Optical Coatings:
A Short Process Overview

Optical components and high power coatings
for lasers in industry, medicine and research

Outline

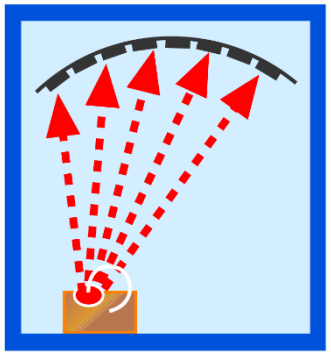
- **Introduction to LASEROPTIK**
- **Coating Technologies – Process Alternatives**
  - Conventional Evaporation (RE / E-Beam)
  - Ion Assisted Deposition (IAD)
  - Ion Beam Sputtering (IBS)
- **Aspects affecting the coating performance**
- **Summary**

Key numbers about LASEROPTIK

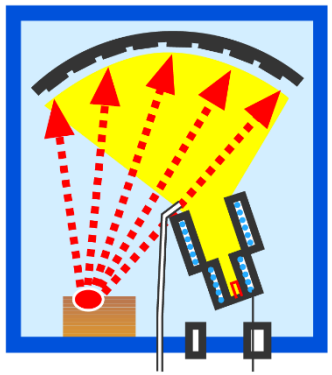
- 1984: founded
- 1998: first ISO:9001 cert.
- >75 employees
- 29 coating machines (9 IBS)
- 4 coating methods
- 157nm – FIR, all coating types
- 24h-Express service
- 1,000+ coatings online in LOOP
- Ø 140,000 coated optics / year

Overview: Coating Technologies

Evaporation

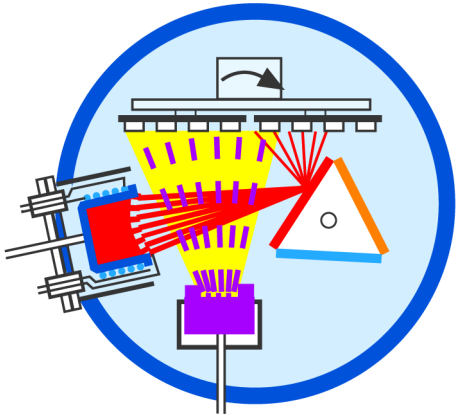


e-beam
+
boat-evap.

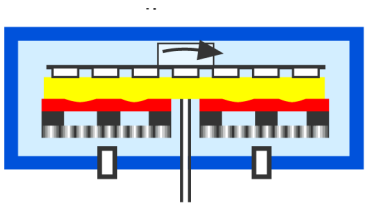


IAD

Sputtering

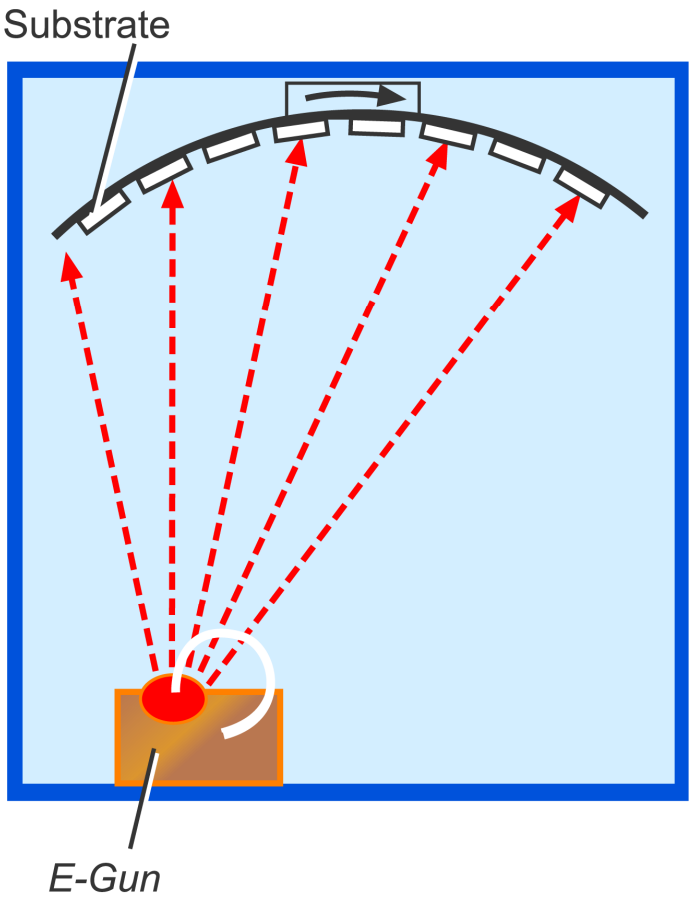


IBS



Magnetron-
Sputtering

Conventional Evaporation (RE / E-Beam)



