Large-area optical coatings grown by Spatial ALD

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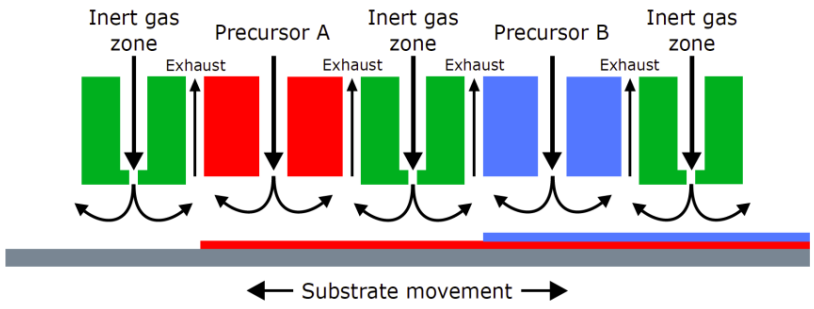
Abstract

- Spatial ALD, substrate temperature 150 °C
- Prototype Beneq SCS1000 reactor
- Substrate size 400 x 500 mm, borosilicate glass ($n \approx 1.52$)
- Multilayer films
  - Al_2O_3 [TMA+H_2O]
  - ZnS [$(C_2H_5)_2Zn$, DEZ + H_2S]
- Good optical thickness control, process stability

Introduction - Spatial ALD (1/3)

- Precursors enter substrate through coating head
- Precursors separated by inert gas zones
- Substrate or coating head moves, covering whole substrate
- Film is formed, thickness controlled by number of precursor passes
- One pass can be one or more growth cycles depending on coating head configuration



Schematic of Spatial ALD working principle. Figure adapted from [1].

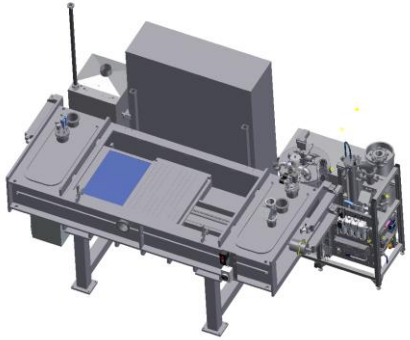
Introduction - Optical films (2/3)

- Manipulation of reflectance or transmittance for a substrate
- Wavelength ranges vary for deep UV (≈220 nm) to IR (> 800 nm)
- Typically consisting of transparent, lossless thin film materials
  - E.g. TiO_2, Ta_2O_5, ZnS, HfO_2, Al_2O_3, SiO_2, MgF_2
- Index difference between two films causes thin film interference
- ALD suitable due to
  - Digital control of layer thickness
  - Construction of effective/”new” materials (e.g. multilayers, laminates)

Introduction - Spatial ALD + Optical films (3/3)

- Spatial ALD appealing as a method to produce optical films with possibilities including
  - Improved process time vs. pulsed ALD
  - Capability to produce thick coatings
  - Possibility for large substrates

