コーティング内で発生する位相ズレによる波面誤差について

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Technology in Astronomy

Point Source Sensitivity

- In background-limited observations,

$$S/N = \frac{C_{obj}}{\sqrt{\sigma_{obj}^2 + \sigma_{bg}^2 + \sigma_{dark}^2 + \sigma_{read}^2}} \sim \frac{C_{obj}}{\sigma_{bg}} = \frac{f_{obj}\varepsilon t}{\sqrt{\frac{f_{bg}}{\int \varphi_{(\theta)}^2 d\Omega}\varepsilon t}} = \sqrt{\frac{f_{obj}^2 \varepsilon t \int \varphi_{(\theta)}^2 d\Omega}{f_{bg}}}$$

$$Point\ Source\ Sensitivity \equiv \frac{1}{t} \propto \varepsilon \int \varphi_{(\theta)}^2 d\Omega \sim \varepsilon SR^2$$

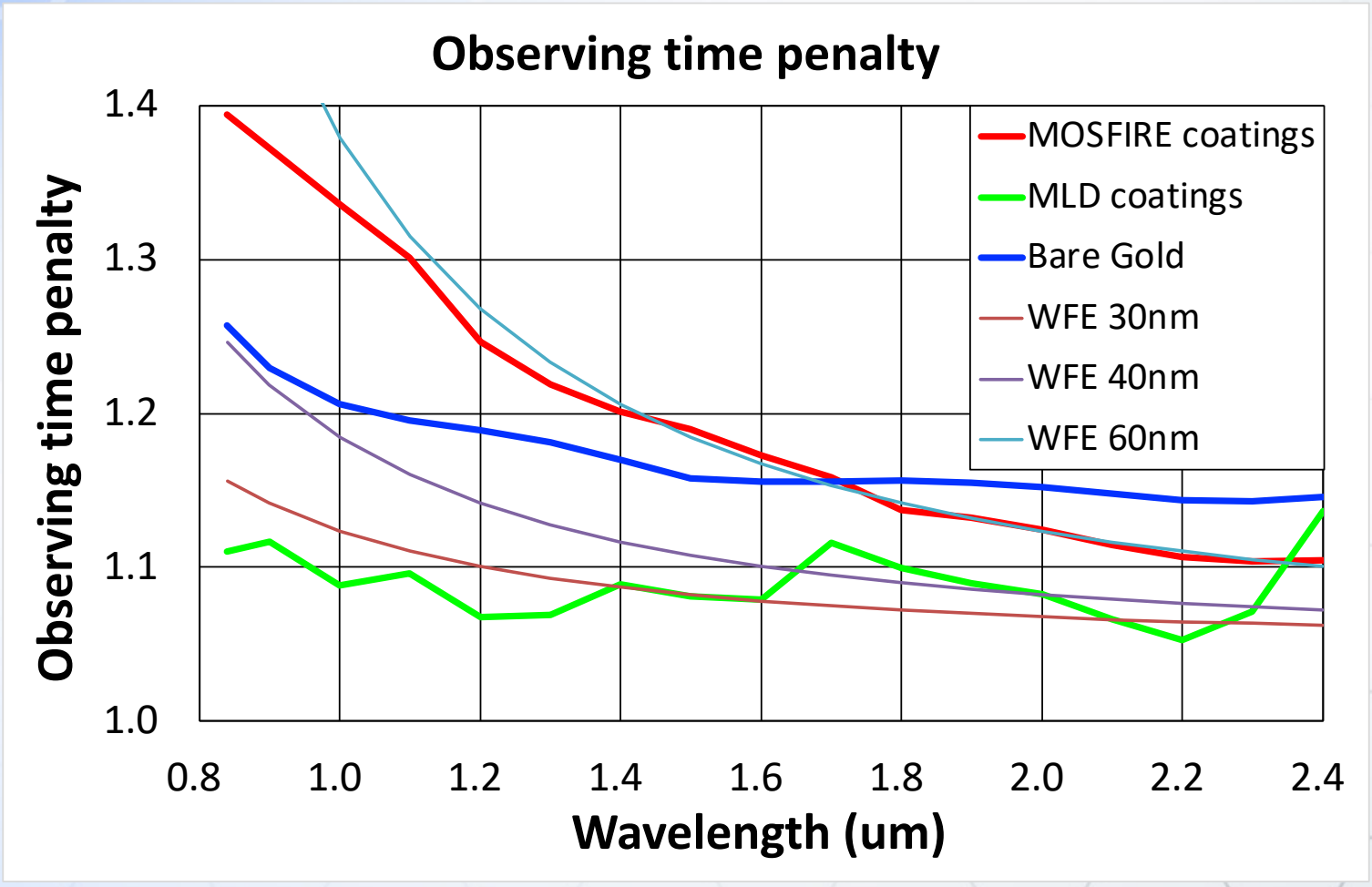
throughput

PSF profile

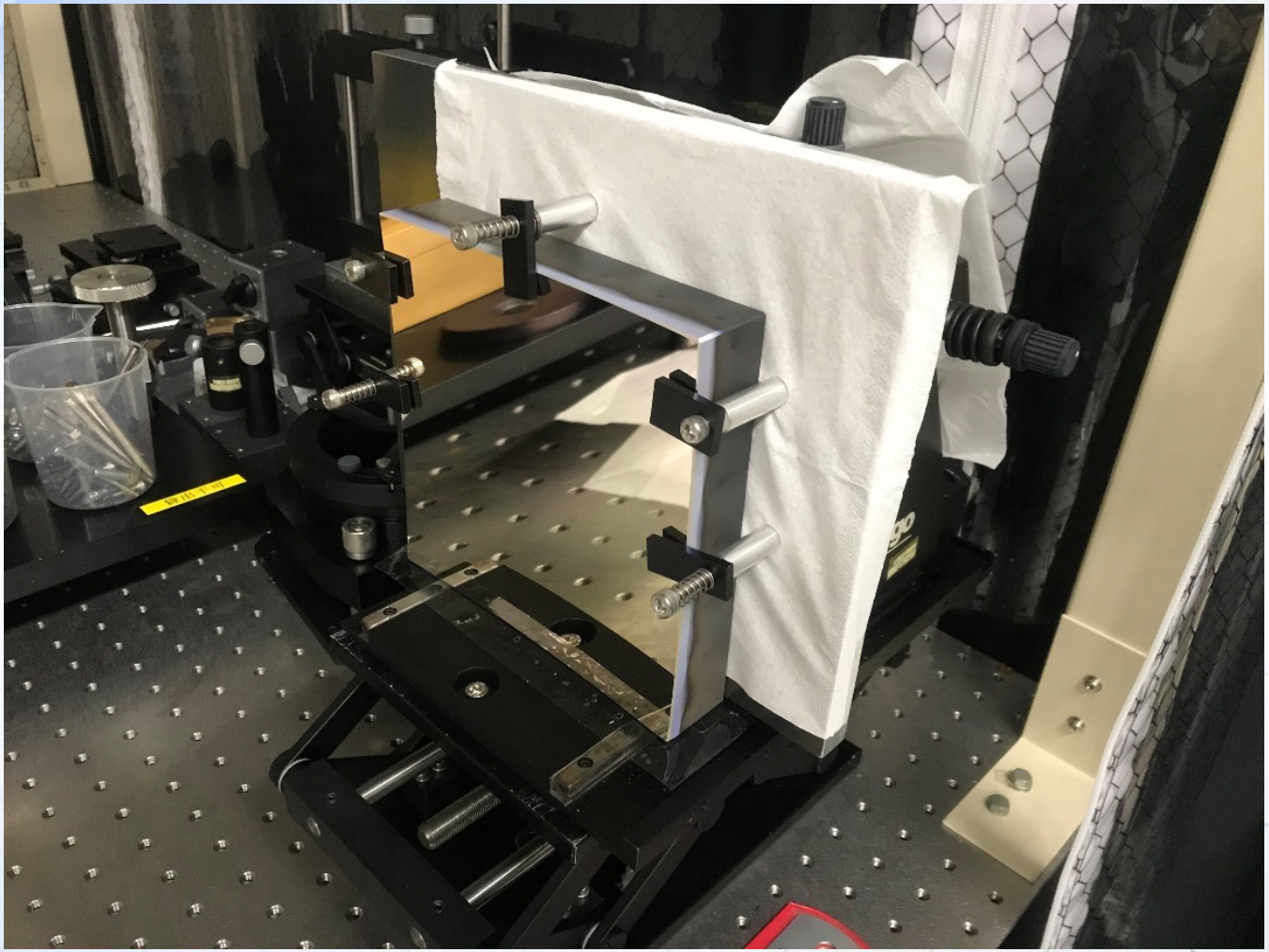
Strehl Ratio ← Wavefront error

- MLD coatings provide higher throughput, but thicker MLD coatings are expected to induce stress (deformation) on the mirror surface, i.e., wavefront error.

