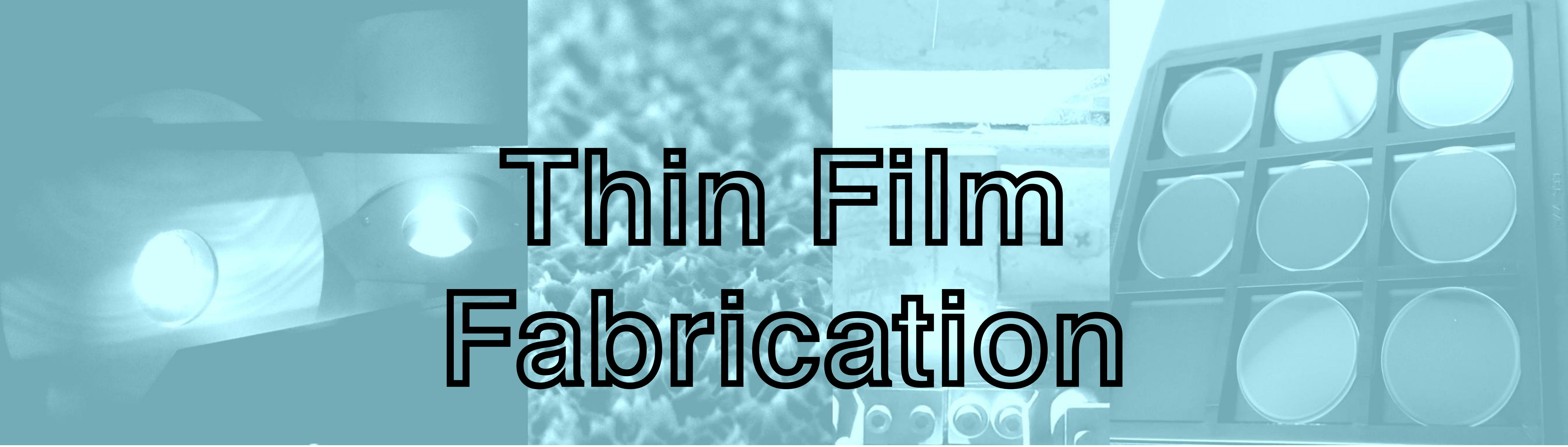


Thin Film Fabrication

Guest Lecture:

FYS.510: Optical thin films and waveguides

DSc Jarno Reuna

OCRICOM Oy

Introduction:

OCRICOM

Optical Coatings Research & Innovation Company

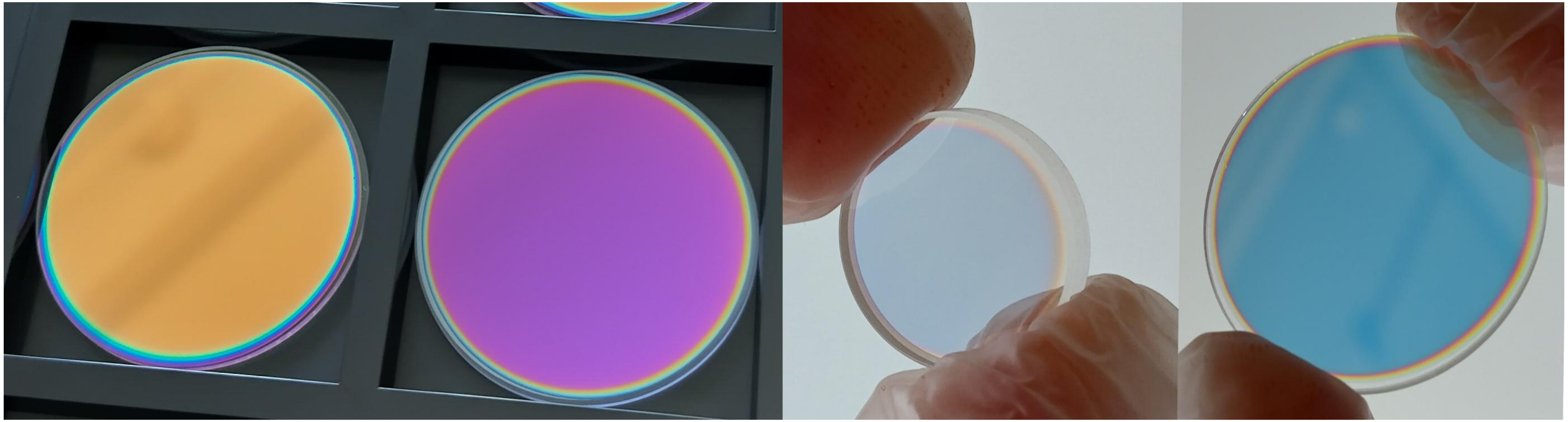
- Founded in Oct 2023, began operation in 1.1.2024.
- Background at Tampere University Optoelectronics Research Centre (ORC).

- Co-Founder, CEO, DSc Jarno Reuna
- Tekniikankatu 1, D132, 33720 Tampere
- www.ocricom.com

