

# *E-Beam Coating Technology for EUVL Optics*

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### **Multilayer performance**

- R = 69.5 % @ 13.0 nm
  - > 68 % routinely
- temporal stability
- contamination under EUV exposure
- resistivity to cleaning

### **Scaling of coating technology**

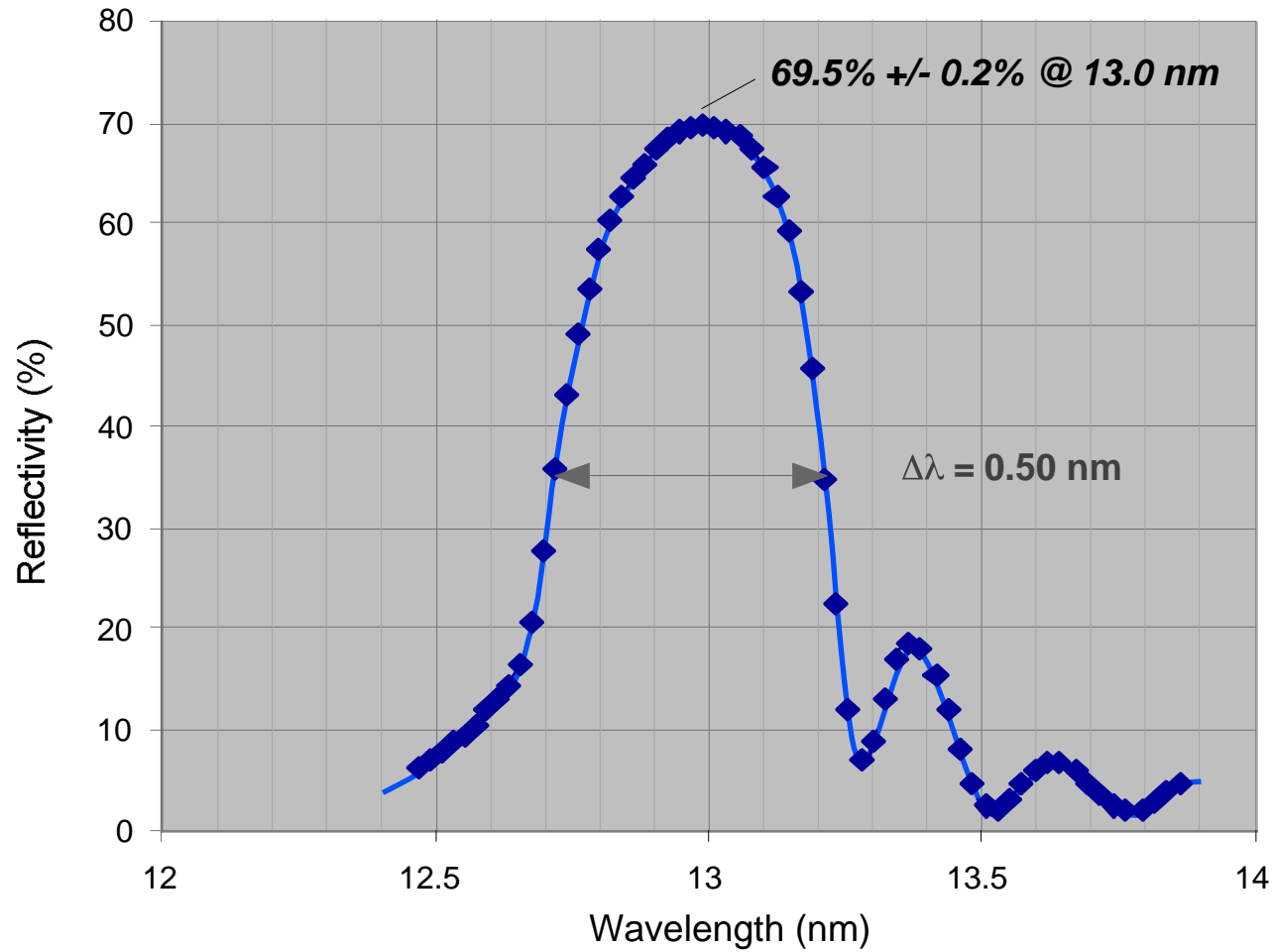
- coating realistic test surfaces (6 inch)
  - flat & curved
- automation of process
- first results volume production

