

Wideband Multilayer mirrors for EUV optical systems

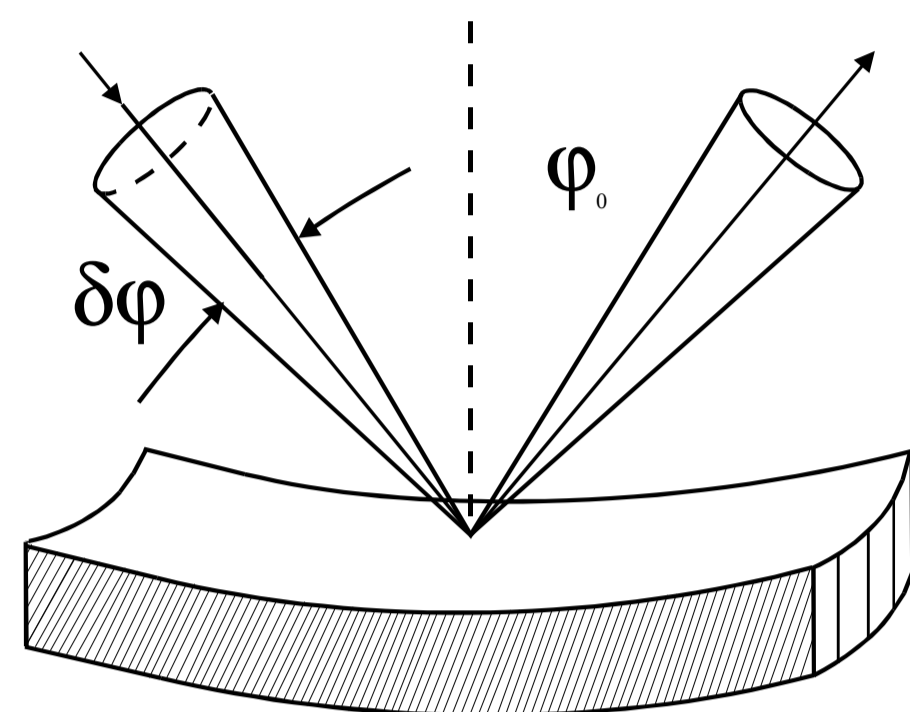
I. Kozhevnikov¹, A. Yakshin², E. Zoethout², E. Louis², H.-J. Mann³, S. Müllender³, and F. Bijkerk²

¹Institute for Crystallography, Leninsky prospect 59, Moscow, Russia,
²FOM Rijnhuizen, PO Box 1207, 3430 BE Nieuwegein, The Netherlands, www.rijnh.nl
³Carl Zeiss SMT AG, D-73446 Oberkochen, Germany

email: yakshin@rijnh.nl

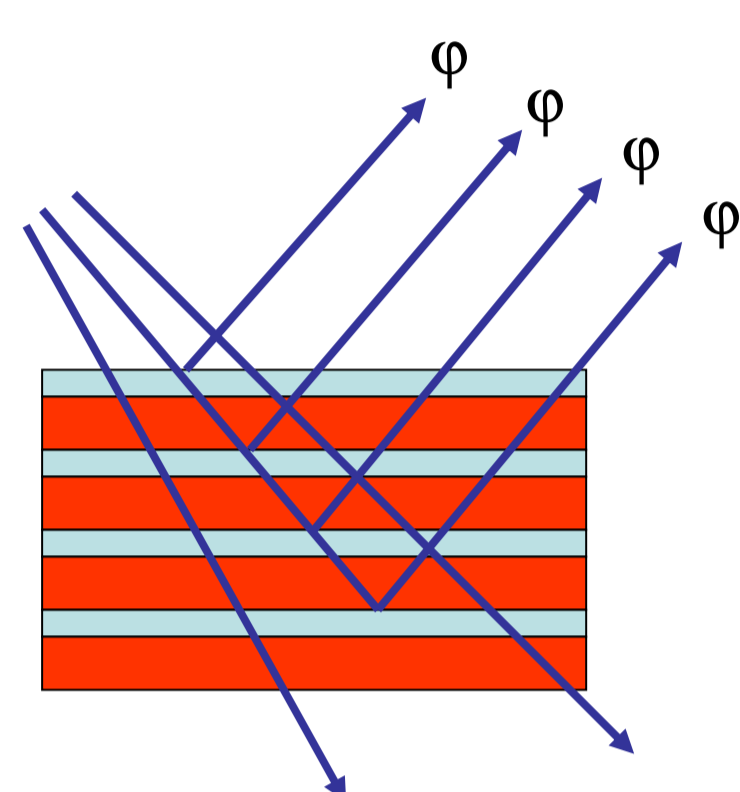
Motivation

In case of a large aperture optical system producing a diffraction limited resolution, the variation of an incidence angle φ_0 of a beam along a mirror surface as well as the divergence of radiation $\delta\varphi$ on a mirror surface may be more than the angular bandpass of a periodic multilayer structure. Hence, it is necessary to design and to fabricate multilayer mirrors with a wide angular bandpass.



