ALD Thin Films for Infrared Applications

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Beneq Oy in nutshell

Established:	2005
Location:	Espoo, FINLAND
Personnel:	130
Sales offices:	Finland, Germany, China, USA (Beneq, Inc.)
Sales network:	More than 50 sales representatives worldwide

Beneq in 30 seconds

Thin Film Equipment

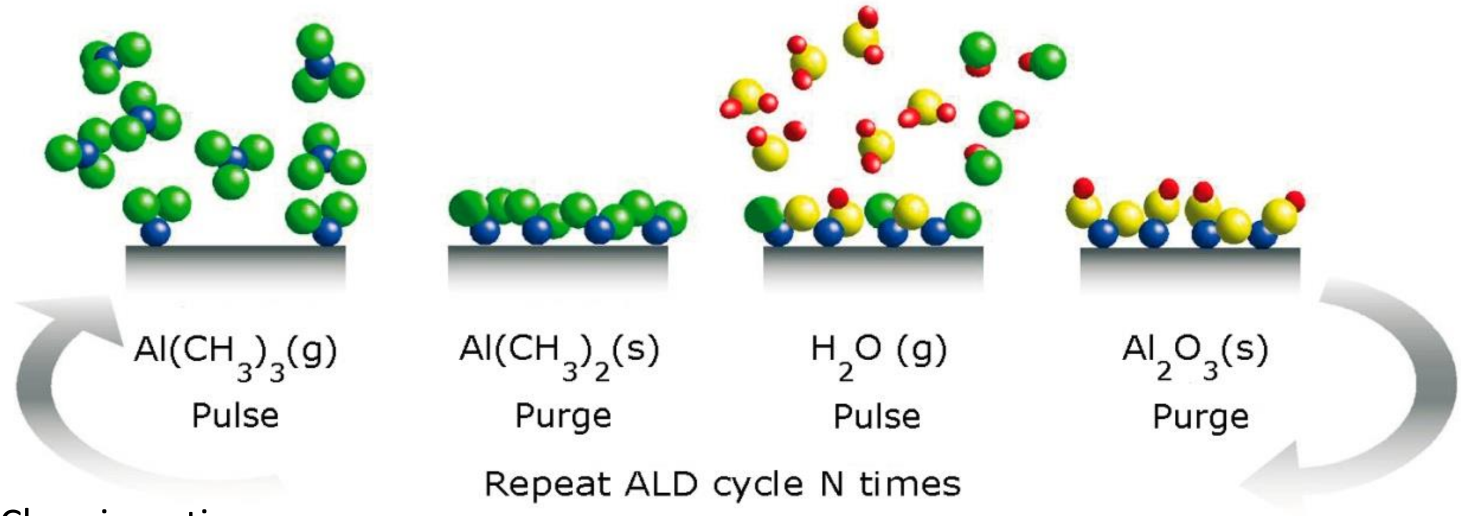
Coating Services

Lumineq® Displays

ALD principle

- Tri-methyl Aluminum (TMA) + water (H_2O) =

Aluminum oxide (Al_2O_3) + methane (CH_4)



Chemisorption

Covalent bonding

Excellent adhesion, low stress, high density

Excellence of Atomic Layer Deposition

- Large choice of materials for different purposes (depends on precursor chemistry)
- High/low n index materials for optics
- 3 D substrates, double side and inner surface coatings
- Processing in cleanroom environment
- Accurate thickness control (digital process)
- Engineering of novel materials
- Properties are achieved / limited mainly by ALD system performance
  - Suitable chemistry
  - Process parameters
  - System desing

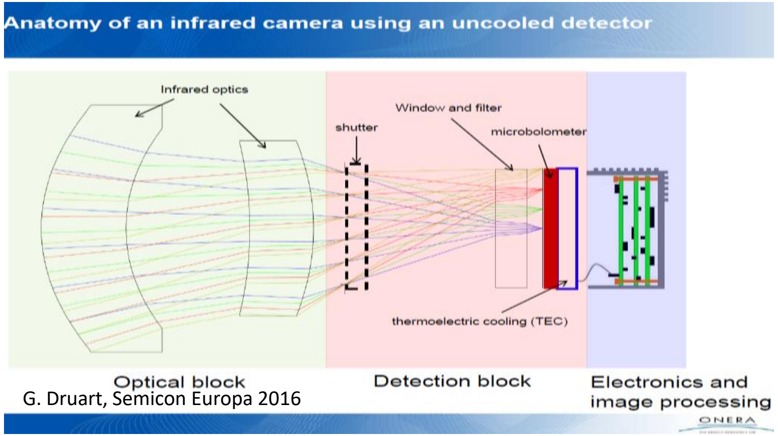
Excellence of Atomic Layer Deposition

- High density
- Pinhole free thin films
- High uniformity
- Conformality
- High repeatability
- Low stress
- Good Adhesion