+ high evaporation rate

+ high LIDT, esp. pulsed

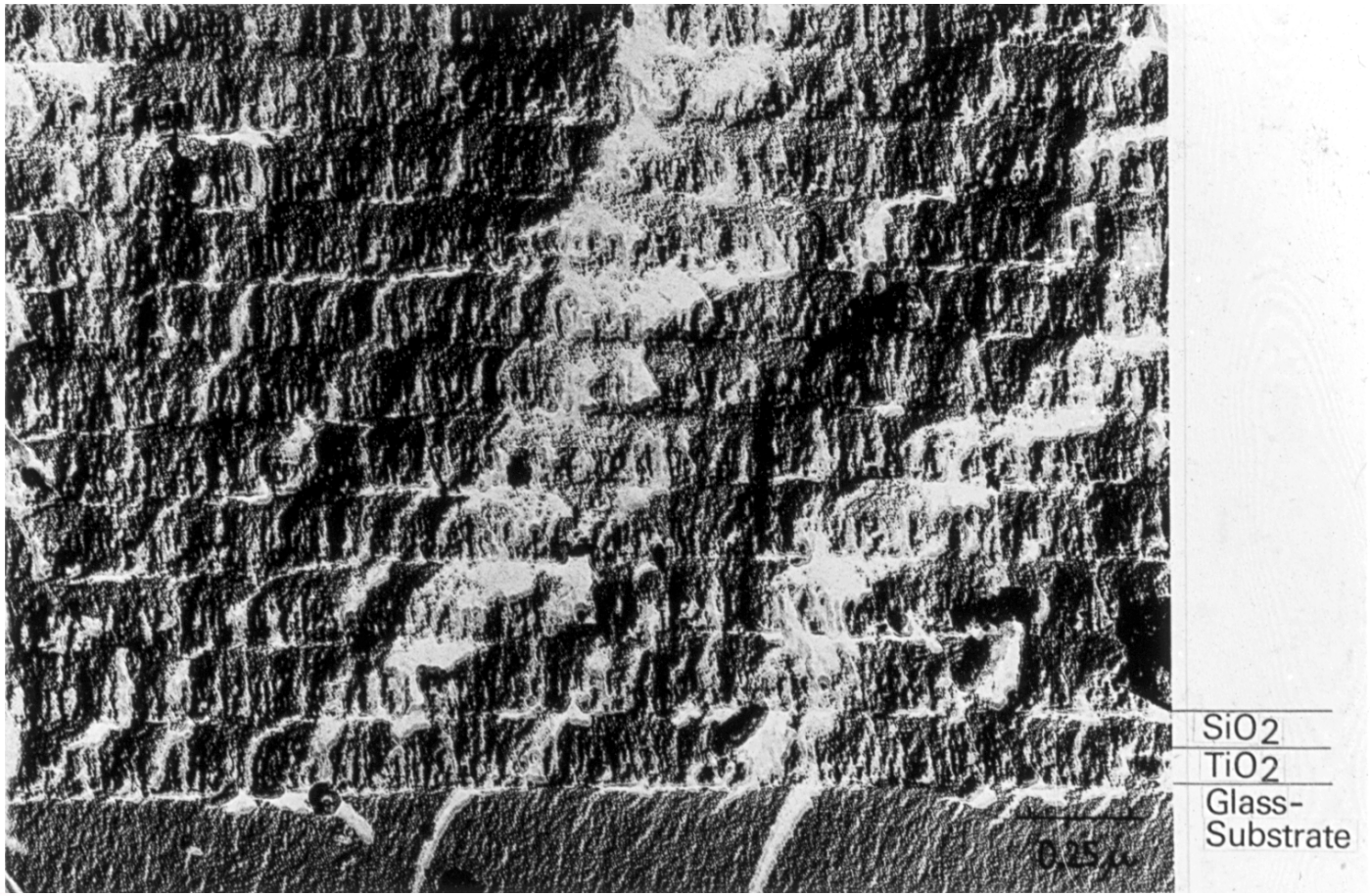
+ DUV to IR

+ cost efficency

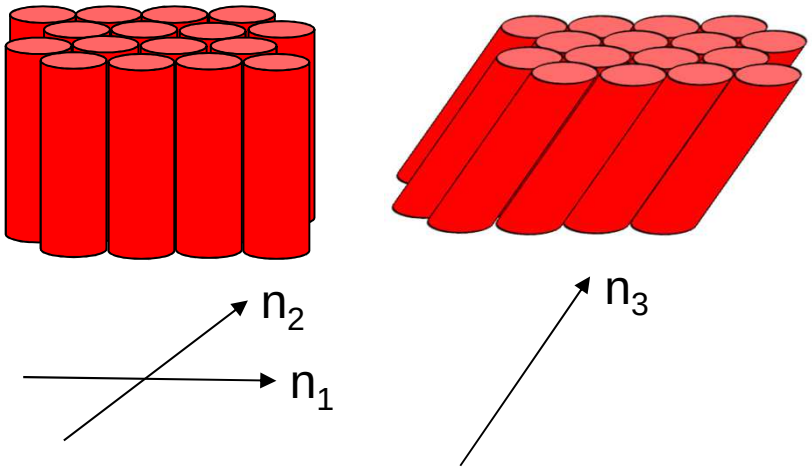
- thermal drift, packing density approx. 75-85% of bulk material

- internal stress (tensile)

Conventionally coated TiO_2-SiO_2 Mirror



Structure-related birefringence[1]