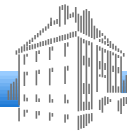
### **Conclusions**

# Mo/Si Reflectivity

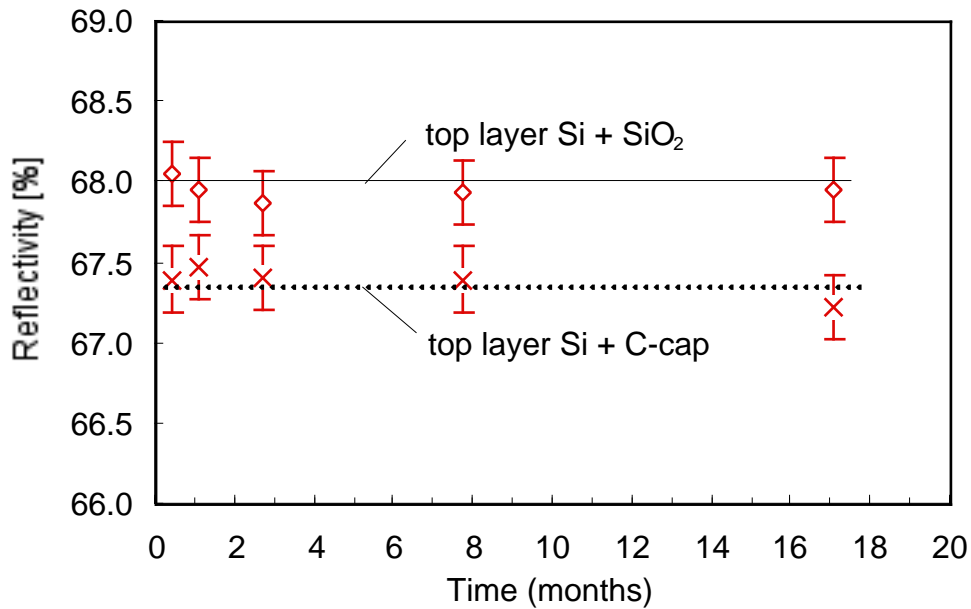


- SXR measurement at PTB/BESSY (R @ 1.5° off-normal, time scan)
- Uncapped Mo/Si
- E-beam deposition method





Peak reflectivity @ 13.0 nm (near-normal incidence)  
unexposed ML (storage in air)



## Peak reflectivity

- SiO<sub>2</sub> cap: no loss 1.5 year
- C cap: < 0.2% loss 1.5 year  
(PTB uncertainty: +/- 0.2%)

## d-spacing

- No measurable change in  $d_{max}$

⇒ **No sign of reflectivity loss over 1.5 year period**

### Issues to be assessed

- surface degradation (oxidation, etc.)
- surface contamination (carbon deposition)

Model: Jonkers & Bisschops

- physisorption  
equilibrium: few monolayers
- EUV induced cracking  
chemisorption

- stack degradation (intermixing, change of layer microstructure, etc.)