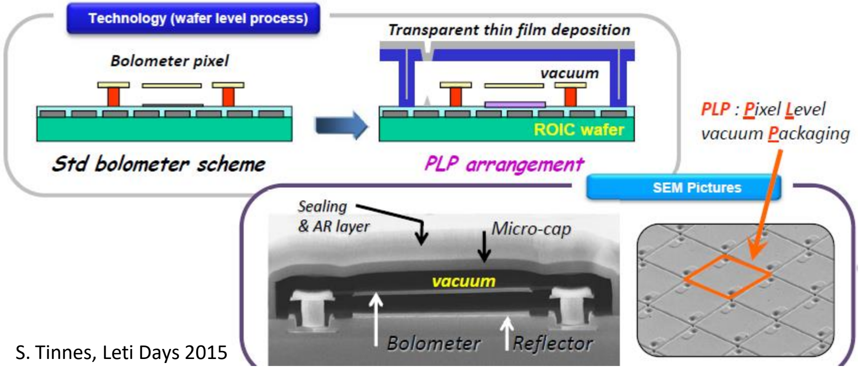
- Novel materials/materials design and modification -> choice of properties

ALD solutions for uncooled IR imaging

- Low resolution/cost IR sensors for nightvision like applications in smartphones /consumer and automotive have been expected to drive the market
- Removal of thermo electric compounds, shutter and window as well as scaled down sensors, wafer level optics and wafer level packaging are driving cost reduction



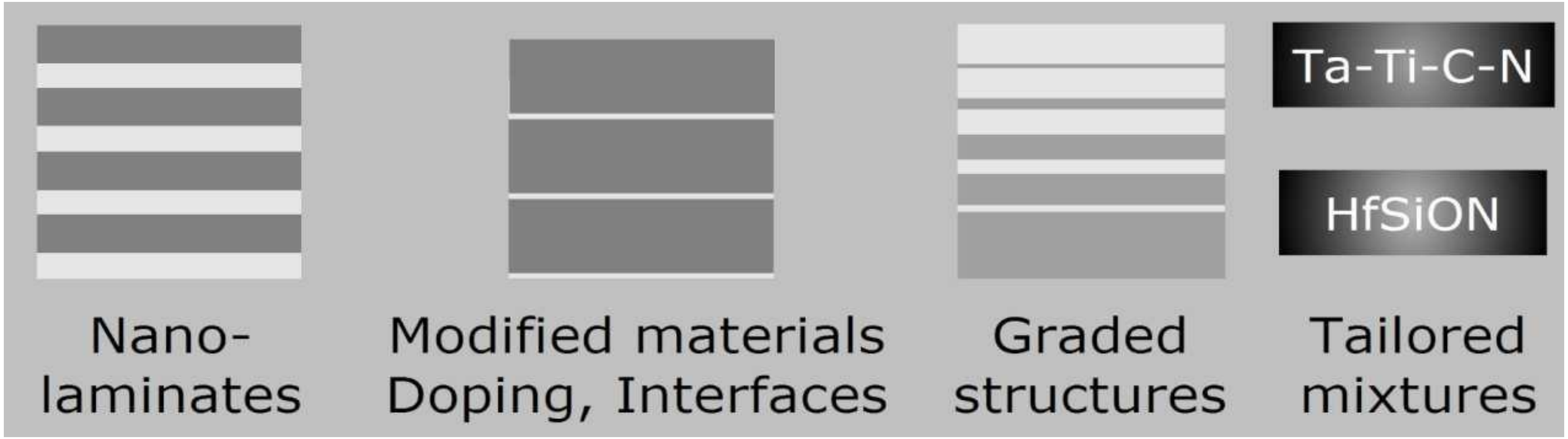
G. Druart, Semicon Europa 2016



S. Tinnes, Leti Days 2015

- Key challenges associated with IR sensors technology include thinner and uniform bolometer film e.g. VOx, TiOx…, conformality over complex 3D structures
- ALD (thermal and/or plasma) technology meets these requirements
- Applications include sealing and AR layers