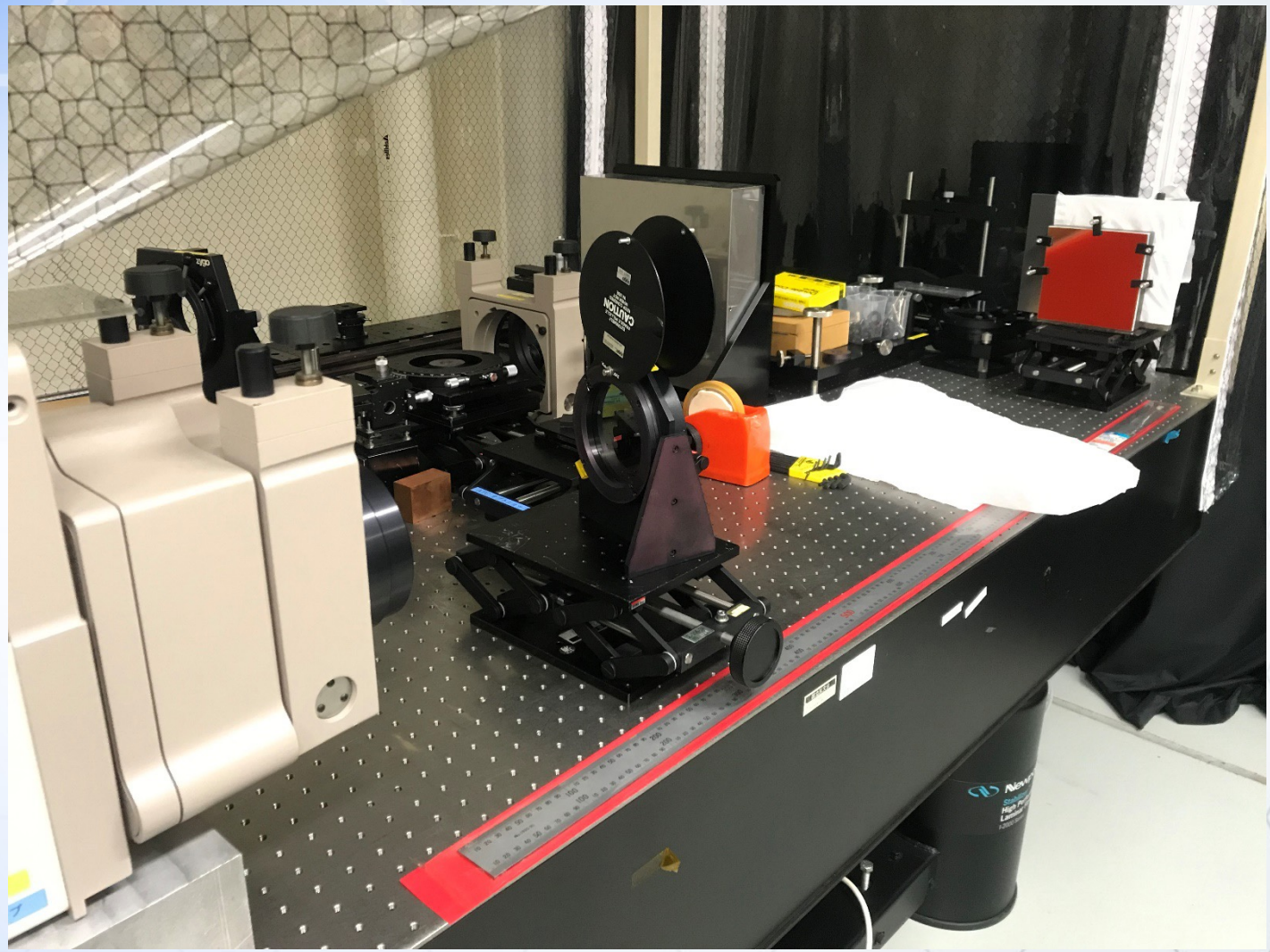
Point Source Sensitivity



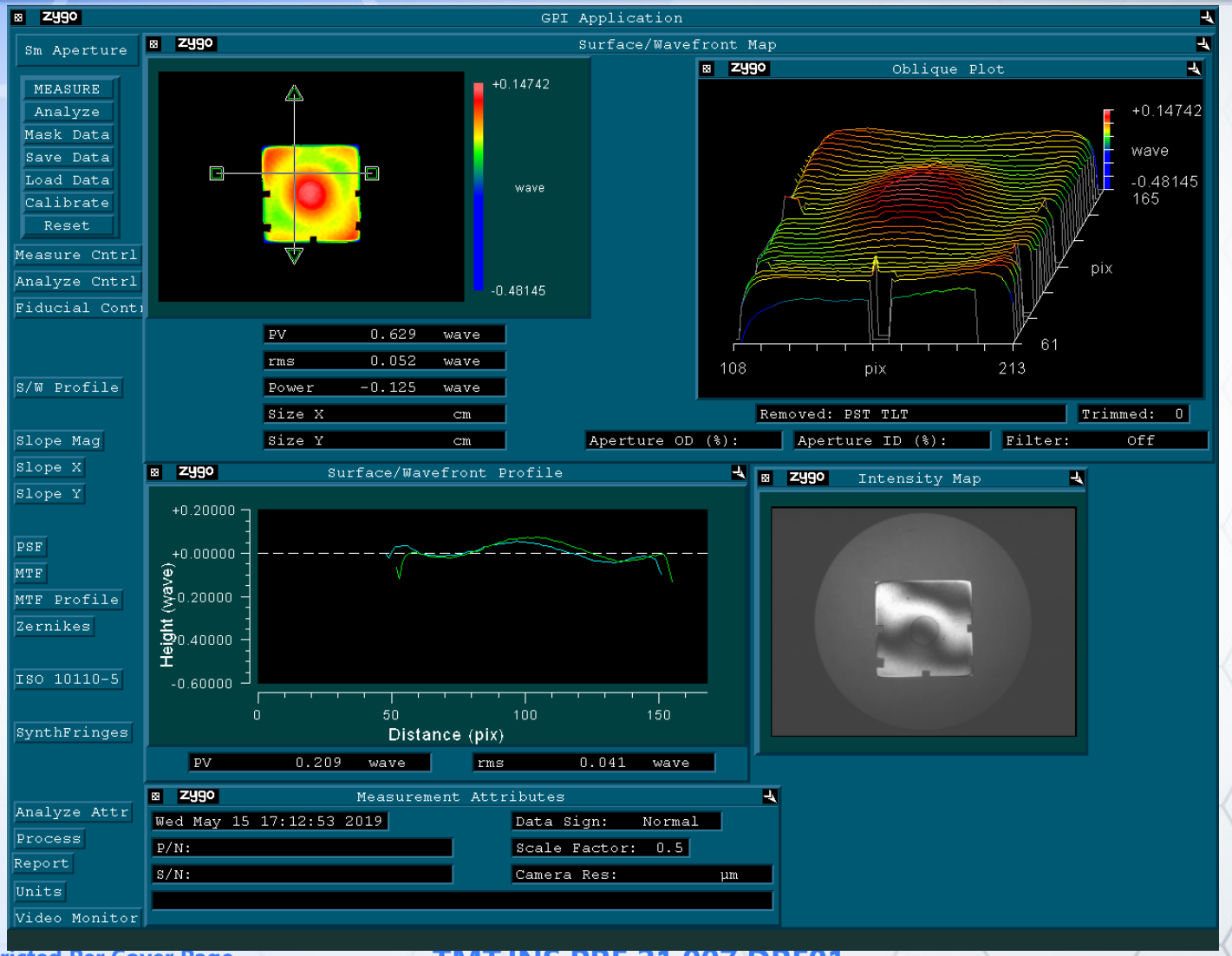
Prototyped concave mirror



