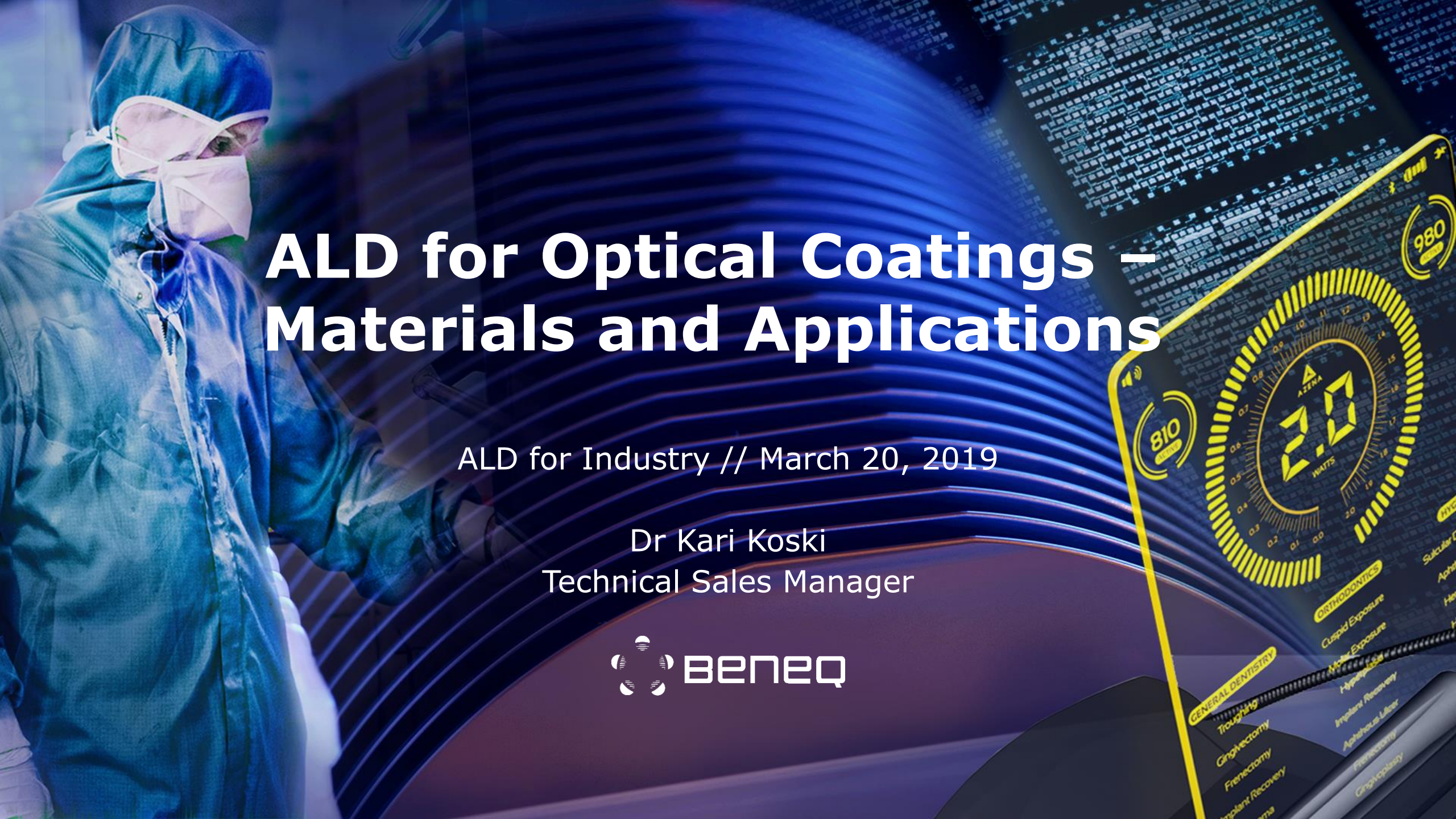


ALD for Optical Coatings – Materials and Applications

ALD for Industry // March 20, 2019

Dr Kari Koski
Technical Sales Manager

BENEQ

Outline

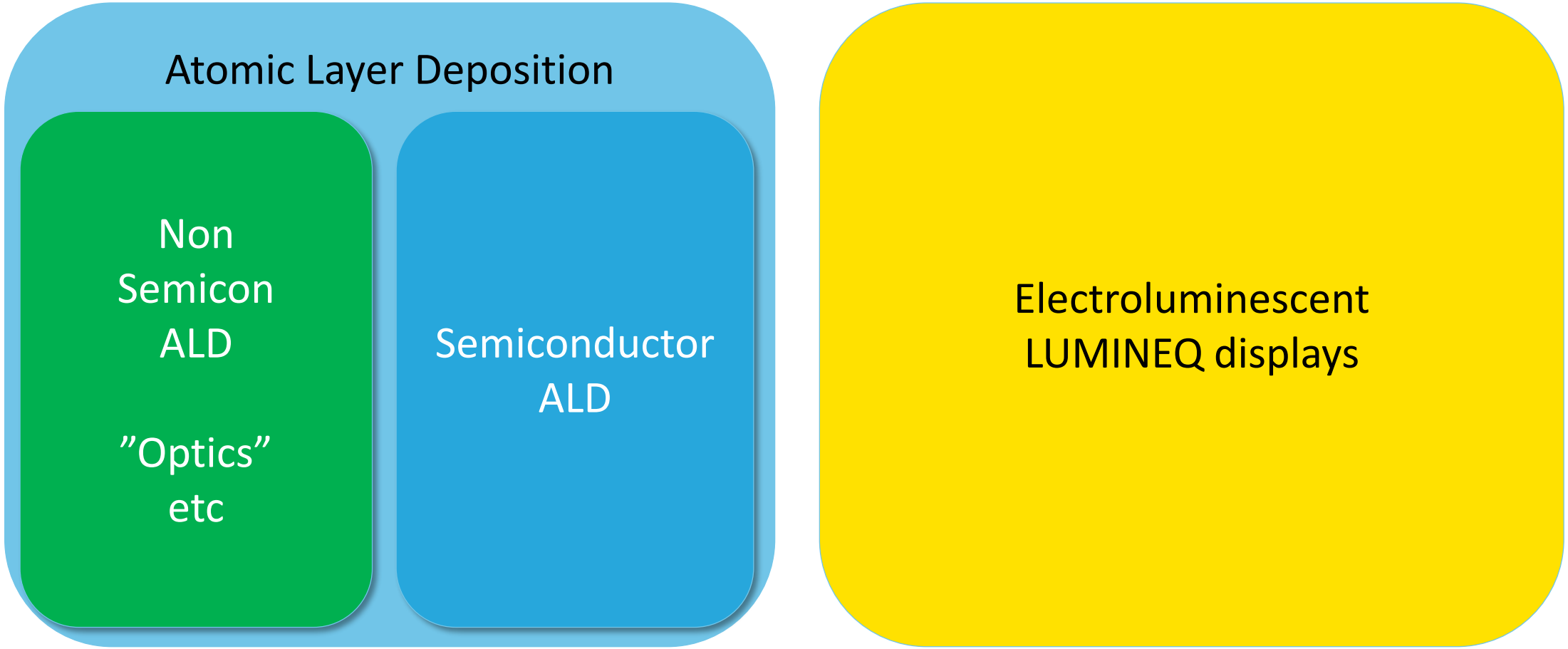
- Beneq – company presentation
- ALD for optics; from properties to structures
- Examples and case studies
- ALD tools for optics