Beneq SCS1000 ALD reactor

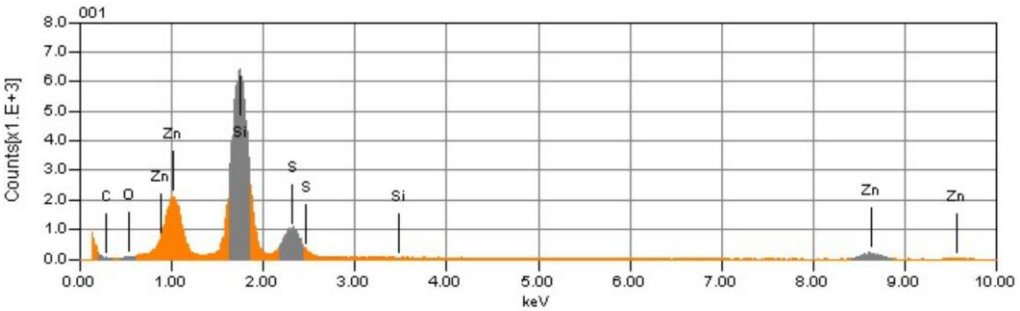


Schematic of the reactor

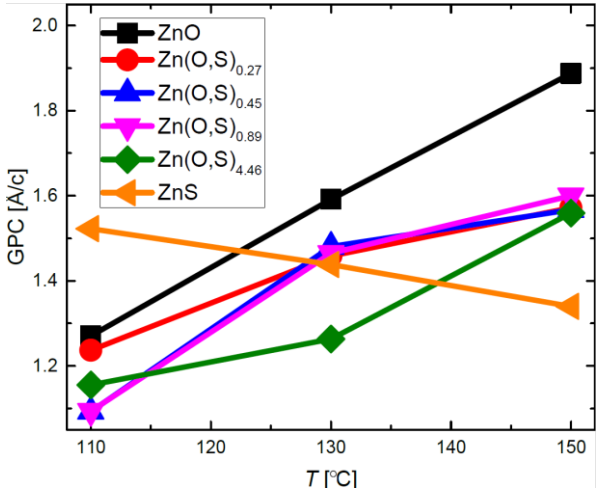
Figures (C) Beneq Oy

Experimental (1/3)

- Choose high and low index materials as ZnS [DEZ, H_2S] and Al_2O_3 [TMA+H_2O] from preliminary testing at 150 °C



EDX data for 150 °C grown ZnS on Si by Spatial ALD. [2]

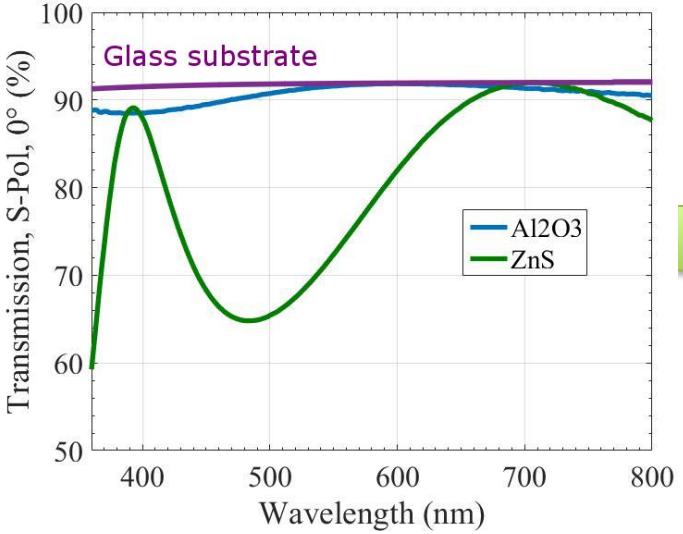


GPC data vs. Substrate temperature for ZnO, $Zn(O,S)_x$ and ZnS films. [2]

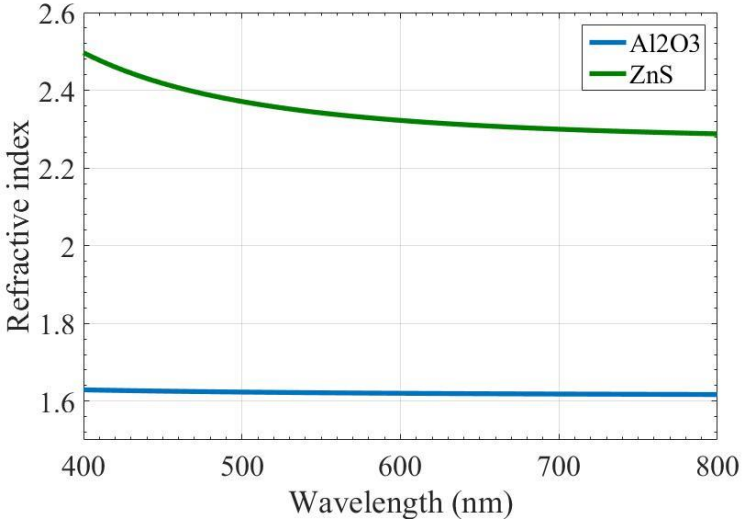
[2] Heikkinen, I.T.S. 2016. Characterization of Zinc Oxide, Sulfide and Oxysulfide Thin Films Grown By Spatial Atomic Layer Deposition. Master's Thesis. Aalto University School of Science.