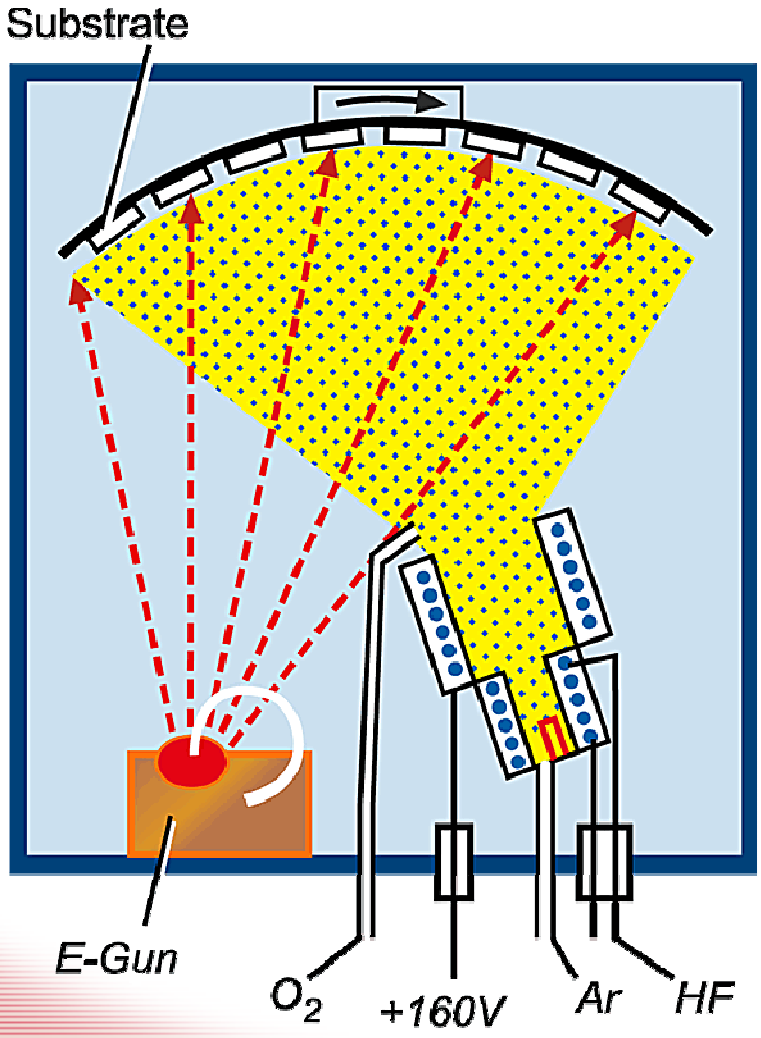


- Two axes normal to the columnar axes (n_1, n_2) one axis along the columnar axis (n_3)
- Tilt in the angle of vapor incidence (α) results in a tilted column orientation angle (β)
- Highest refractive index along the columnar axis (n_3)
- Tilt reduces the achievable refractive index

Material	α	β	n_1	n_2	n_3
ZrO_2	30°	16.1°	1.948	1.969	2.033
ZrO_2	65°	47.0°	1.502	1.575	1.788
TiO_2	30°	16.1°	2.452	2.452	2.552

[1] H.A. Macleod, J. Vac. Sci. Technol. A **4**, 3 (1986)

Ion Assisted Deposition (IAD)



