2019 OIC Manufacturing Problem Contest

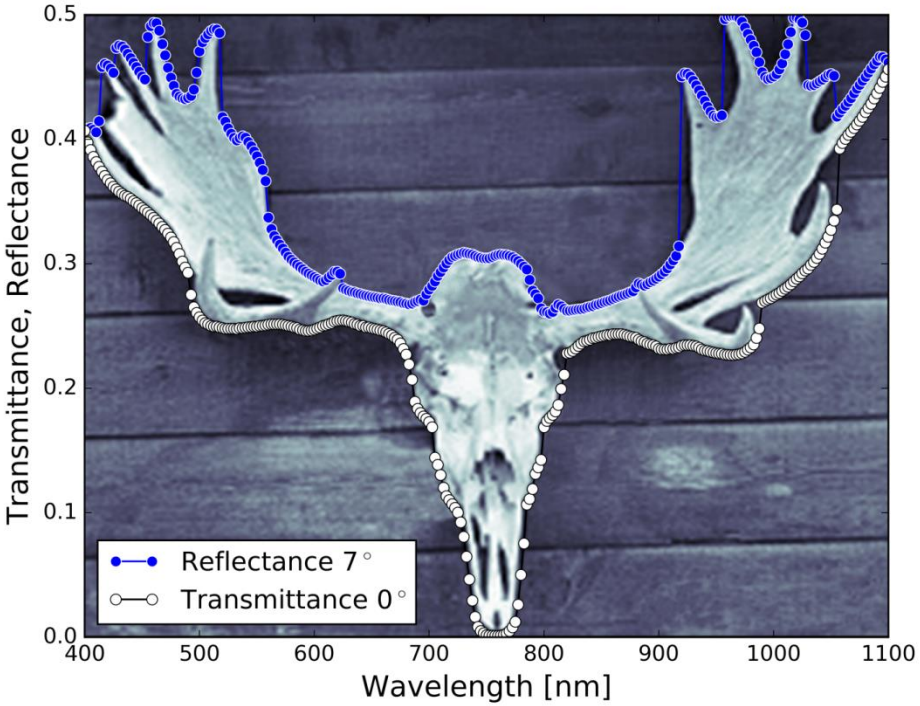
Daniel Poitras[1], Li Li[1]
Michael Jacobson[2], Catherine Cooksey[3]

[1] *National Research Council of Canada, Ottawa, Canada.*
[2] *Optical Data Associates, Tucson, USA.*
[3] *National Institute of Standards and Technology, Gaithersburg, USA.*

June 2019, Santa Ana Pueblo, New Mexico, USA

Past Contest Problems

1. **2001 – Bow Lake Problem – R,T targets, R+T=1, visible**
2. **2004 – Oblique AOI, visible**
3. **2007 – CIE, yellow-blue-clear, absorbing layer**
4. **2010 – T, Log-scale, vis**
5. **2013 – T, vis-NIR**
6. **2016 – Moose Skull Problem – R,T targets, R+T<1**



Optical Interference Coatings

2019 Problem

yucca [yuhk-*uh*]

noun

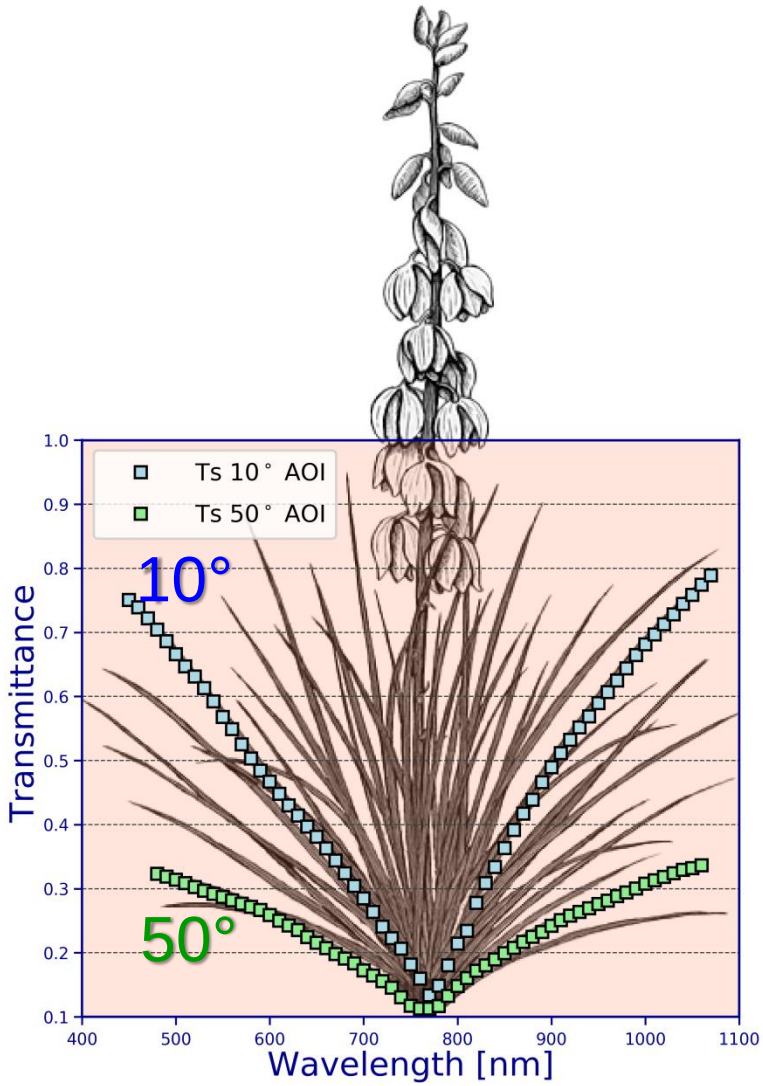
1 any plant belonging to the genus *Yucca*, of the agave family, native to the warmer regions of America, having pointed, usually rigid, sword-shaped leaves and clusters of white, waxy flowers: the state flower of New Mexico.

Dictionnary.com

- **2019**

  "Yucca" Problem

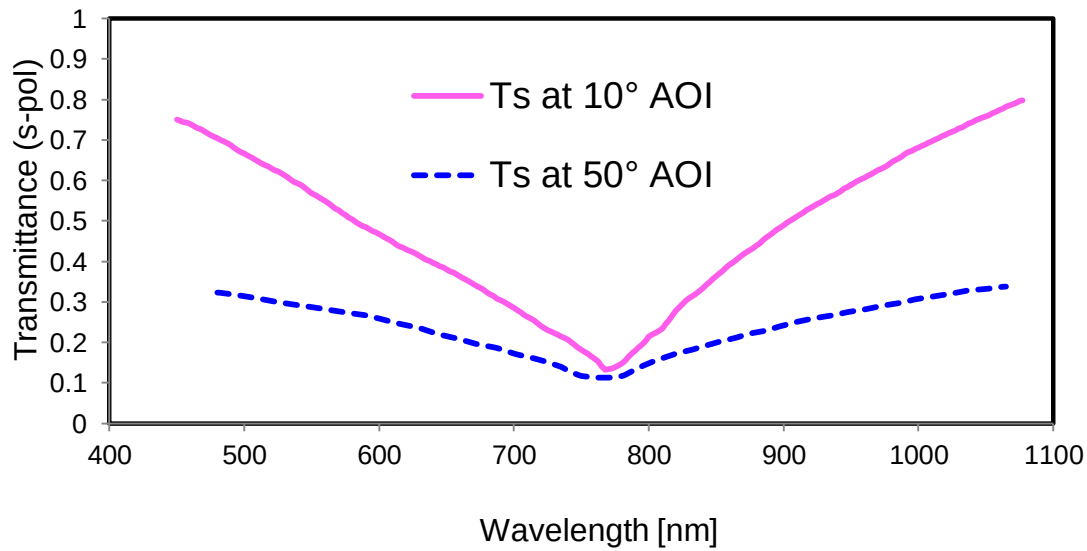
- **Wavelength range: 400–1100nm**
- **Transmittance spectra**
- **Angles of incidence: 10°, 50°**
- **Polarization: S**
- **Substrate: BK7, 1-mm thick, 2" ϕ (*Edmund Optics*)**
- **Any design**
- **Any fabrication method**
- **No hazardous materials**



- **Evaluation Team**

Measurements done at 2 independent evaluation labs:

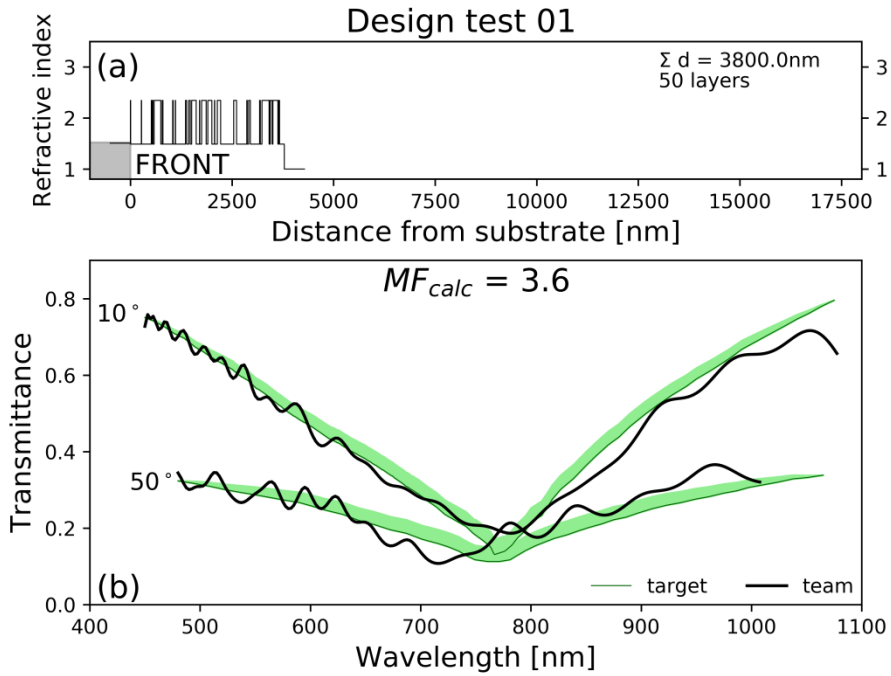
- ODA (Mike Jacobson)
- NIST (Catherine Cooksey)