Experimental (2/3)

- Determination of optical constants
  - Spectrophotometric measurement of transmission
  - Fitting data to a dispersion model (Cauchy)



Fitting



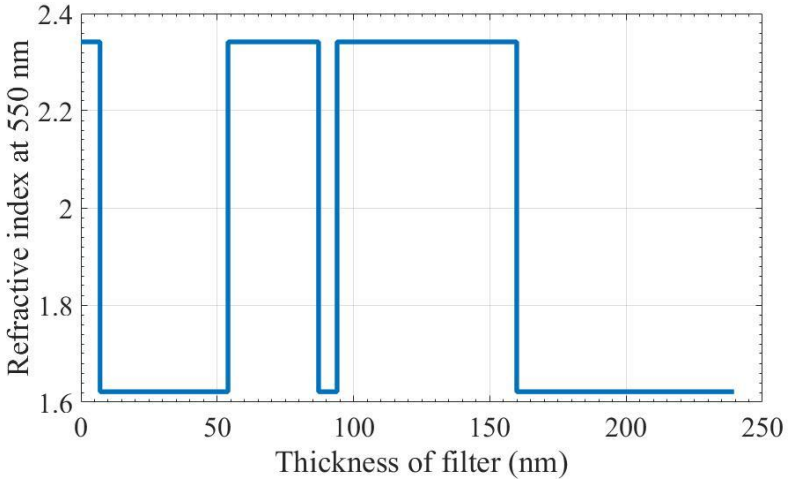
Experimental (3/3)

- Construction of optical coatings
- Deposition at identical parameters to single films
  - Pressure 50 mbar
  - Carrier gas flow 0.5 SLM per nozzle
  - Substrate temperature 150 °C
- Substrate size 400 x 500 mm glass

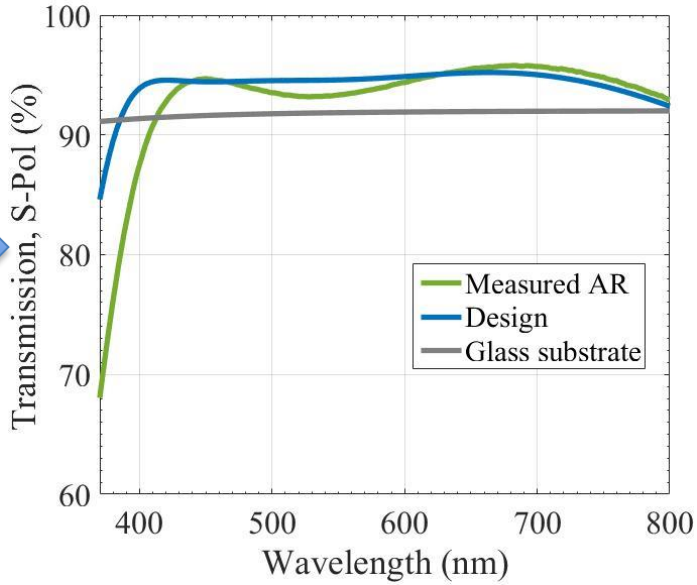
Film	Growth rate (nm/c)	Line speed (m/min)
ZnS	0.12	9
Al_2O_3	0.13	9

Results - Anti-reflective coatings (1/5)