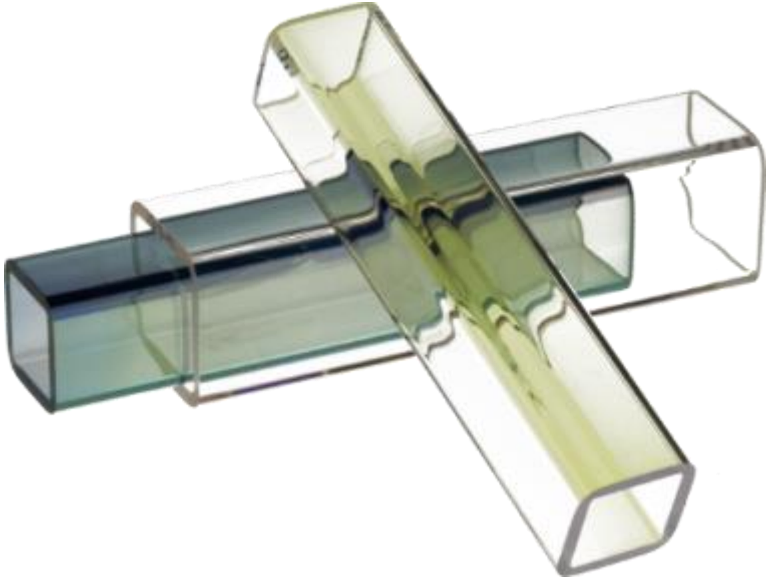
Artificial and novel materials by ALD



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

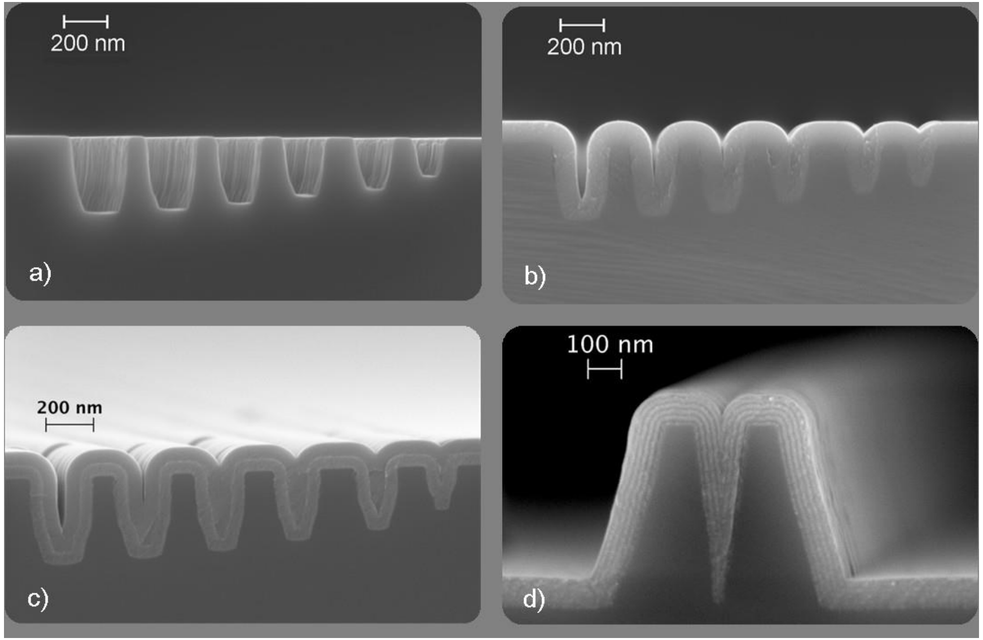


ALD processes for optics

- Vacuum, low pressure 1 bar, torr, hPa
- Plasma PEALD
- Thermal ALD
- Spatial 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
  - Tench filling
  - High aspect ratio objects

Conformal thin films

- Slot structures on silicon
- ALD coatings: amorphous TiO_2 and Al_2O_3 (T=120 degrees)



Scanning electron micrographs of slot structures:

a) No coating

b) 100 nm of TiO_2

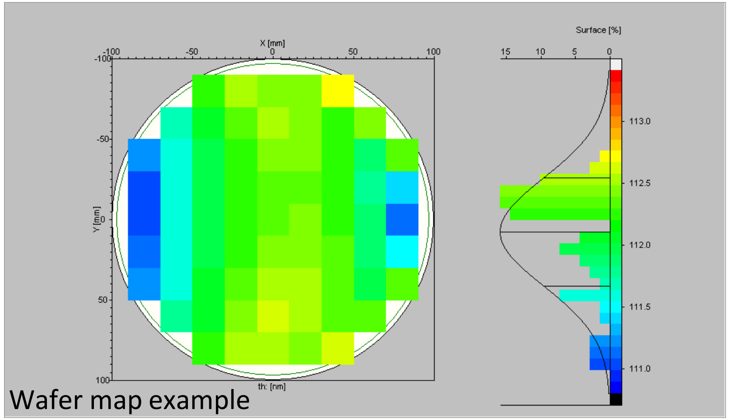
c) 50 nm of Al_2O_3+ 50 nm of TiO_2

d) 5 * (10 nm of Al_2O_3+ 10 nm of TiO_2)

Photo courtesy of Aalto University, Finland

Uniform thickness

- Al_2O_3 at 200C using TMA + H_2O process
- Batch size: 25 pcs of 200mm wafers
- Cycle time 7.8s, 1000 cycles
- Within wafer thickness variation: 0.39%
- Wafer-to-wafer thickness variation: 0.16%
- Wafer-to-wafer index variation: 0.01%