### Feasibility of cleaning the optics

- cleaning by UV-generated  $O_3$

Ref: S. Oestreich et al; SPIE 4146-07, San Diego 2000

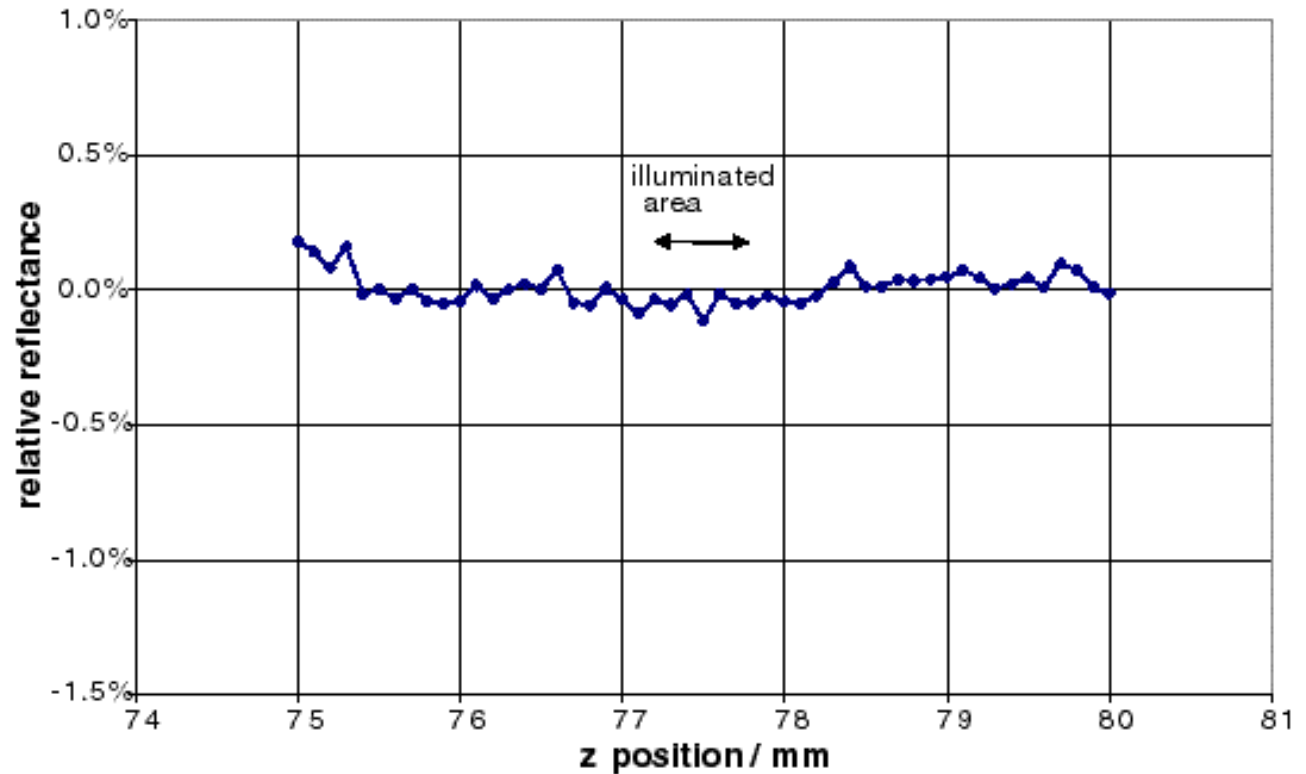
## Exposure under “clean” conditions

ZEISS



Collaboration with Roman Klein, PTB, Berlin

- 9.5 h @  
2.5 mW/mm<sup>2</sup>  
(total: 84.6 J/mm<sup>2</sup>)
- $3 \times 10^{-8}$  mbar
  - mainly water
  - no C<sub>x</sub>H<sub>y</sub> added
  - unbaked system



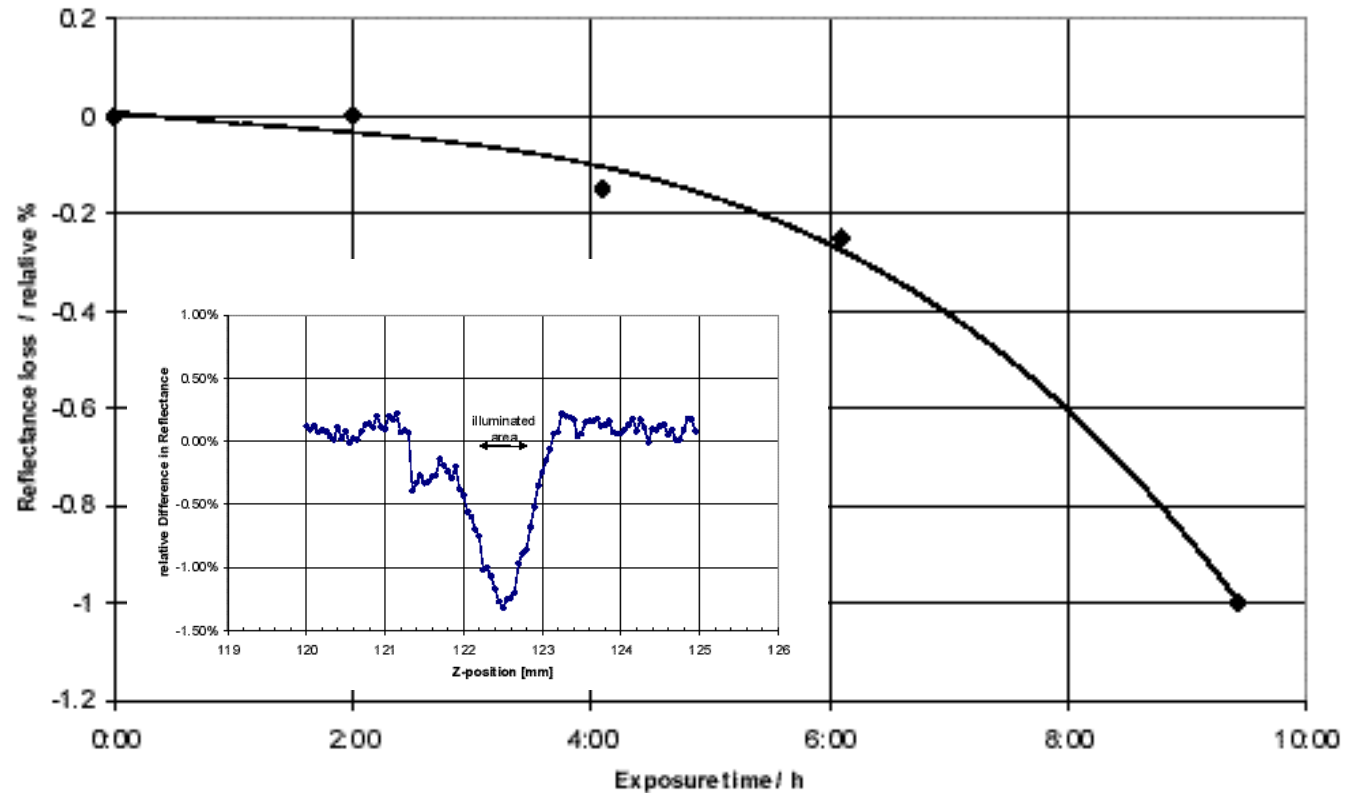
**No ML degradation in vacuum without C<sub>x</sub>H<sub>y</sub>**