- 1. Sensitive design, 400 x 500 mm glass
  - 6 layers, total thickness 240 nm
  - Single-sided coating

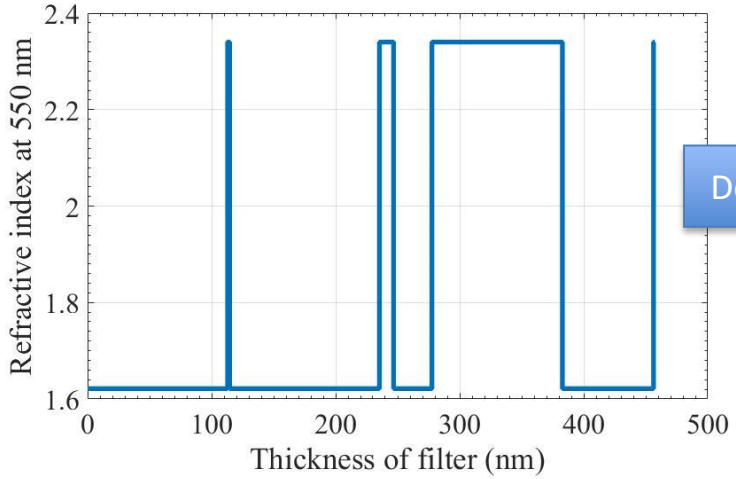


Deposition

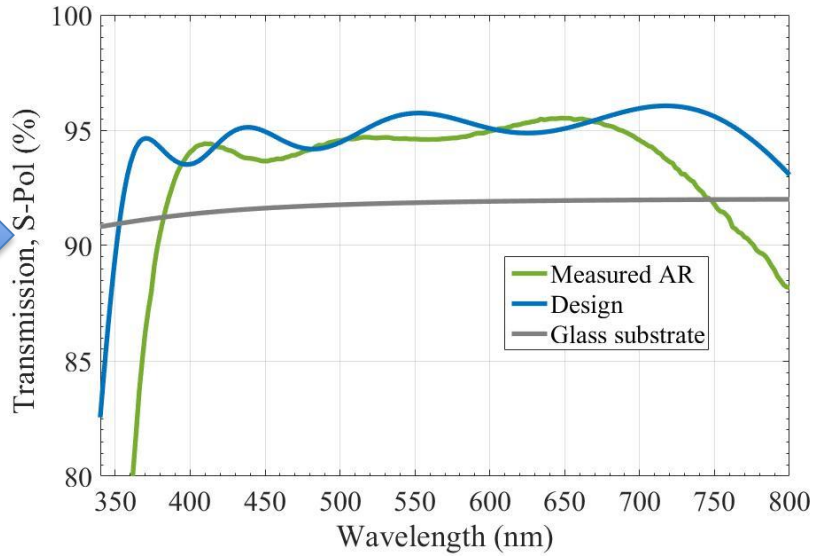


Results - Anti-reflective coatings (2/5)

- 2. Insensitive design, 400 x 500 mm glass
  - 8 layers, total thickness 457 nm
  - Single-sided coating