+ high packing densitiy, approx. 95% of bulk material

+ stress can be modified

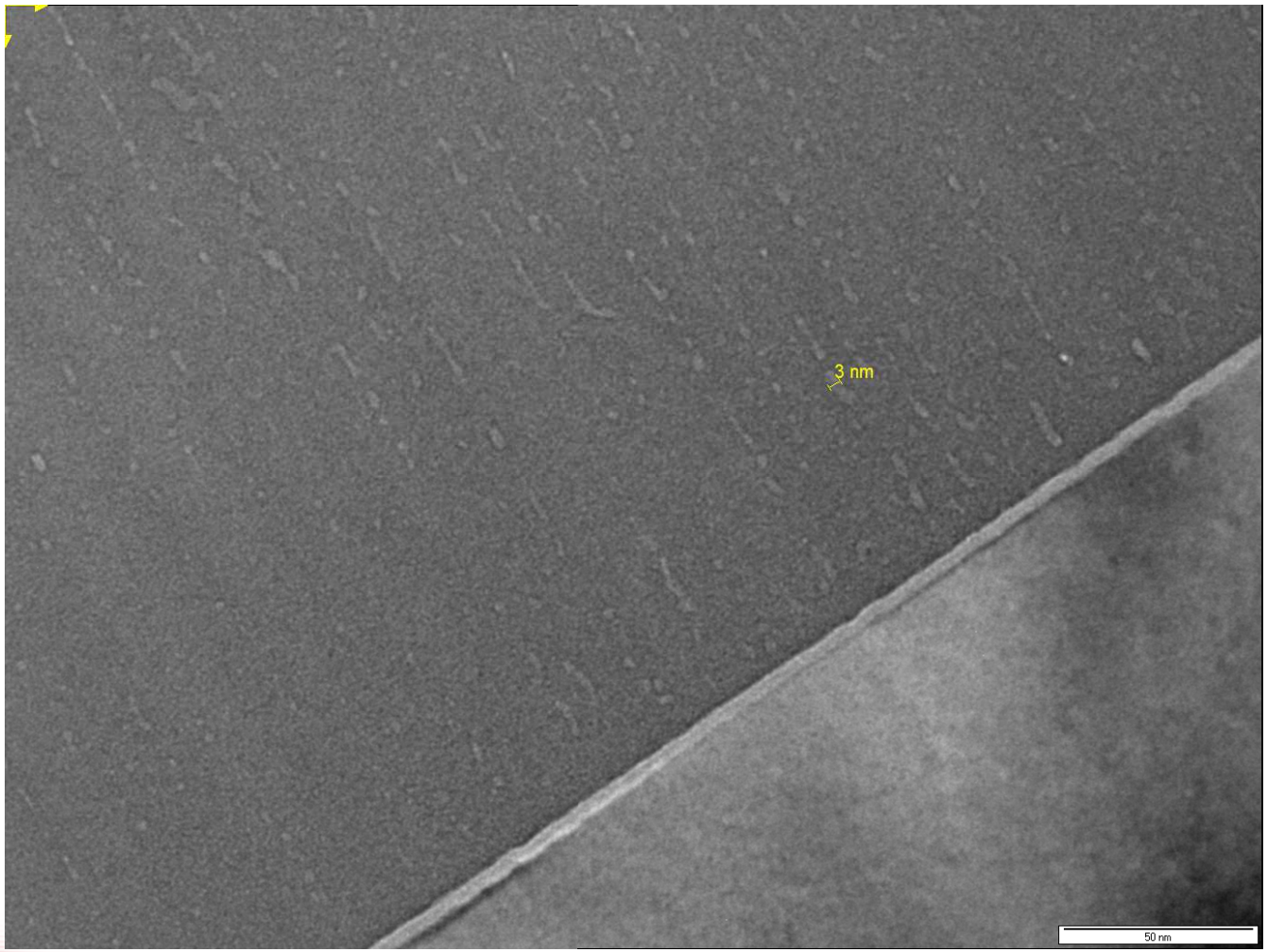
+ high deposition rate

+ high precision

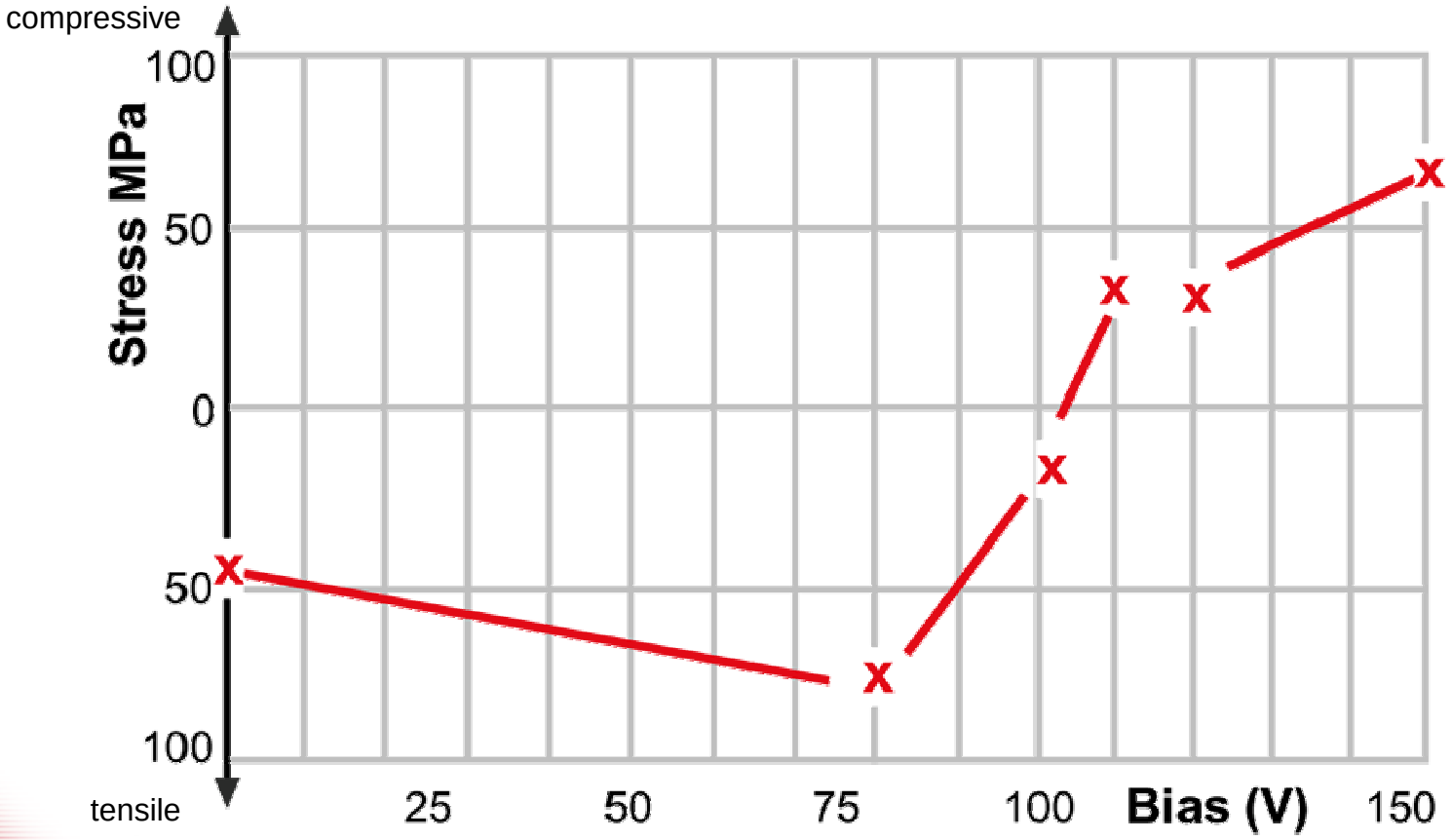
± VIS/NIR: LIDT ~ e-beam

PDS

IAD-Nb_2O_5-Film (TEM)

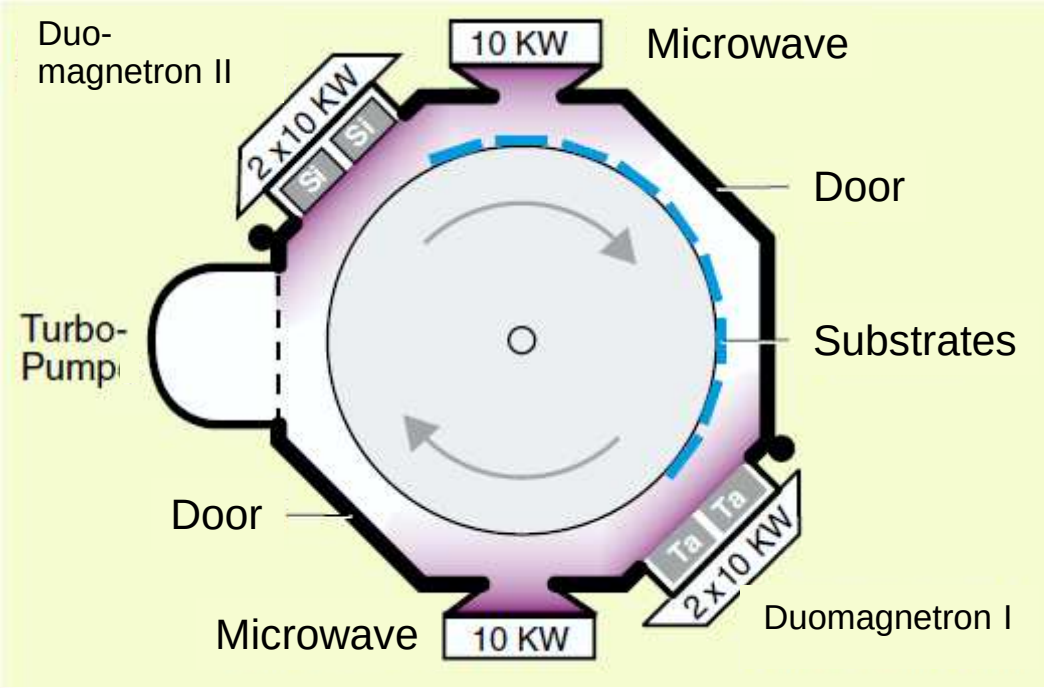


Coating stress depending on Ion-assist (Bias-Voltage)