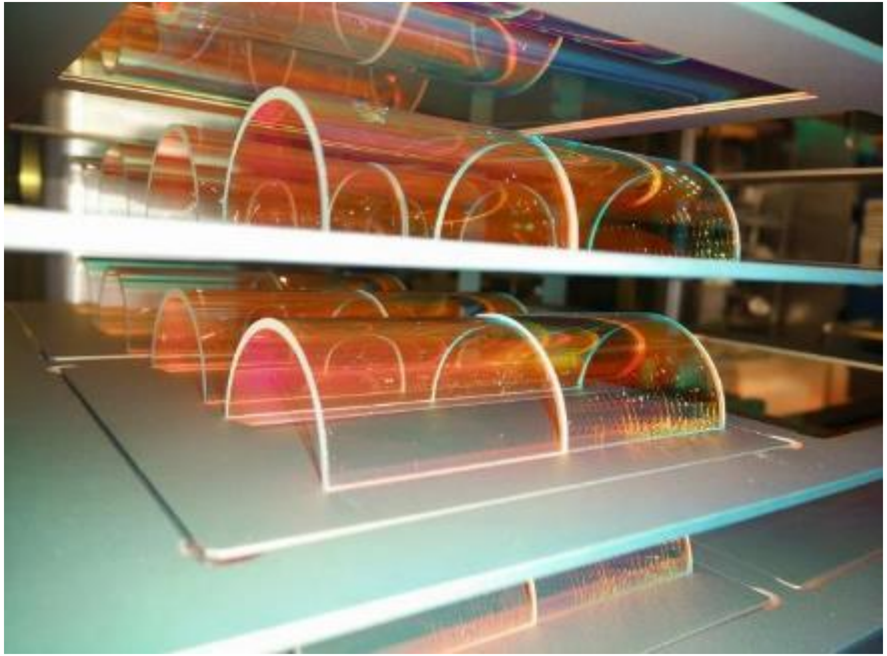


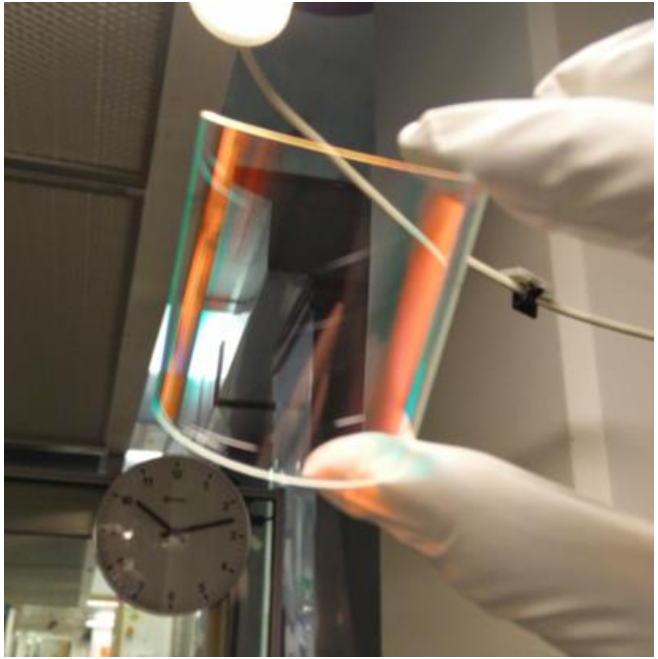
Wafer map example

Wafer	Wafer average thickness (nm)	Wafer σ/ave (%)	Refractive index, ave @633 nm
1	112,08	0,49	1,6465
2	112,06	0,51	1,6465
3	112,08	0,46	1,6464
4	112,11	0,39	1,6464
5	112,09	0,44	1,6464
6	112,10	0,37	1,6463
7	112,12	0,41	1,6464
8	112,11	0,45	1,6463
9	112,09	0,42	1,6463
10	112,13	0,42	1,6463
11	112,14	0,41	1,6462
12	112,11	0,39	1,6462
13	112,15	0,38	1,6463
14	112,18	0,36	1,6462
15	112,20	0,37	1,6464
16	112,23	0,35	1,6463
17	112,22	0,32	1,6462
18	112,26	0,33	1,6462
19	112,33	0,36	1,6462
20	112,36	0,38	1,6463
21	112,40	0,35	1,6462
22	112,46	0,33	1,6463
23	112,52	0,37	1,6463
24	112,62	0,36	1,6462
25	112,67	0,34	1,6463
Ave	***112,23***	***0,39***	***1,6463***

Case study: ALD 3D NIR filters

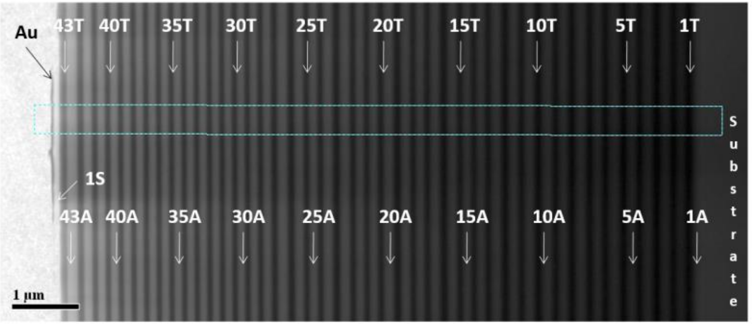
- Optical near infrared structure on inner wall of a glass cylinder.
- CCD vision system