Interferometer set up

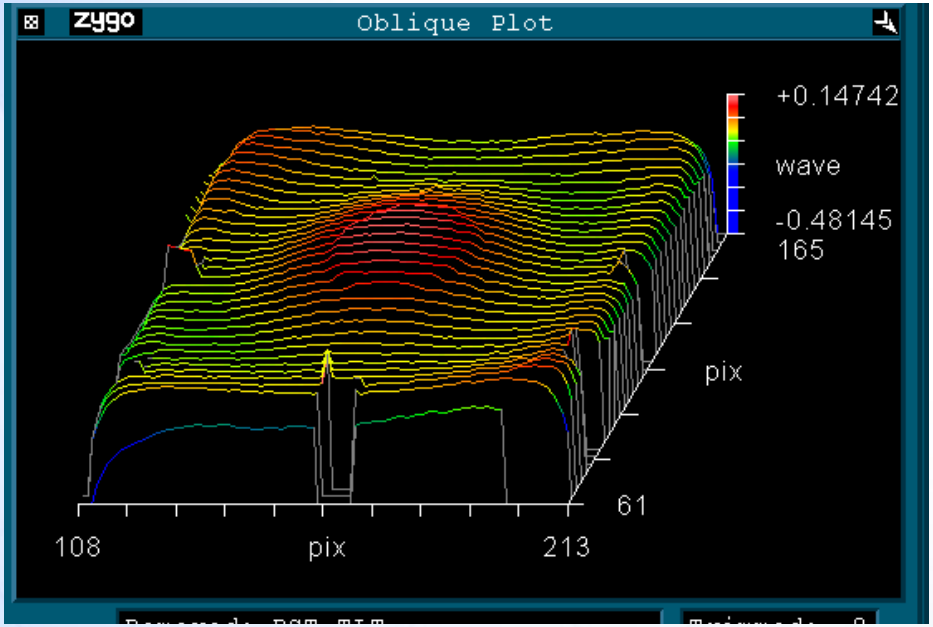


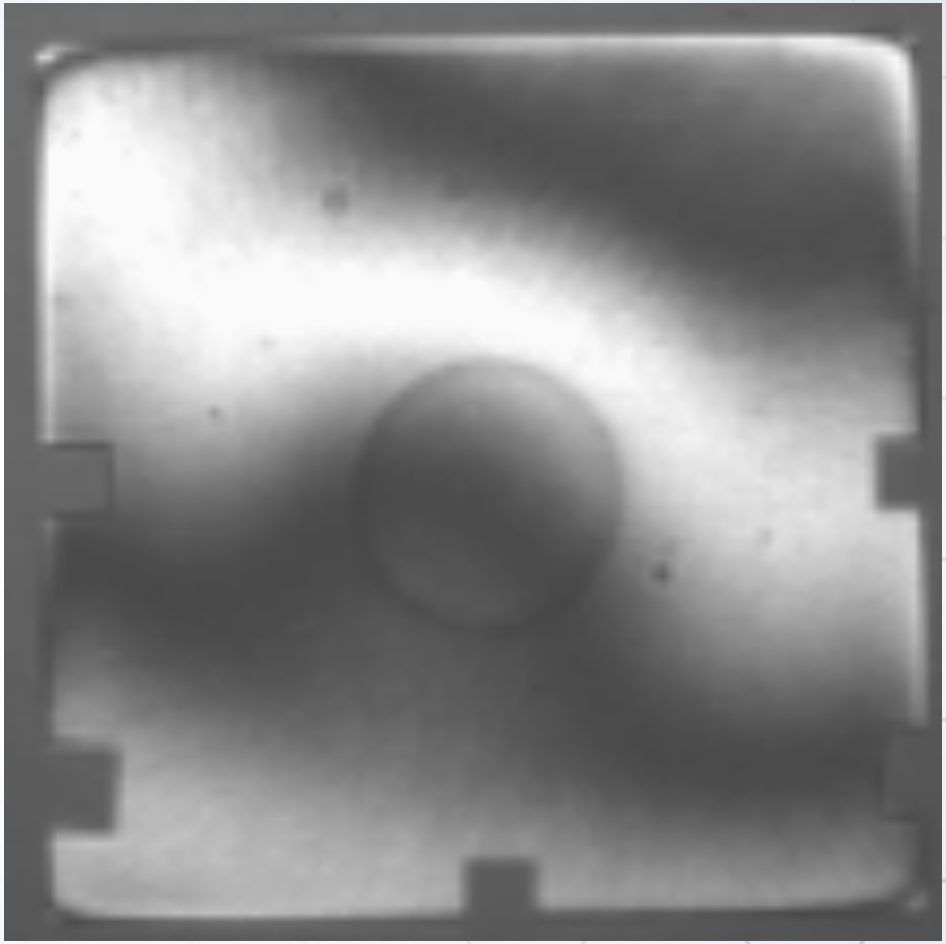
Surface shape measurement results