7 Layers HfO_2-SiO_2 1064 nm from Hf-Metall deposited on fused silica. Substrate temperature approx. 200 °C

Magnetron-Sputter-Machine with Duo-Magnetrons

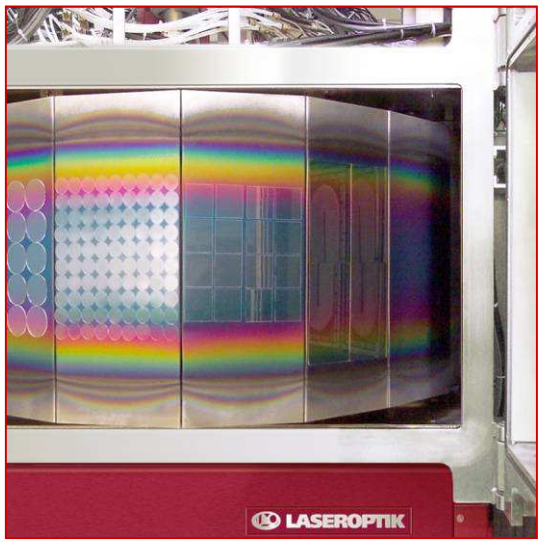


+ very dense and hard Layers, suitable for spaceborn applications

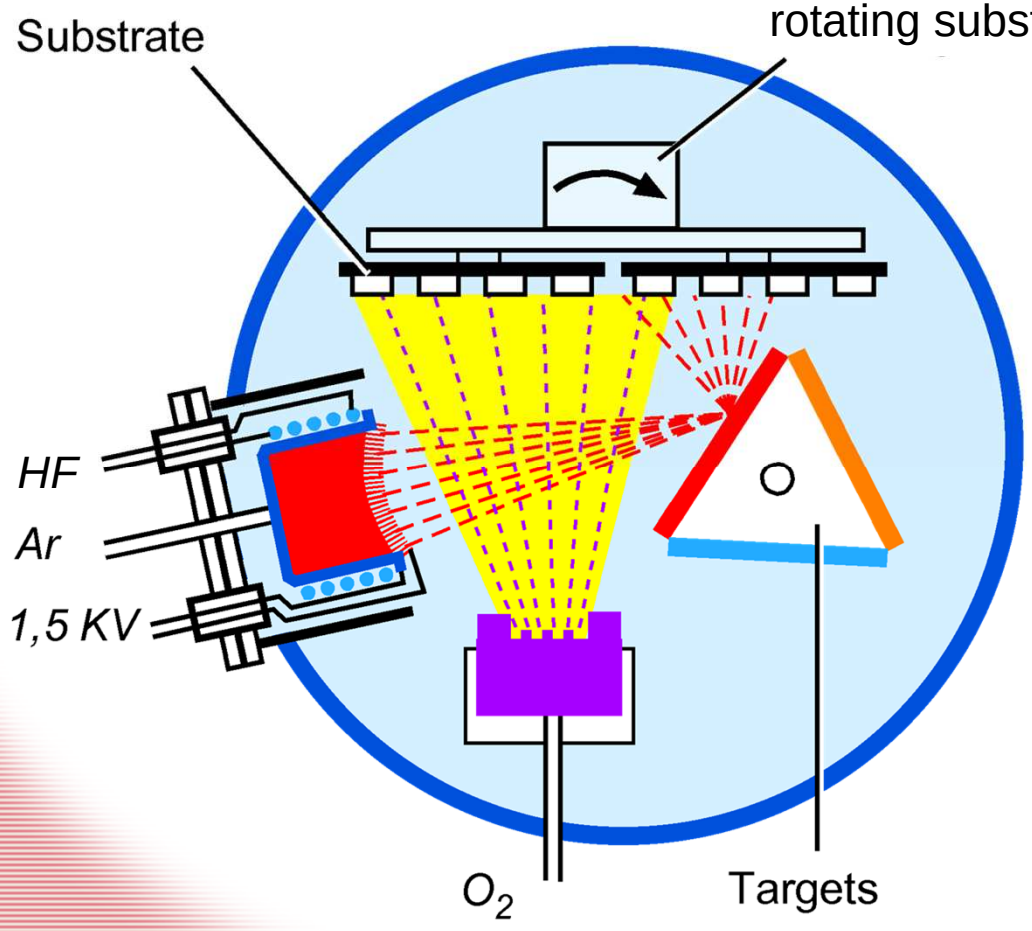
+ high precision

+ high LIDT for UV-Coatings and cw-applicationd

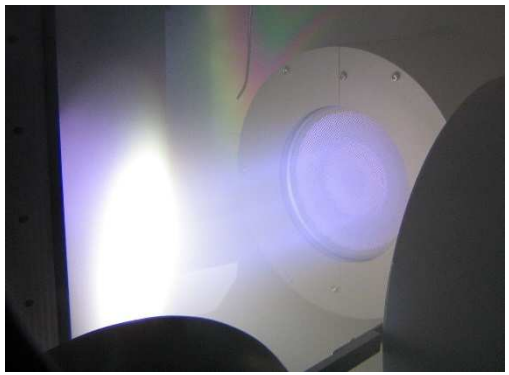
– compressive stress



Ion Beam Sputtering (IBS)

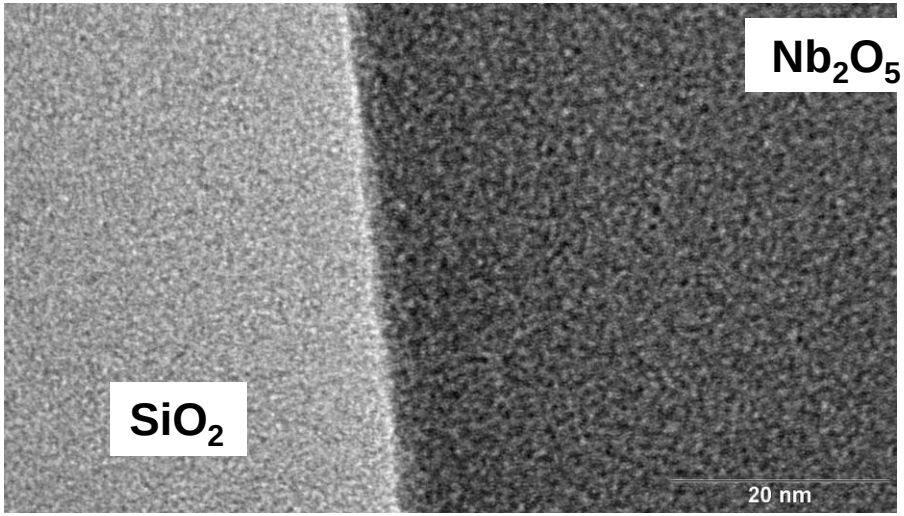


+ excellent microstructur
+ high density
+ highest precision
+ lowest losses
– compressive stress
  (compensation possible)
– low rates und small areas