## Exposure under “C<sub>x</sub>H<sub>y</sub>-rich” conditions

ZEISS



- $0.13 \text{ mW/mm}^2$   
(total:  $4.6 \text{ J/mm}^2$ )
- partial  $\text{C}_{30}\text{H}_{22}\text{O}_4$   
 $\sim 2 \times 10^{-10} \text{ mbar}$   
(Santovac-5 at 39 C)
- total  $\sim 1 \times 10^{-7} \text{ mbar}$



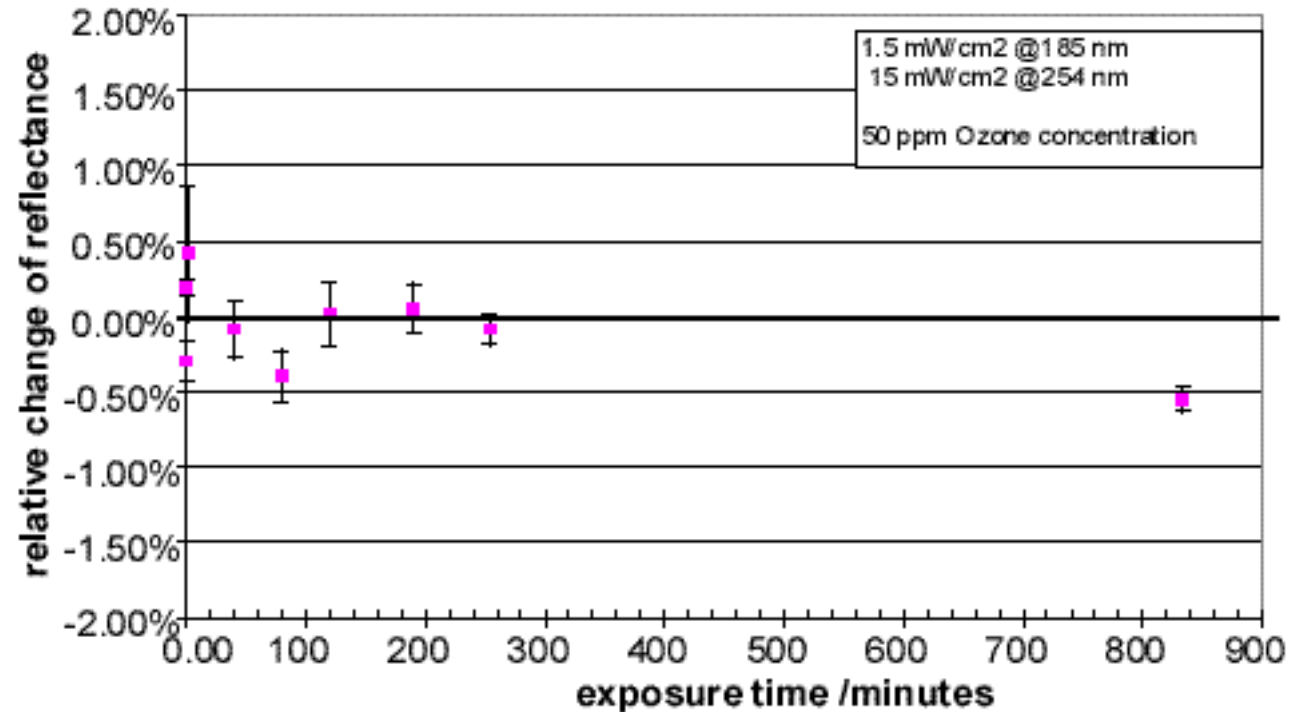
**Measurable reflectance loss in “C<sub>x</sub>H<sub>y</sub>-rich” conditions**  
**SEM analysis shows C-contamination**