Beneq – Industrial ALD solutions

- Established in 2005, FINLAND
- Worldwide operations
- Long history in ALD
- One of the largest cleanrooms in Europe
- 2000 m2 cleanroom / 40 ALD reactors

- We are helping customers in:
- Development services
- Coating services
- ALD tool engineering
- Customer care

Business lines



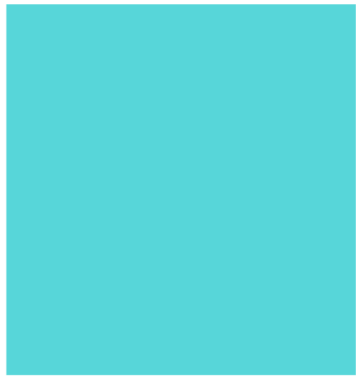
Atlas of ALD


New Research World
State of Optics
Unknown Aliens
Kingdom of OLED
Silver Mountains
Decoration
Sea of Opportunities
MLD
Moisture Barriers Island
Semiland
Solarlandia
Continent of ALD

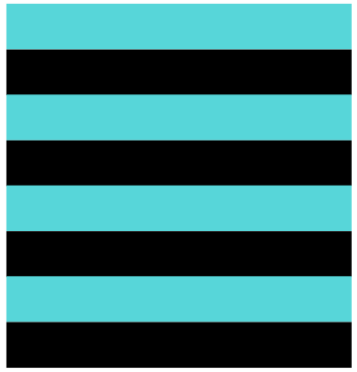
ALD for optics

Desired properties from coating method for optical coatings	Characteristics of ALD
Films optically suitable (for application)	Dense, stoichiometric, non-absorbing transparent films; Absorbing films (e.g. metals)
Stability of coatings	Dense, stoichiometric films - typically stable
Precise thickness of coated layers	”Digital” layer-by-layer thickness control
Sharp interfaces	Interfaces typically sharp depending on material selection, low interdiffusion between layers
Complex shapes can be coated uniformly	Extremely conformal films
Low cost per coated piece	Can be performed in a batch reactor

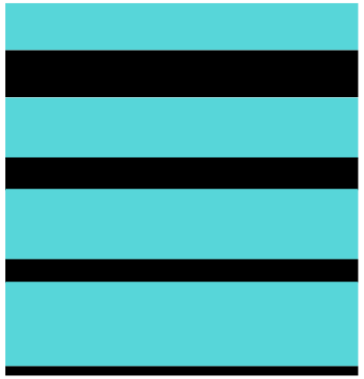
Optical coatings by ALD – basic structures



Single films: Al_2O_3, TiO_2, SiO_2, HfO_2, Ta_2O_5, ZnO, ZnS, AlN ...



Laminate films: Al_2O_3-TiO_2, TiO_2-SiO_2, Al_2O_3-HfO_2, ...



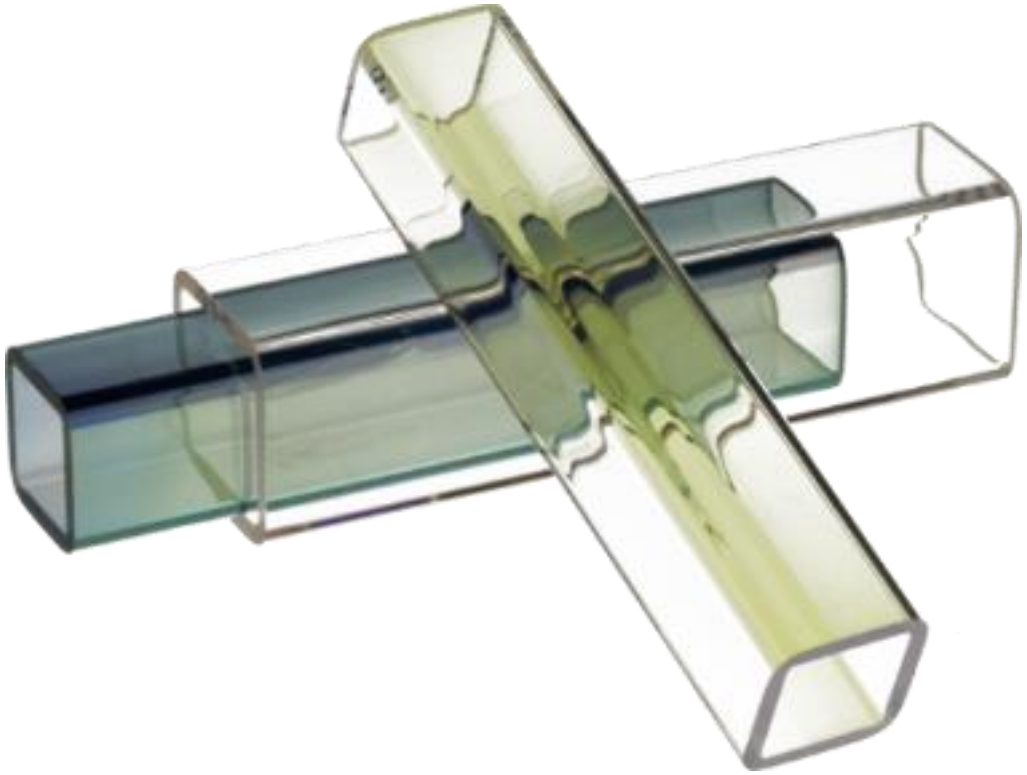
Gradient films: Al_2O_3-TiO_2, TiO_2-SiO_2, Al_2O_3-HfO_2, ...