Reflection from a periodic mirror

Bragg condition: $\lambda \approx 2d \cos \varphi \Rightarrow \Delta\varphi \sim \sqrt{\frac{\Delta\lambda}{\lambda}}$ at near normal incidence

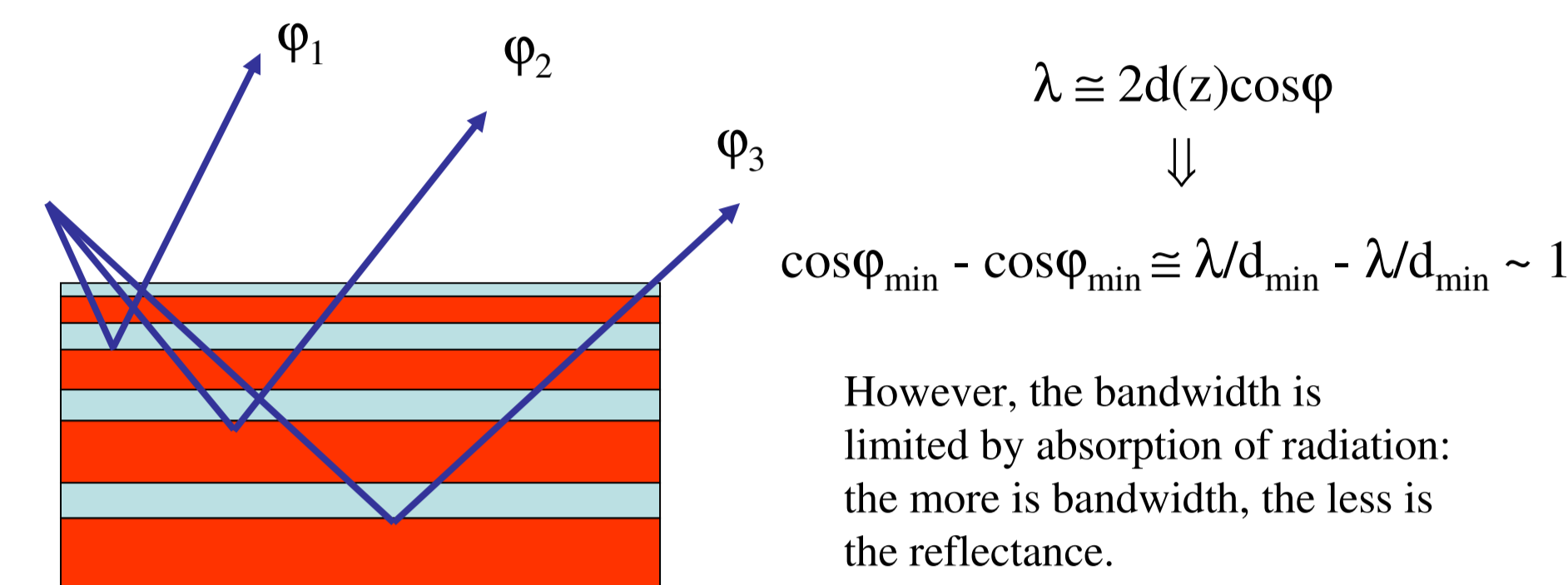


Amplitude reflectance from a single period $r \sim \epsilon_1 - \epsilon_2 \Rightarrow N \sim 1/|\epsilon_1 - \epsilon_2|$
 N - number of periods reflecting a beam.
 Let $\lambda = \lambda_0$ corresponds to the Bragg condition, i.e. waves reflected from different boundaries are in phase. If $\lambda = \lambda_0 + \delta\lambda$, then there is a phase shift between waves reflected from the top and from the bottom: $\Delta\Phi \sim 2\pi N \delta\lambda / \lambda$. Condition $\Delta\Phi = \pi$ determines the spectral bandwidth

$$\frac{\Delta\lambda}{\lambda} \sim \frac{1}{N_{\text{eff}}} \sim |\epsilon_1 - \epsilon_2| \ll 1$$

As a result, the angular bandwidth $\Delta\varphi \sim 7-9^\circ$ at near normal incidence and at $\lambda = 13.5$ nm.

Reflection from a depth-graded mirror



$$\lambda \approx 2d(z)\cos\varphi$$

$$\cos\varphi_{\text{min}} - \cos\varphi_{\text{max}} \approx \lambda/d_{\text{min}} - \lambda/d_{\text{max}} \sim 1$$

However, the bandwidth is limited by absorption of radiation: the more is bandwidth, the less is the reflectance.