Surface shape measurement results

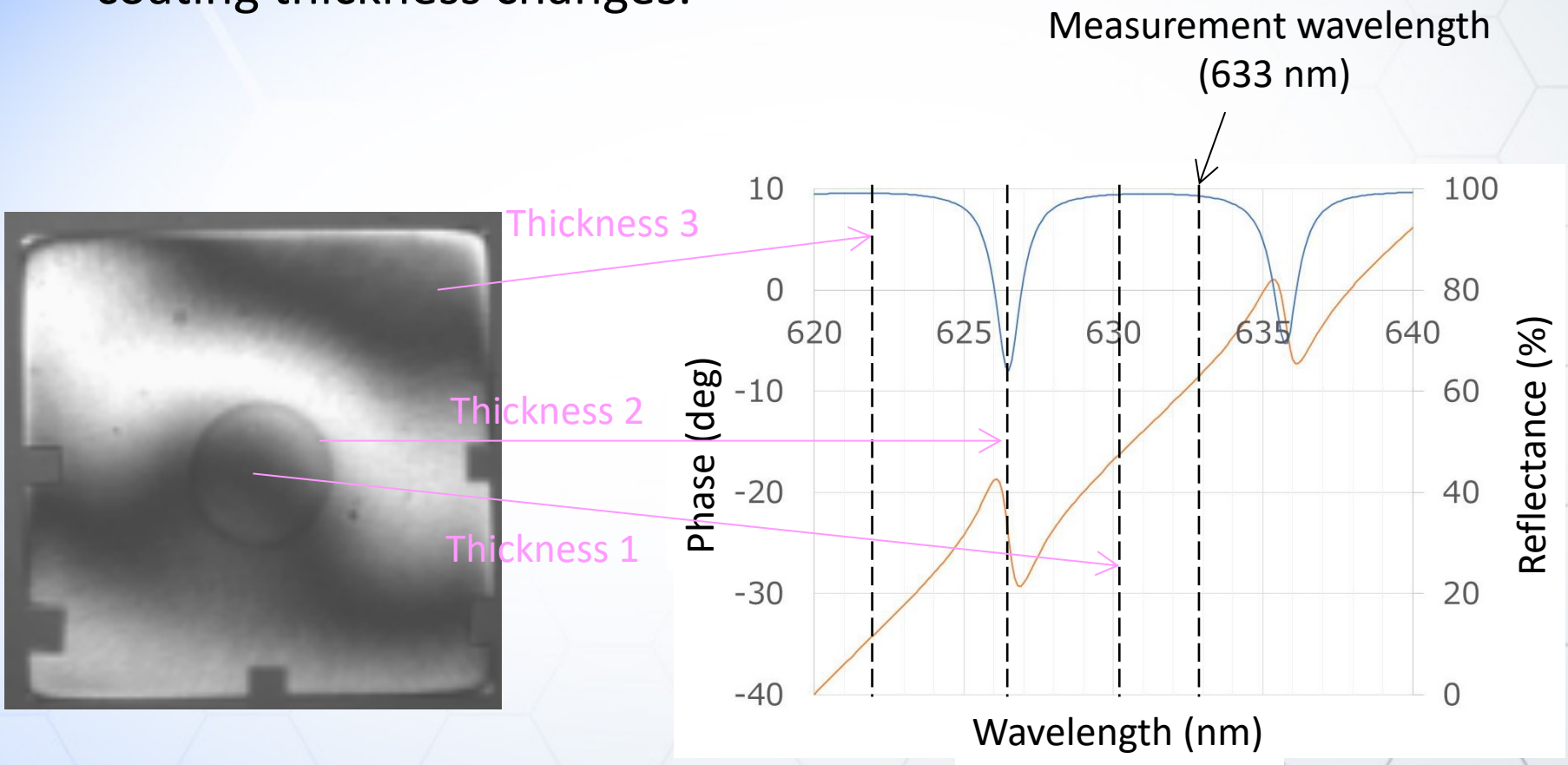
- Island pattern
  - 50 mm dia.
  - 20 – 30 nm height