Mixtures: $Al_xTi_yO_z$, $Ti_xSi_yO_z$, $Al_xHf_yO_z$, ...

ALD Optical applications

- Dielectric mirrors
- Anti-reflective coatings
- Filters
- Complex optical systems

- Night vision devices
- Micro displays
- Lasers
- Space applications
- Machine vision
- Image sensors
- Lense structures
- Tubes, wires, channels, fibers

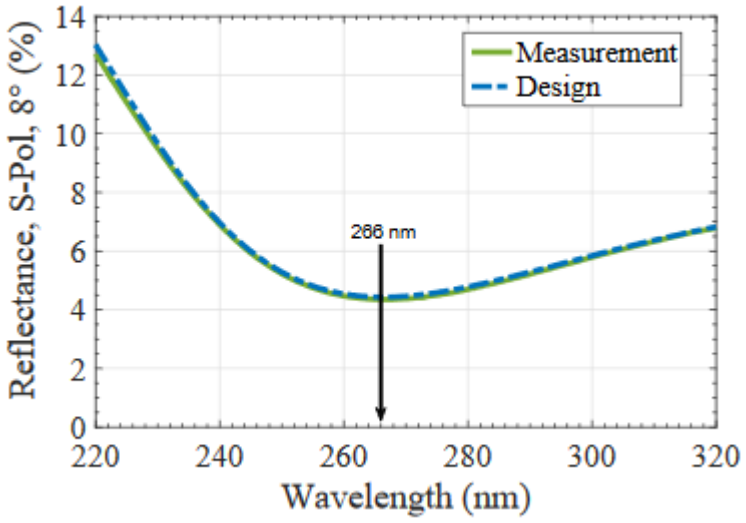


ALD processes for optics

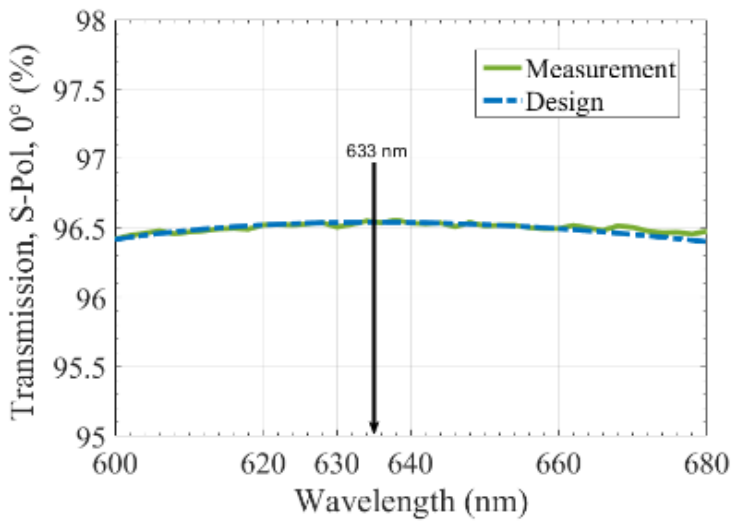
- Vacuum, low pressure 1 bar, torr, hPa
- Plasma PEALD (rotary batch ALD tool or single wafer process)
- Thermal ALD (single wafer or batch process)
- Spatial ALD (roll-to-roll or rotary ALD)
- Most common optical materials: Al_2O_3, TiO_2, SiO_2:Al, ZnO, ZnO:Al, ZnS
- 3D substrates
  - Tubular objects, inside/outside surfaces
  - Double side coatings, flat substrates
  - Nanofabrication coatings
  - Trench filling
  - High aspect ratio objects

Example – single films in a filter stack (1/3)

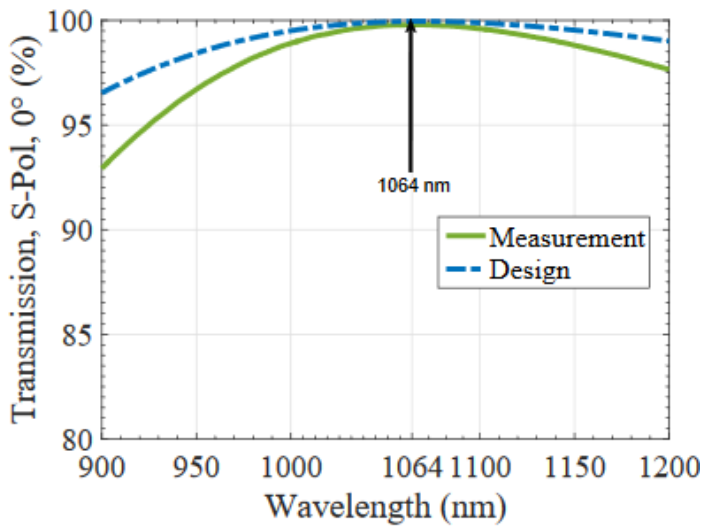
- Anti-reflective coatings for laser wavelengths



266 nm AR
(single-side)



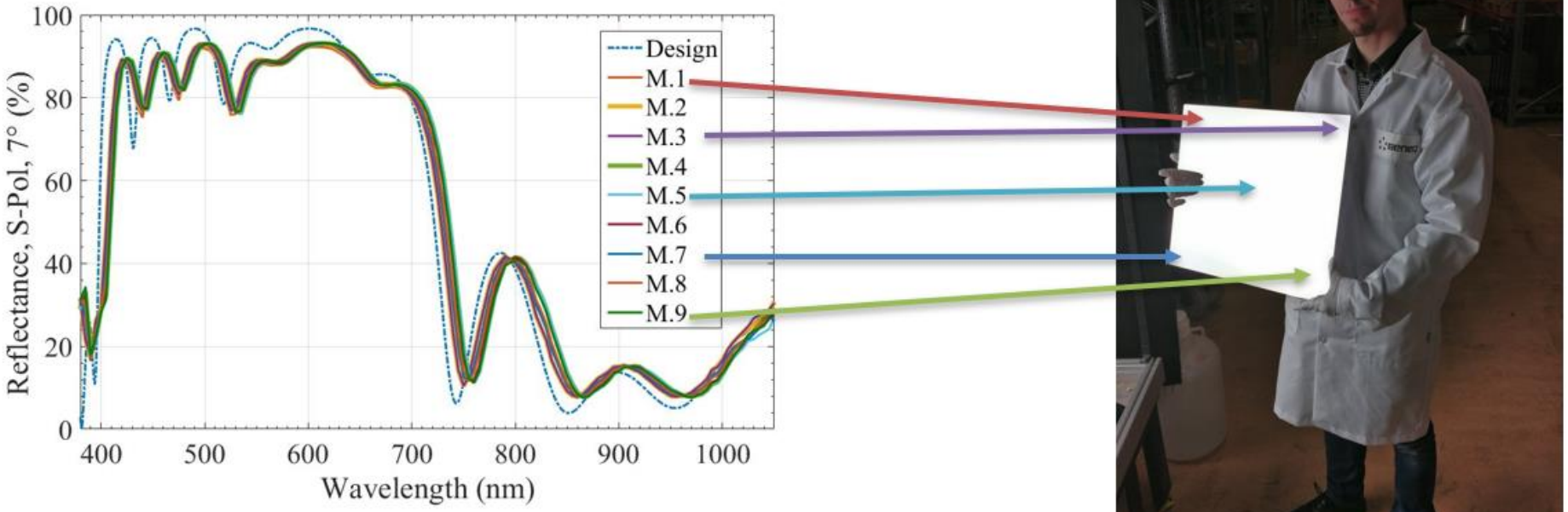
633 nm AR
(single-side)