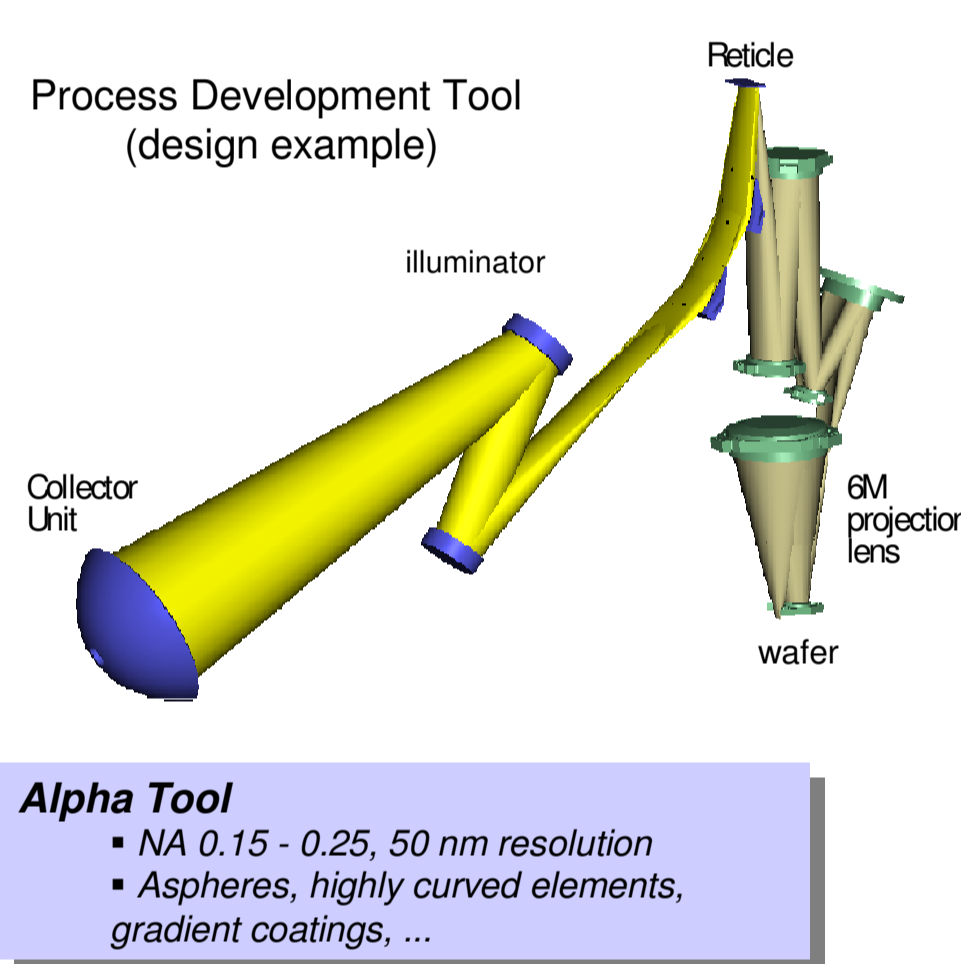
Designing basing on the minimization of the merit function*:

$$MF(d_1, d_2, \dots, d_N) = \sum_j [R_{\text{calc}}(\varphi_j; d_1, d_2, \dots, d_N) - R_{\text{des}}(\varphi_j)]^2$$

$R_{\text{des}}(\varphi)$ is the desired reflectivity profile (constant in the simplest case)

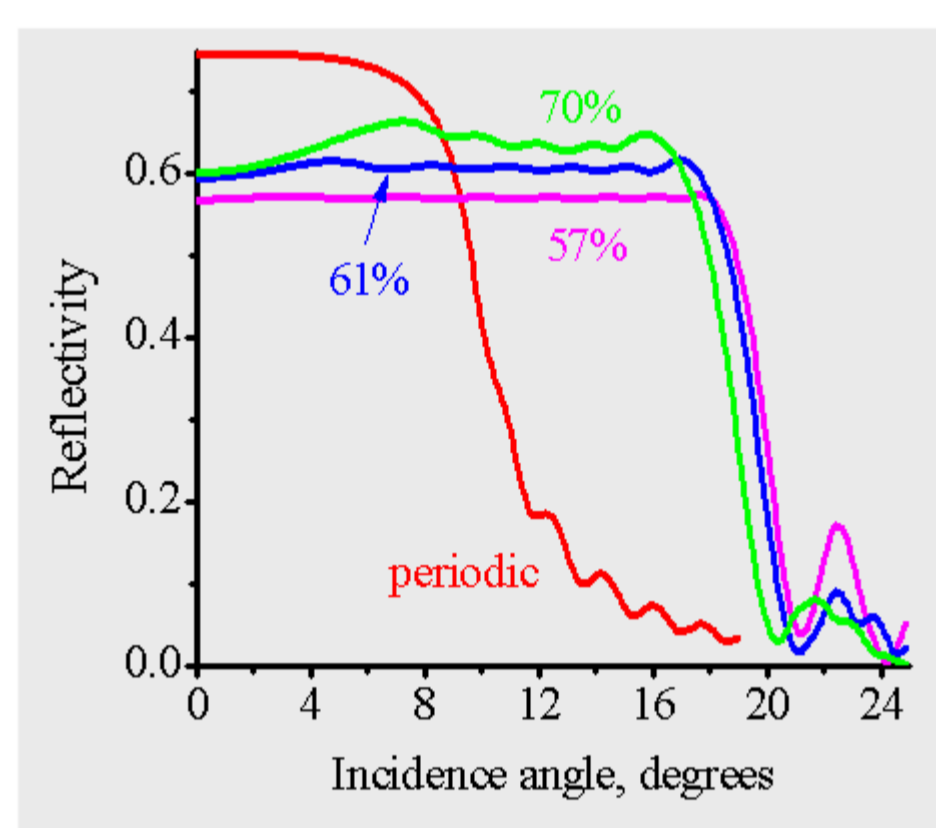
* I.V.Kozhevnikov et al., "Design of x-ray supermirrors", Nucl. Instrum. Methods A, 460 (2001) 424-443