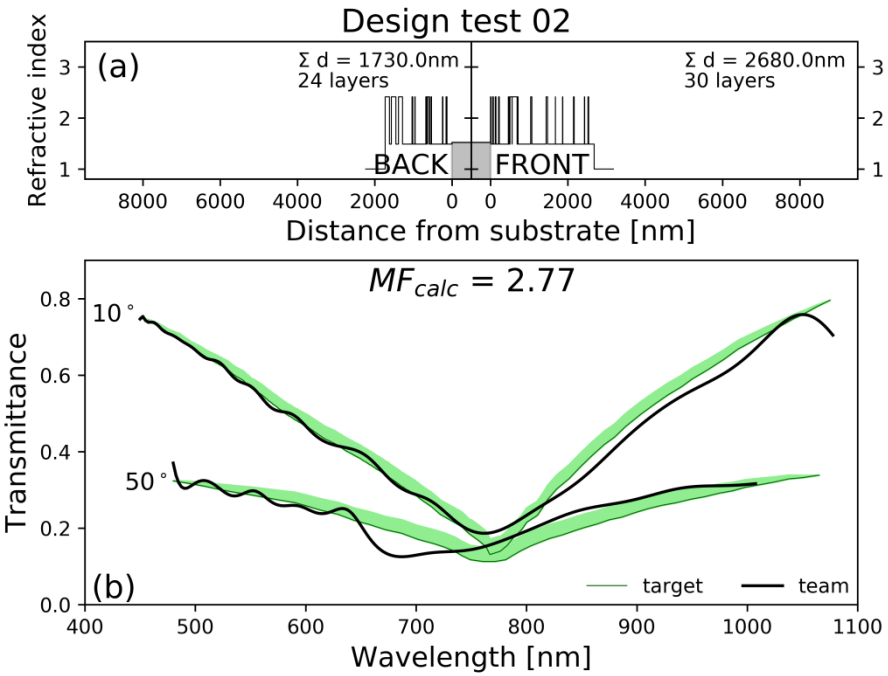
$$MF = \left\{ \frac{1}{(N_{10} + N_{50})} \left[\sum_{i=1}^{N_{10}} \left(\frac{T_{s10,i} - T_{s10,i}^{D}}{\Delta T_{s10,i}} \right)^2 + \sum_{i=1}^{N_{50}} \left(\frac{T_{s50,i} - T_{s50,i}^{D}}{\Delta T_{s50,i}} \right)^2 \right] \right\}^{1/2}$$

- **2019 Problem Analysis**
  - Design

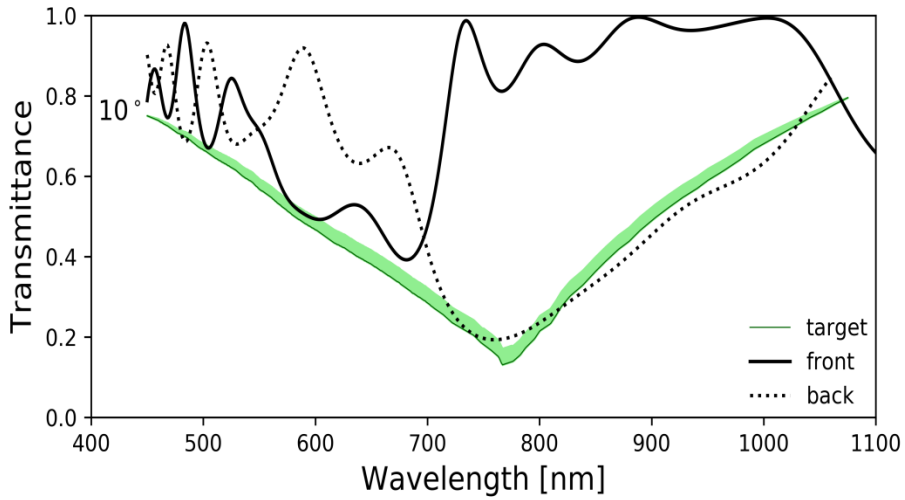
1-side design, MF = 3.60
3.8um, 50 layers

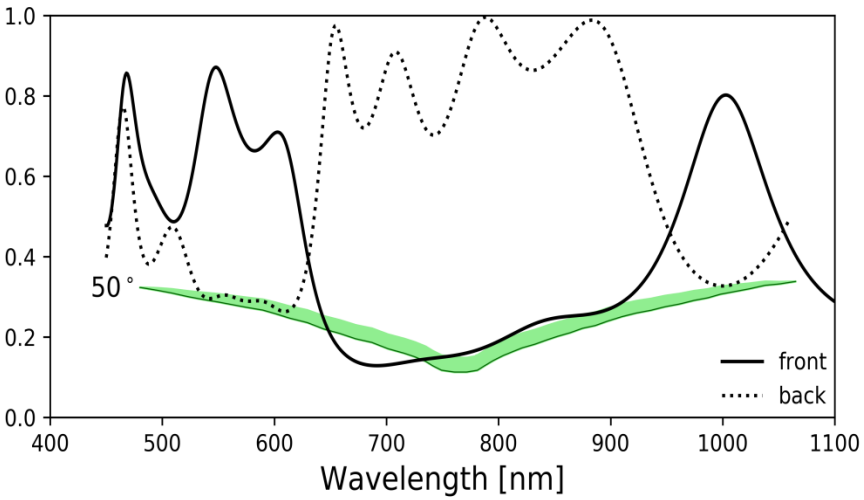


2-side design, MF = 2.77
2.68 + 1.73um, 30 + 24 layers



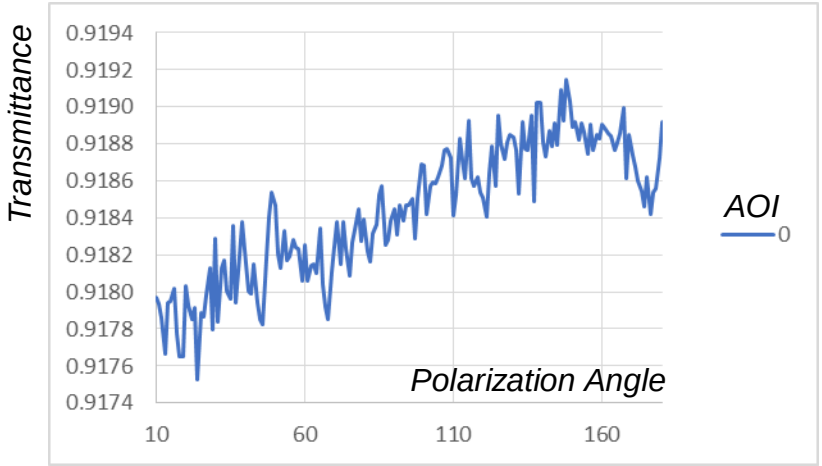
- **2019 Problem Analysis**
  - Design: Matching Peaks and Valleys in 2-side Coatings

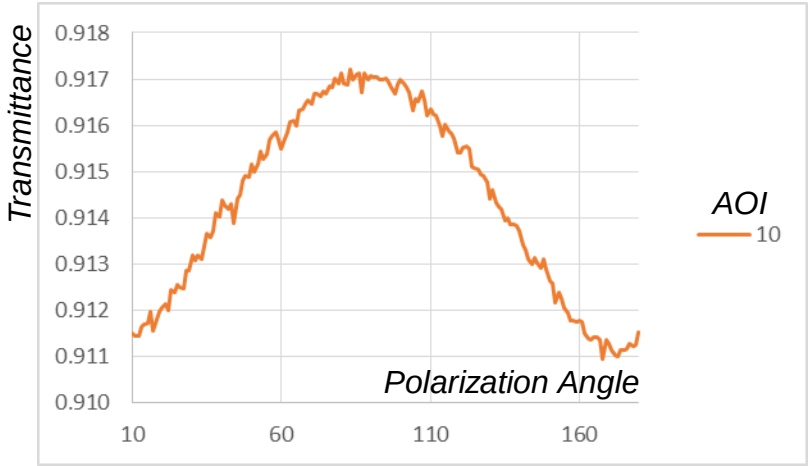


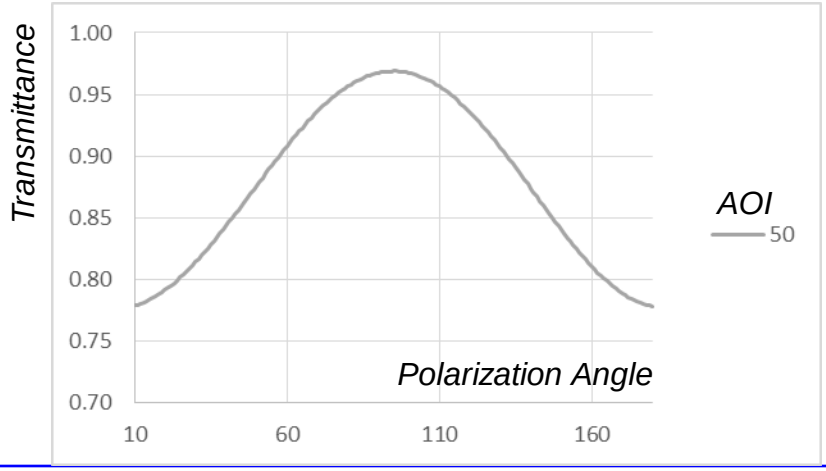


- **2019 Problem Analysis**
  - Measurement
    - ***Sensitivity to polarization variation***
    - ***Beam deviation***
    - ***High angle of incidence***
    - ***Sensitivity to angle variation***