# Ozone cleaning of ML mirrors



Collaboration with Bas Mertens, TNO/TPD, Delft, NL

- *UV produced ozone*
  - $O_3$
  - $O$
- *Low heat load*
- *Standard ML samples (not contaminated)*



Settings typically lead to 4 nm/min removal of C (TNO/TPD data on carbon contaminated samples)

## **Mo/Si mirrors withstand $O_3$ -treatment**

### **Multilayer performance**

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  - > 68 % routinely
- temporal stability
- contamination under EUV exposure
- resistivity to cleaning

### **Scaling of coating technology**

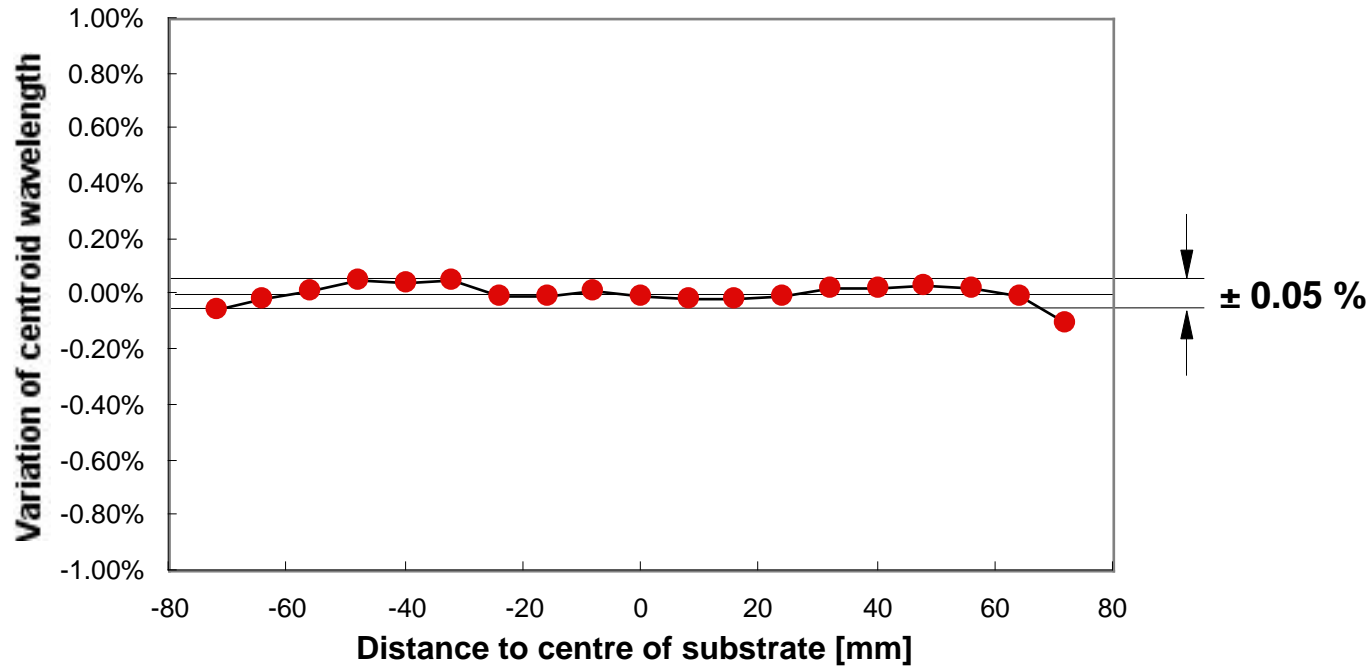
- coating realistic test surfaces (6 inch)
  - flat & curved
- automation of process
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### **Conclusions**