1064 nm AR
(two-sided)

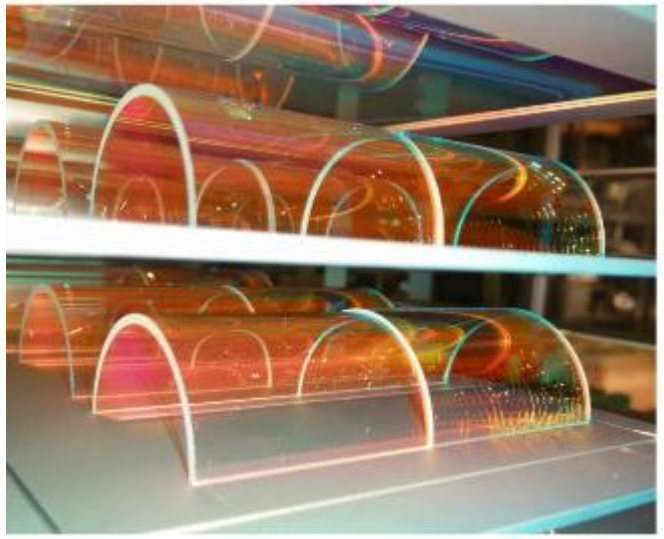
Example – single films in a filter stack (2/3)

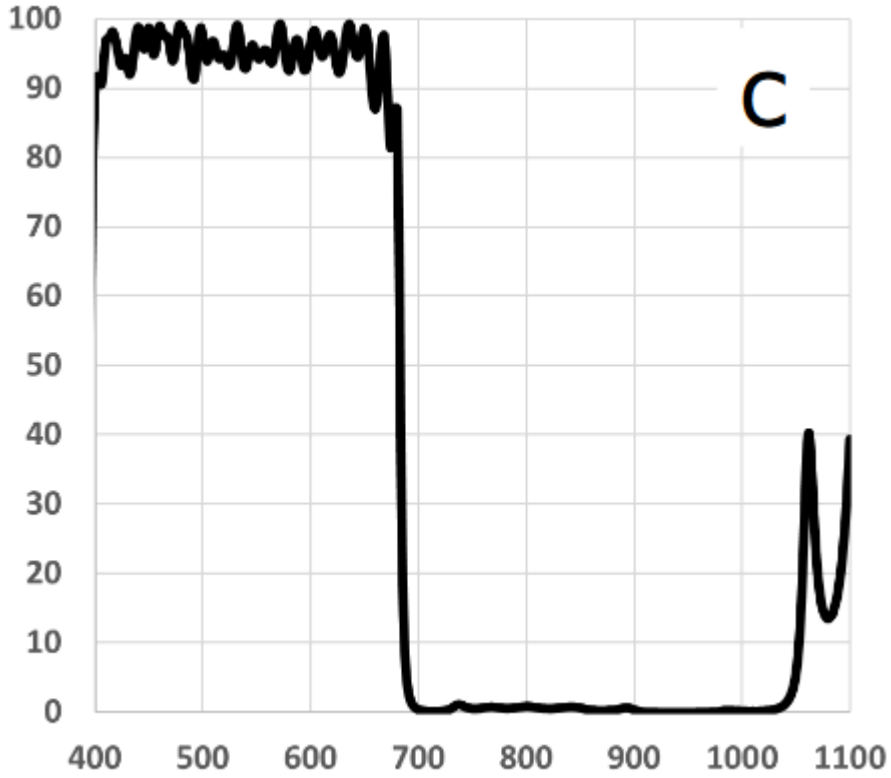
- Mirror-like coating on large glass sheets (1,5 µm)
- Made with spatial ALD (Beneq SCS1000)



Example – single films in a filter stack (3/3)

- Single films of Al2O3, TiO2
- Producing an optical stack
- 77 layers, 5.5 µm
- Deposited on curved glass cylinders



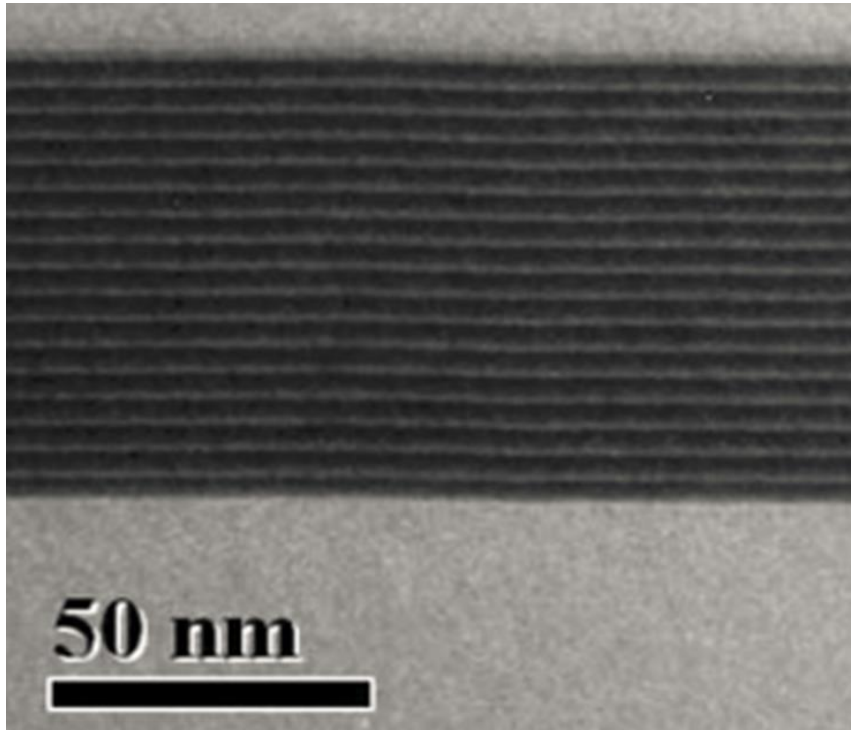


Wavelength vs. Transmission of the filter stack

Example – single films in a filter stack (3/3)