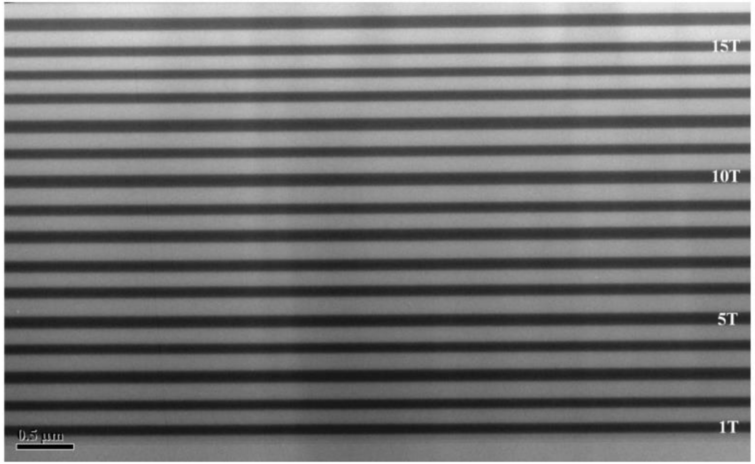


Case study: ALD 3D NIR filters

- ALD process:
- For TiO2 (TiCl4 + H2O)
- For Al2O3 (TMA + H2O)
- T=240 degrees



Layers 1-16

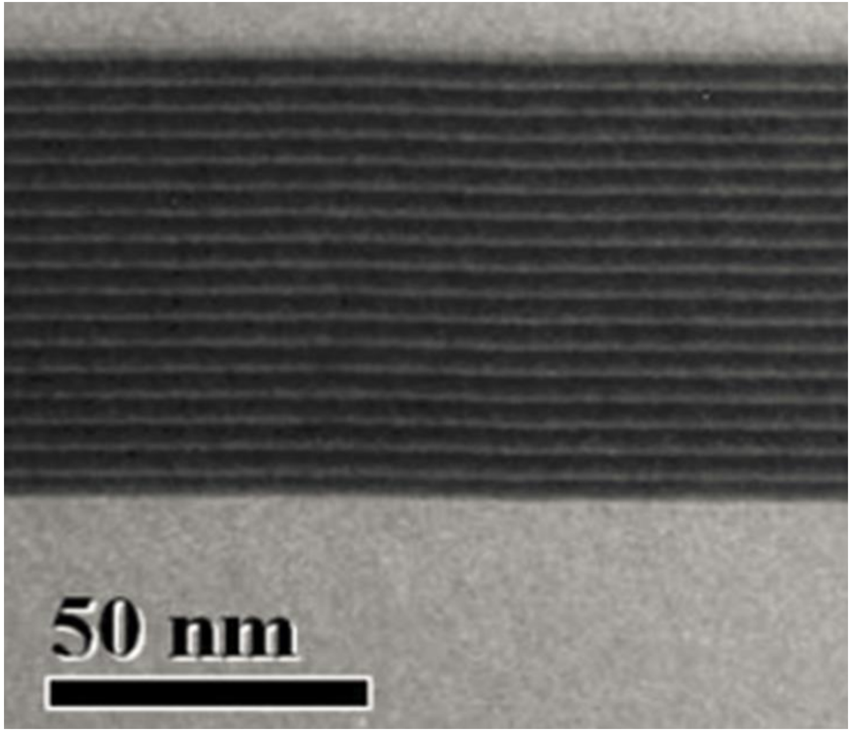


Al2O3 – AlxTiyOz – TiO2
Structure: 86 layers alternating Al2O3/TiO2

Case study: ALD 3D NIR filters

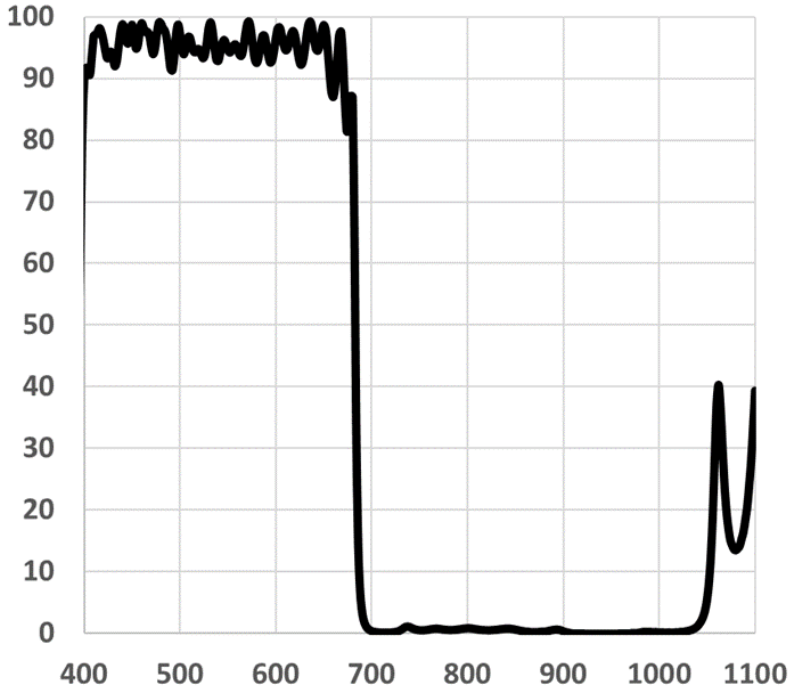
Al2O3 – AlxTiyOz – TiO2
77 layers alternating Al2O3/TiO2 = 5.45 μm

- TiO2 in-situ modification (Al or Si)
- Interface modification by AlCl3+H2O based Al2O3
- Cutting layer: to prevent crystallization of TiO2 by 0,6 nm Al2O3 every 4 nm



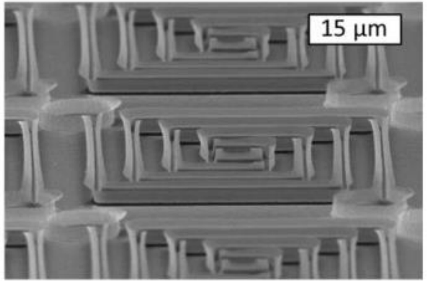
Case study: ALD 3D NIR filters

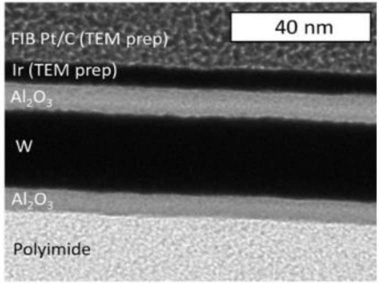
- Optical transmission for NIR filter.
- T(vis) > 90 %
- Cut-off 3 %