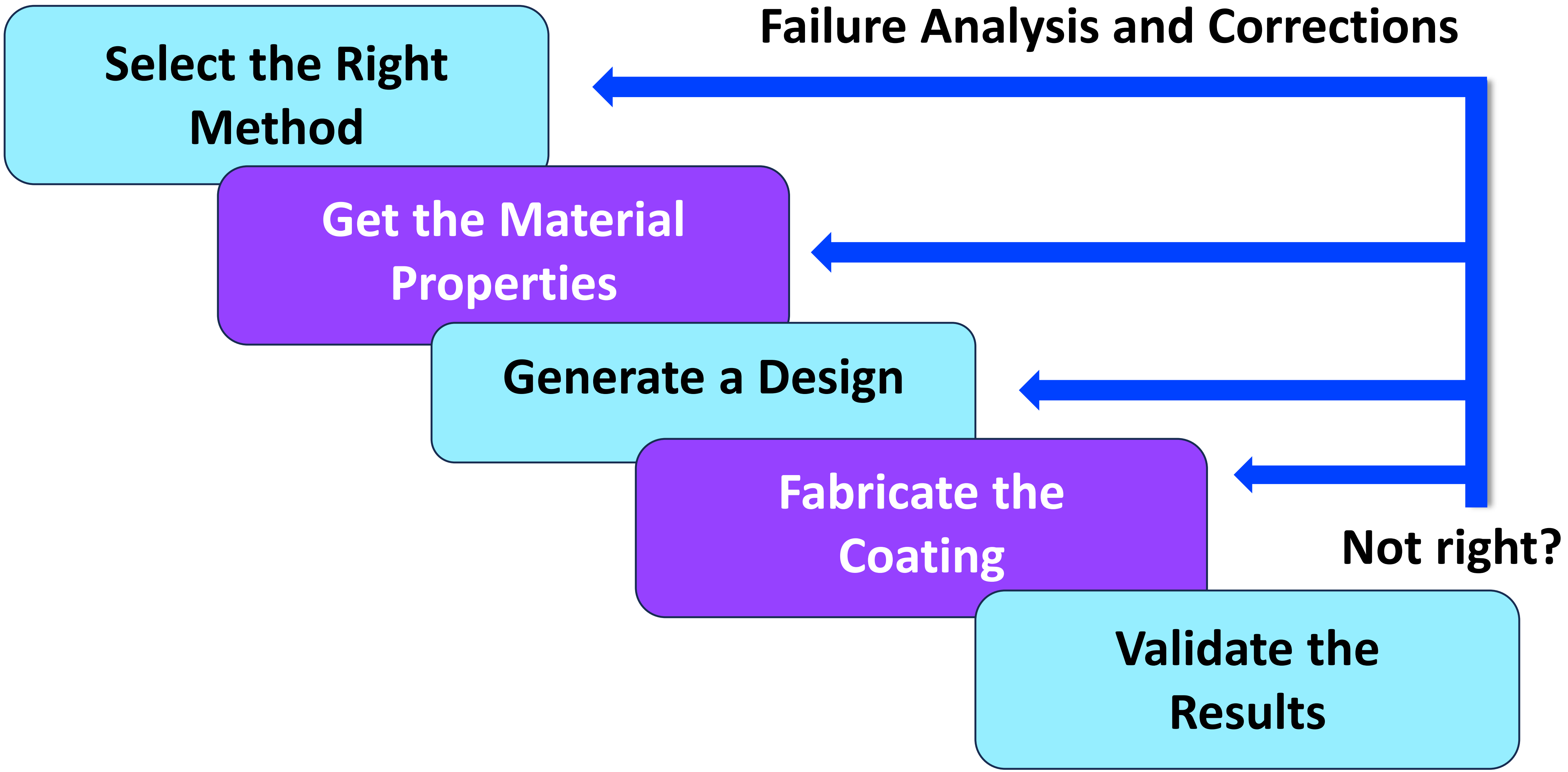
In short:

Optical Coatings, Thin Film Deposition, Ion Beam Sputtering, Electron Beam Evaporation, Cleanrooms, PECVD, ALD, AFM, Design, Photonics, Research, Consultation, III-V Semiconductors, System Sales

Outlook



Coating Fabrication: Simple Process Flow



Thin Film Fabrication Methods

Physical

Physical Vapor Deposition (PVD)

- **Evaporation**
  - **Electron Beam**
- **Sputtering**
  - **Ion Beam**

Chemical

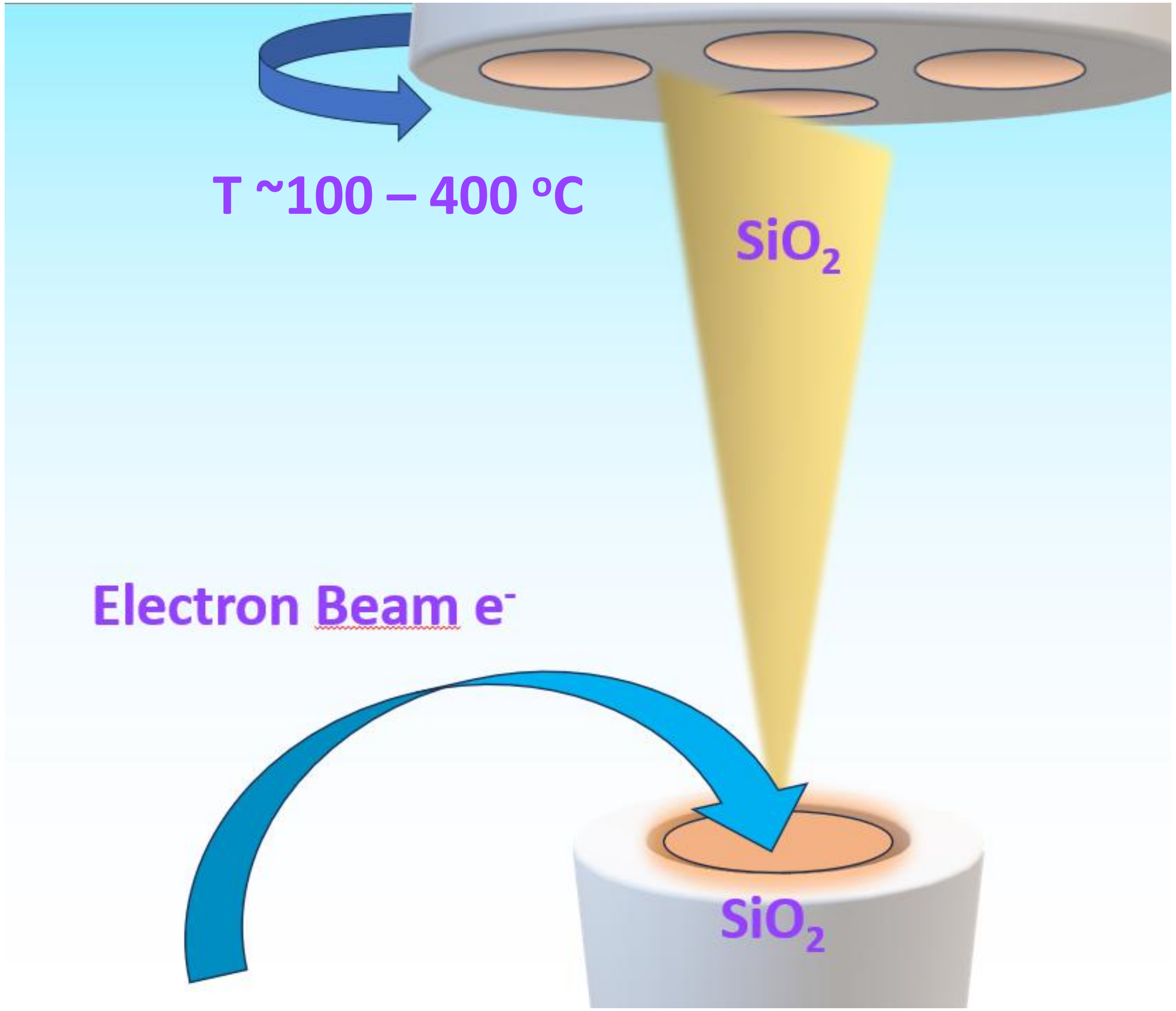
Chemical Vapor Deposition (CVD)