- ***Controlling the Polarization: Example with BK7 (at 800 nm)***

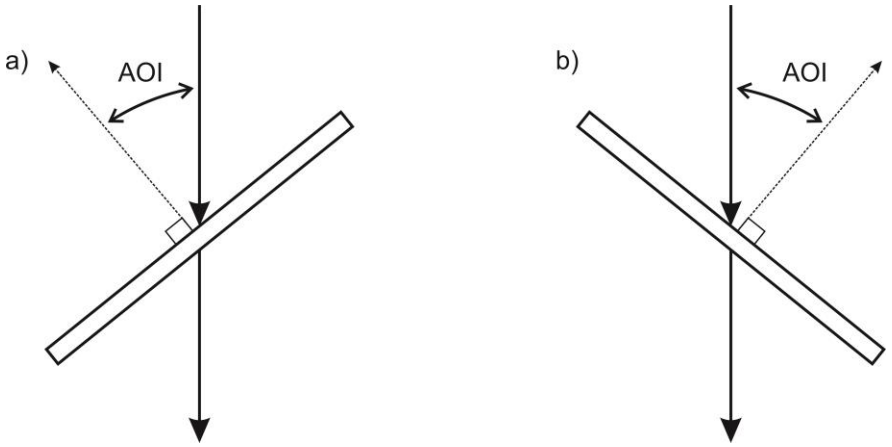




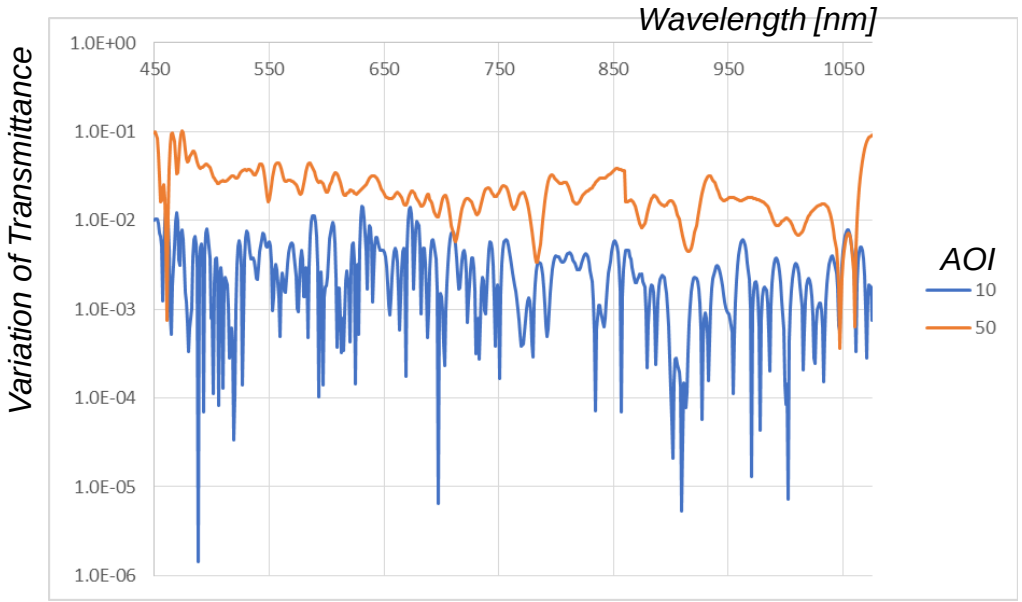


2019 OIC Manufacturing Problem Contest

- ***Measurements at Large Oblique Angles***

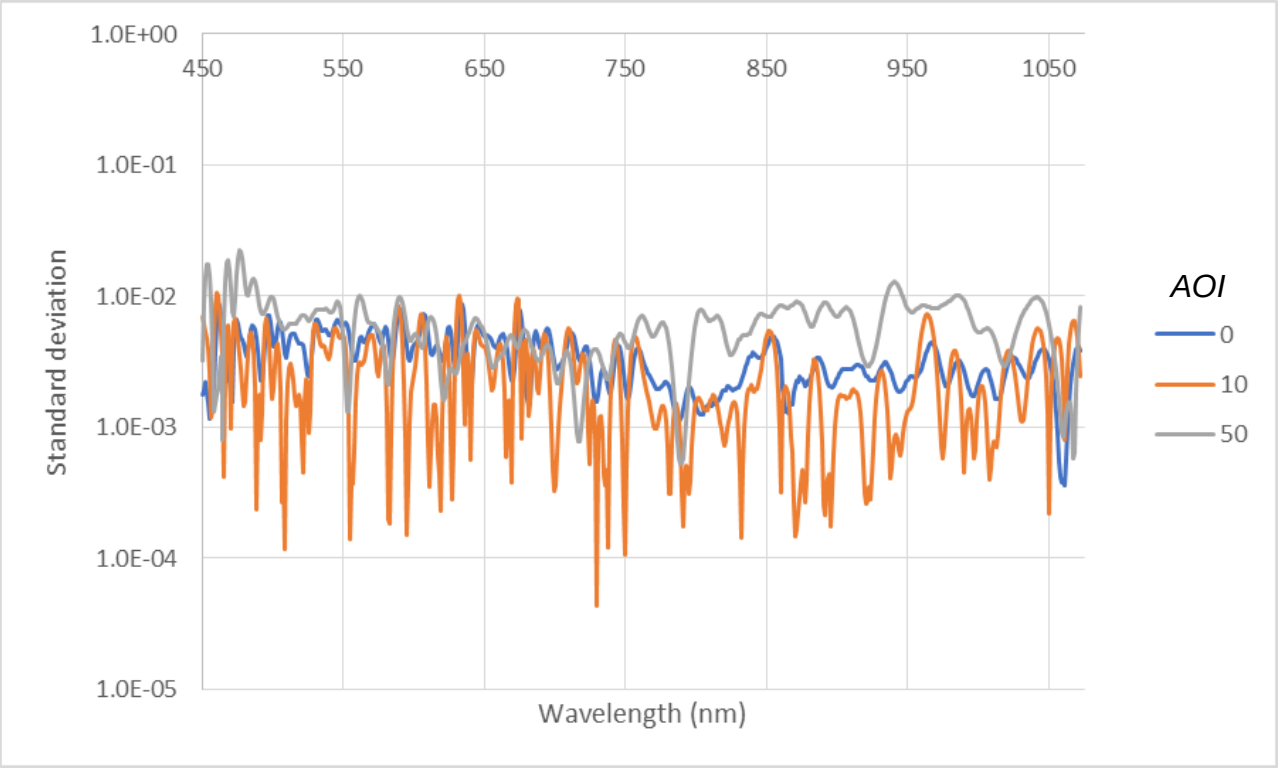


Surface uniformity, beam deviation (alignment, stress)



- ***Controlling the Angle of Incidence and Position:***

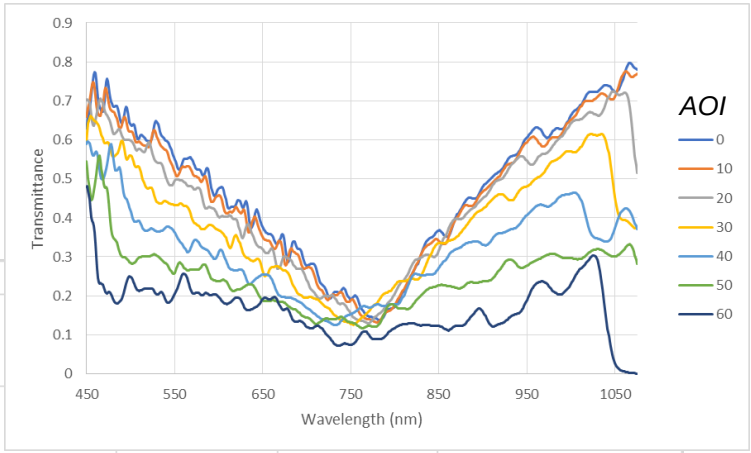
Example of deviation of 3 measurements done on 3 different days