- Transmission depends on viewing angle



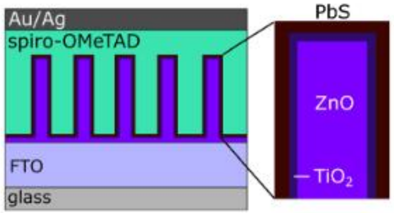
Examples of ALD films in IR-sensing

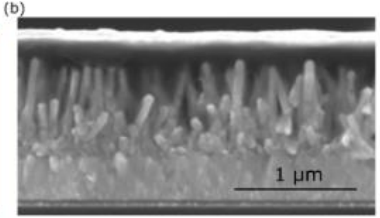
- Microbolometer[1]
  - Al_2O_3 / W / Al_2O_3
  - Al_2O_3 / Ru / Al_2O_3
- Short Wavelength Photodetector[2]
  - ALD TiO_2 / ALD PbS on ZnO nanowires





Figures from [1]



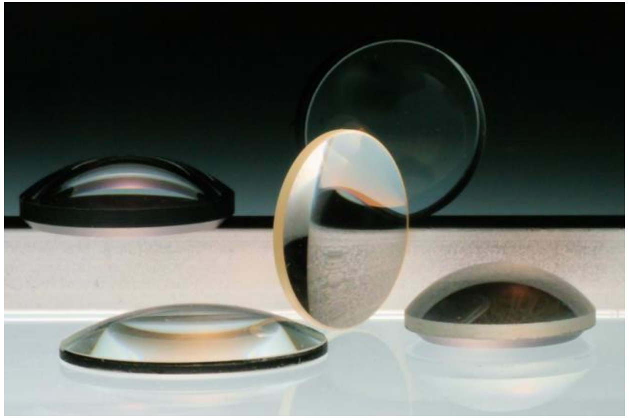


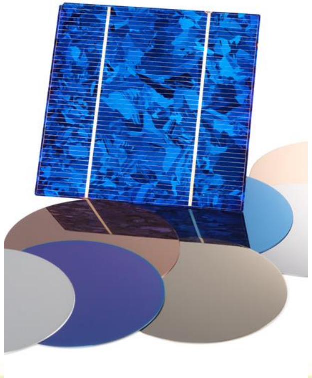
Figures from [2]

[1]Eigenfeld, Nathan Thomas. "*Ultra-thin Materials from Atomic Layer Deposition for Microbolometers*" (2015). *Mechanical Engineering Graduate Theses & Dissertations*. 114.
[2]Xu et al. 2015. Atomic layer deposition of absorbing thin films on nanostructured electrodes for short-wavelength infrared photosensing. Applied Physics Letters 107.