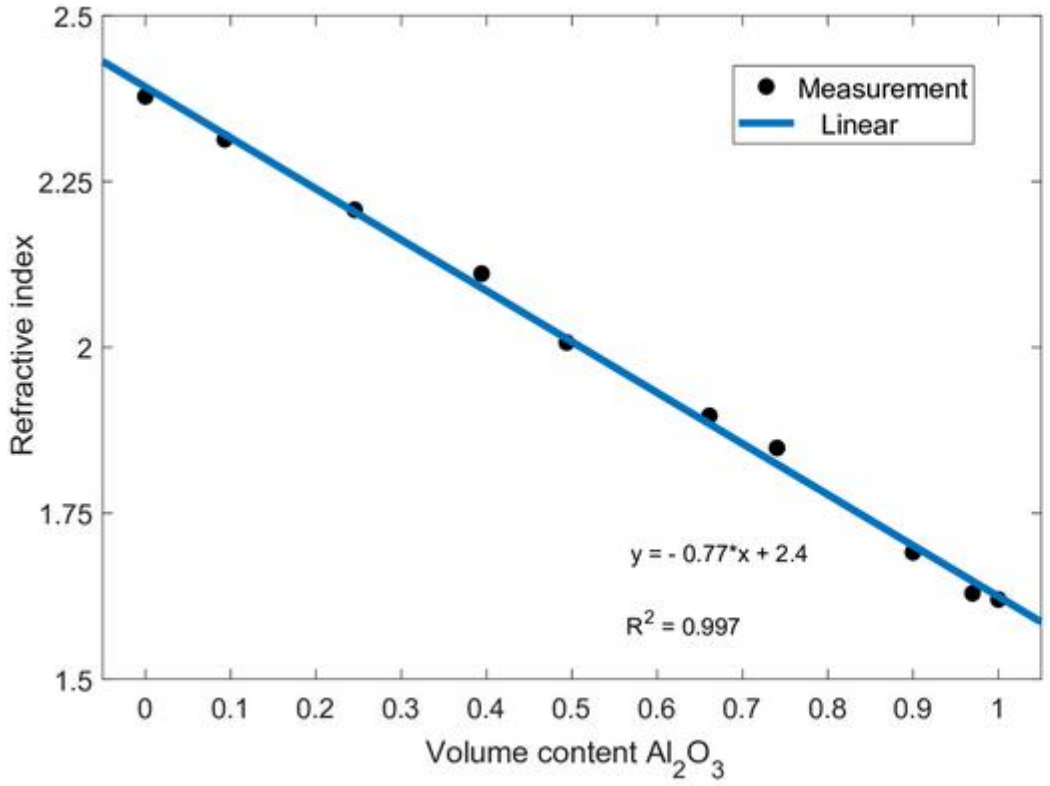
- Al_2O_3 – $Al_xTi_yO_z$ – TiO_2
- 77 layers alternating Al_2O_3/TiO_2 = 5.5 μm

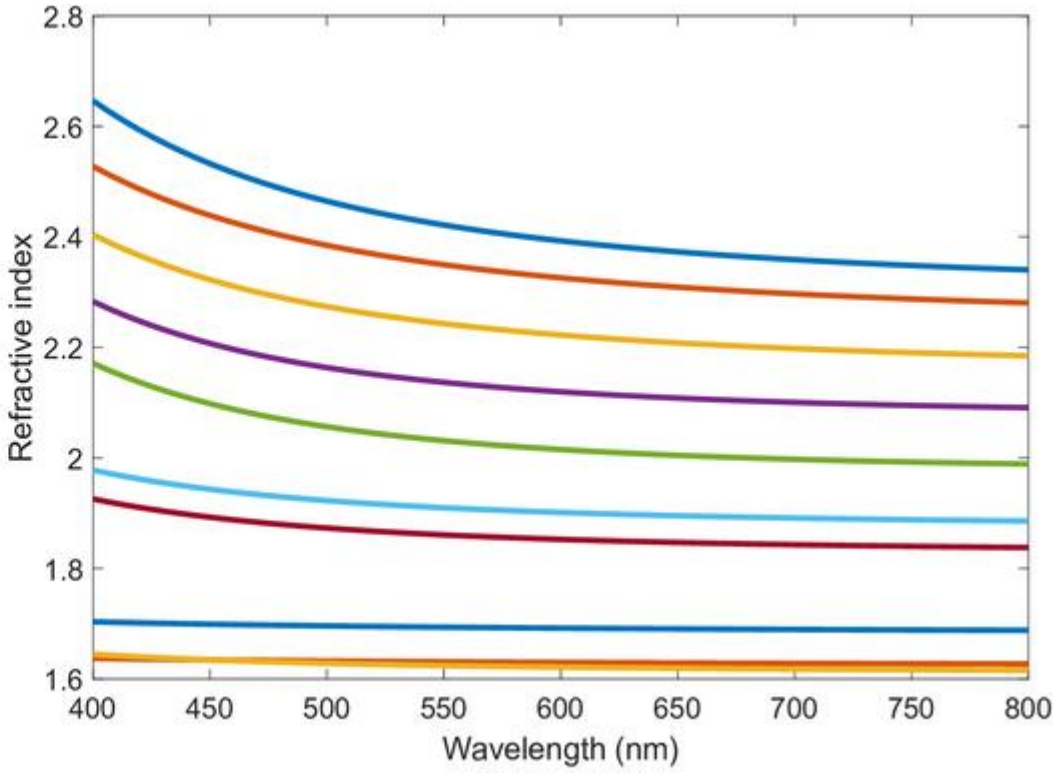
  - TiO_2 in-situ modification (Al or Si)
  - Interface modification by Al_2O_3
  - Cutting layer: to prevent crystallization of TiO_2 by 0,6 nm Al_2O_3 every 4 nm