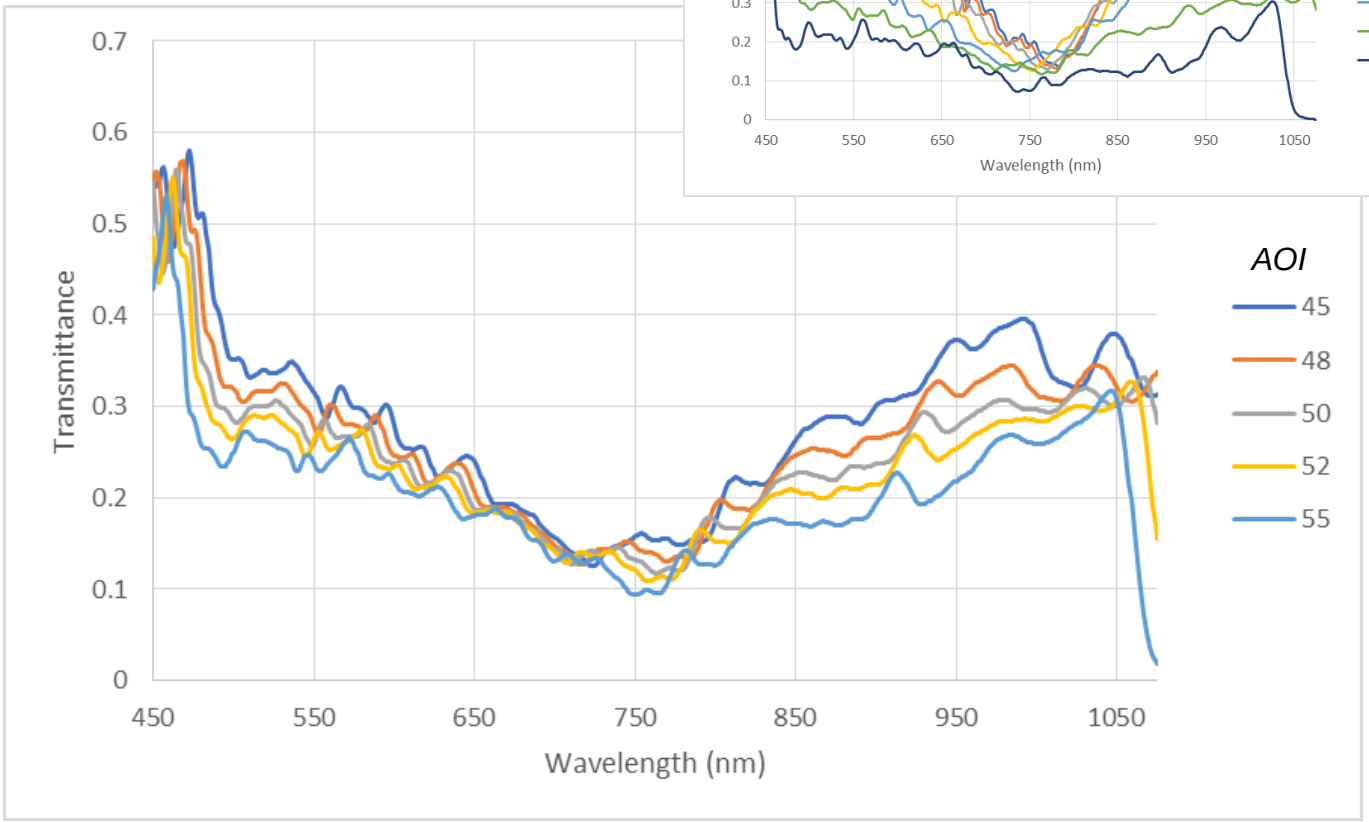


2019 OIC Manufacturing Problem Contest

Optical Interference Coatings

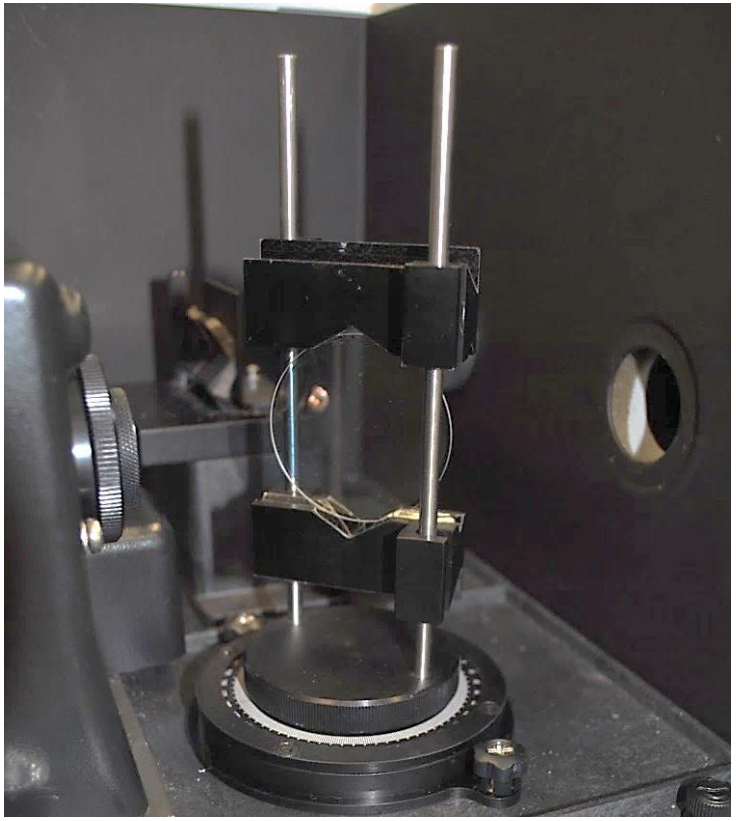
Example of AOI Sensitivity



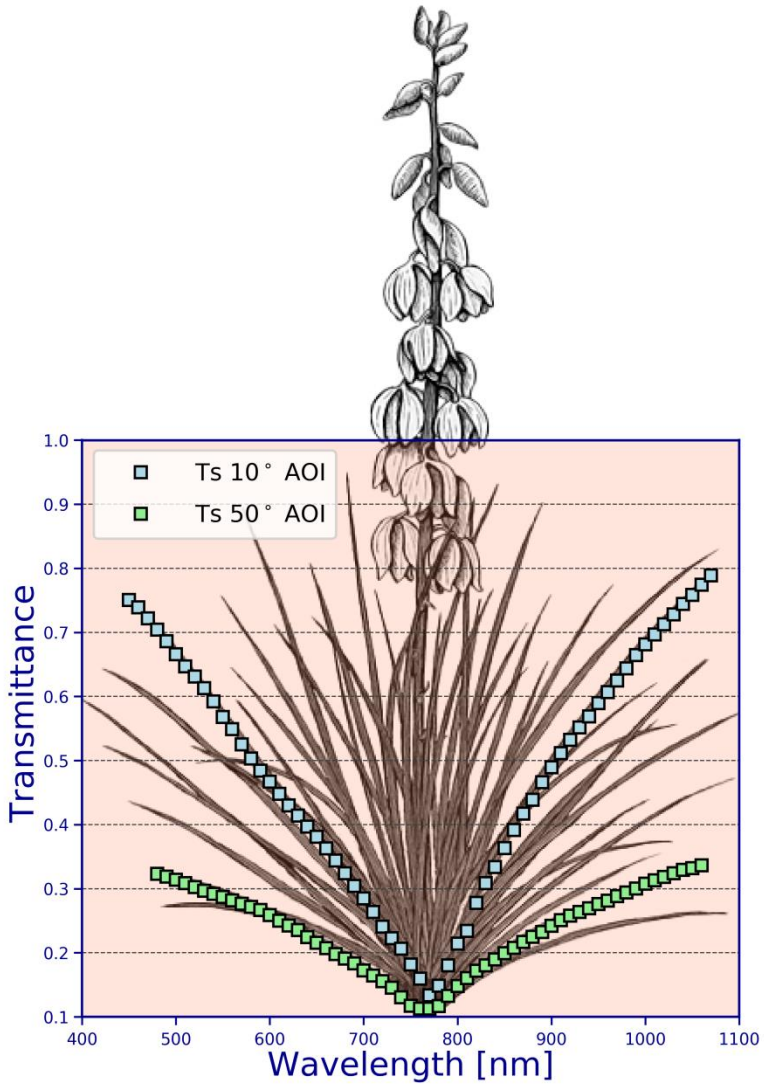


Optical Interference Coatings

Some Variable Angle Transmittance Sample Holders…

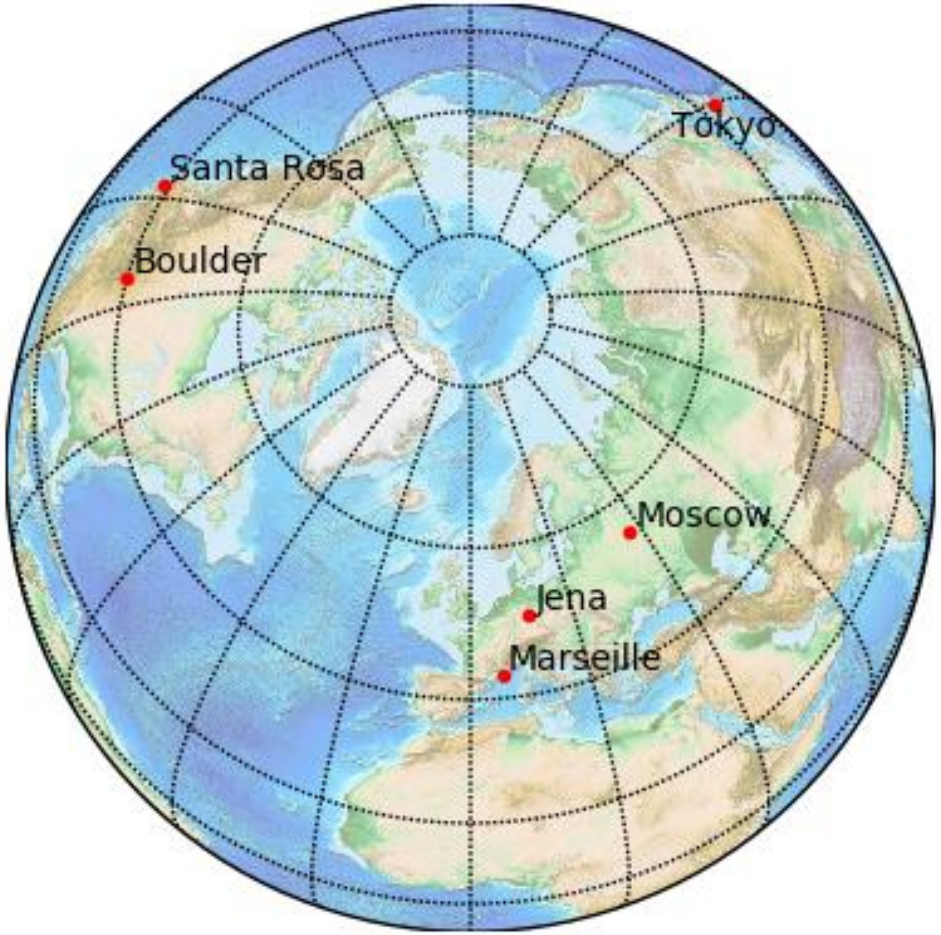


- **Expected Difficulties**
  - Design robustness
  - Measurements
  - Thickness control



- **Participants**

Team Leaders	Organizations
Zach Gerig	FiveNine Optics, Boulder CO , USA
Julien Lumeau	Institut Fresnel, Marseille, France
Vladimir Ponomarev	OptiSpark, LLC Moscow,, Russian Federation
Marc Lappschies	Optics Balzers, Jena, Germany
Masahiro Akiba	TOPCON Corporation, Tokyo, Japan
Lucas Alves	Viavi Solutions, Santa Rosa CA, USA
Karen Hendrix	Viavi Solutions, Santa Rosa CA, USA
Andrew Hulse	Viavi Solutions, Santa Rosa CA, USA



- **Samples and Info Received from Participants**

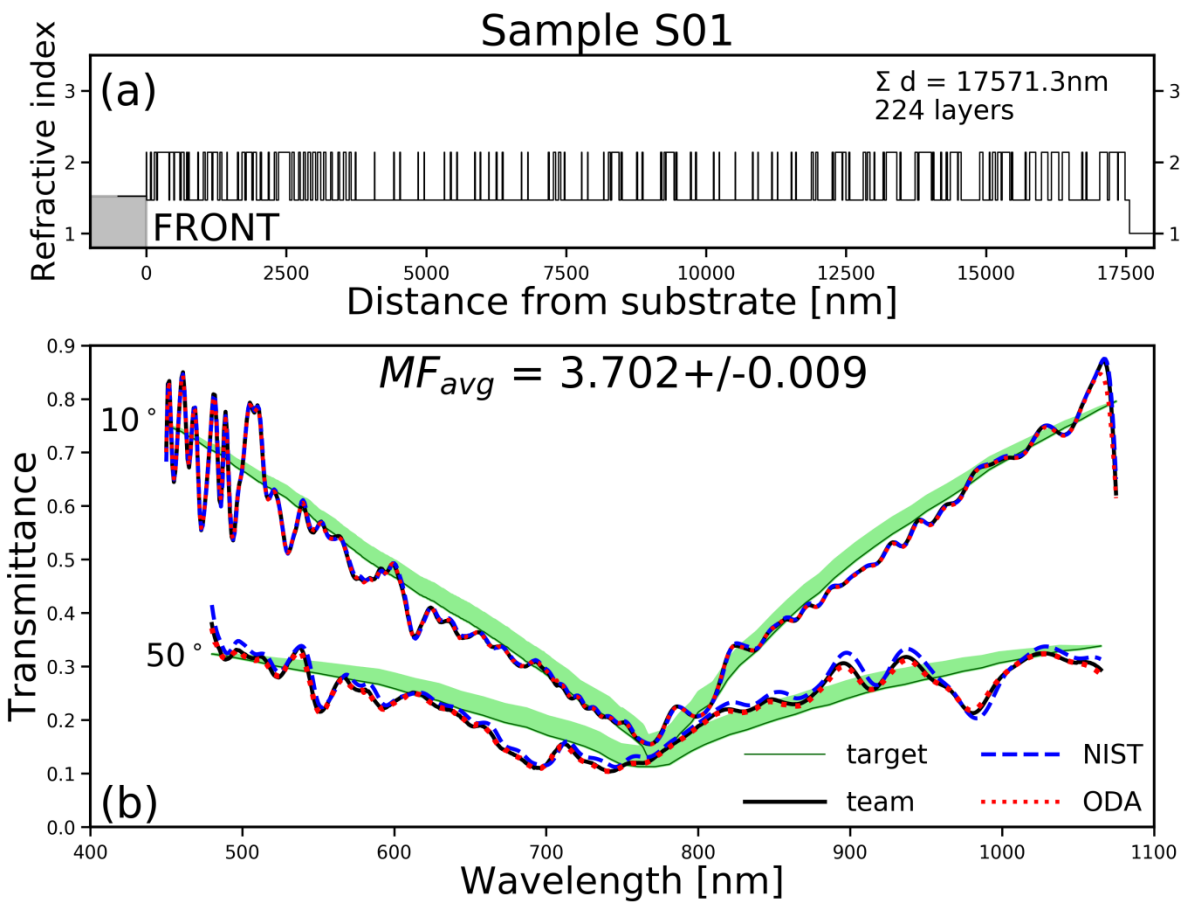
	#Layers (front+back coatings)	Total thickness (um)	MF Design	MF Meas	Additional information
S01	224	17.6	2.030	3.671	Magnetron sputtering
S02	68+57	6.5+5.3	0.59	0.88	Ion-beam sputtering
S03	178	12.9	2.14	2.53	Magnetron sputtering
S04	255	16.1	1.106	2.411	Magnetron sputtering
S05	86+78	6.57+6.40	0.445	1.608	PARMS-Helios800, optical broadband monitoring
S06	64+62	7.32+6.60	0.740	7.130	PIAD (Bühler SYRUSpro); monitoring Buhler OMS5000
S07	70+68	6.06+6.47	0.439	2.353	
S08	32+42	3.73+4.51	0.46	2.646	SURUSpro 710; monitoring OMS 5000
S09	74+64	7.36+6.67	0.46	2.61	PARMS (Bühler HELIOS); monitoring Buhler OMS5100