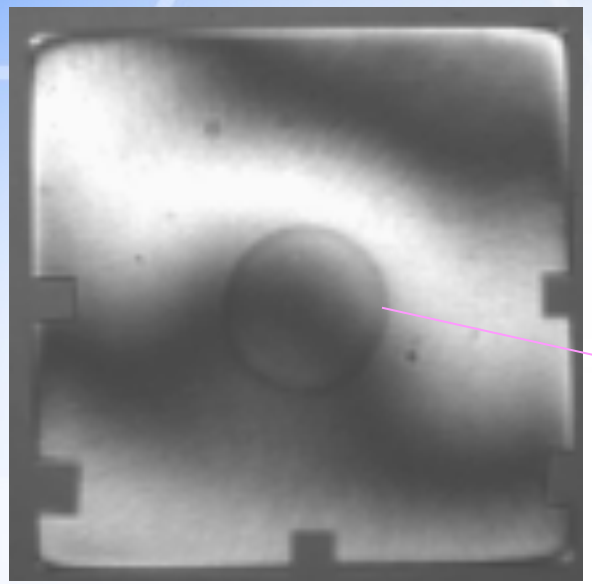


Vendor's model

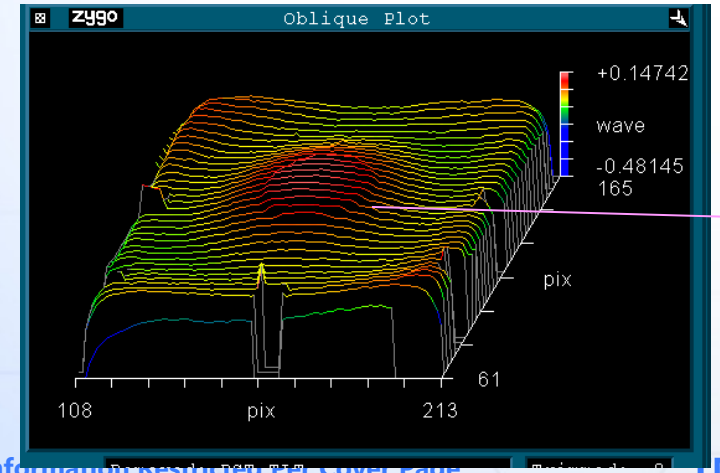
- The phase and R profile shifts along the wavelength if the coating thickness changes.