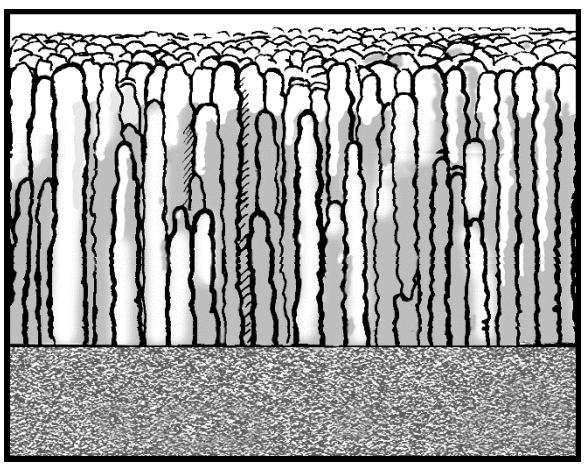
IBS-Coating with amorphous structure (TEM)

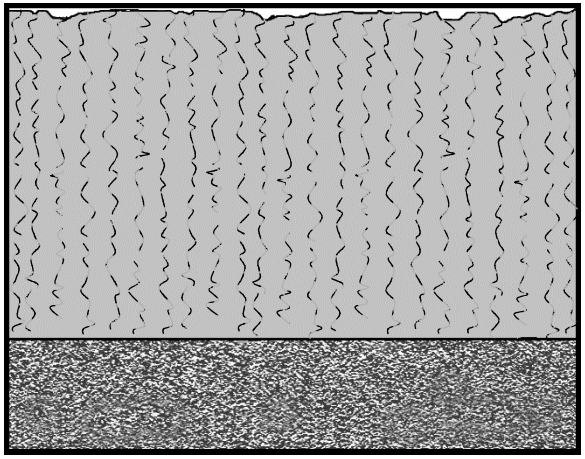
Bandpasscoating



Zoom

Layer Structure (schematic)





without assist:
columnar structure
– thermal drift
– tensile stress

RE (EBE + TE)

intermediate assist:
nano-cavities
± better thermal stability
+ intrinsic stress variable

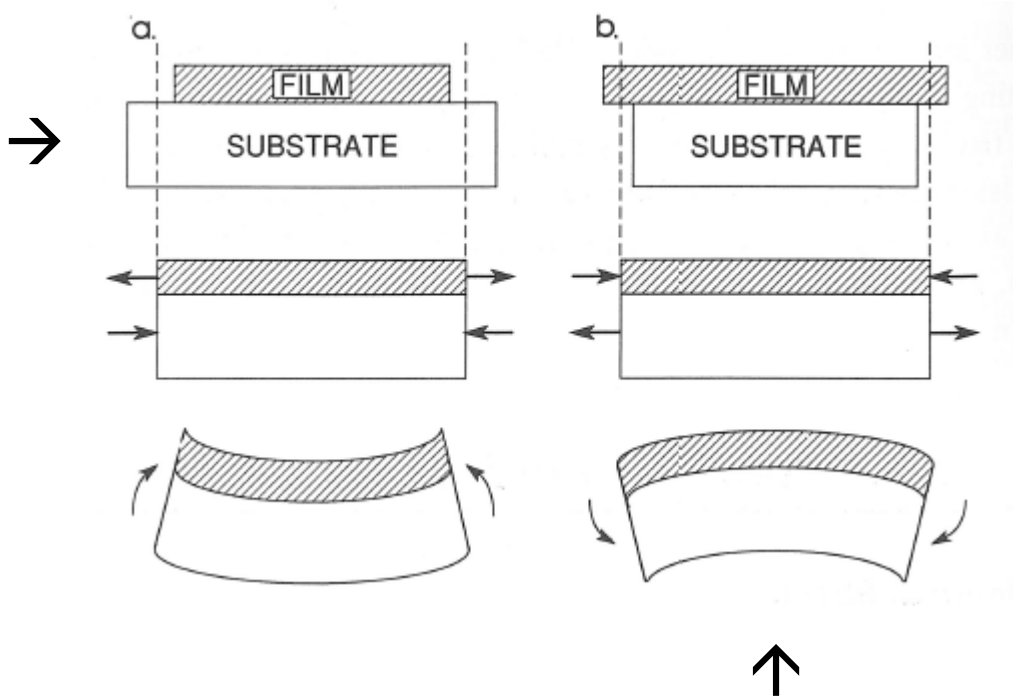
IAD

high assist:
dense structure
+ low thermal drift
– high compressive stress

MS + IBS

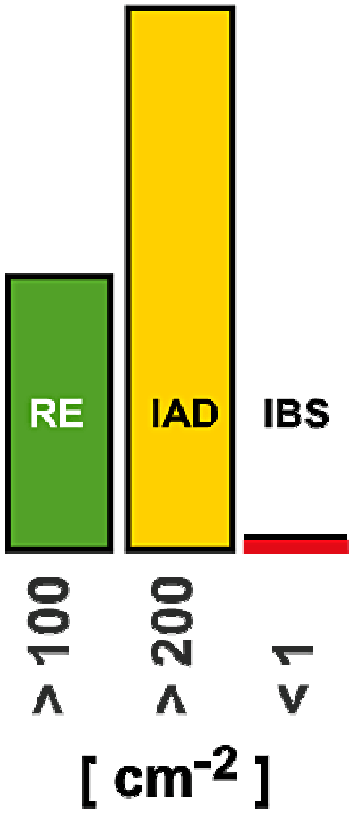
intrinsic stress

RE (EBE+TE):
Porose structure, usually tensile stress. Deflection is usually dependent on the environment conditions (temperature, moisture)