- **PECVD**
- **ALD**

Sol-gel

Plating

Electron Beam Evaporation



Pros

+ **Low** Cost, Losses, amount of target material
+ **Moderate** Deposition rate

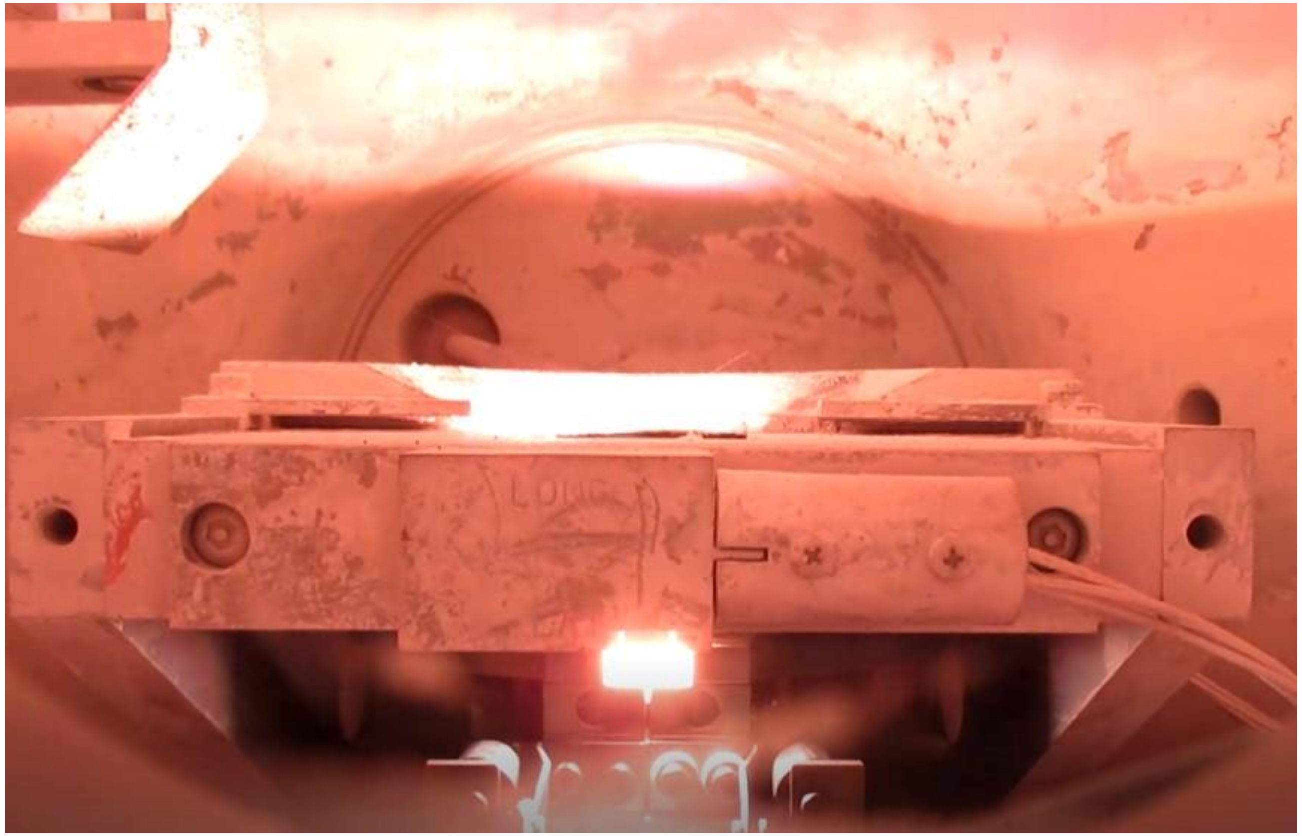
Cons

- **High** Deposition Temperature for Oxides
- **Porousness =>** issues with humidity