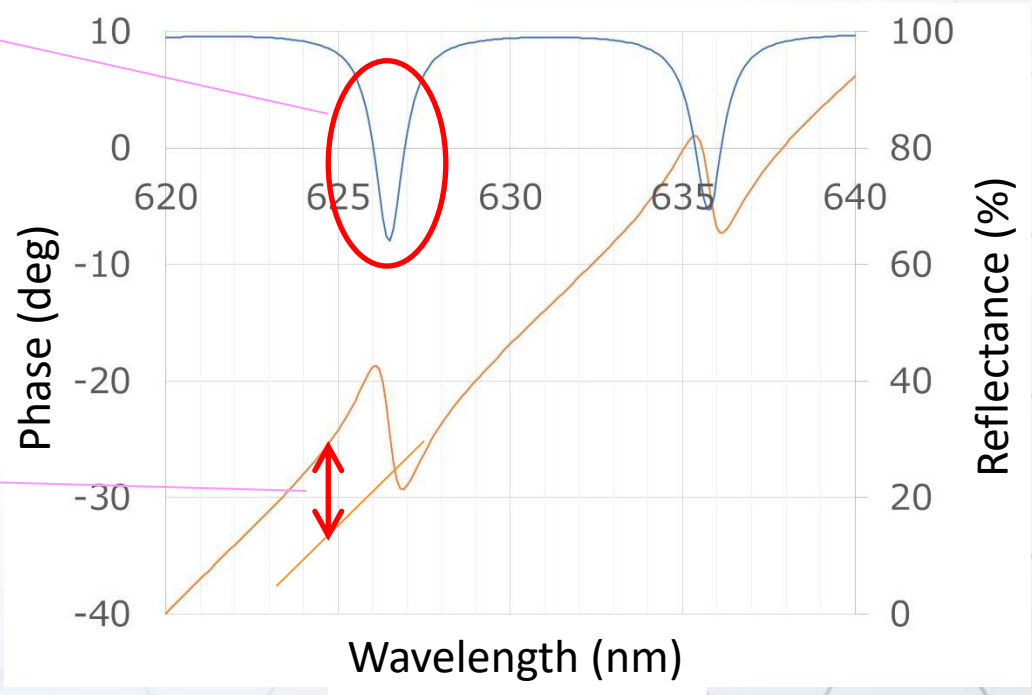


Vendor's model



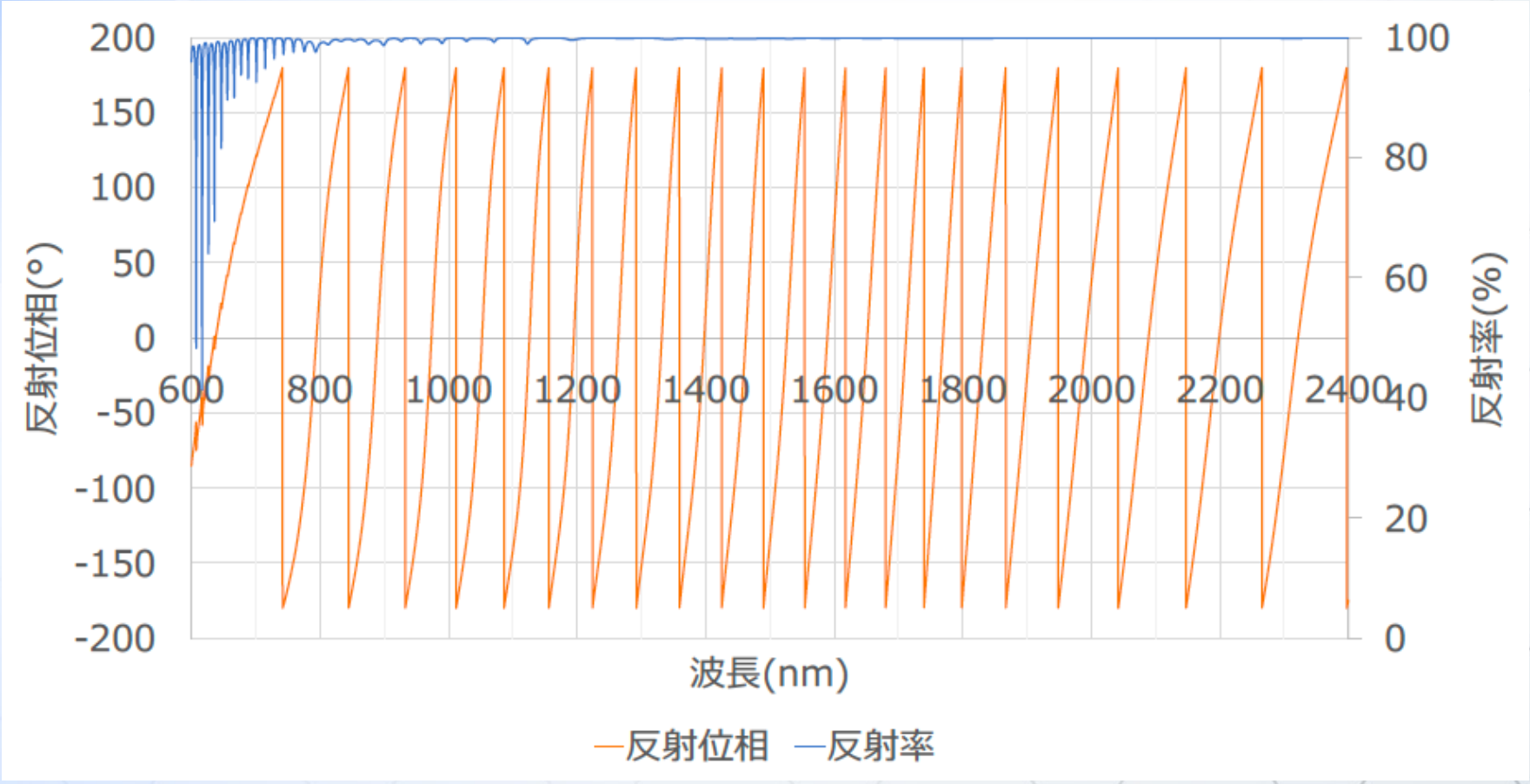
- We have some other measurements to support the model.