EUV coatings for Alpha Demo Tool optics

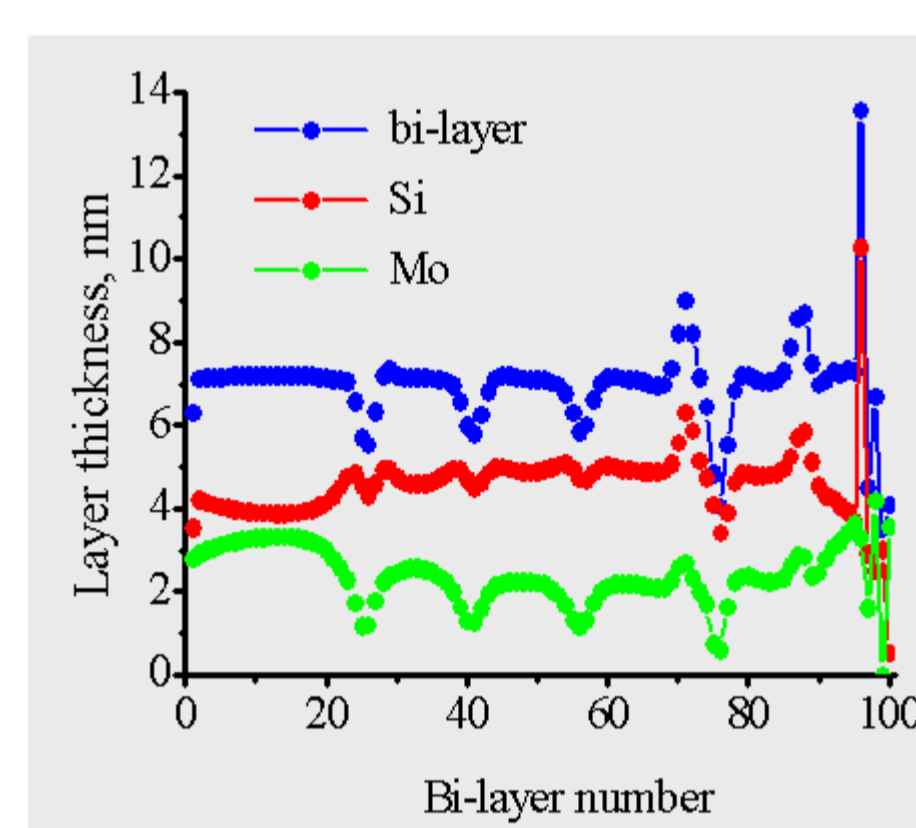


Reflectivity of periodic and depth-graded Mo/Si multilayer mirrors

Reflectivity (at $\lambda=13.5$ nm) of periodic and depth-graded Mo/Si mirrors designed to obtain the constant reflectivity R_0 in the $[0, 18^\circ]$ angular interval