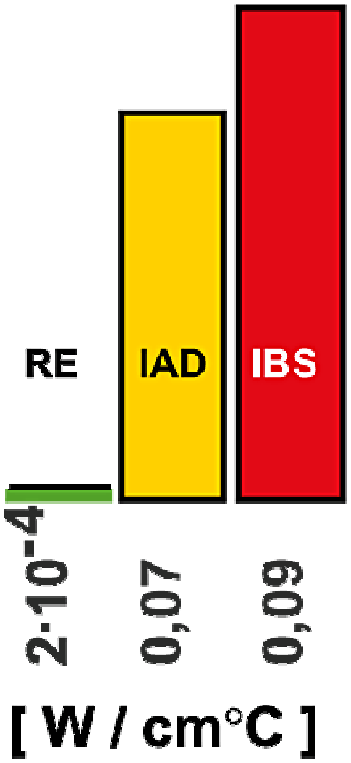


Ionenbased Processes (IAD, MS, IBS):
dense structure, medium to high compressive stress. Deflection can be estimated and compensated in many cases.

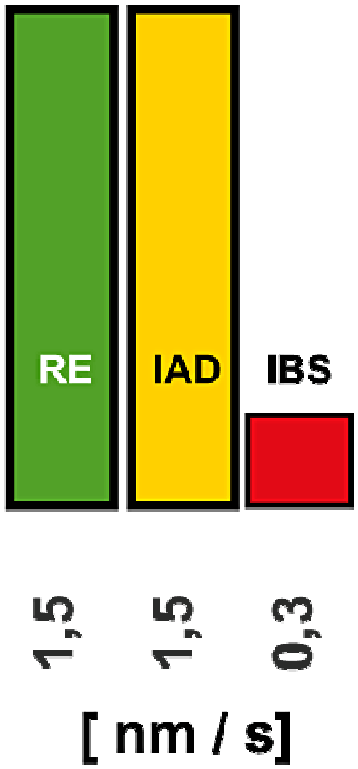
defect density



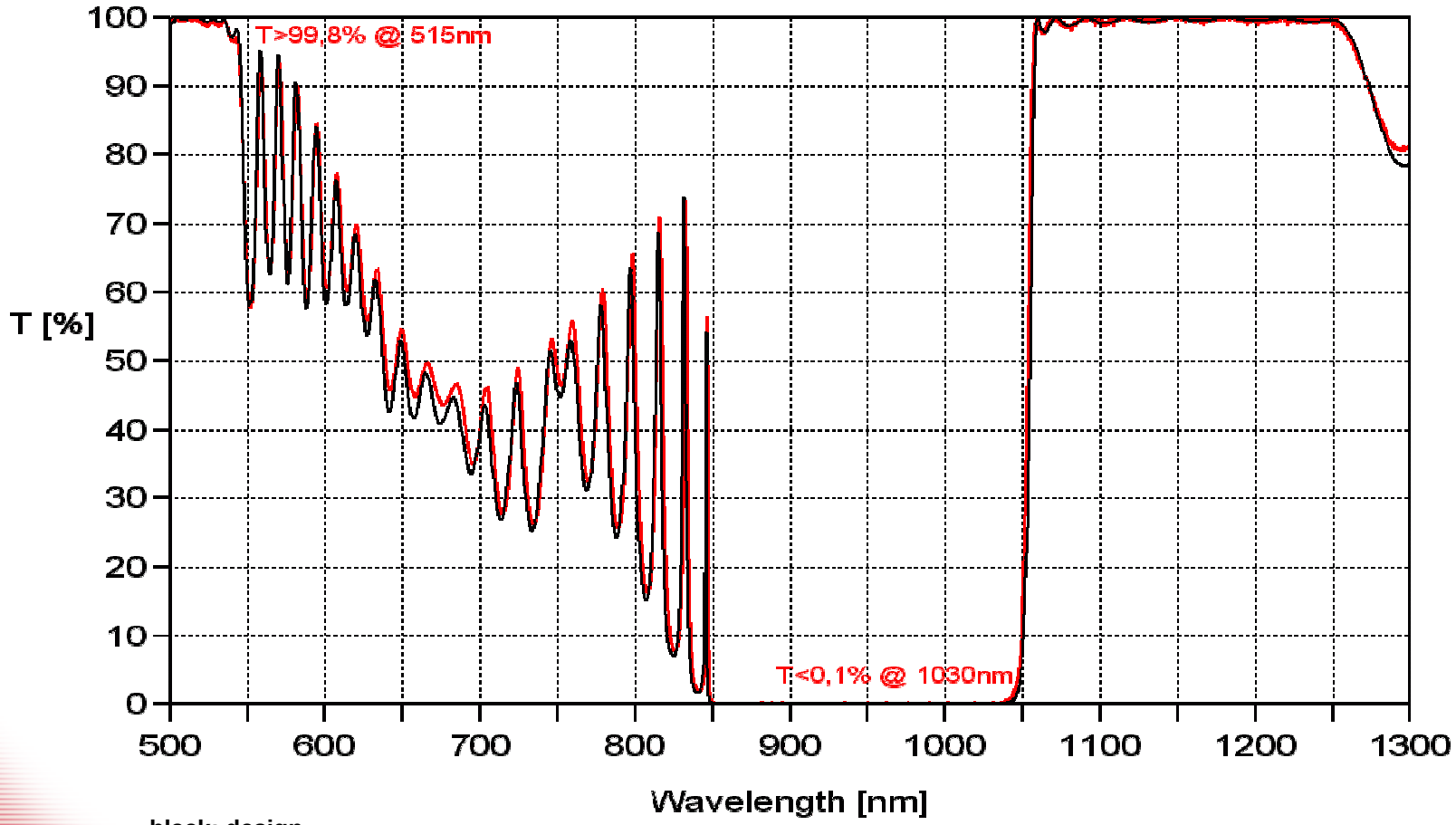
thermal conduct.