ALD for IR optics

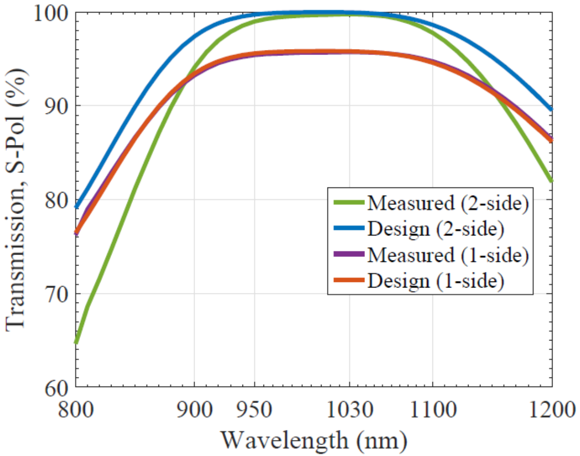
- ALD available for multiple imaging applications (hyperspectral, thermal)
- Digital and stable ALD process: management of coating thickness for target wavelength (filter thickness <-> wavelenght)
- Many of the traditional ALD lossless VIS-region film materials extend well to the IR
  - ZnS -> 25 µm
  - Al_2O_3 -> 9 µm
  - TiO_2 -> 12 µm
  - SiO_2 -> 8 µm

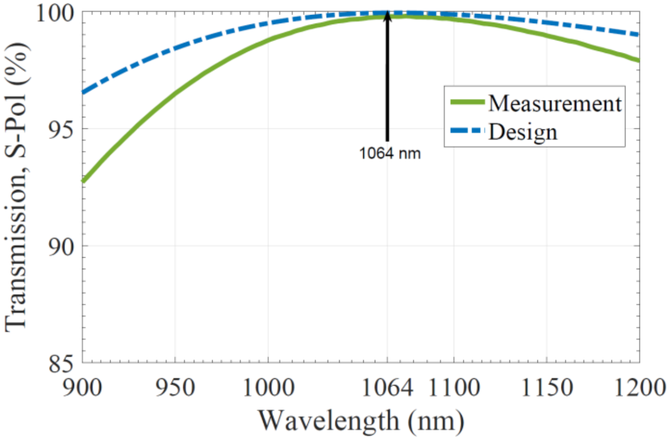




Near-infrared anti-reflective coatings

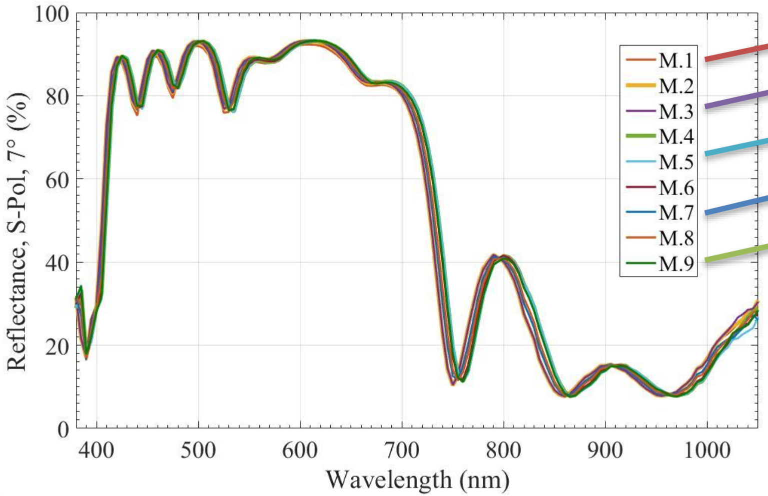
- High transmission into substrate, low reflection from surface
- Typically T > 99.9 %, very low losses, suitable for lasers
- Curved, complex shapes easily coated
- Can be used for functionalization of structures with high aspect ratios