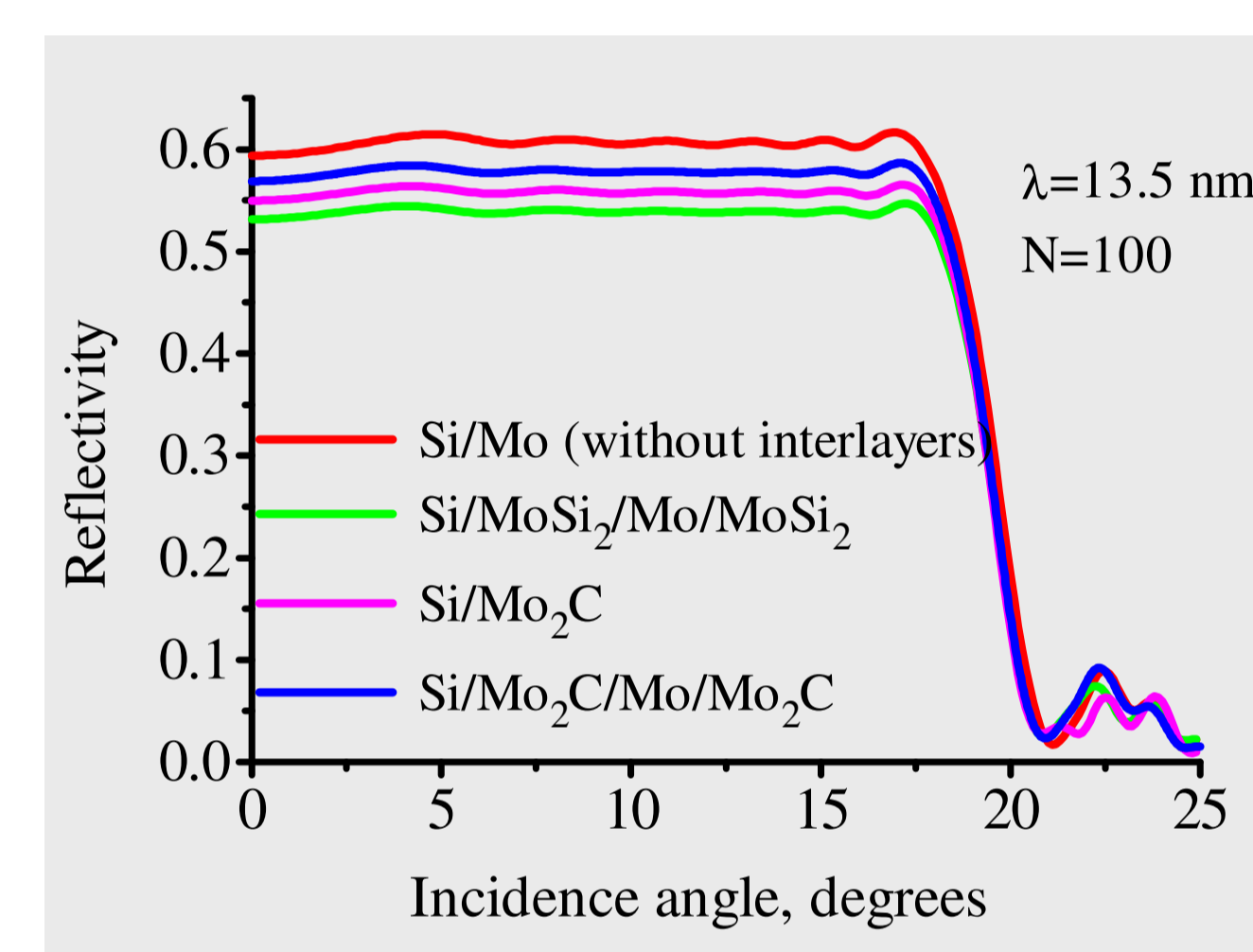


Depth-distribution of layer thickness for Mo/Si mirror designed to provide the 61% reflectivity at $\lambda=13.5$ nm in the $[0, 18^\circ]$ angular interval



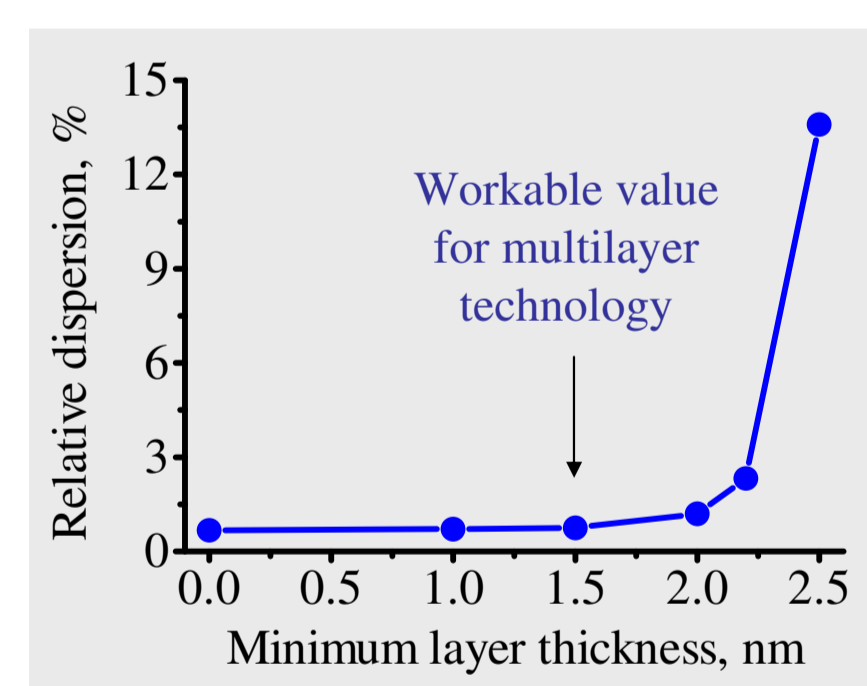
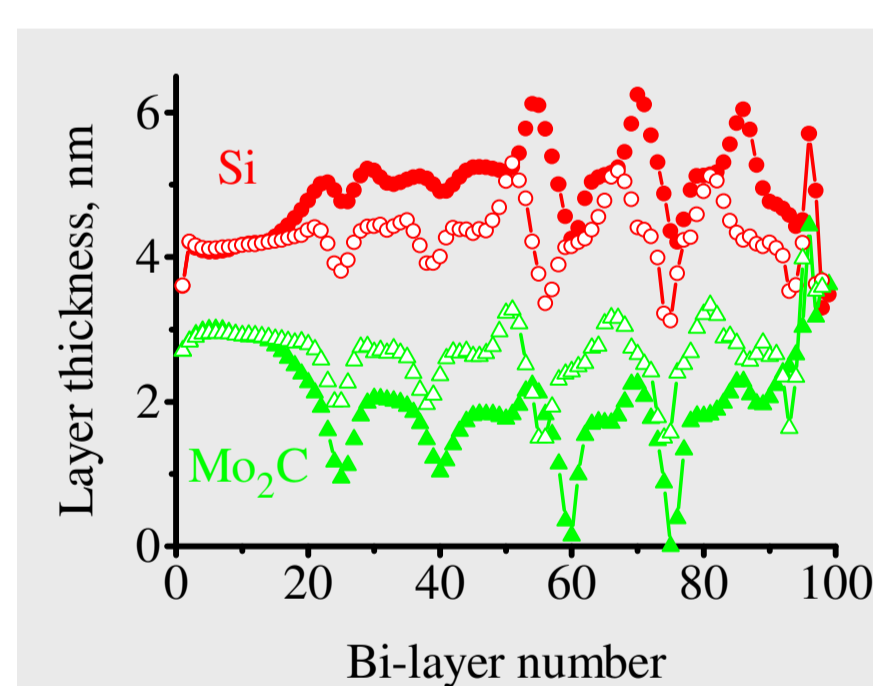
Maximum plateau reflectivity is conditioned by radiation absorption