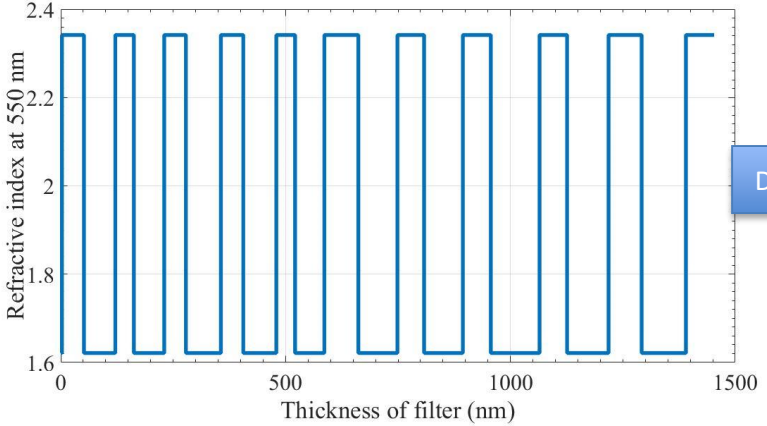


Deposition

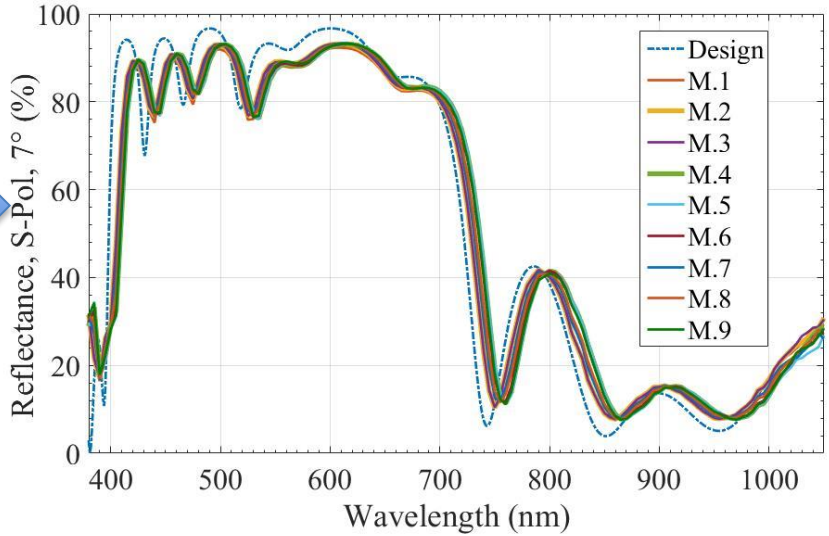


Results - Mirrorlike infrared-pass filter (3/5)

- Total thickness 1450 nm
- High reflectance in visible range (mirrorlike appearance), passes infrared light through