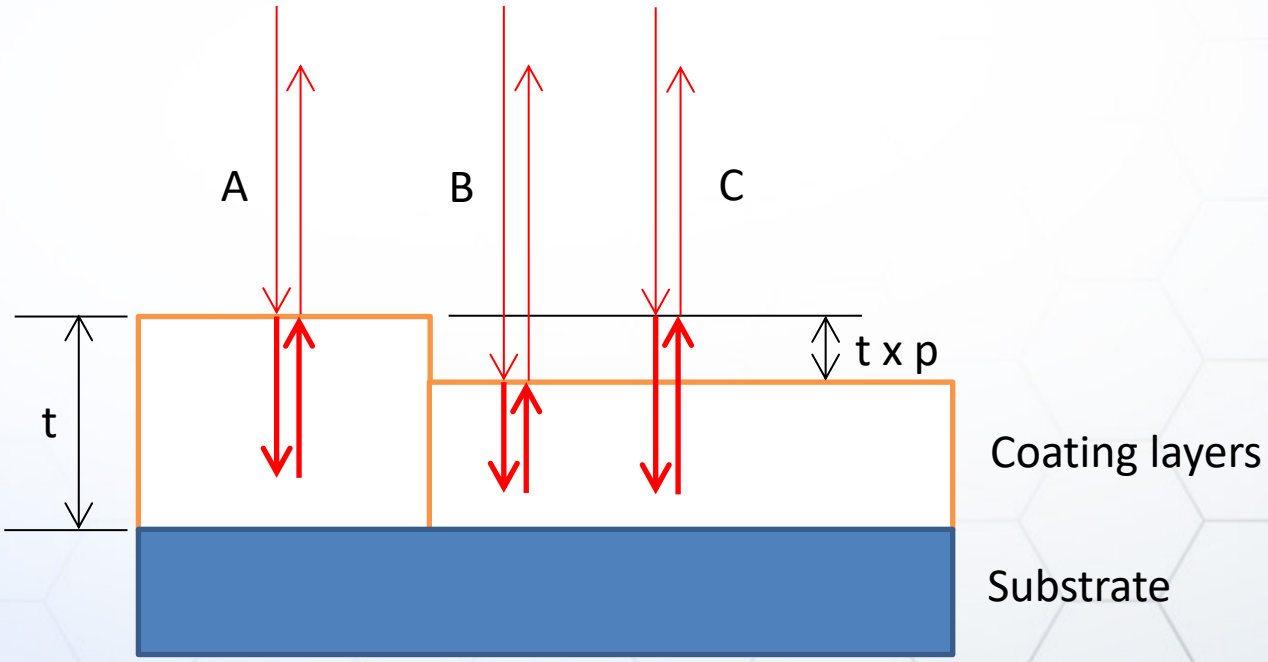
Vendor's model

- The phase changes a lot along the wavelength



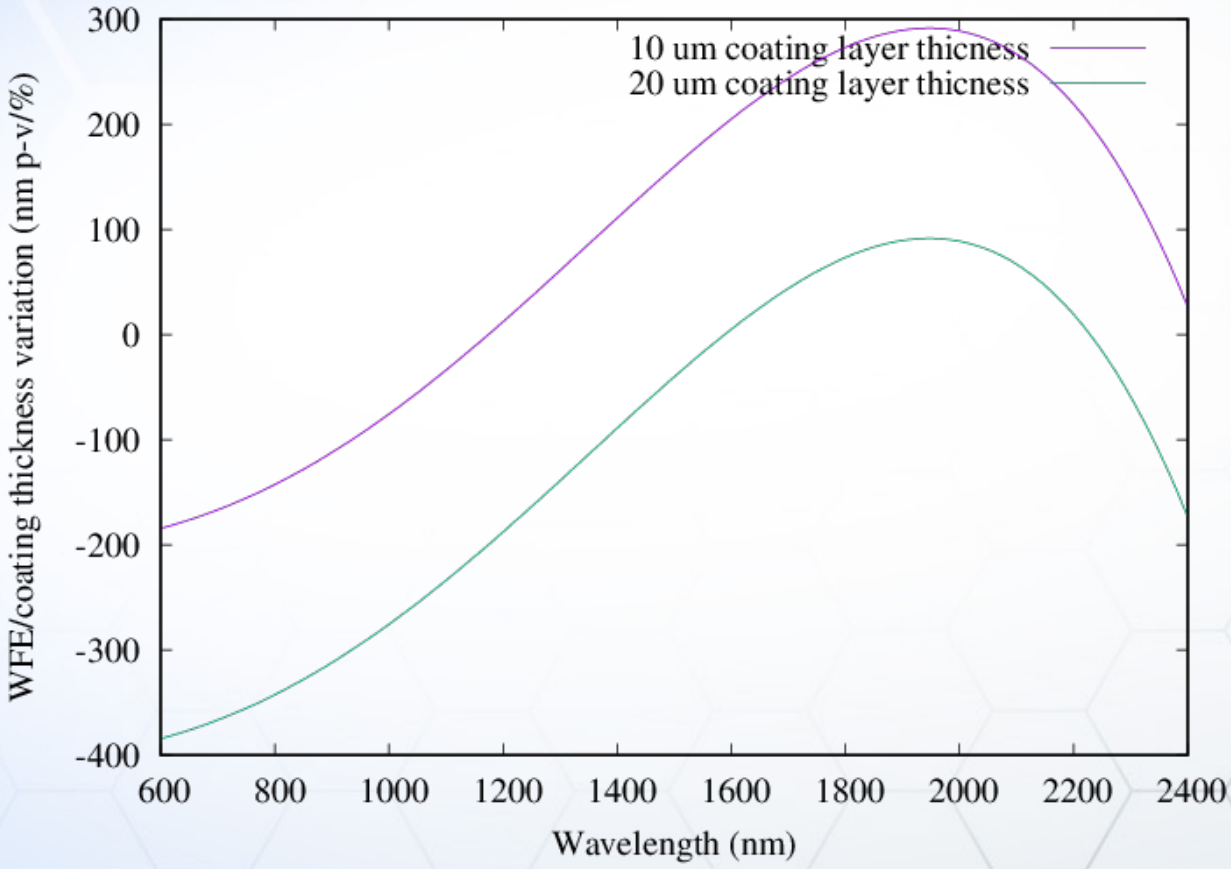
Calculation (WFE/non-uniformity)

- I calculated an optical path difference between A and C for different non-uniformity % (p).



Results for MLD coatings (WFE/non-uniformity)

- 1% coating non-uniformity results in 400 nm p-v WFE which is of course intolerable, c.f. 5 – 10 nm p-v WFE per surface



Discussions

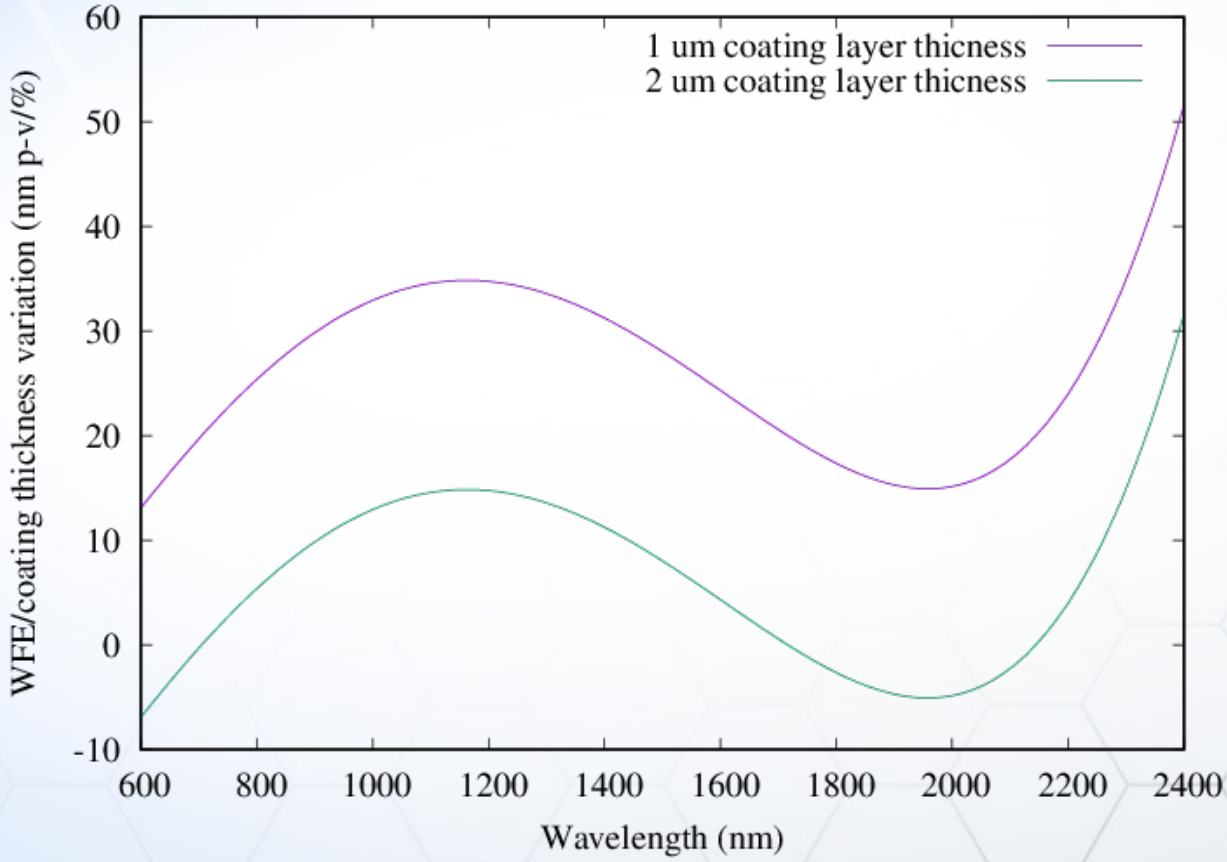
- The vendor expects 2% non-uniformity for the prototyped mirror substrate.
- The phase shift due to the coating thickness non-uniformity may be compensated by DMs if it has a low order pattern (up to 2^{nd} order).
  - But the non-uniformity pattern depends on multiple parameters like geometry of the coating gun and the substrate, substrate size and shape, and rotary motion of the substrate.