# Uniformity on 6" flat



- Status deposition on 6" flat ULE substrate
- SXR measurement at PTB/BESSY  
(centroid wavelength of R( ) @ 1.5° off-normal)



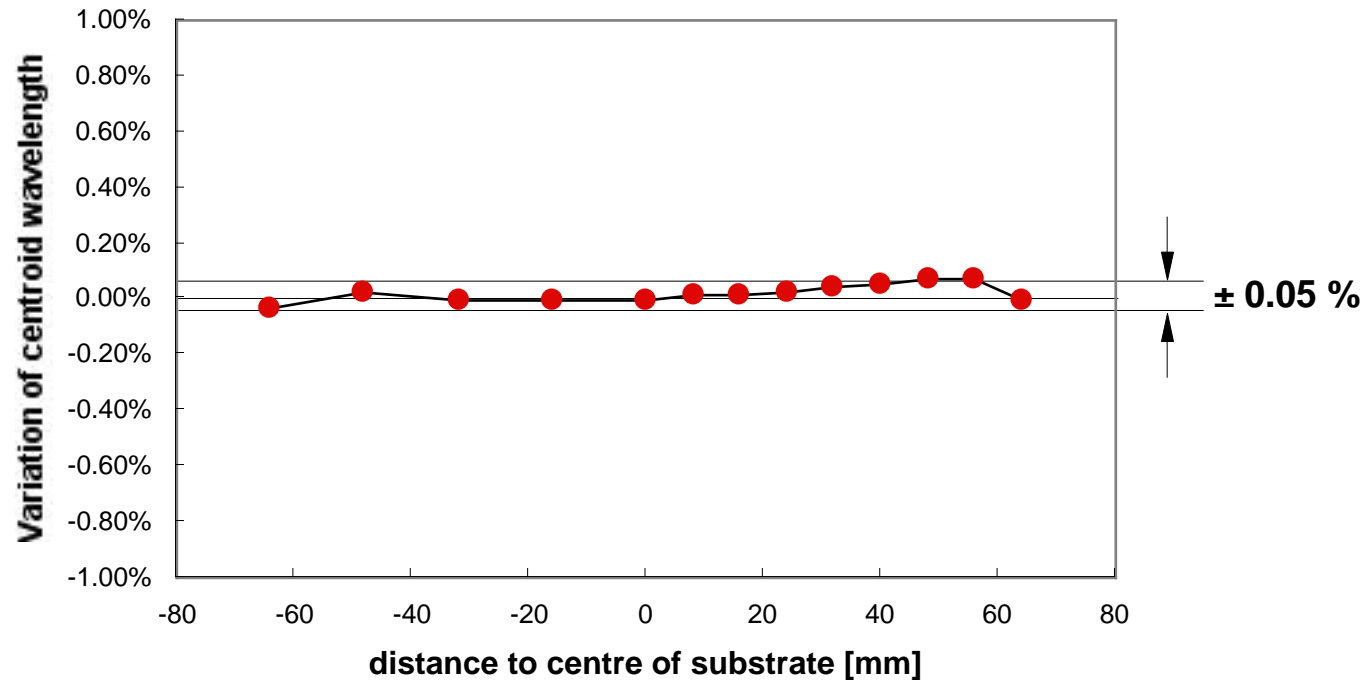
**Uniformity coating within ± 0.05% over 6" diameter**

Ref: E. Louis et al; SPIE 4146-06, San Diego 2000

## Uniformity on 6" curved



- deposition on 6" RoC 381 mm substrate
- SXR measurement at PTB/BESSY  
(centroid wavelength of R( ) @ 1.5° off-normal)



**Uniformity coating within  $\pm 0.05\%$  over 6" diameter on RoC 381 mm**

Ref: E. Louis et al; SPIE 4146-06, San Diego 2000



### Current set-up at FOM

- multi-purpose R&D facility, not optimized for production
- fully automated process
- present electron-gun used at low power
- upgrade to faster deposition feasible:  
full stack Mo/Si in 4.5 hours demonstrated