Choice of materials for wide bandpass multilayer mirrors



The effect of interlayers is more pronounced for depth-graded multilayers as compared with periodic one.

Mo2C/Si The effect of physical and technological factors on the reflectivity: impossibility of deposition of ultra-thin layers

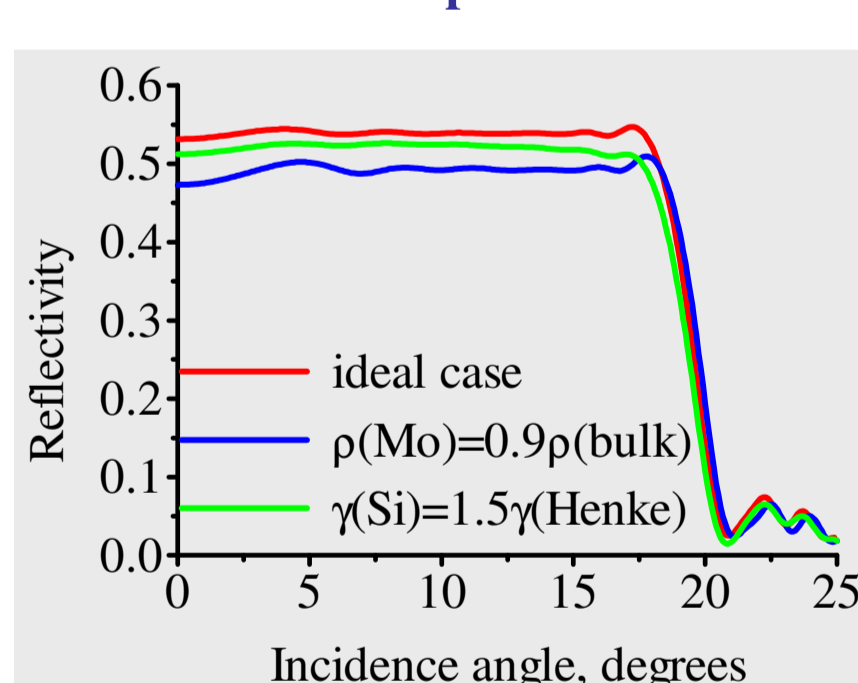


Filled symbols: no limitation on layer thickness. Unfilled symbols: minimal thickness is 1.5 nm. Relative dispersion of the reflectivity is the same in both cases.

