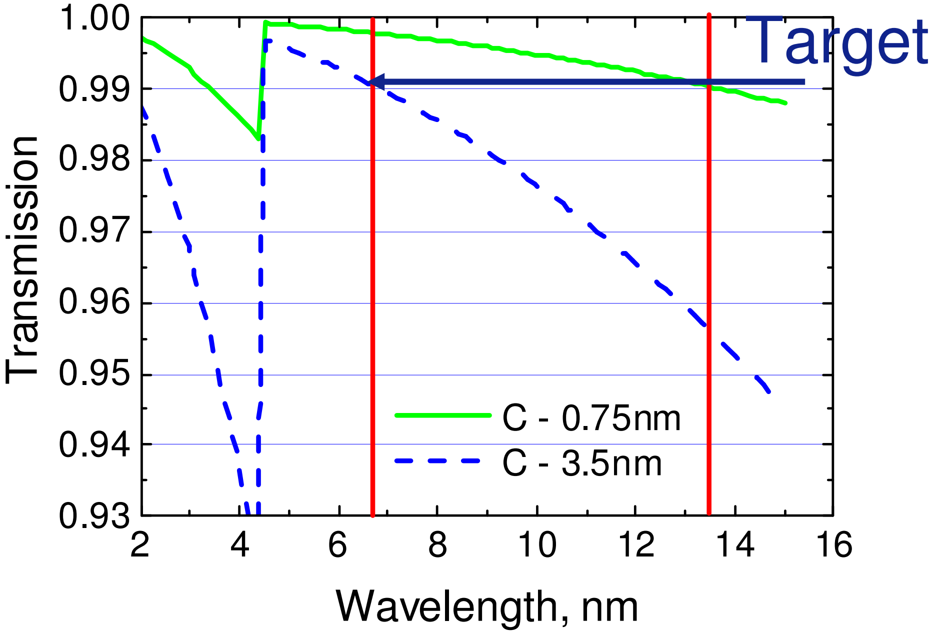
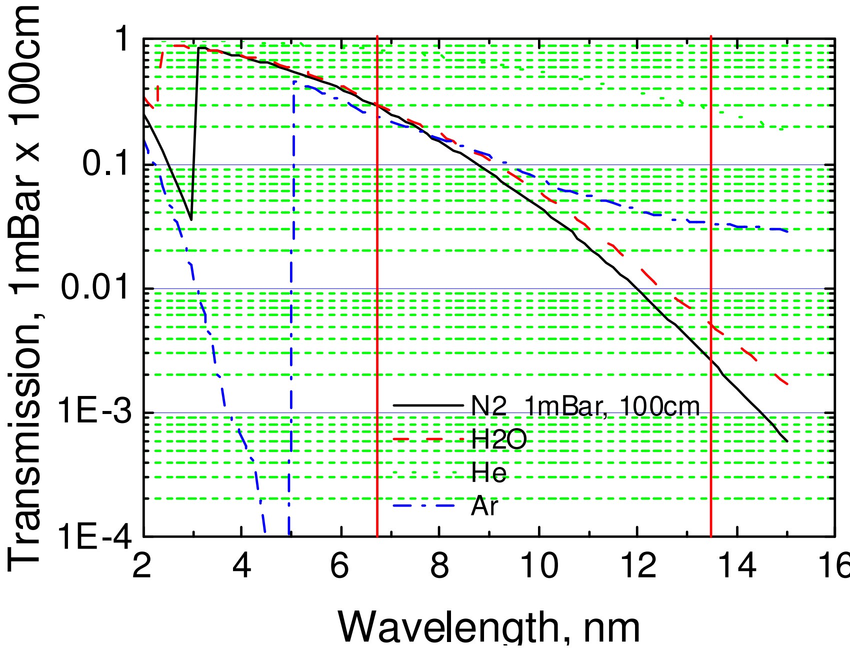
Transmission of C and absorption in gases
6.7 nm vs 13.5 nm

Carbon-contaminated mirror



No transmission penalty for the same C growth (<10% for optical column) or 5x thicker C on MLMs can be tolerated for the same transmission loss

Gas absorption



Less transmission loss (~10%) or Gas absorption is 10-1000x less →
- Less strict vacuum specs
- Mitigation schemes will work much better

Throughput comparison 13.5 and 6.x systems

Theoretical CE 1:1 for 6.x and 13.5

Theoretical Optical throughput 3x for 6.x vs 13.5 nm

Source/Optics wavelength mismatch 1/3 for 6.x vs 13.5 nm

Vacuum environment transmission 1.2x for 6.x vs 13.5 nm

Total throughput for 6.x vs 13.5 nm is comparable

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Summary and conclusions

- Lithography for 6.x nm wavelength has a potential to extend EUVL beyond 11 nm node
- ML coating
  - Has a potential of for high reflectivity (up to 80%) for LaB_4C
  - Currently demonstrated reflectivity is 44% thus better inter-layer diffusion control is required
- EUV source
  - 2 potential source fuels are investigated: Tb and Gd
  - CE 1.8% has been demonstrated
- Optimization of EUV source spectrum with ML optics is required
- Transmission of gases and contaminants for 6.x is significantly (up to 5x) better than for 13.5 nm

- 6.x EUVL has a potential for a throughput comparable with 13.5 nm lithography at higher resolution

Acknowledgements

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