- **Independent Evaluation of Samples**

	ODA	NIST
Instrument	Cary 5000	Perkin Elmer Lambda 1050
Beams	Double-grating and double-beam	Double-beam
Wavelength range	400 – 1100 nm, 1.0 nm step	400 – 1100 nm, 1.0 nm step
Light-source	Tungsten-halogen / deuterium	Tungsten-halogen / deuterium
Detectors	Photomultiplier / PbS	Photomultiplier / InGaAs
Transmittance accuracy	±0.2% in visible, ±0.2% in NIR	±0.6% in visible, ±0.6% in NIR

RESULTS

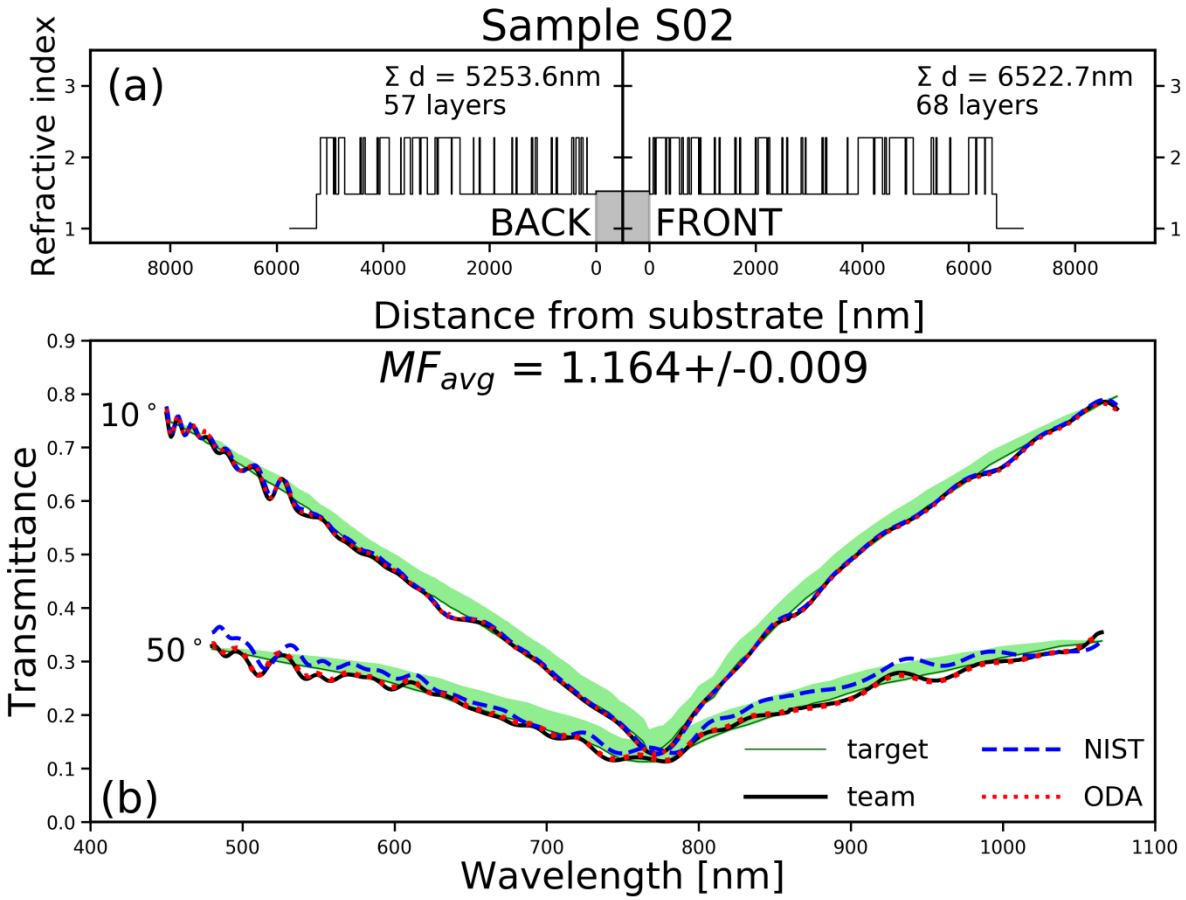
- **Sample S01**



2019 OIC Manufacturing Problem Contest

RESULTS

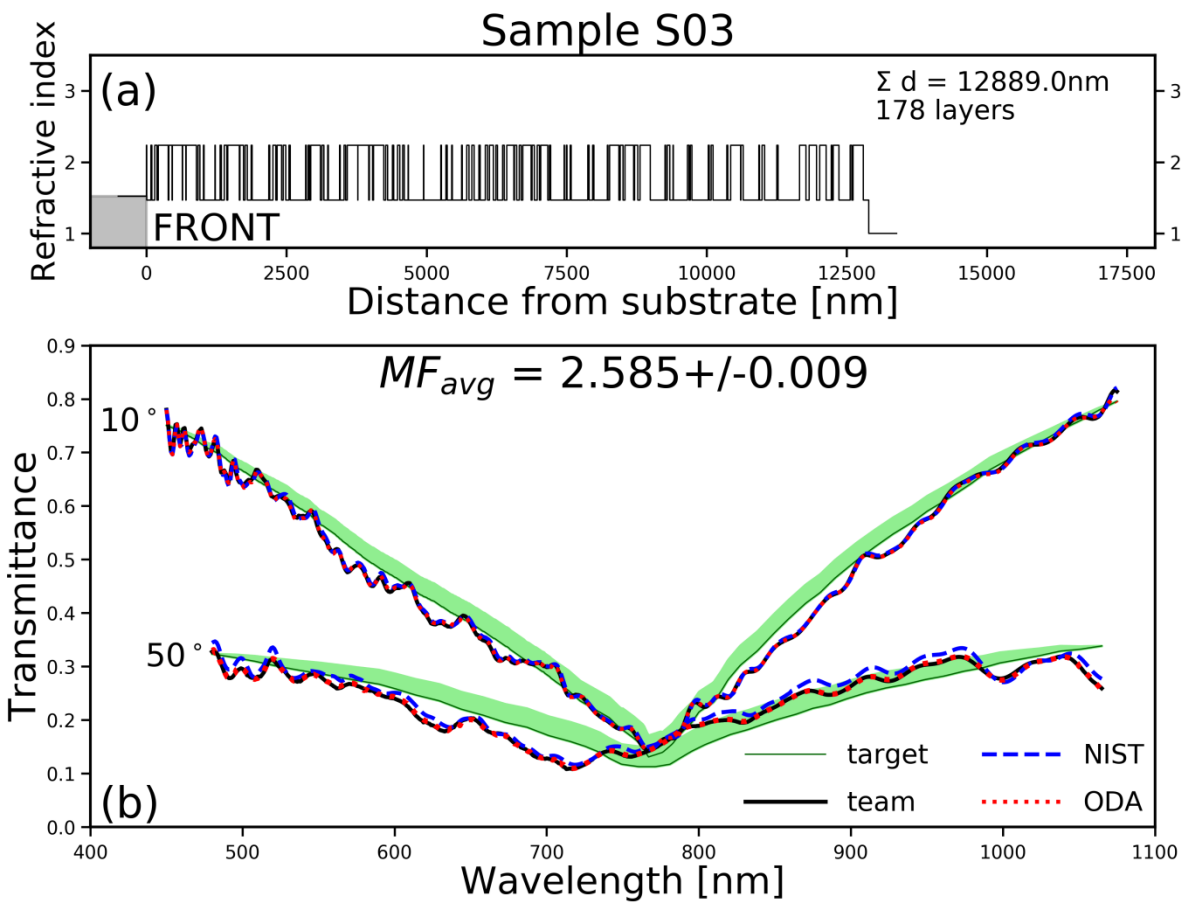
- **Sample S02**