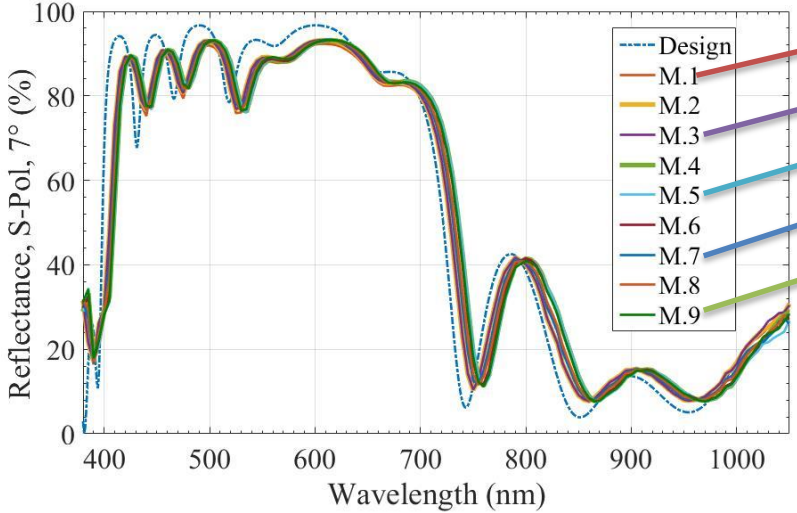


Deposition

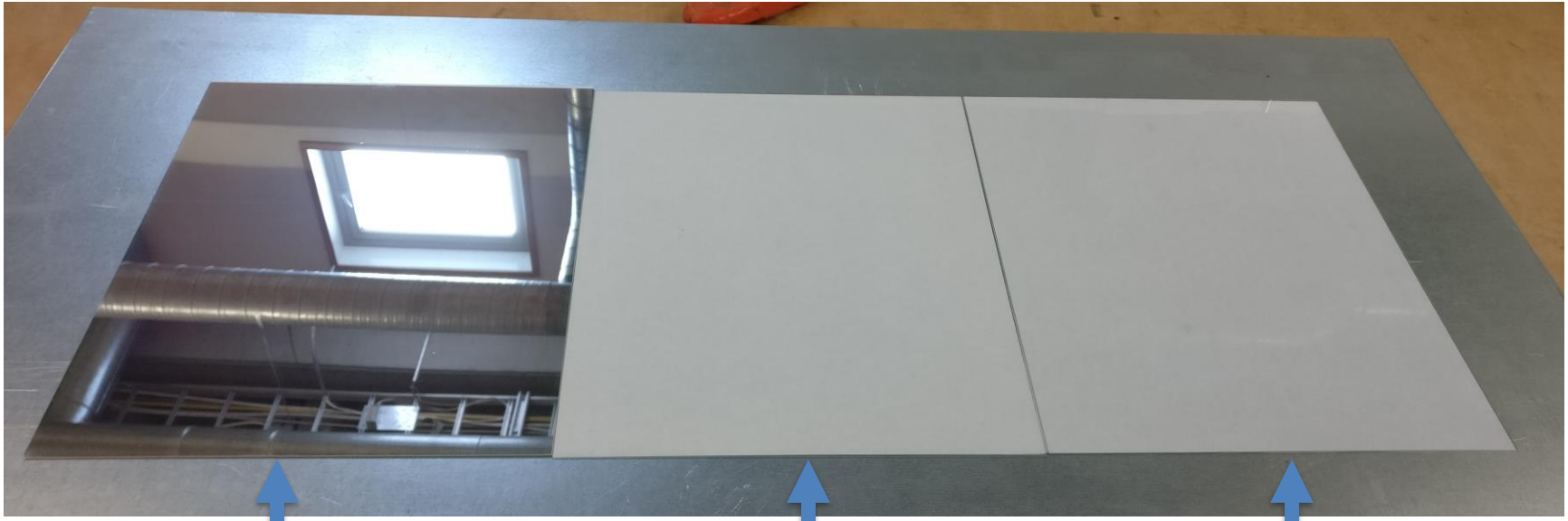


Results - Mirrorlike infrared-pass filter (4/5)

- Performance measured from 9 points spanning substrate
  - High R zone, R_{avg} > 84 % (400-750 nm)
  - Low R zone, R_{avg} = 17 % (800-1050 nm)
- Deviation causes from design speculated as
  - Total optical thickness too high -> systematic error in GPC of either material?
  - Unaccounted losses -> scattering from ZnS?



Results (5/5)



Mirrorlike IR-pass filter

Anti-reflective coating

Uncoated glass

Summary (1/2)

- Optical coatings by Spatial ALD using Al_2O_3 and ZnS at 150 °C on large glass substrates demonstrated
- Optical thickness control for non-repeating thickness layers without in-situ monitoring possible even for thick films

Summary (2/2)

- Further research could target
  - Increased number of possible optical films
  - Homogeneity of films, film growth with spatial ALD
  - Methods to achieve higher throughputs, faster process times
  - Applications where conformality is key [3], e.g. diffractive gratings

References

- [1] Poodt, P. & Cameron, D. C. & Dickey, E. & George, S. M. & Kuznetsov, V. & Parsons, G. N. & Roozeboom, F. & Sundaram, G. and Vermeer, A. J. Vac. Sc. Technol. A 30 (2012) 010802.
- [2] Heikkinen, I.T.S. 2016. Characterization of Zinc Oxide, Sulfide and Oxysulfide Thin Films Grown By Spatial Atomic Layer Deposition. Master’s thesis. Aalto University School of Science.
- [3] Poodt, P. & Mameli, A. & Schulpen, J. & Kessels, W. M. M. (Erwin) and Roozeboom, F. Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films 35, 021502 (2017).