OCRICOM

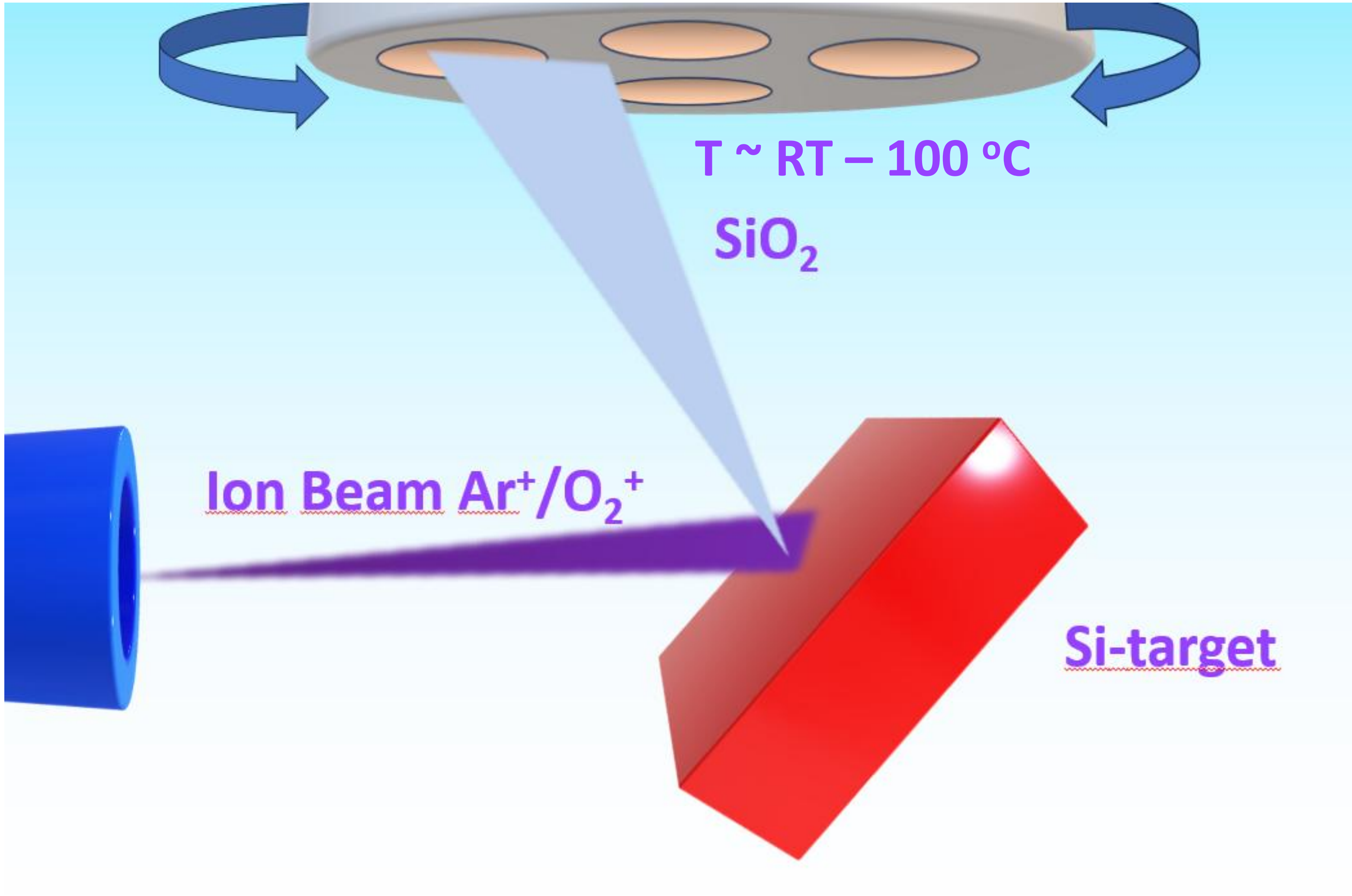
EBE

- **Electron Beam Evaporation** is still the industry work-horse in thin film deposition, largely due to its established status and moderate pricing versus its versability.
- **Suitable for a large variety of materials** Oxides, Fluorides, Sulfides, Metals, Semiconductors.
- At **TAU** it's possible to deposit at least SiO_2, TiO_2, Al_2O_3, Ta_2O_5, SiO, MgF_2, Si, Bi_2O_3, ZrO_2, Au, Ti, Pt, Ni, Ge, Cr, Ag, Al, (ITO).



- **Typical coatings:** Laser mirrors on lenses, Anti-reflection (AR) coatings, High-reflection (HR) mirrors, Laser diode coatings (AR/HR), Passband/Stopband filters, Polarizing coatings, Metal contacts, Metallic mirrors

Ion Beam Sputtering

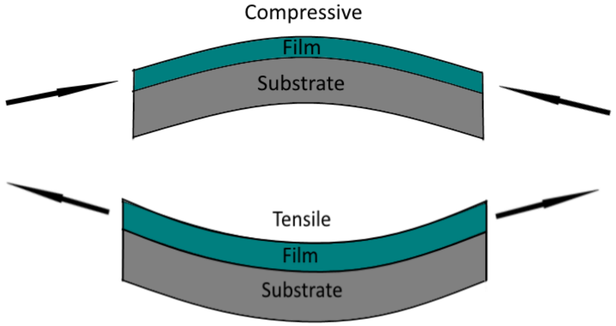


Pros

+ **Low** Loss, Scattering, Deposition Temperature
+ **High** Laser Damage Threshold, Packing Density, Hardness, Controllability

Cons

- **High** Intrinsic Film Stress, Cost
- Limited Material Selection

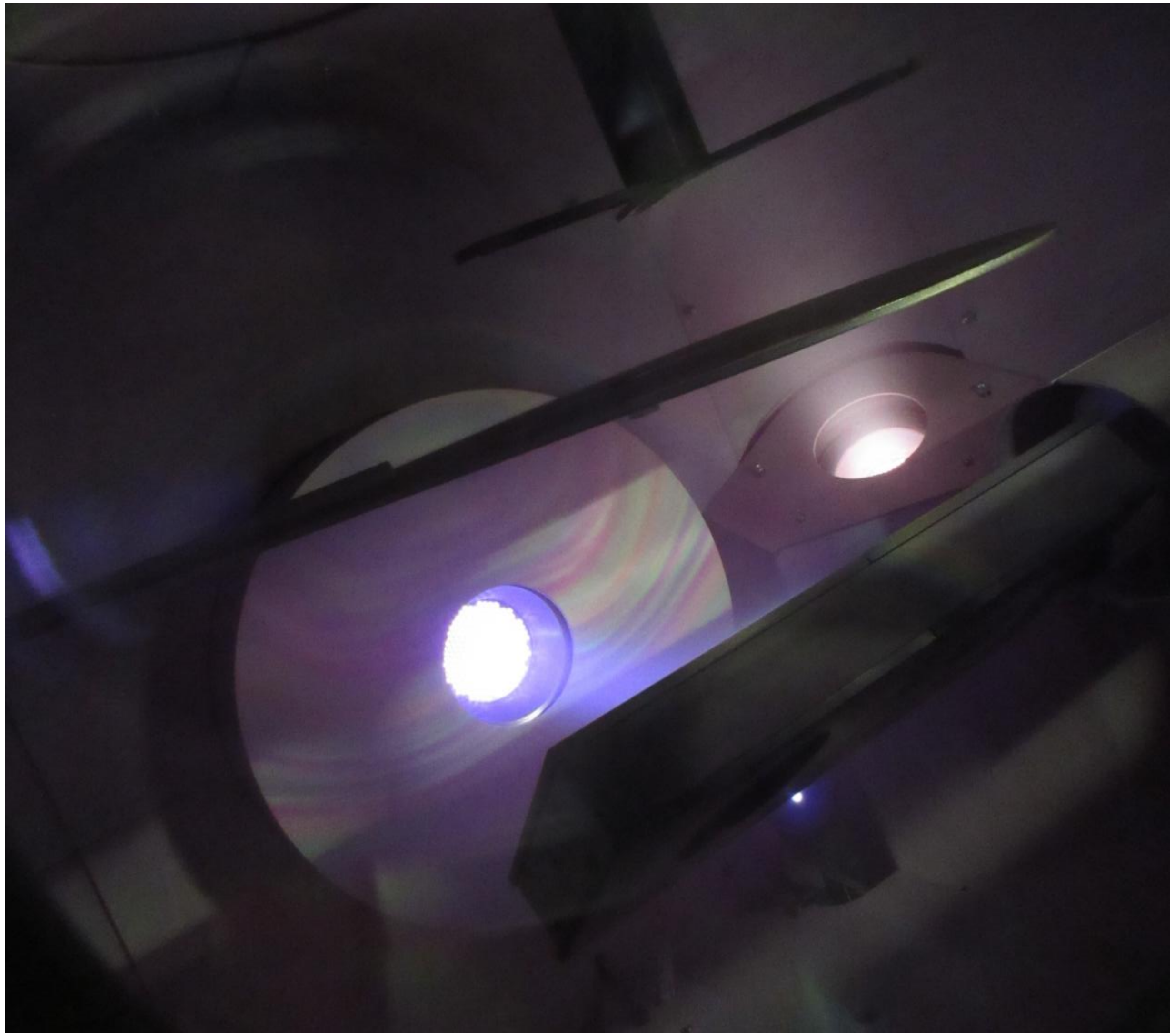


OCRICOM

- We use CEC **Ion Beam Sputtering** system (IBS) that provides top-notch quality coatings for **flat optics**.