2019 OIC Manufacturing Problem Contest

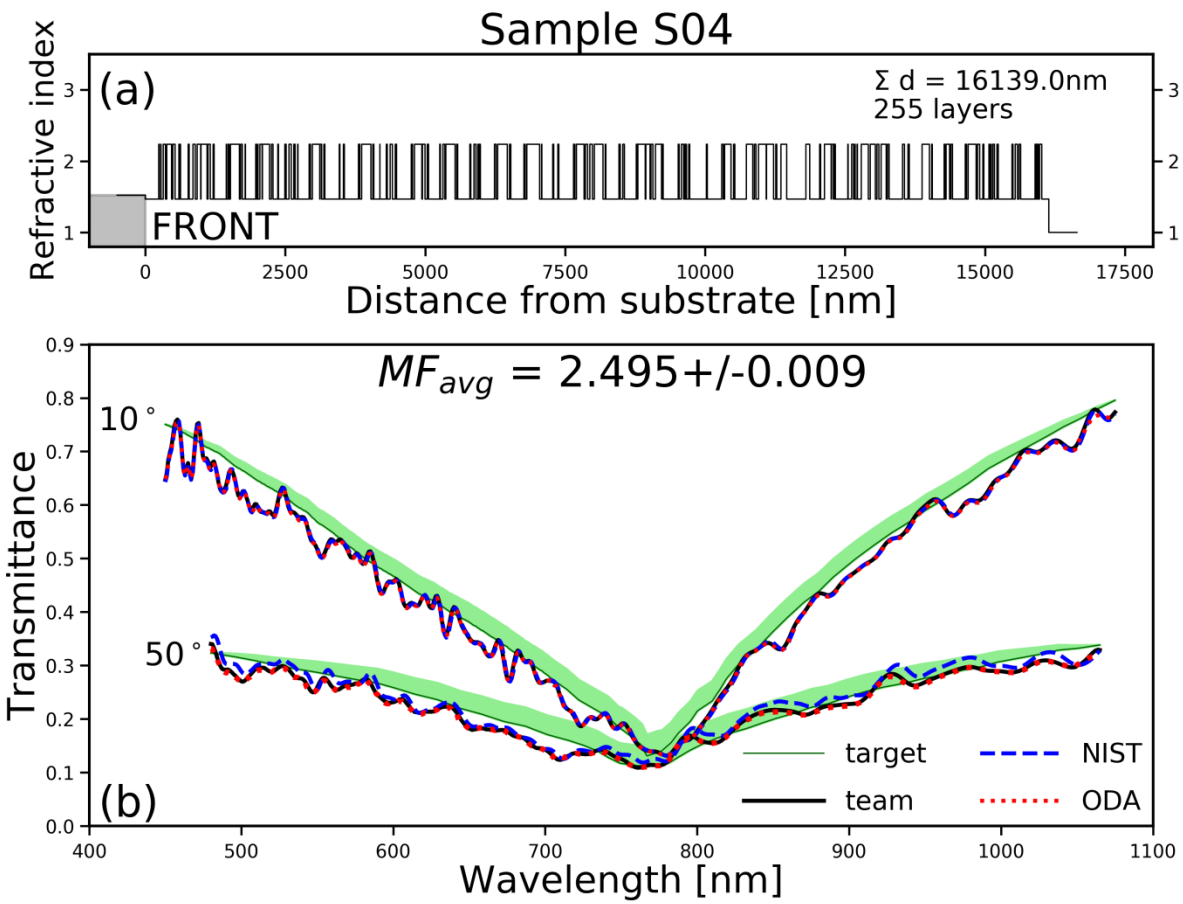
RESULTS

- **Sample S03**



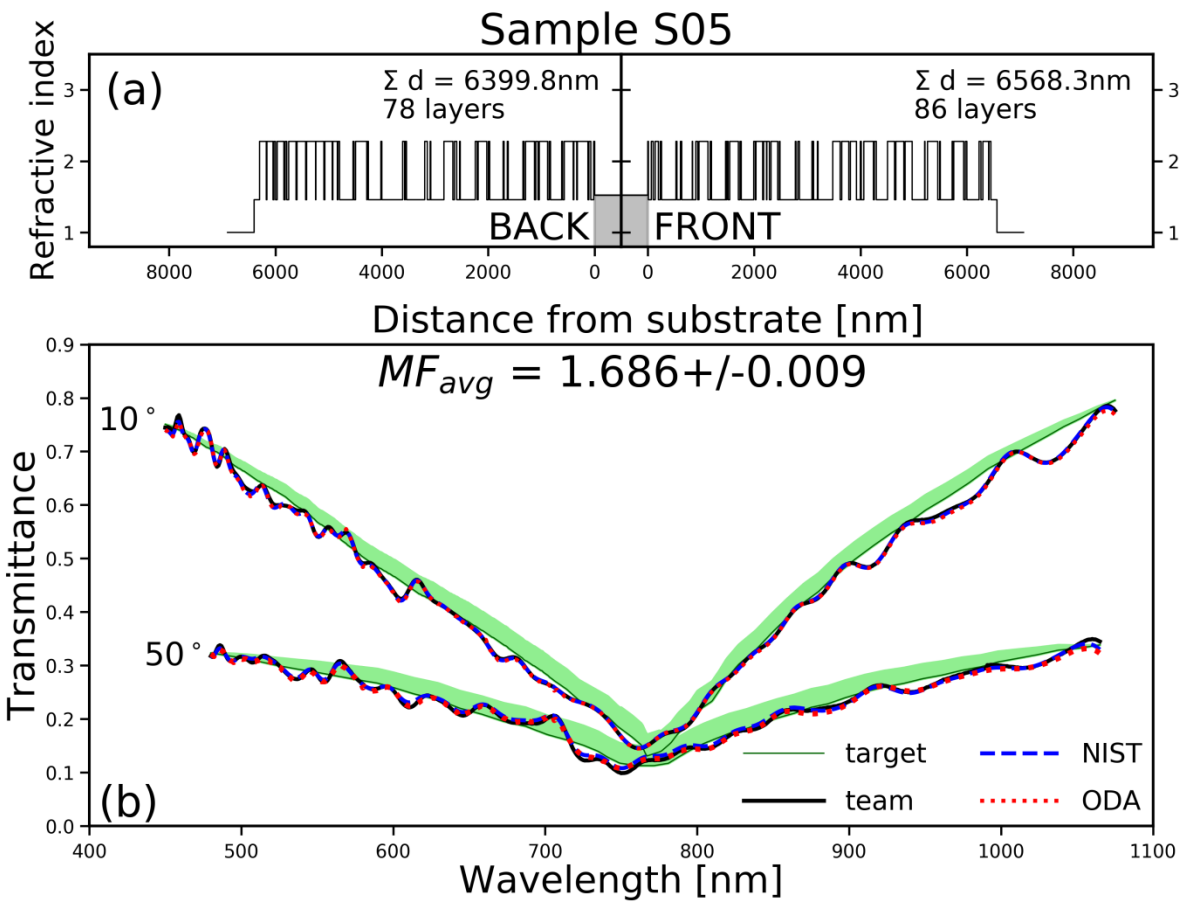
RESULTS

- **Sample S04**



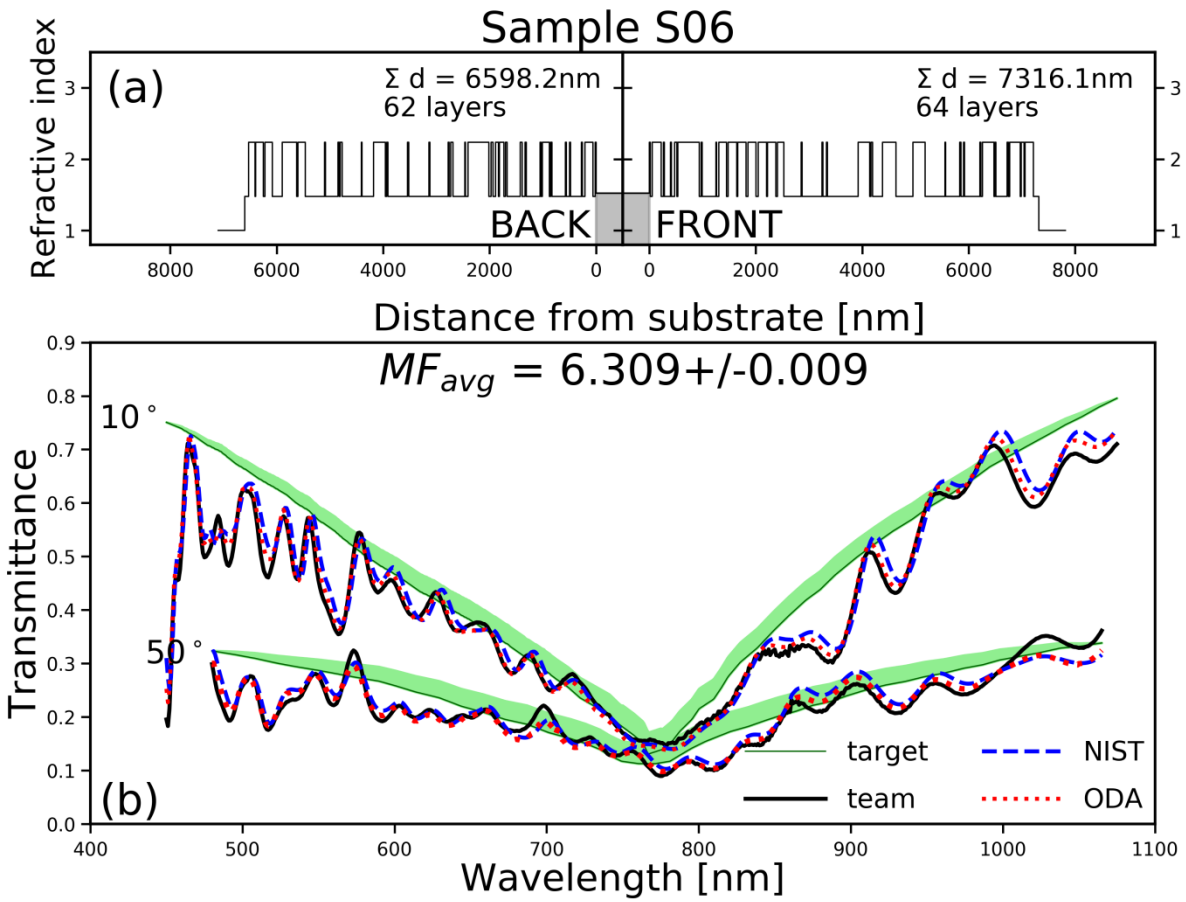
RESULTS

- **Sample S05**



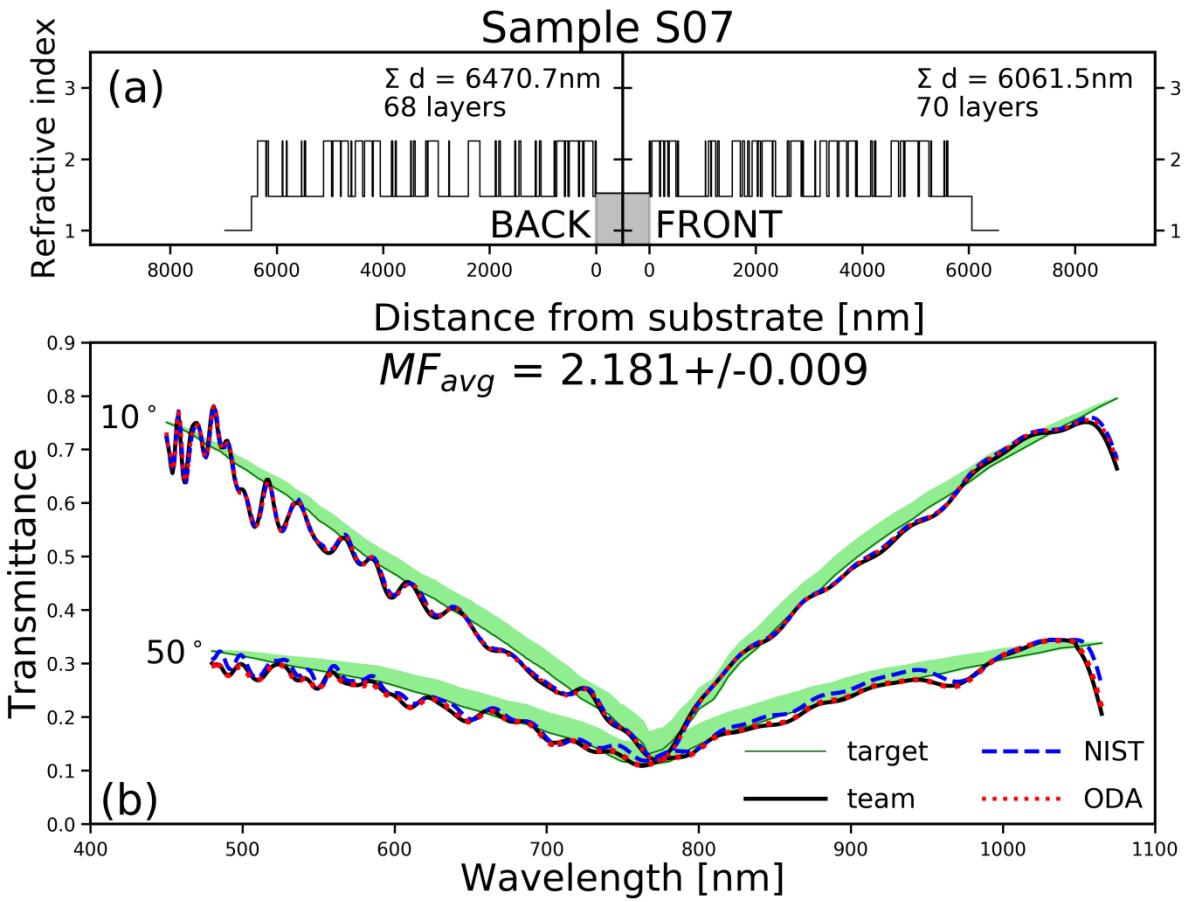
RESULTS

- Sample S06



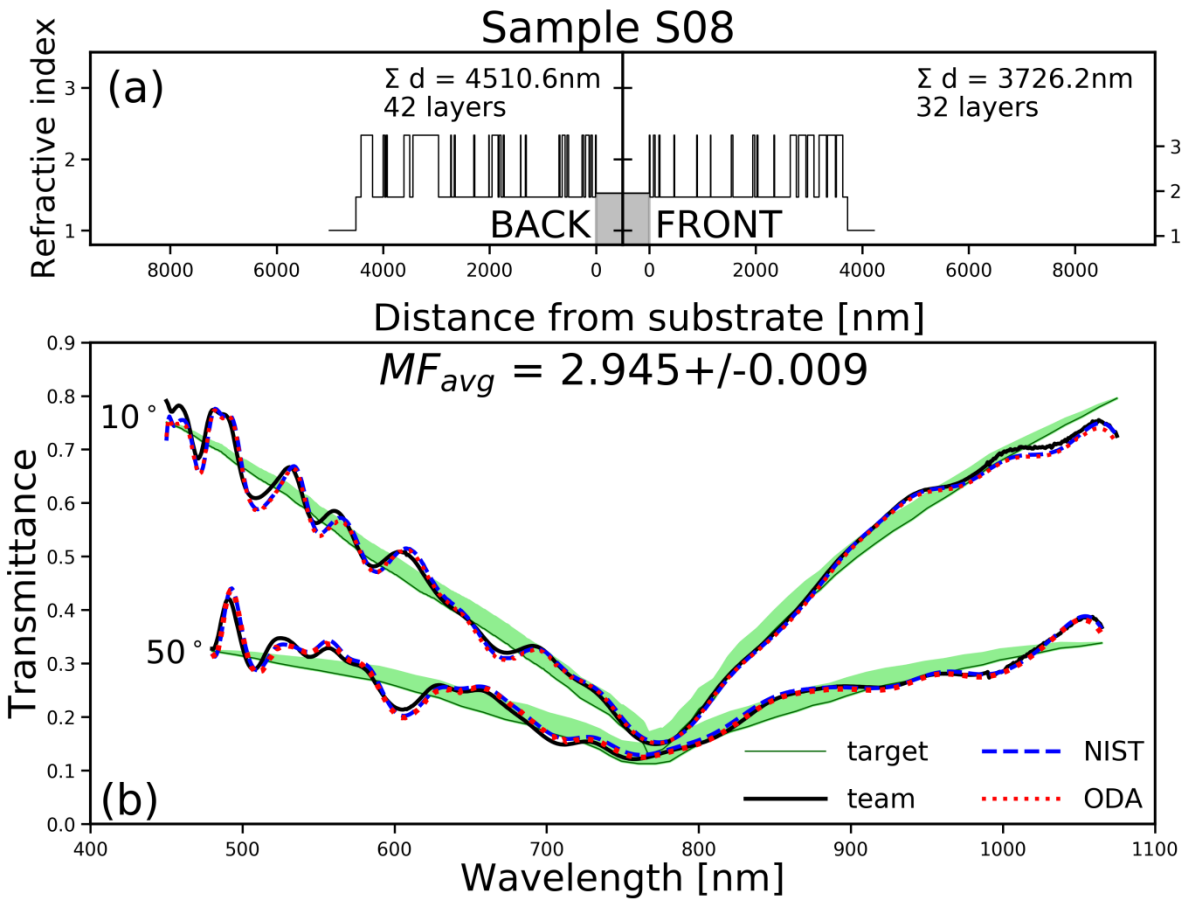
RESULTS

- Sample S07



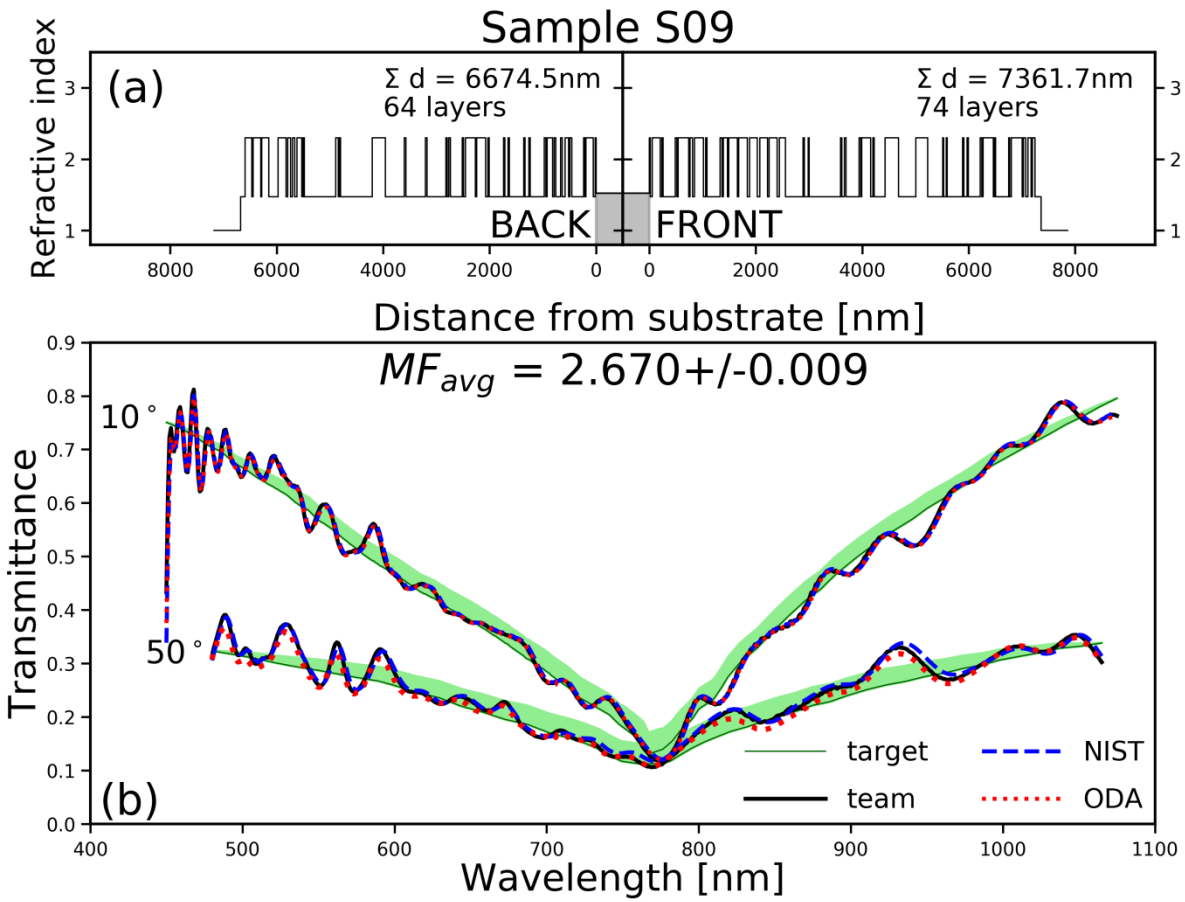
RESULTS

- **Sample S08**



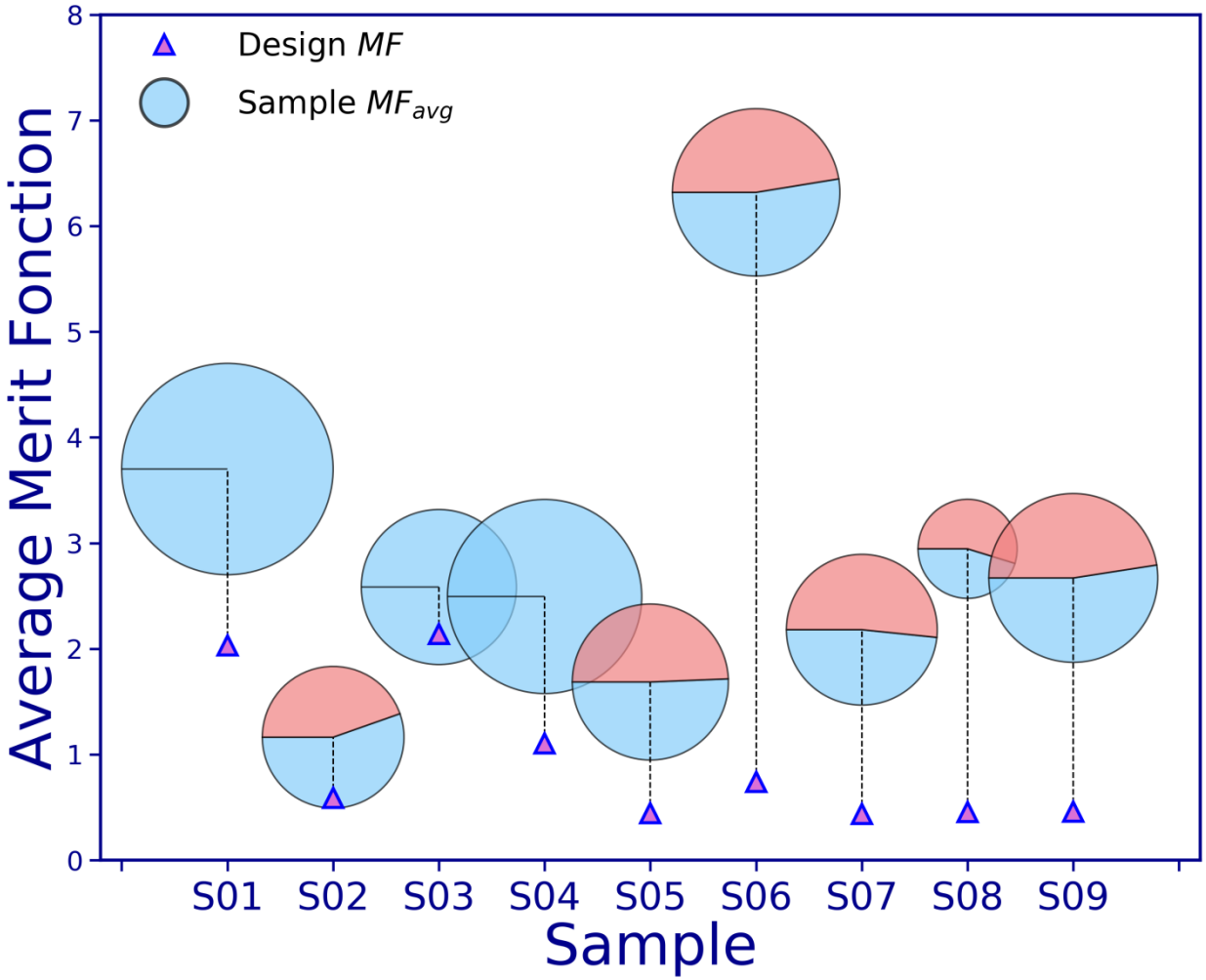
RESULTS

- **Sample S09**

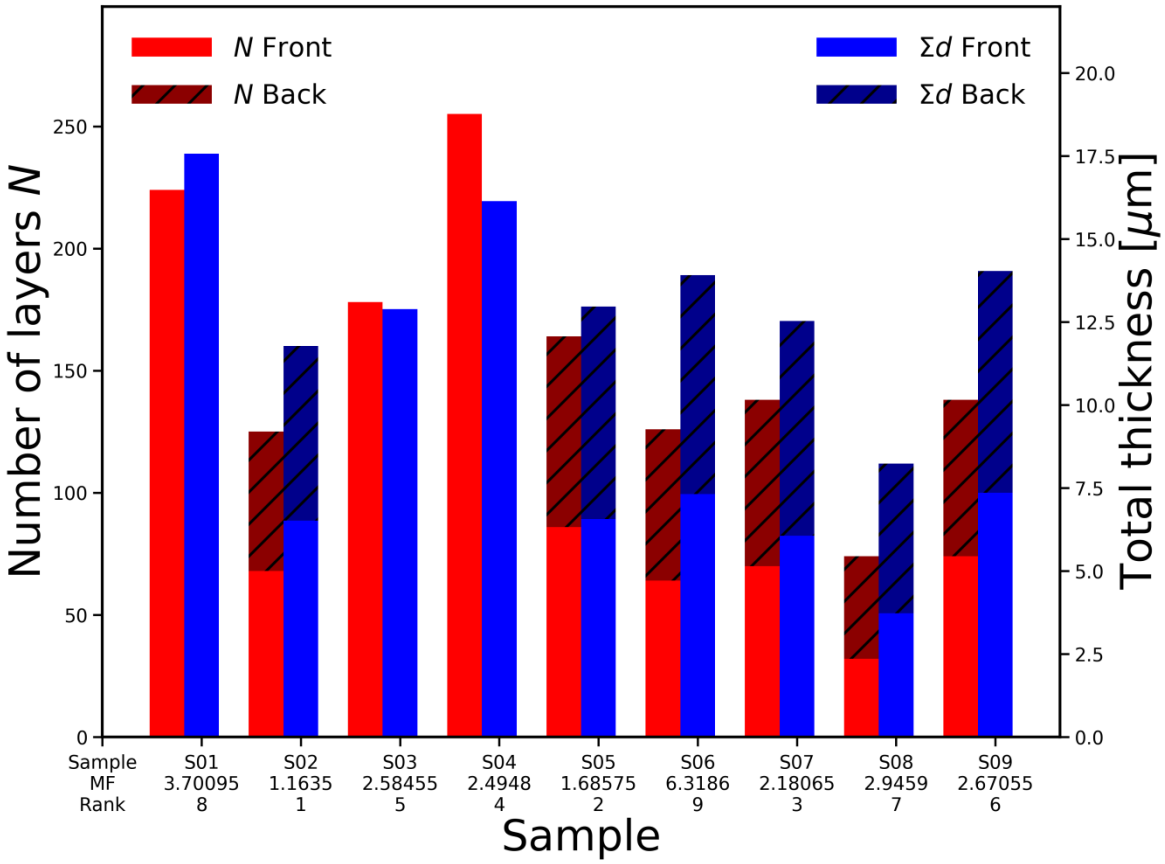


- **Results Analysis**

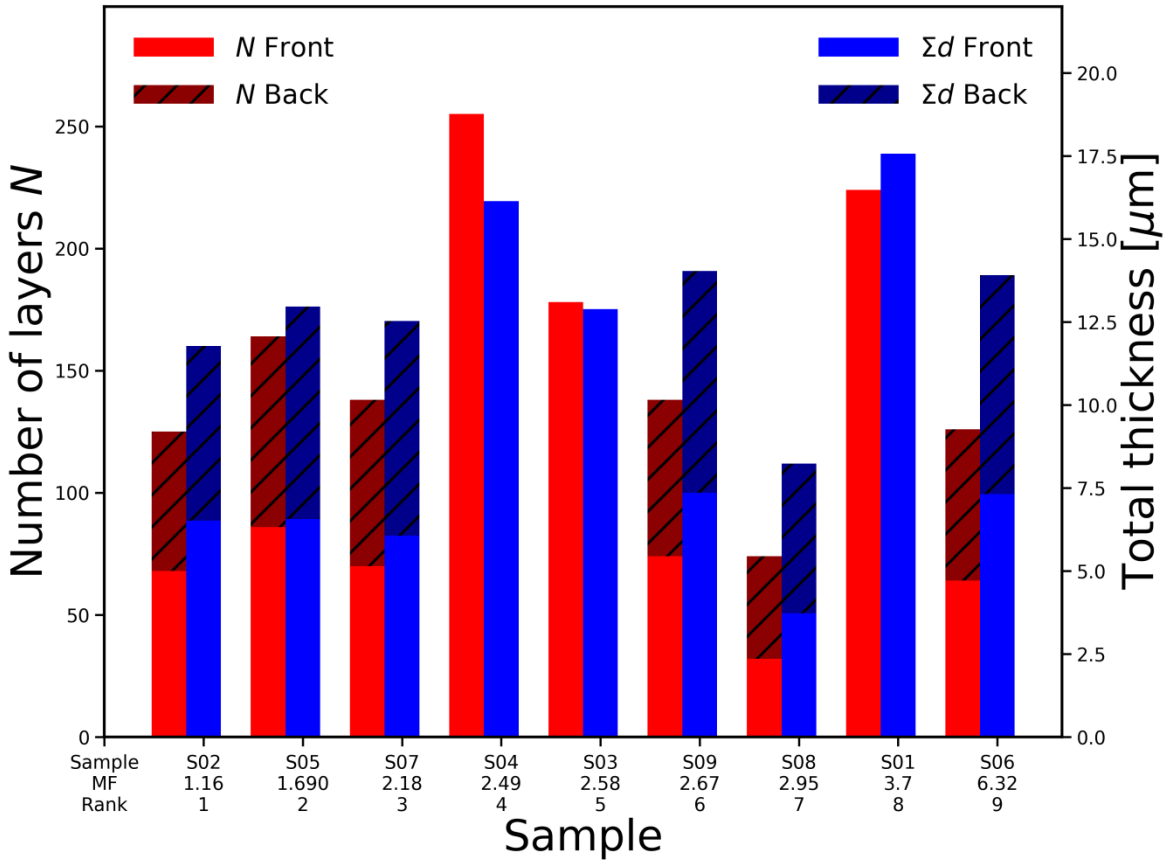