Example – Laminated films

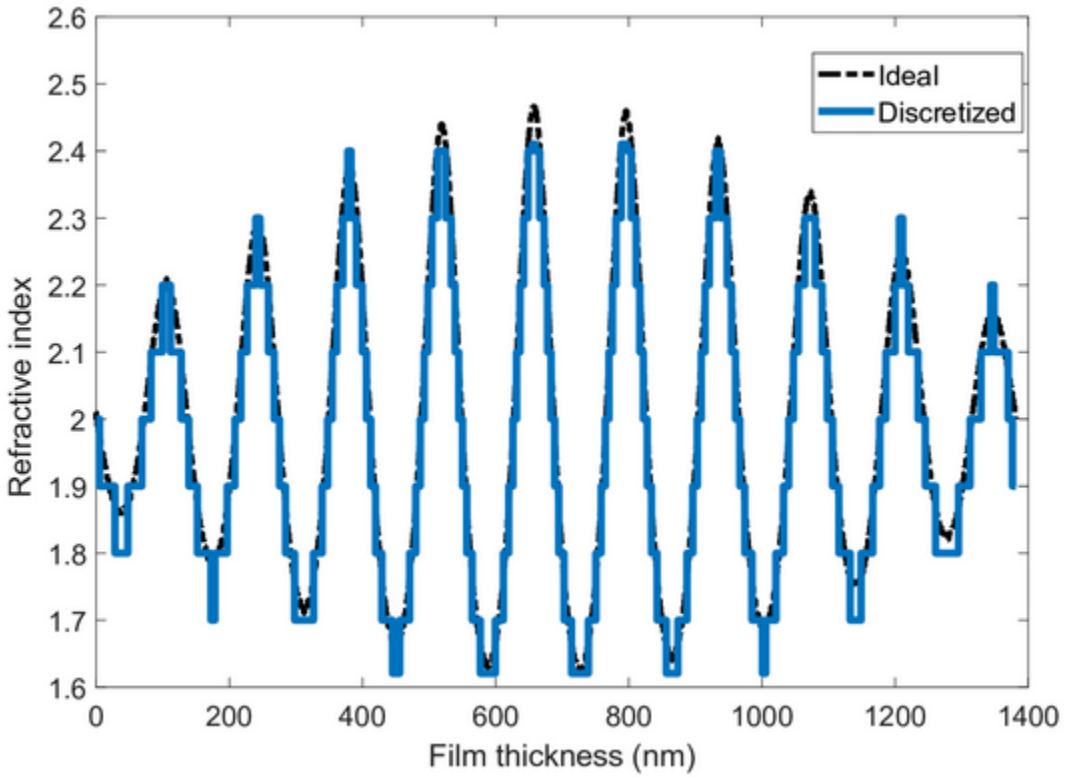
- Refractive index behaviour in laminated Al2O3-TiO2 system
- Direct consequence: ability to tailor refractive index to application

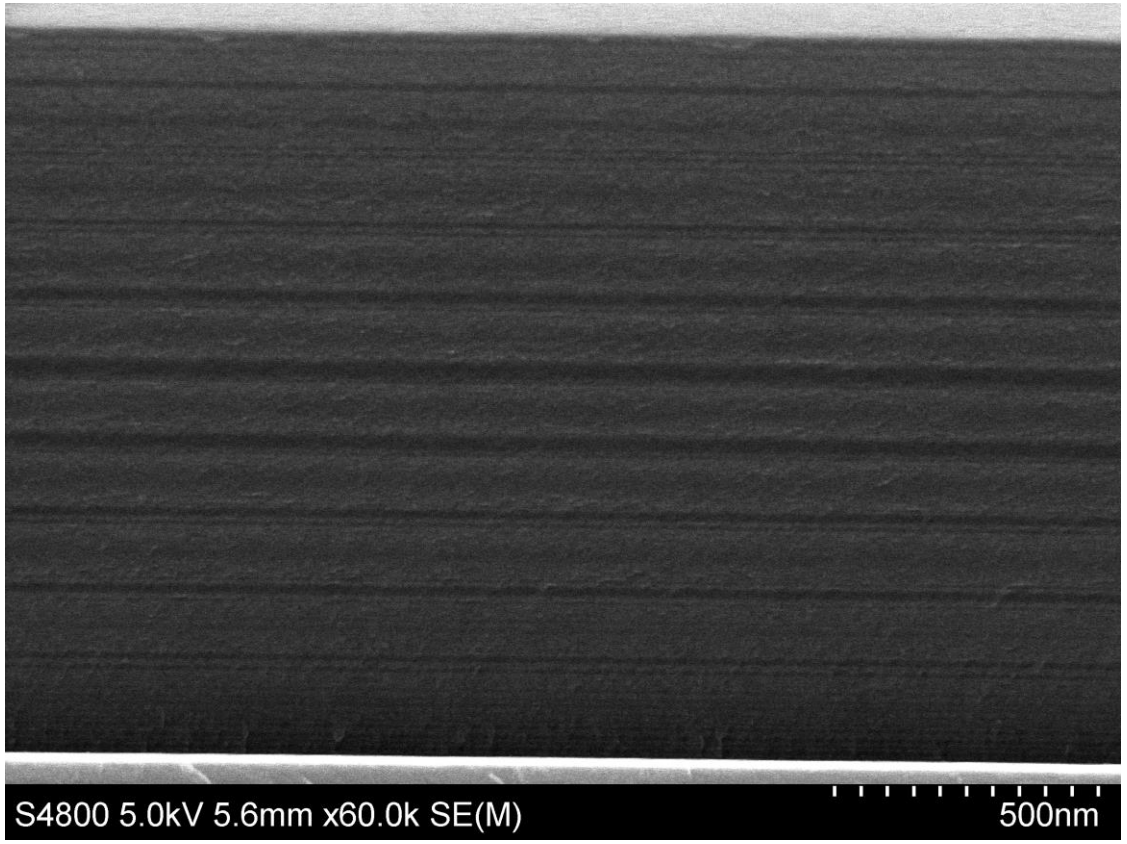




Example – graded structure

- Because of linearity, tailored indices manufactured so that an apodized rugate filter is possible. Gradiental change in refractive index over the filter (1.3 µm)