deposition rate



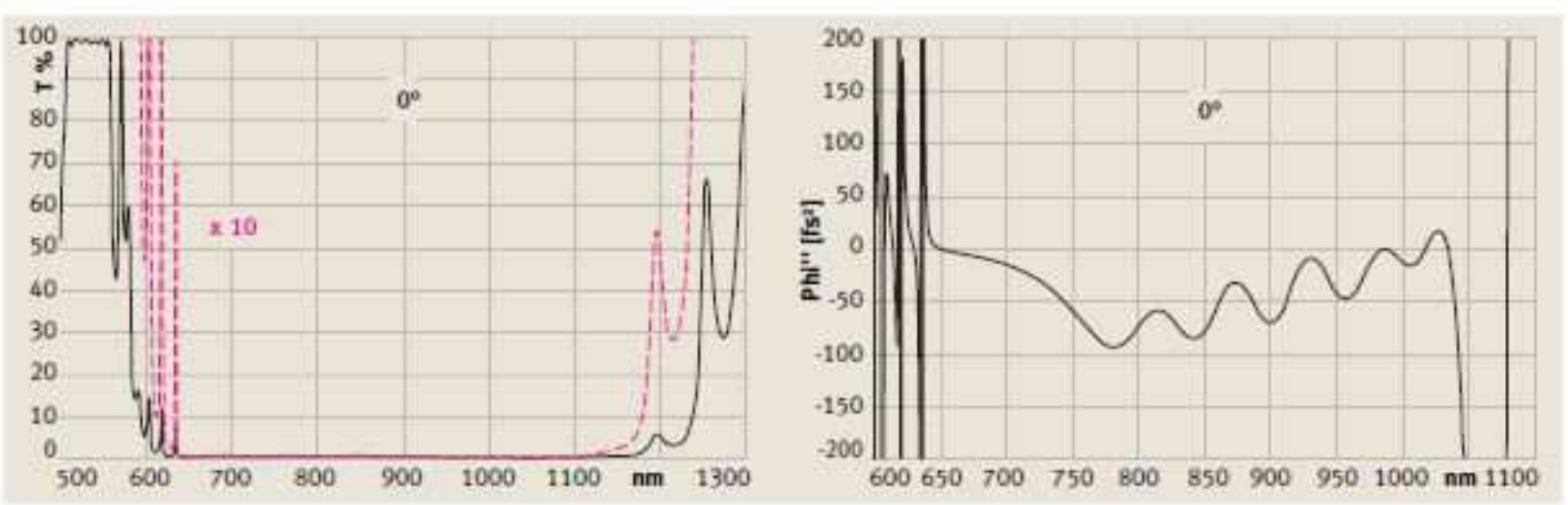
IBS: Example for Precisioncoatings



black: design
red: measurement

HT515nm HR1030nm HT1065-1240nm/0°

IBS: GDD optimized Broadband Mirror



HT 532 nm HR 650-1100 nm /0-15° GDD opt. [B-10888]

532 nm: T› 95%; 650-1100 nm: R› 99.9%; 780-1010 nm: GDD (R) = -88 -› 0 fs² ± 50 fs² (IBS-coating)

Chia, S.-H., Cirmi, G., Fang, S., Rossi, G. M., Mücke, O.D., Kärtner, F. X., *Two-octave-spanning dispersion-controlled precision optics for sub-optical-cycle waveform synthesizers,* in: Optica, Vol. 1 (2014), Iss. 5, pp. 315-322

Low loss mirrors (IBS)

	Scattered light TSb	Absorption	Reflection CRD
HR532nm/0°	4.9 ppm (1) (int. ARS)	10.2 ppm (2)	> 99.997% (2) (T~5ppm)
HR633nm/0°	1.1 ppm (1)		> 99.998% (T~5ppm)
HR1064nm/0°	(< 1 ppm) (3)	< 2 ppm (4)	> 99.999% (T~5ppm)
HR2940nm/0°	24 ± 12 ppm (6)		99.994% (5) (T=36 ppm)

(1) measured at IOF Jena
(2) measured st LZH
(3) calculated from roughness
(4) measured at ILT Aachen
(5) Customer feedback
(6) based on 1-R-T

Conclusion

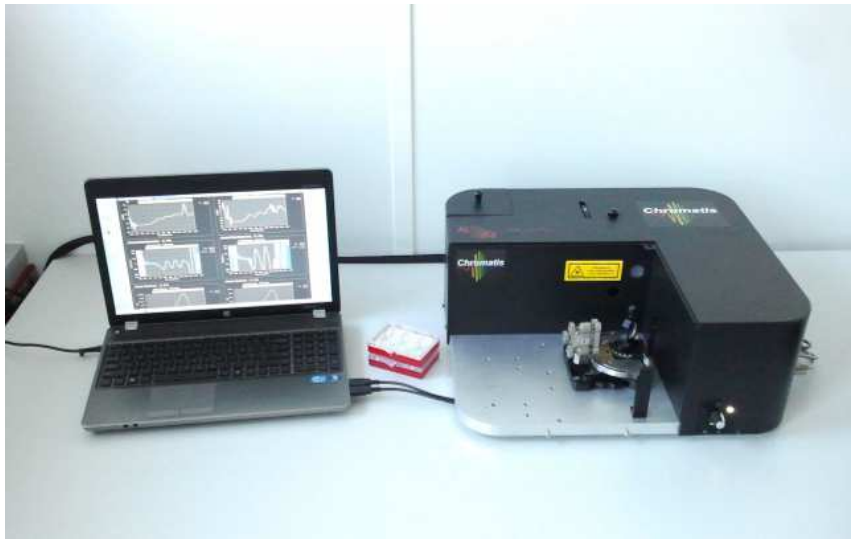
• Conventional E-beam coatings still offer a high LIDT for many applications. The large selection of layer materials and the good scalability of the process enable a high flexibility.

• In case of higher and highest precisions, ion based processes like IAD, MS or IBS are used. The last one is used especially for low loss optics and GDD optimized mirrors, which demand a maximum of accuracy.

• In general:
In order to achieve an optimal solution, the right choice of coating material and deposition process is critical.

Thank you for your attention !

Messung der GDD



„Chromatis“
600…1650nm
- AOI 0°, 7°-60°
- simultan s- und p-pol
- Einzelspiegel & Spiegelpaare

„DispMeter“
- 500-1050nm
- AOI 0°, 45°s-pol