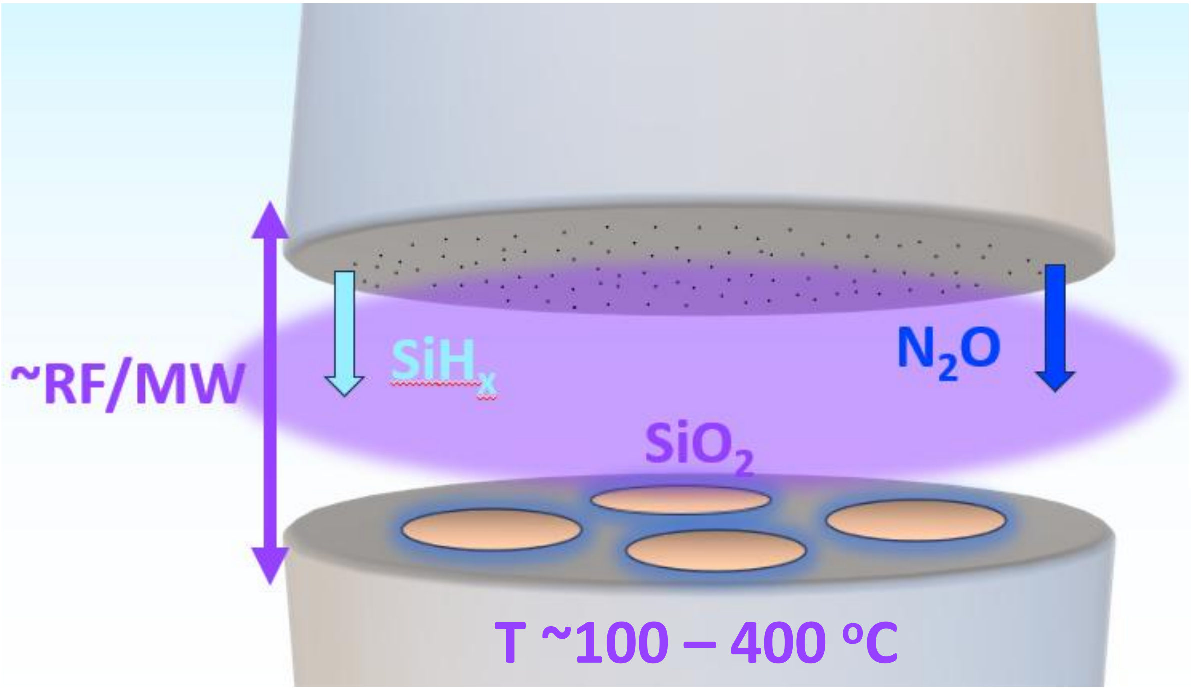
- Equipped with a secondary ion source (N_2, O_2, Ar, H_2) for cleaning & assisting, and broadband optical monitoring (BBM).

- Available materials at **TAU**: Al_2O_3, SiO_2, Ta_2O_5, TiO_2, AlN_x, SiN_x, (TaN_x, TiN_x) and TaO/SiO, TiO/AlO mixtures



- **Typical coatings:** Laser mirrors on lenses, Anti-reflection (AR) coatings, High-reflection (HR) mirrors, Laser diode coatings (AR/HR), Passband/Stopband filters, Polarizing coatings

Plasma Enhanced Chemical Vapor Deposition



PECVD SiNx:

$SiH_x + NH_x \rightarrow SiN_x\ (+H_2)$

or $SiH_x + N \rightarrow SiN_x\ (+H_2)$

PECVD SiOx: $SiH_x + N_2O \rightarrow SiO_x\ (+H_2 + N_2)$

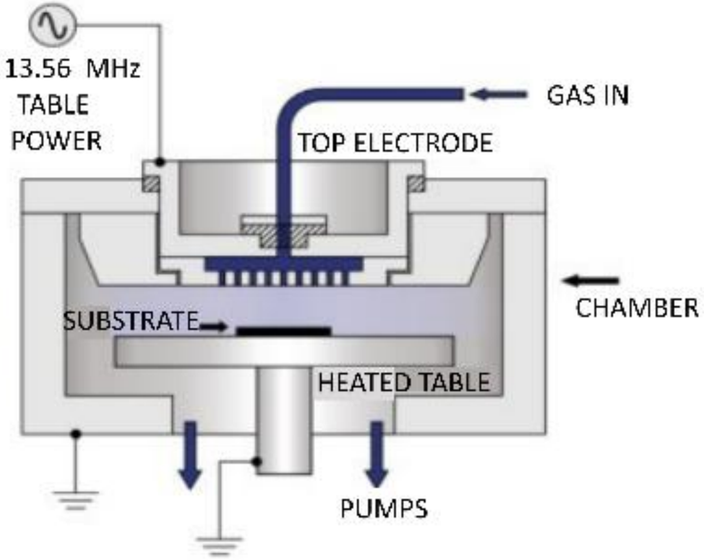
Pros

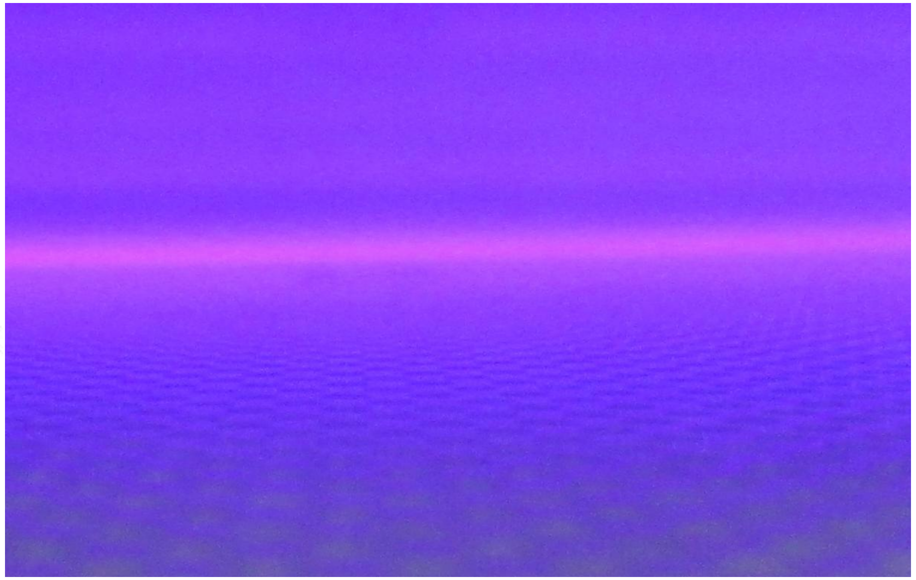
+ **Low** Cost
+ **High** Deposition rate, Packing Density (parameter dependent)
+ Somewhat conformal
+ Large area coatings (ie. Photovoltaics)

Cons

- Samples are in contact with the plasma
- **High** Deposition temperature
- Incorporation of by-products