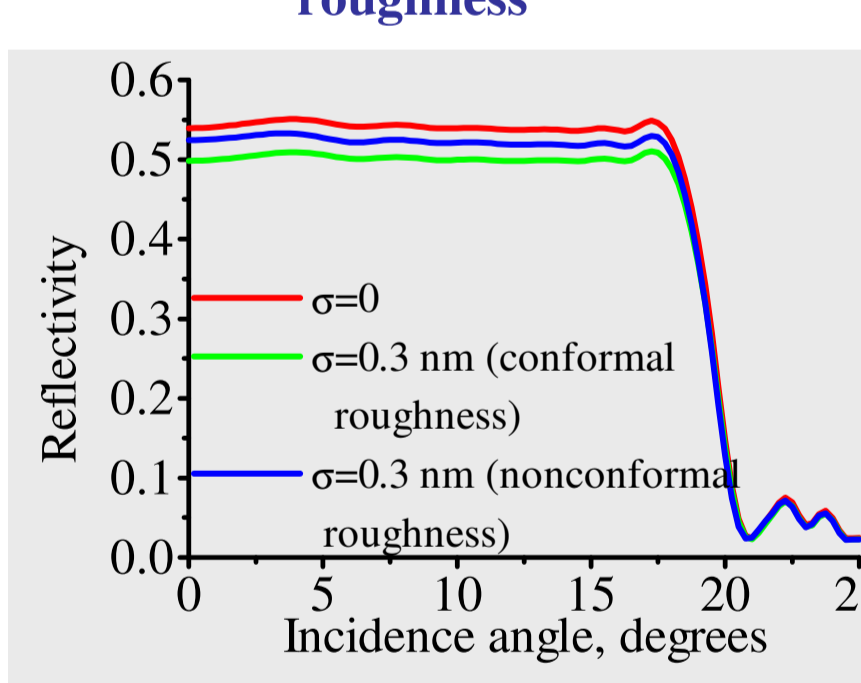
This effect is not very critical for existing technology