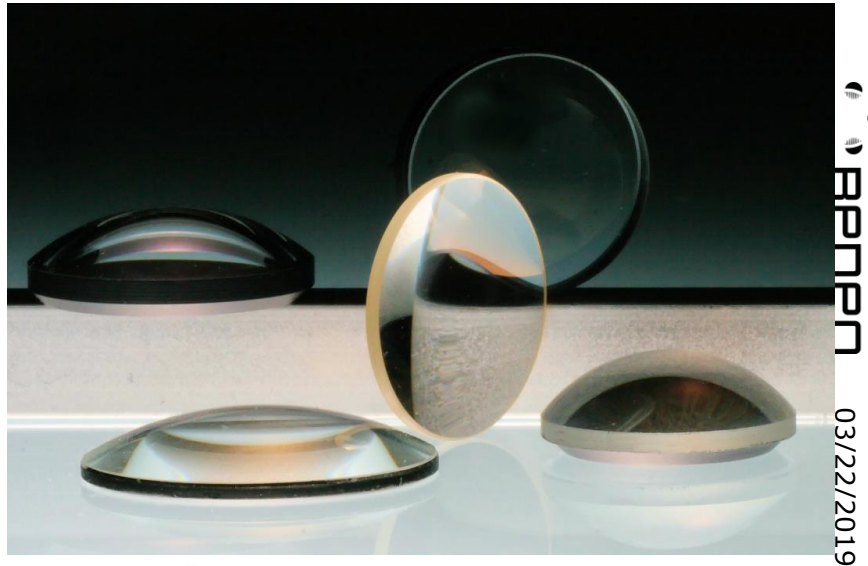


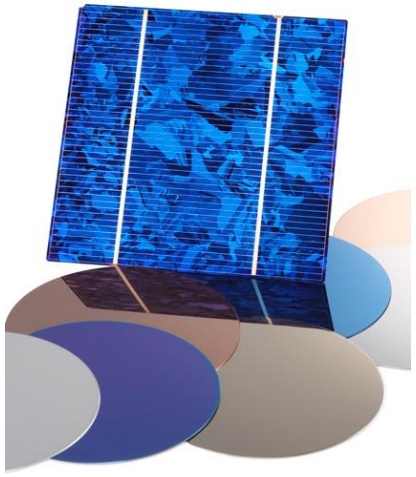
ALD for IR optics

- ALD available for multiple imaging applications (hyperspectral, thermal)

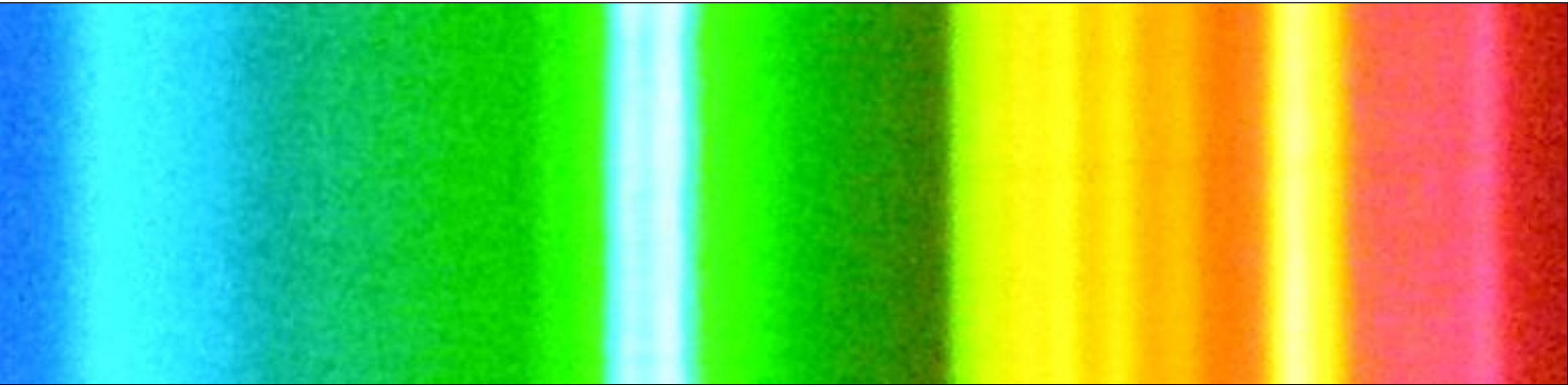
- Digital and stable ALD process: management of coating thickness for target wavelength (filter thickness <-> wavelength)

- Many of the traditional ALD lossless VIS-region film materials extend well to the IR
  - ZnS -> 25 µm
  - Al_2O_3 -> 9 µm
  - TiO_2 -> 12 µm
  - SiO_2 -> 8 µm





Filling of Diffractive Gratings



The challenge
The customer was looking for ways to adjust the optical performance of their diffractive gratings and to keep the gratings free from debris.

The customer
A leading optical system manufacturer

Beneq solution
Beneq used ALD to fill the grating structure completely with a high refractive index material to boost the optical performance. The resulting structure is essentially flat, which helps keep the structure clean.