PECVD





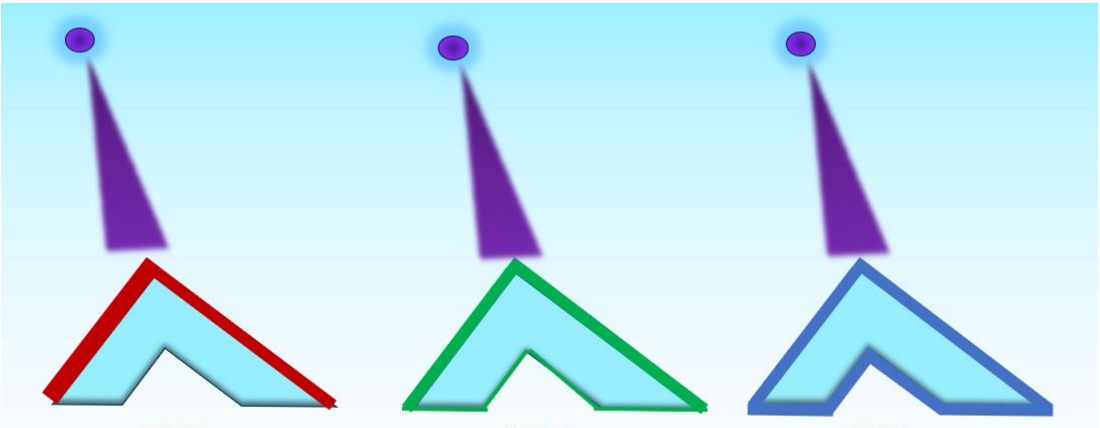
- At **TAU**, capable of depositing SiO_2 and SiN_x and cleaning/activating with NH_3 and N_2 plasma processes.
- **Typical coatings:** Single-layer films, Hard masks, Anti-reflection (AR) coatings, Passivation layers, Insulating layers

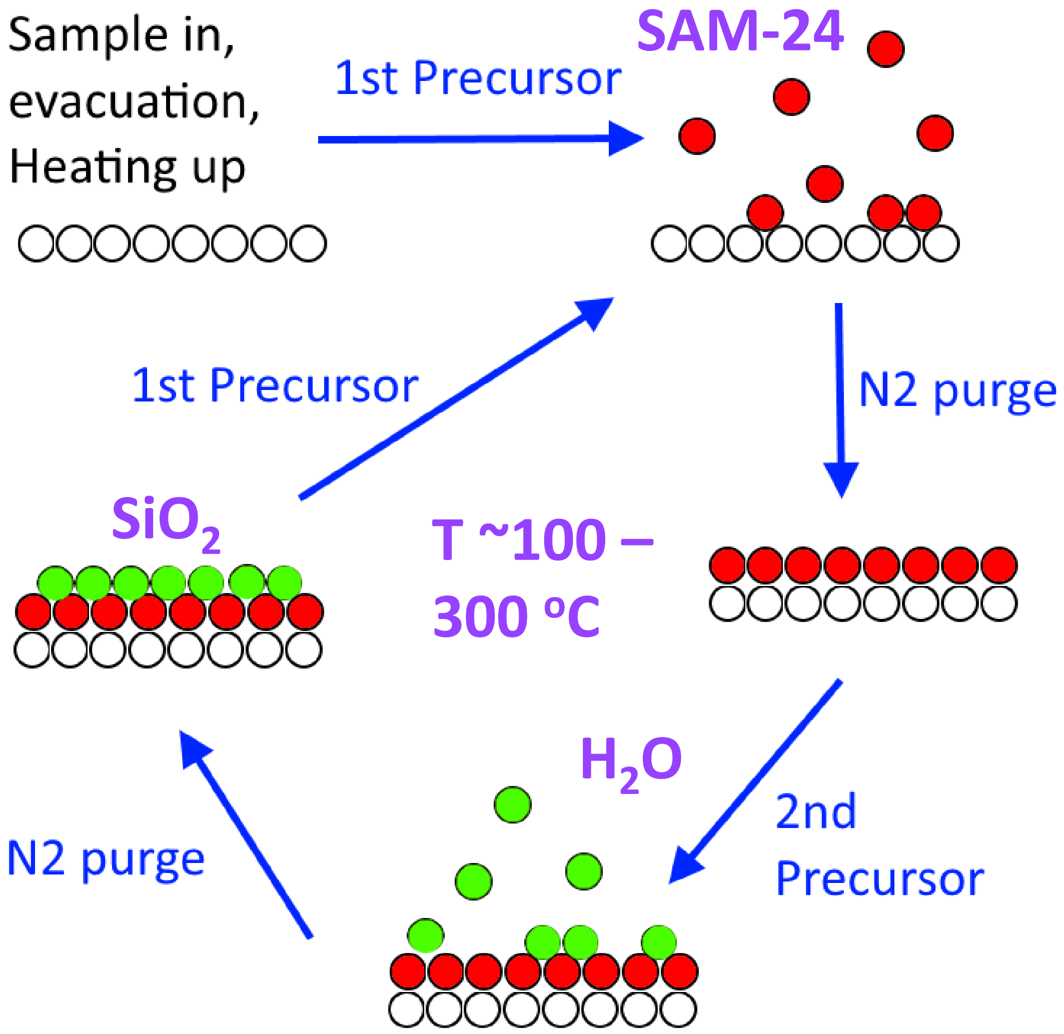
Atomic Layer Deposition

Pros

\+ **Uniform** conformal coatings

\+ **Low** intrinsic film stress





Cons

\- **High** Cost

\- **Low** Deposition rate (conventionally) => Slow

OCRICOM

ALD

- Rapidly developing technology with established industry applications.