### Further enhancement investigated with commercial coating equipment

- evaporation flux of e-beam scales with power e-beam
- commercial equipment materials change time ~ seconds
- pilot experiments high-speed deposition carried out  
show good perspective for high R coatings

➔ ***Full stack deposition within 1-1.5 hours feasible***

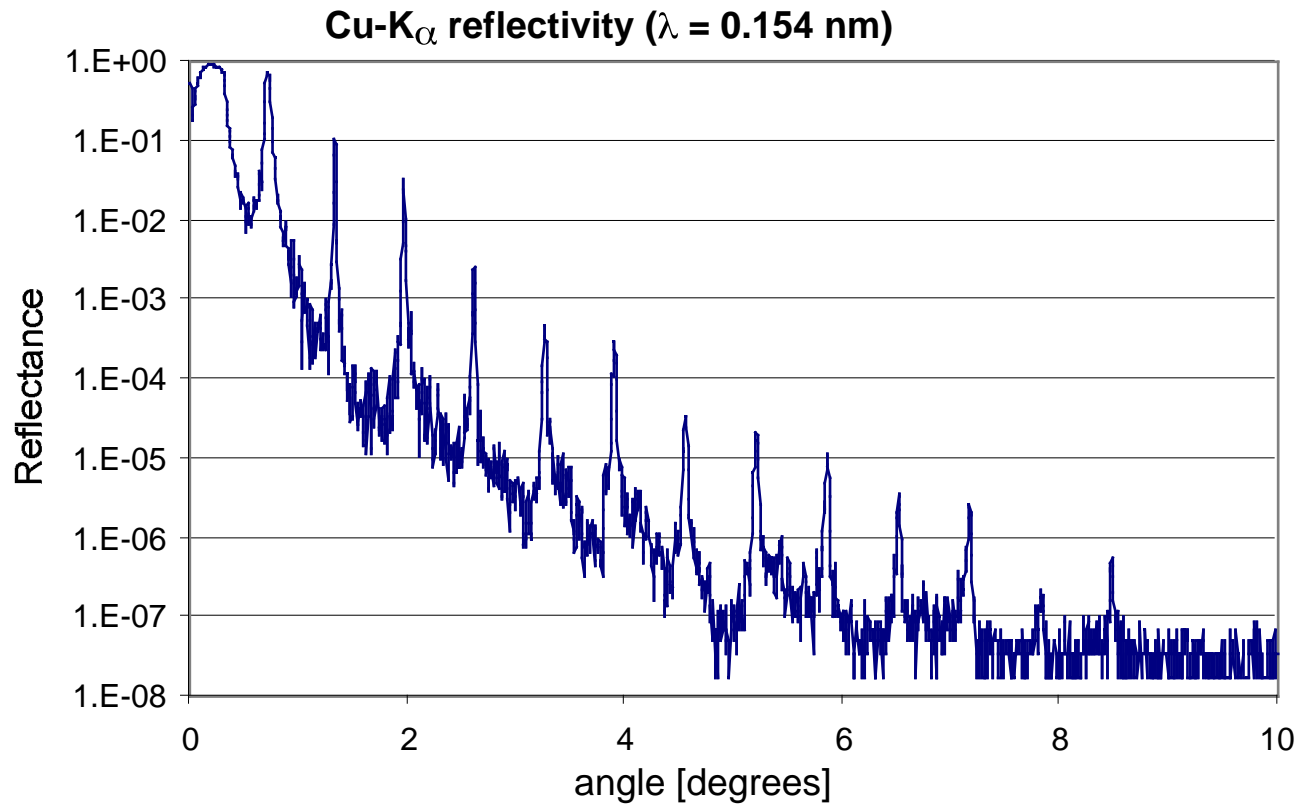
➔ ***Experimental verification in progress***

## ***pilot experiment commercial e-beam system***

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- full stack Mo/Si multilayer
- no *in-situ* monitoring during growth