Radius ∝ total thickness
Blue : front side
Red : back side



2019 OIC Manufacturing Problem Contest



2019 OIC Manufacturing Problem Contest

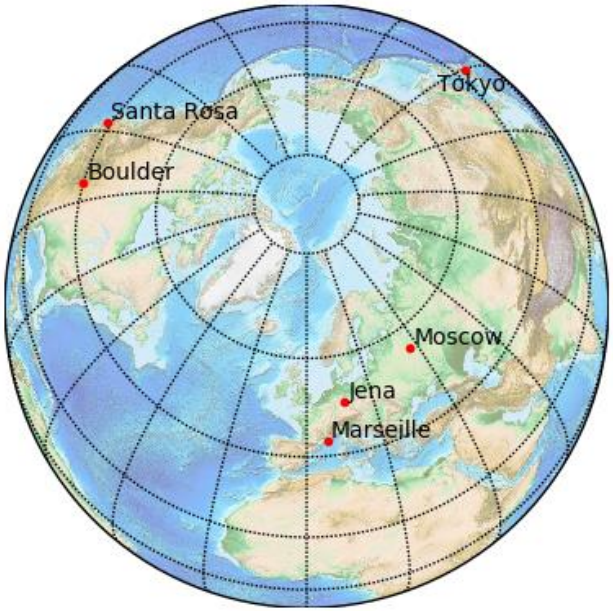


2019 OIC Manufacturing Problem Contest

	#Layers (front+back coatings)	Total thickness (µm)	MF Design	MF Meas	MF ODA	MF NIST	MF Ave.	Rank.
S01	224	17.6	2.030	3.671	3.574 +/-0.006	3.830 +/-0.006	3.020 +/-0.004	8
S02	68+57	6.5+5.3	0.59	0.88	0.891 +/-0.006	1.436 +/-0.006	1.164 +/-0.004	1
S03	178	12.9	2.14	2.53	2.530 +/-0.006	2.640 +/-0.006	2.585 +/-0.004	5
S04	255	16.1	1.106	2.411	2.539 +/-0.006	2.451 +/-0.006	2.495 +/-0.004	4
S05	86+78	6.57+6.40	0.445	1.608	1.728 +/-0.006	1.644 +/-0.006	1.686 +/-0.004	2
S06	64+62	7.32+6.60	0.740	7.130	6.478 +/-0.006	6.141 +/-0.006	6.309 +/-0.004	9
S07	70+68	6.06+6.47	0.439	2.353	2.272 +/-0.006	2.090 +/-0.006	2.181 +/-0.004	3
S08	32+42	3.73+4.51	0.46	2.646	2.890 +/-0.006	3.001 +/-0.006	2.945 +/-0.004	7
S09	74+64	7.36+6.67	0.46	2.61	2.489 +/-0.006	2.852 +/-0.006	2.670 +/-0.004	6

Conclusions

- There are problems that are easier with 2-side coated designs
- Measurements at high AOI demand care
- THANK YOU!!



Acknowledgment

- We would like to thank *Edmund Optics* for the generous donation of BK7 substrates for the contest.