Discussions

- We may be able to measure the non-uniformity pattern by measuring the reflectance pattern. (Venancio 2016. See later in the slides)
  - The coating vendor said that it is impractical to achieve uniformity at 0.01 % level.
  - Since a single layer of SiO2 is known to be ~0.2 nm compared to ~170 nm which is λ/4 thickness, non-uniformity at best is ~0.1%.

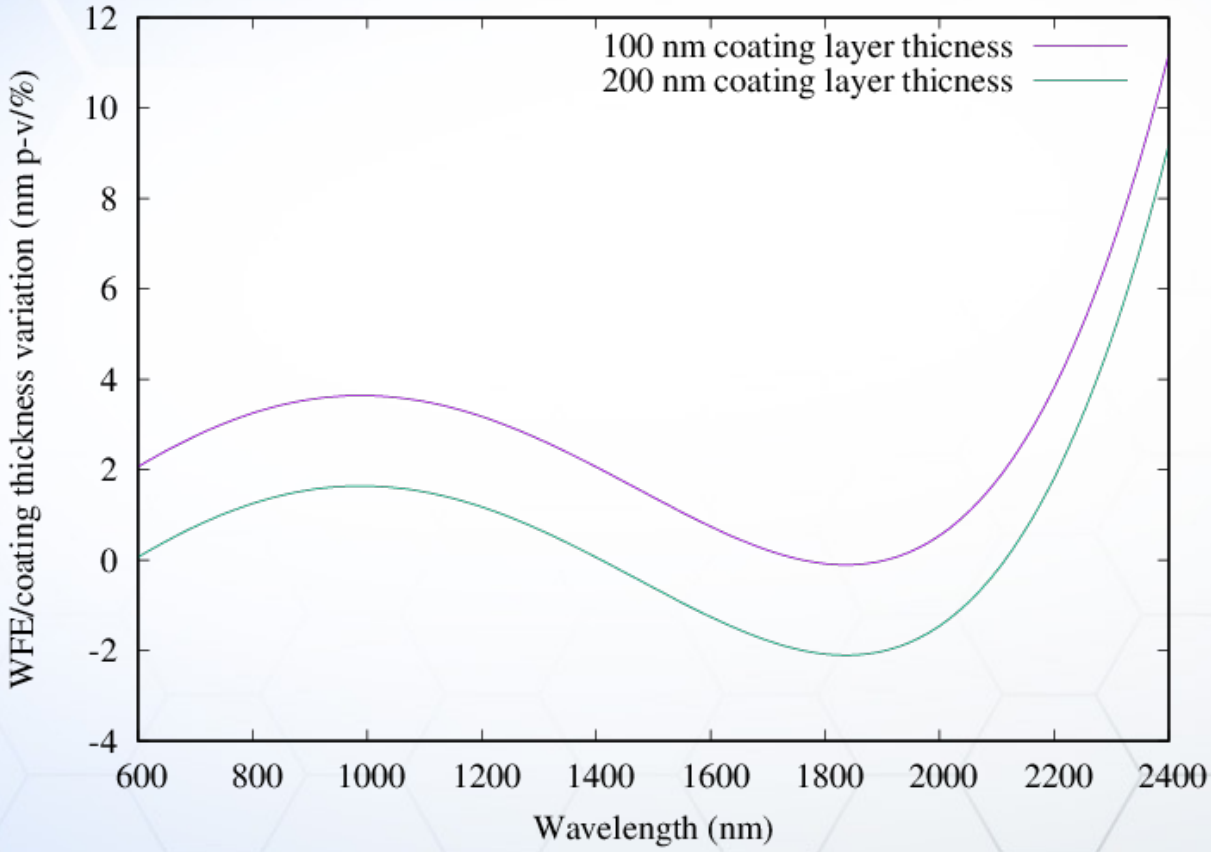
Results for eAg coatings (WFE/non-uniformity)

- Enhanced silver (eAg) coatings have some MLD coatings over a silver layer. 1% non-uniformity results in 35 nm p-v WFE.



Results for pAg coatings (WFE/non-uniformity)

- Protected silver (pAg) coatings have a single SiO2 layer over a silver layer. 1% non-uniformity results in 11 nm p-v WFE.



PSS comparison

	誘電体多層膜	増反射膜＋銀	保護膜＋銀	AR coating on CaF2	単位
WFE	438.0	33.0	1.2	11.8	nm p-p
TPmax	1.000	0.996	0.989	0.998	%/100
TPmin	0.987	0.985	0.976	0.988	%/100
TPave	0.998	0.991	0.985	0.996	%/100
PSS (WFE)	0.546	0.997	1.000	1.000	
PSS (TP)	0.998	0.991	0.985	0.992	
PSS/element	0.545	0.987	0.985	0.991	

Summary

誘電体膜を使用する際は、
反射（透過）位相の計算を忘れずに。

Acknowledgments

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