Mo/Si The effect of physical and technological factors on the reflectivity

Inaccuracy in optical constants of materials composed structure

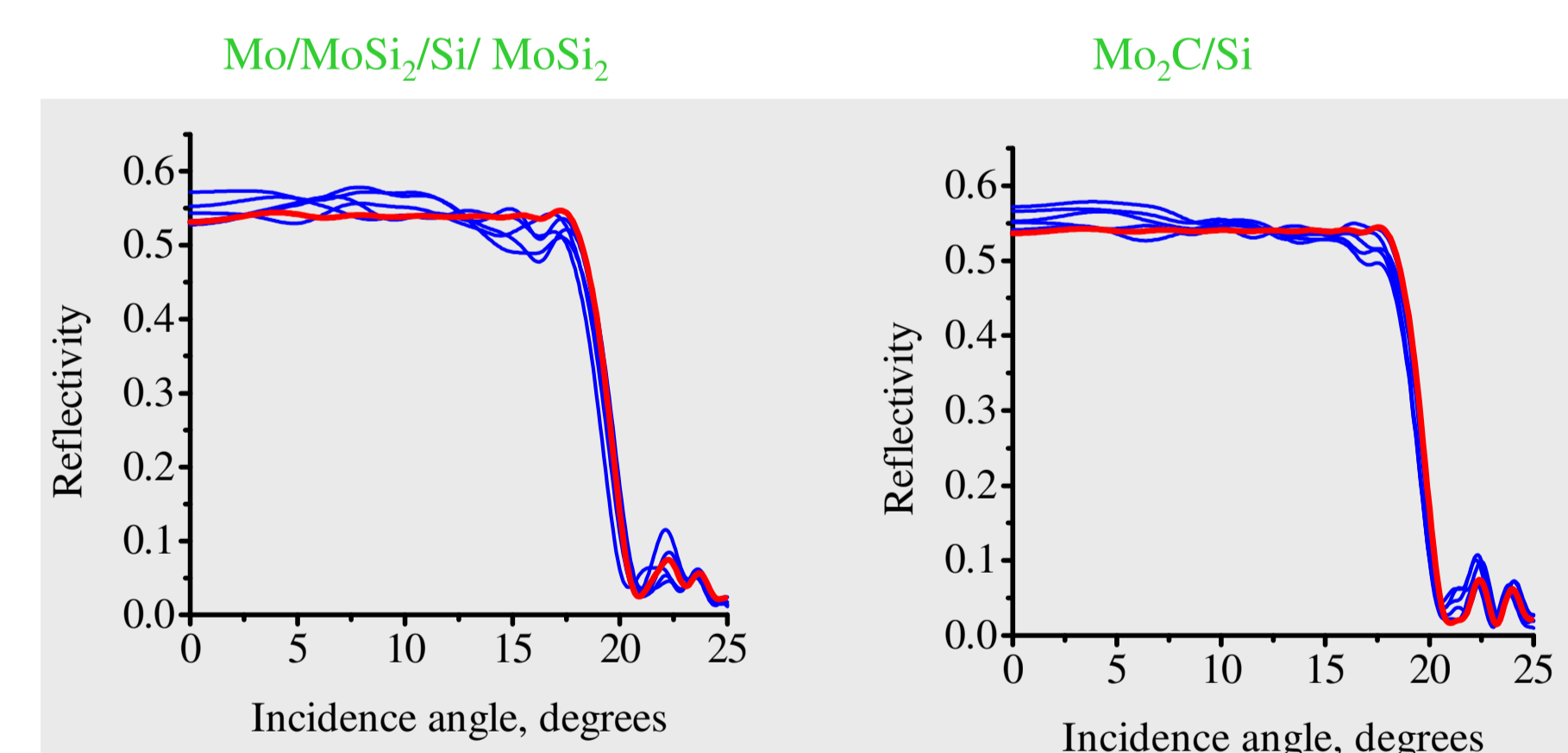


The effect of interfacial roughness



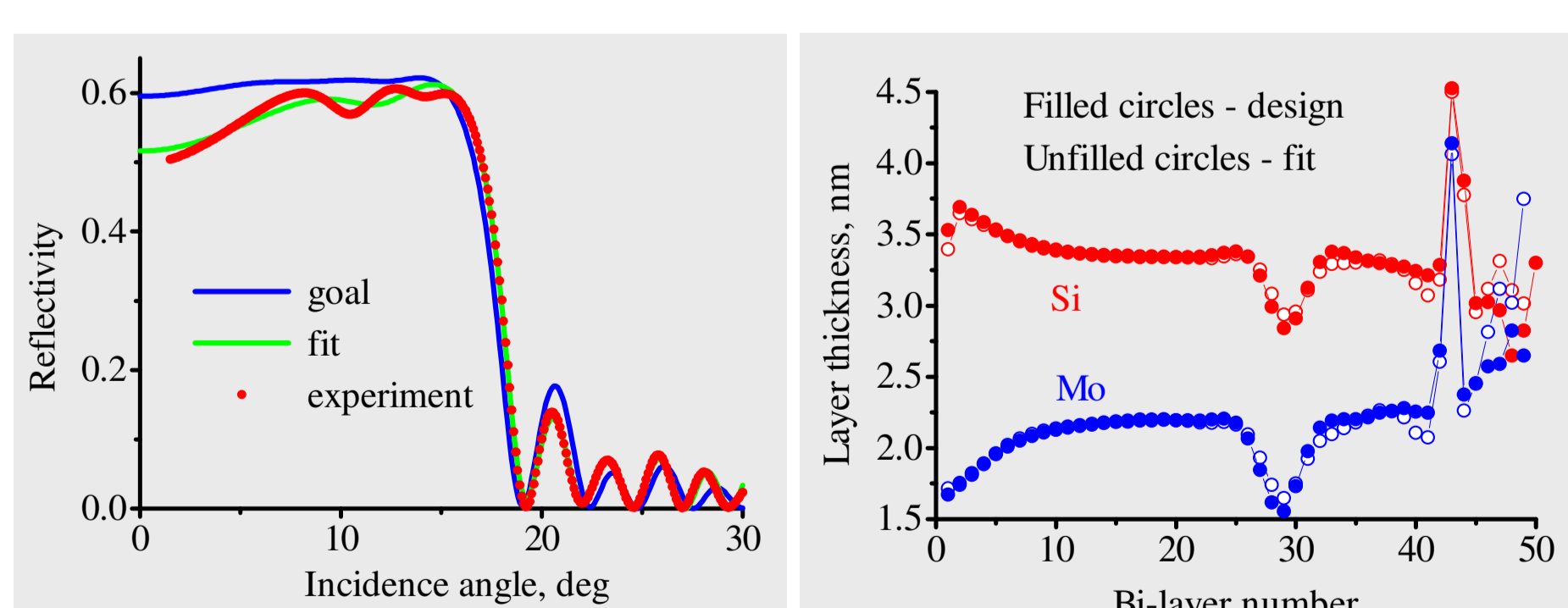
No essential distortion of the reflectivity plateau is observed

The effect of random layer fluctuations



The effect is more pronounced for four-component mirror

First experiment: Mo/Si mirror, N = 49.5, lambda = 13.5 nm



More detail study of internal structure of mirrors is necessary

Technological issue:

Layer thickness variation $\Delta d = 0.02$ nm results in a shift of the reflectivity curve by
 (a) $\Delta\lambda = 2\Delta d = 0.04$ nm in case of mirror with a wide spectral bandpass, what can be neglected in practical applications,
 (b) $\Delta\varphi = (2\Delta d/d)^{1/2} = 4.3$ degree in case of near normal incidence mirror ($d = 7$ nm) with a wide angular bandpass, what is unacceptable for practice.

Therefore, it is necessary to provide an extremely high accuracy of layers deposition in case of depth-graded multilayer mirrors with a wide angular bandpass.

Conclusions

1. The possibility to design EUV multilayer mirrors with a wide angular reflectivity bandpass was demonstrated theoretically and experimentally. The constant reflectivity up to 60% can be achieved in the $[0, 18^\circ]$ range of incidence angle.
2. The strong effect of interlayers on the maximum possible reflectance was found. Therefore, multilayers with stable interfaces ($\text{Mo}_2\text{C}/\text{Si}$ or $\text{Mo}/\text{Mo}_2\text{C}/\text{Si}/\text{Mo}_2\text{C}$) look more preferable for practice.
3. The crucial factor resulting in a deformation of the reflectivity curve is random layer fluctuations, which thereby should be less than 0.02 nm.
4. Further development of depth-graded multilayers requires better understanding of internal structure of mirrors and more precise control of layer thickness.

Acknowledgments