Combination of PVD and ALD

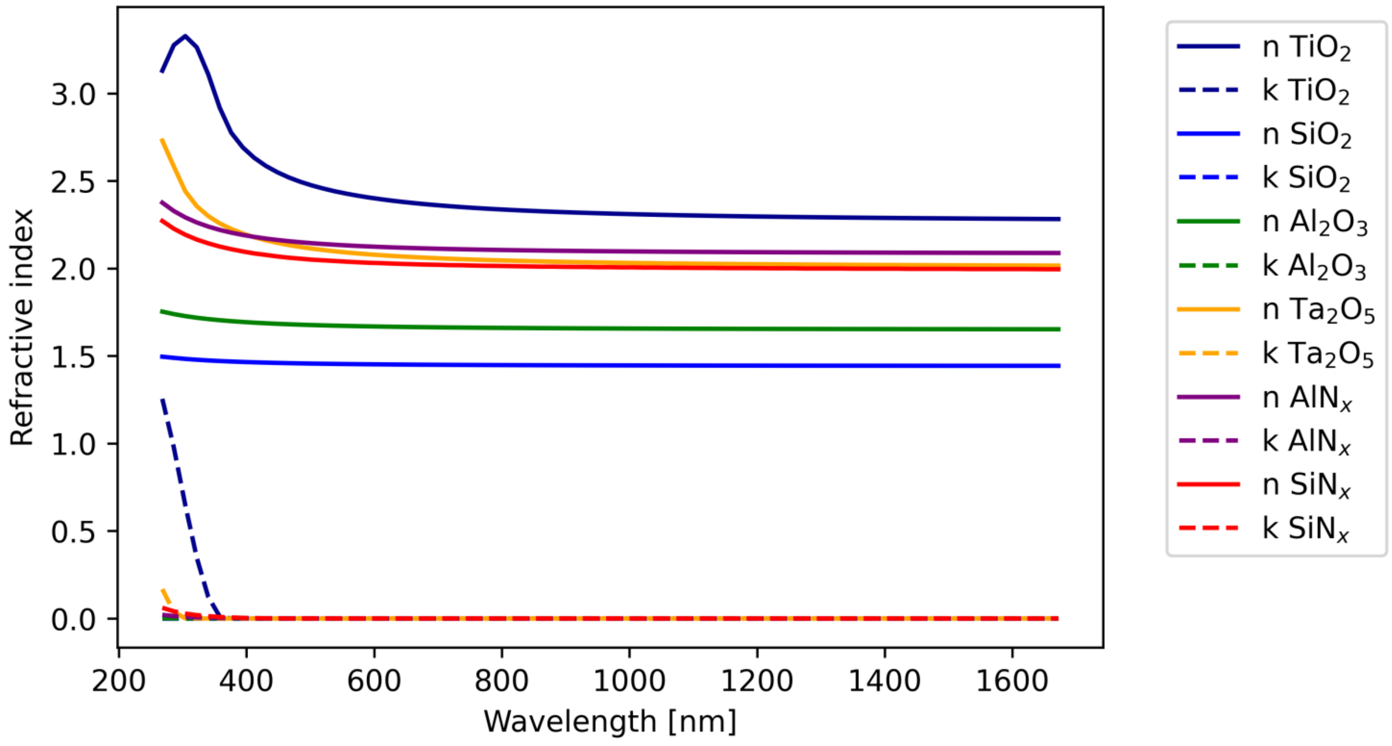
- **Typical coatings:** Conformal coatings, Passivation layers, Insulating layers, Color Coatings, (Optical Coatings)

OCRICOM

Finding out the optical properties

- **Every** system produces a bit different material properties
- **Measure and analyze** test samples from the system you're going to use
- **Few methods:**
  - Ellipsometry
  - Spectrophotometry (R%/T%/A%)
- **Literature Values**

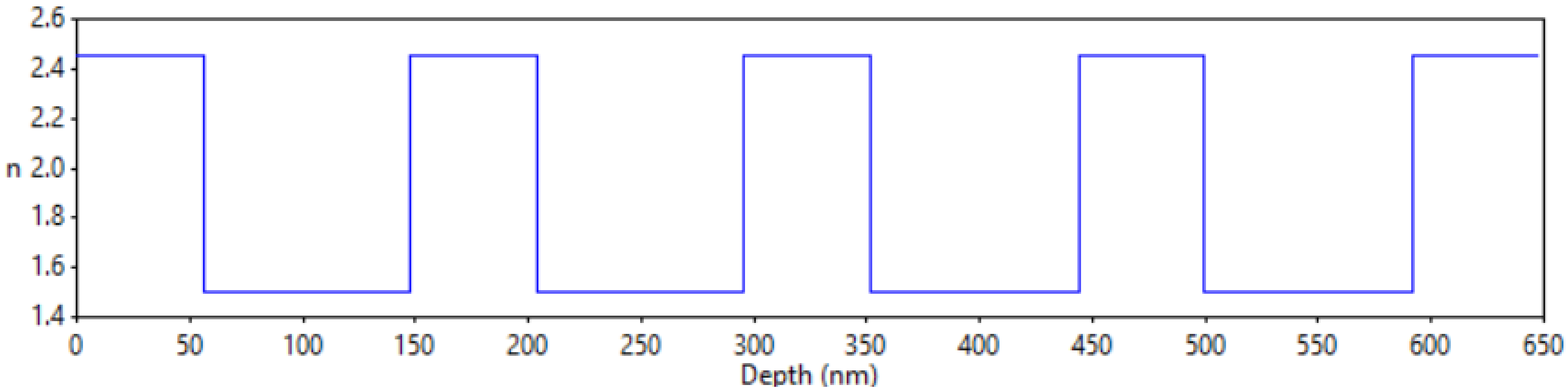
  (refractiveindex.info)



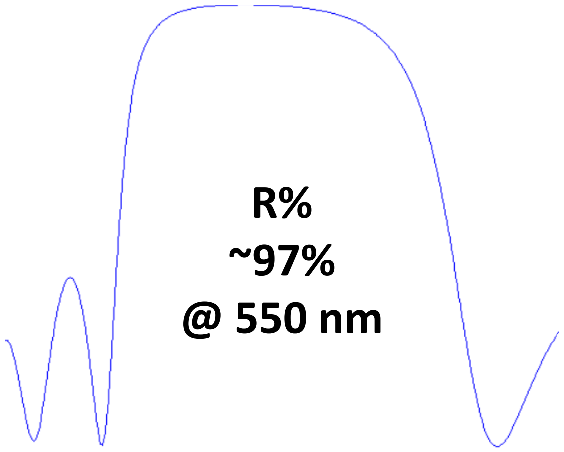
- **Fit the optical properties (*n & k*):**

Linear fit, Sellmeier, Tauc-Lorentz, Effective Medium Approximation

Design



- Start with a **good** starting design:
  - Experience, Books, Publications
- Optimize, Vary design & Reoptimize, Sanity-Check



Available software include efficient algorithms:

- **Commercial**: EssentialMacleod, OptiLayer, FilmStar, OpTaliX, TFCalc
- **Freeware**: OpenFilters, PoCal, Filmetrix, FreeSnell, openTMM