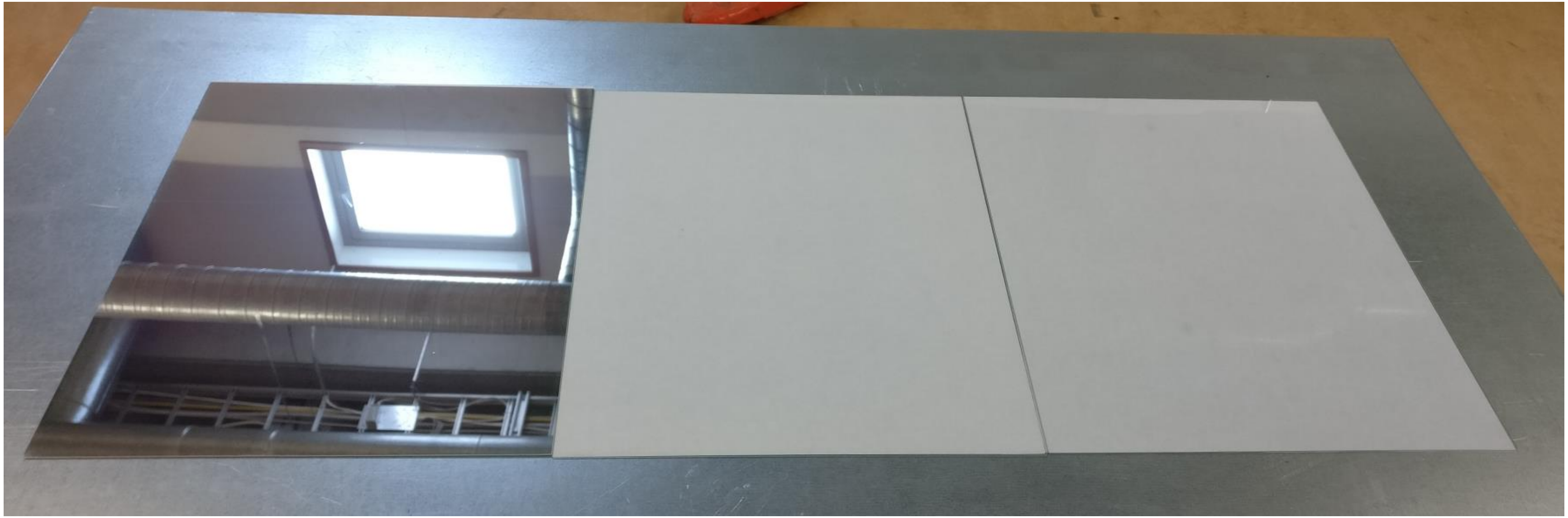


ALD Example - Mirrorlike infrared-pass filter (1/2)

- It is also possible to combine the visual look and infrared properties with thick filters (> 1 µm)
- Shown a glass coated with ALD ZnS-Al_2O_3 to look like a mirror – passes IR radiation through
- Large substrates possible (e.g. 400 x 500 mm glass)



ALD Example - Mirrorlike infrared-pass filter (2/2)



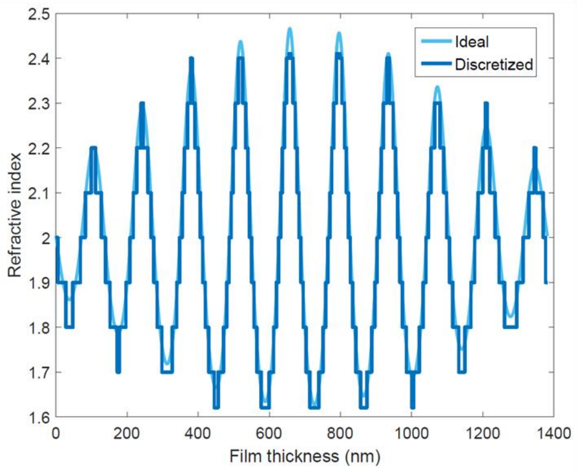
Mirrorlike IR-pass filter

Uncoated glass

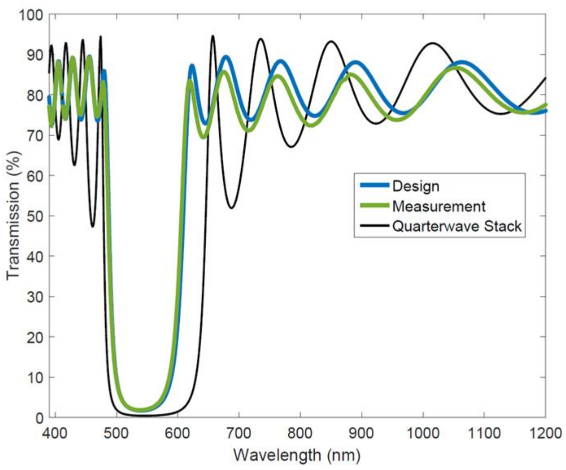
AR coating

ALD Example – Rugate notch filter

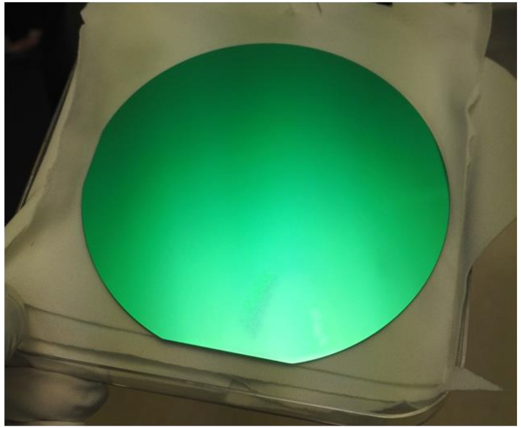
137 equivavalent bilayers



Index profiles



Performance



Filter on Si wafer

Excellence in ALD – Thank You!