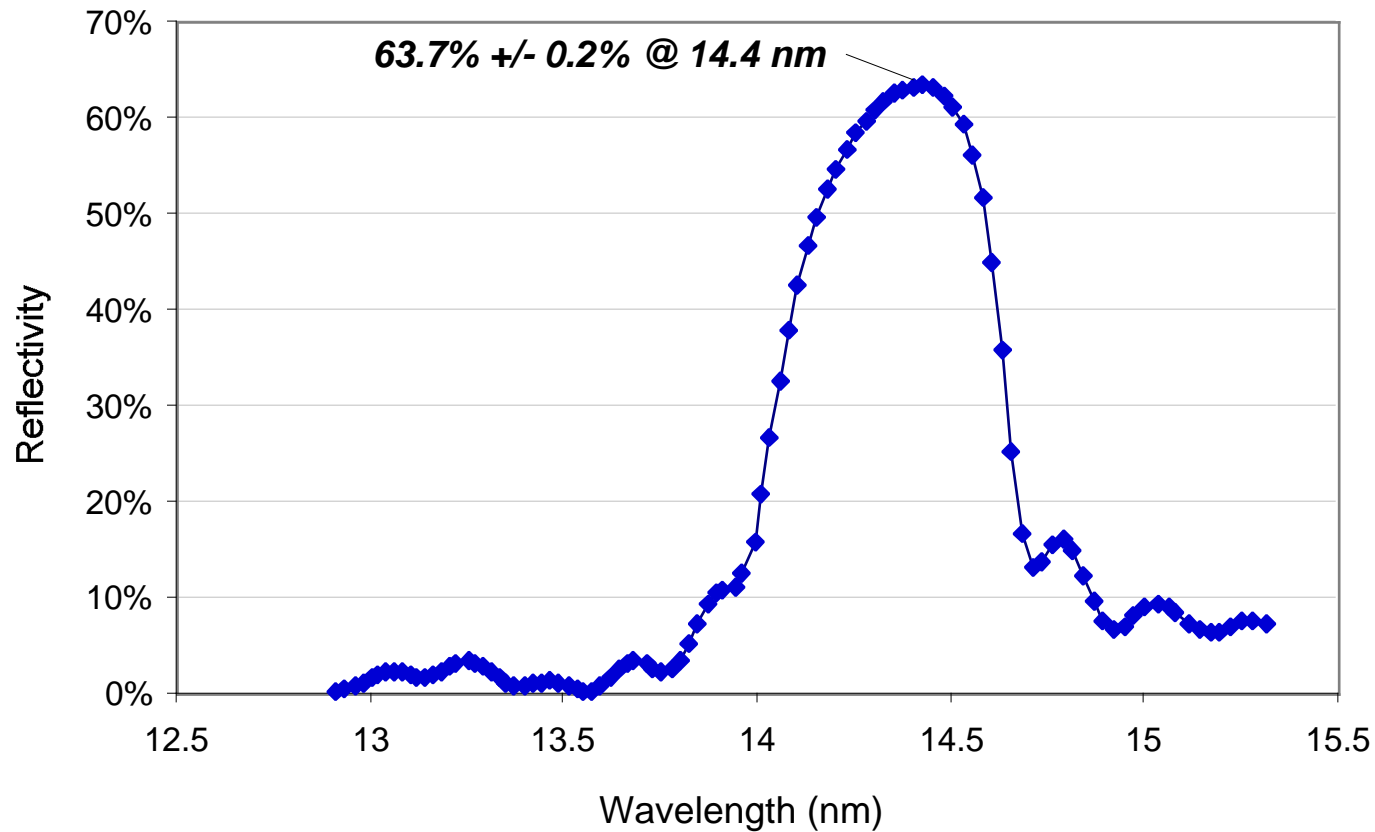


**Pilot experiments result in periodical stack with smooth interfaces ( $\sigma_{\text{rms}} = 0.3$  nm)**

## Result pilot experiment commercial equipment



- SXR measurement at PTB/BESSY (R @ 1.5° off-normal)
- full stack Mo/Si produced in commercial e-beam evaporator
- high speed deposition process



**Pilot experiments result in high reflectivity**

**Process not yet fully optimized; missing factors identified**

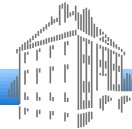
# Conclusions

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- *R=69.5% obtained ( $R > 68\%$  routinely)*
- *R and  $\lambda_{\text{centroid}}$  stable over 1.5 year period*
- *No reduction R under EUV exposure in clean vacuum*
- *Multilayers withstand UV/O<sub>3</sub> treatment*
  - *perspective to resolving C-contamination*
- *Uniformity  $\lambda_{\text{centroid}}$  within  $\pm 0.05\%$  over 6" on flat and curved surface*
- *Coating process fully automated*
- *First ML's from commercial e-beam equipment:  $R = 63.7\%$* 
  - *perspective to volume production*

# Acknowledgements



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