ALD tools for optics

Beneq TFS 200

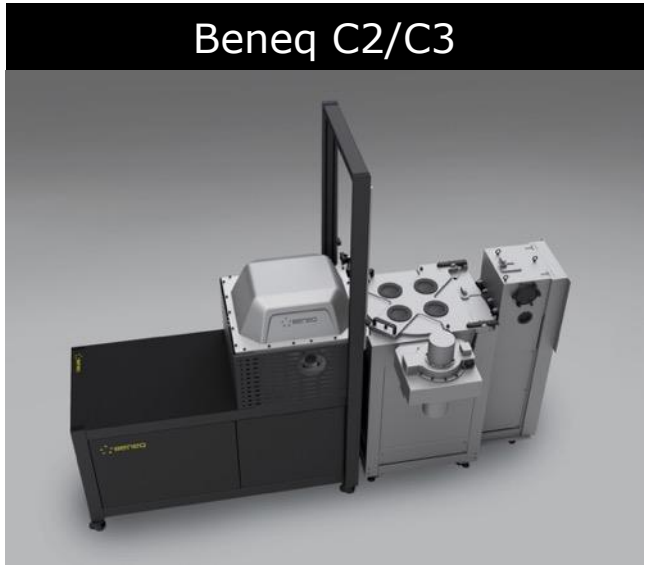
Beneq TFS 500

Beneq P400A and P800

Beneq WCS 600

Beneq C2R

Beneq C2/C3



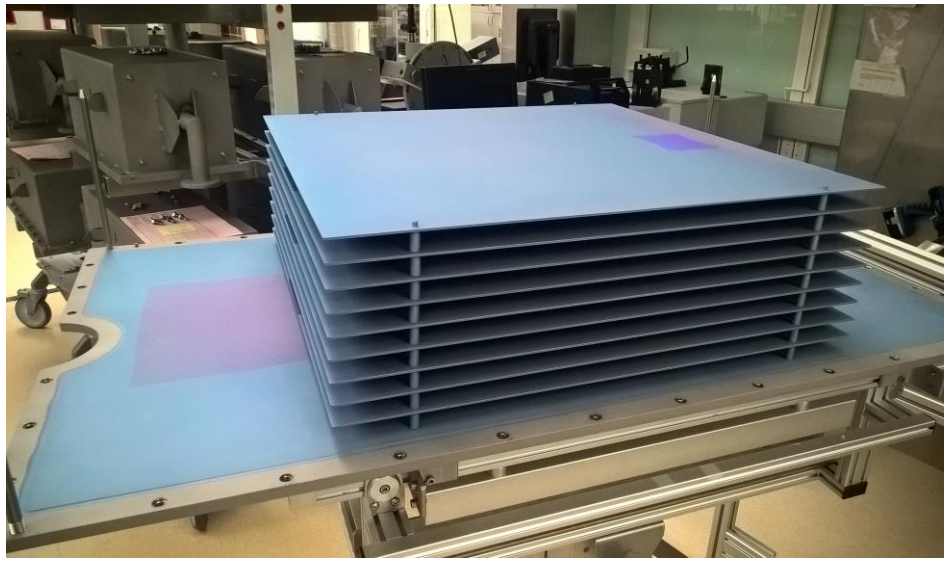
beneq

P400A – Industrial ALD batch for optics

- Production-proven Batch ALD system
- Typical substrate formats: sheets, 3D-parts, wafers
- Typical substrate materials: glass, metal, silicon, ceramic, polymer
- Typical coating materials: Al_2O_3, TiO_2, ZnO, SiO_2:Al, Ta_2O_5, TiN, AlN, ZnS…
- Typical coating thickness 5nm-5µm
- Process pressure ~1mbar
- Process temperature 80…500C
- Typical reaction chamber coating volume 240x240x360 mm

Batch coating

- Large reactor space
- Shelves/sample holders can be fitted depending on application

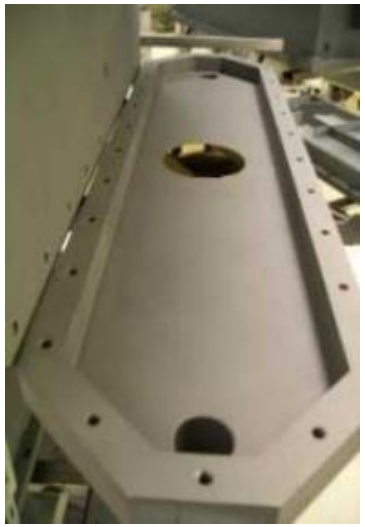


A Beneq P800 reaction chamber for deposition on sheet-like substrates

Fig. 4. Example of the TiO_2 batch for uniform ($\pm 2\%$) coatings, 36 shelves 240×500 (mm), double-sided coatings (8 m^2 of a film).[1]

[1] Maula, J. Atomic Layer Deposition for industrial optical coatings. 2010. Chinese optics Letters Vol. 8, Supplement.

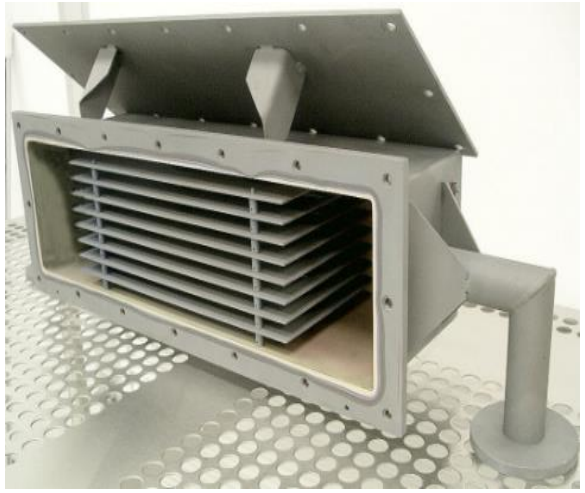
Wide variety of reaction chambers (P400A)

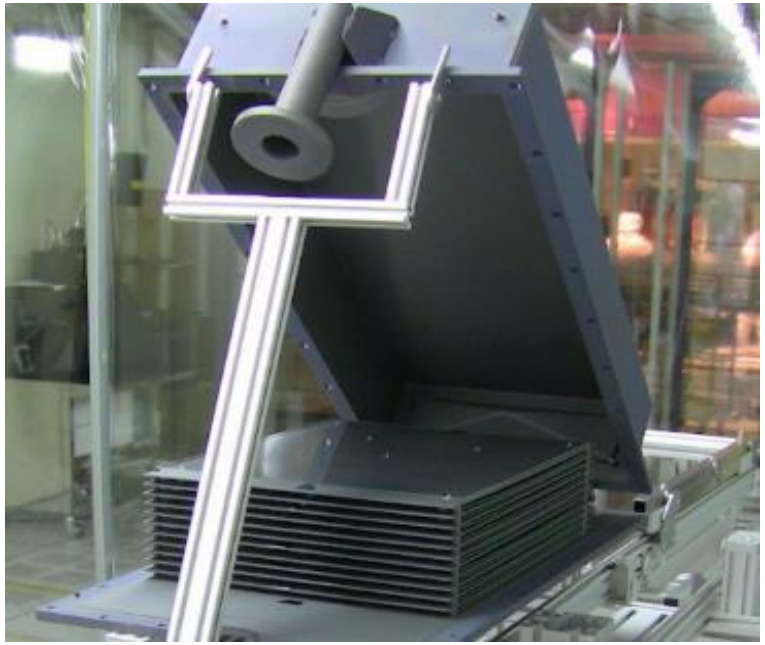


Small (fast):W=170mm H=145mm L=540mm / W=165mm H=25mm L=670mm

Medium 0,7 m long: 250x250x700 mm^3, coating volume 240x240x500 mm^3

Large: W=374mm H=25mm L=840mm





Thank you for your attention!

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