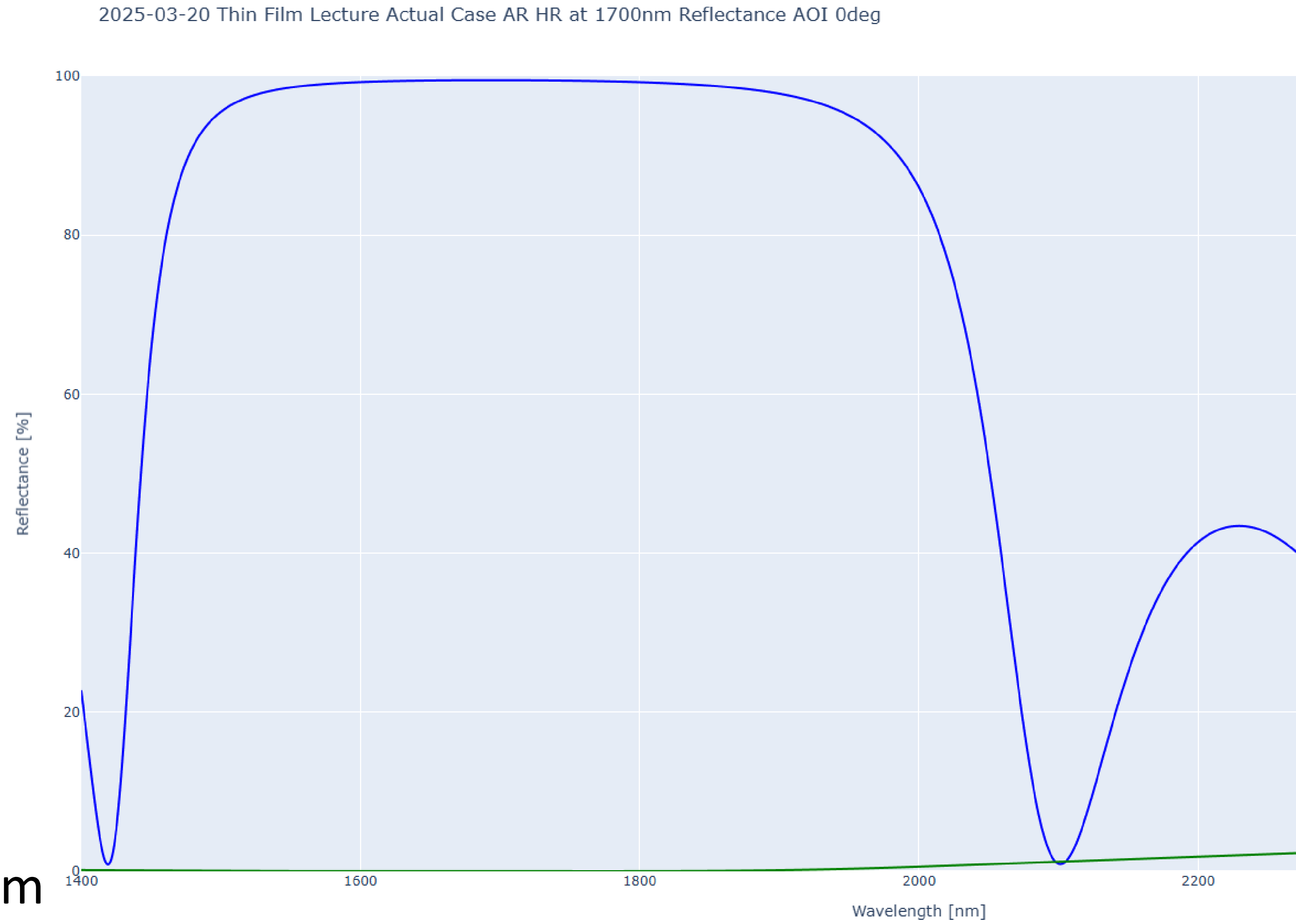
Design Case

- Laser DBR Mirror @1700nm with backside AR on Fused Silica
- **HR**: TiO_2/SiO_2 -DBR

  S | $(HL)^6$H| M
- **AR**: $TiO_2/SiO_2/TiO_2/SiO_2$

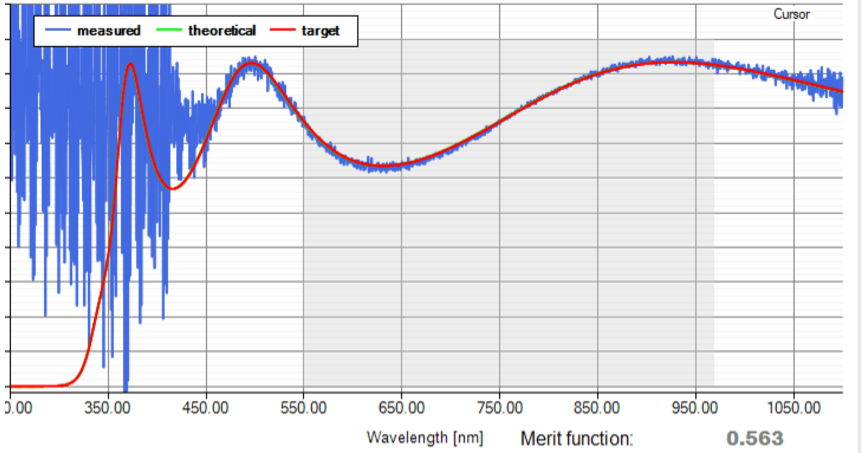
  S | 0.25H 0.3L 1.5H 0.9L | M

- **HR** R% ~99.5%, d ~3µm
- **AR** R% < 0.02%, d~700nm



OCRICOM

Monitoring



Method	**What you get**
• Time	Approximate thickness
• Quartz Crystal Oscillator	Relative thickness
• Optical Monitoring (T%/R%)	Optical thickness (direct performance in limited cases)
• Ellipsometry	Indirect *n* & *t*

Validation

- **The most challenging step** in the process.
- Relatively easy for mediocre targets, but the extreme spectral limits (i.e. R% <0.1% or >99.5%) or very thin layers are difficult to measure directly.
- The target bandwidth places limitations as well. UV and IR ranges require their own specialized setups.
- **Very often**: Does the application work where the coating was needed? Yes? => **Good enough!**

Thank you!

Questions?

Slides available: https://www.ocricom.com/downloads/

Literature

- **H. A. Macleod**, "**Thin-Film Optical Filters**", 2017, ISBN: 978-1-315-27049-4, DOI: https://doi.org/10.1201/b21960
- **R. R. Willey**, "**Practical Design and Production of Optical Thin Films**", 2000, ISBN: 0-8247-0849-0, DOI: https://doi.org/10.1201/9780203910467
- **Z. Knittl**, "**Optics of Thin Films:** ", 1976, ISBN: 0-471-49531-X
- **H. K. Pulker**, "**Coatings on Glass**", 1999, ISBN: 978-0-444-50103-5, DOI: https://doi.org/10.1016/B978-0-444-50103-5.X5000-6
- **P. M. Martin**, "**Handbook of Deposition Technologies for Films and Coatings**", 2010, ISBN: 978-0-8155-2031-3, https://www.sciencedirect.com/book/9780815520313/handbook-of-deposition-technologies-for-films-and-coatings#book-info
- **W. Andrew**, "**Handbook of Physical Vapor Deposition (PVD) Processing**", 2010, ISBN: 978-0-8155-2037-5, DOI: https://doi.org/10.1016/C2009-0-18800-1
- **W. Andrew**, "**Handbook of Thin Film Deposition**", 2012, ISBN: 978-1-4377-7873-1, DOI: https://doi.org/10.1016/C2009-0-64359-2
- **O. Stenzel**, "**The Physics of Thin Film Optical Spectra**", 2005, ISBN: 13 978-3-540-23147-9, DOI: https://doi.org/10.1007/978-3-319-21602-7
- **H. Frey, H.R. Khan**, "**Handbook of Thin-Film Technology**", 2015, ISBN: 978-3-642-05430-3, DOI: https://doi.org/10.1007/978-3-642-05430-3

P. W. Baumeister, "**Optical Coating Technology**", 2004, ISBN: 978-1-315-27049-4, DOI: https://doi.org/10.1117/3.548071