Fluoride Coatings for the DUV-VUV-wavelength range

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OPTICAL COATINGS · OPTICS

Outline

History:	The origin of optical coatings
Introduction:	Substrate and coating materials for the UV wavelength range
	Properties of fluorides
	Coating techniques
Examples:	Optics for Excimer Lasers
	Optics for Higher-harmonics Solid State Lasers
	Ultrafast optics for the VUV range
Summary	

The origin of optical coatings

Alexander Smakula (9.9.1900 - 17.05.1983)

German patent No. 685 767
on 1 November 1935

DEUTSCHES REICH

AUSGEGEBEN AM 23. DEZEMBER 1939

REICHSPATENTAMT

PATENTSCHRIFT

№ 685 767

KLASSE 42h GRUPPE 1 01

Firma Carl Zeiss in Jena

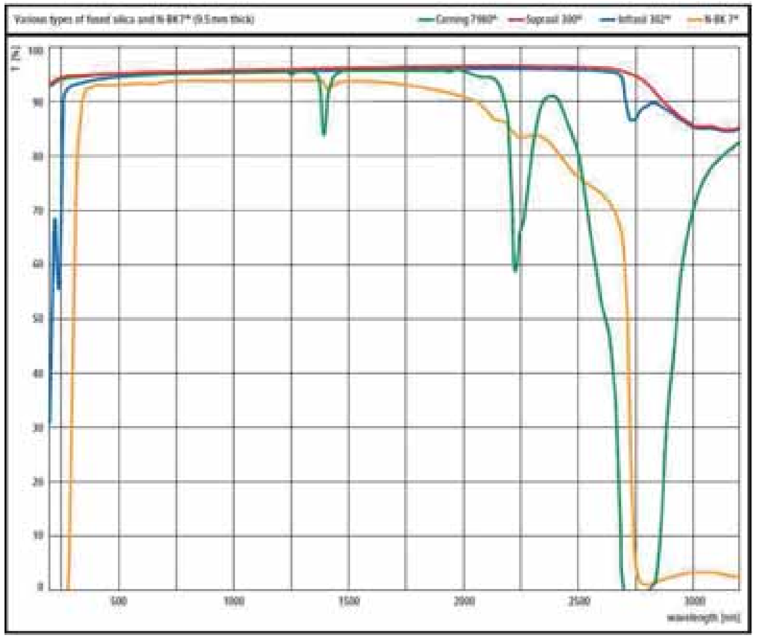
Verfahren zur Erhöhung der Lichtdurchlässigkeit optischer Teile durch Erniedrigung des Brechungsexponenten an den Grenzflächen dieser optischen Teile

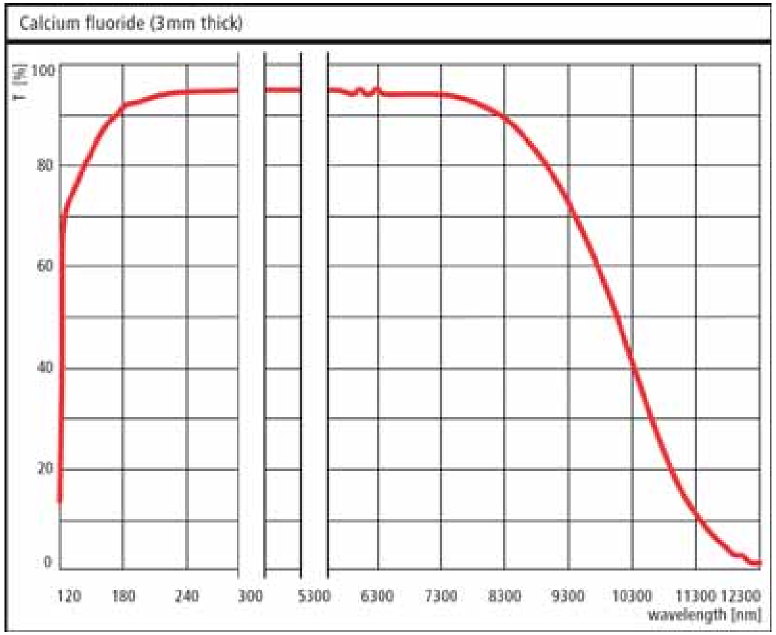
Patentiert im Deutschen Reiche vom 1. November 1935 ab.
Patenterteilung bekanntgemacht am 30. November 1939

- Low index single layer coatings increase the transmittance of lenses and windows
- 1935: Kryolith (Na_3AlF_6); ca. 1942: MgF_2 on heated substrates
- Still the most popular applcation of fluorides
- E-beam-evaporation: 1960s , Magnetron Sputtering: 1977, IBS: 1980s

Substrate and coating materials for the UV wavelength range

Wavelength range	materials
300-400nm	(Ta_2O_5), ZrO_2, HfO_2, Sc_2O_3, Y_2O_3, Al_2O_3, SiO_2, Fluorides
(190) 200-300nm	HfO_2, Sc_2O_3, Y_2O_3 (240-300nm), Al_2O_3, SiO_2, Fluorides
(100) 122-200nm	SiO_2 (170-200nm), MgF_2, LaF_3, AlF_3, CaF_2, GdF_3 …





Extremely large transmission range of fluoride materials

Properties of fluoride materials

Fluorides = salts of fluoric acid; pure ionic bonding:
⇒ strong bonding of the molecules (no dissociation if evaporated)
⇒ weak bonding between the molecules
- ⇒ substrates and coatings are rather soft
- ⇒ Low melting and evaporation points (compared to oxides)

⇒ large coefficient of thermal expansion (CaF_2: 16,7e-6/K; FS: 0,5e-6/K)
- ⇒ thick fluoride layers on FS often crack during cool down from high deposition temperatures

Optical properties:
⇒ Extremely large transmission range (CaF_2: ~125nm - ~8µm)
⇒ Small refractive indices and small refractive index contrast
- ⇒ HR mirrors require a large number of layers
- ⇒ Narrow reflectance bands
- ⇒ High transmittance in the long wavelength range
- ⇒ Relatively high scattering losses

CaF_2	**1,50**
MgF_2	1,43
AlF_3	1,39
LaF_3	1,66 – 1,68
SiO_2	1,56

Refractive indices at 193nm

Structure of fluoride coatings

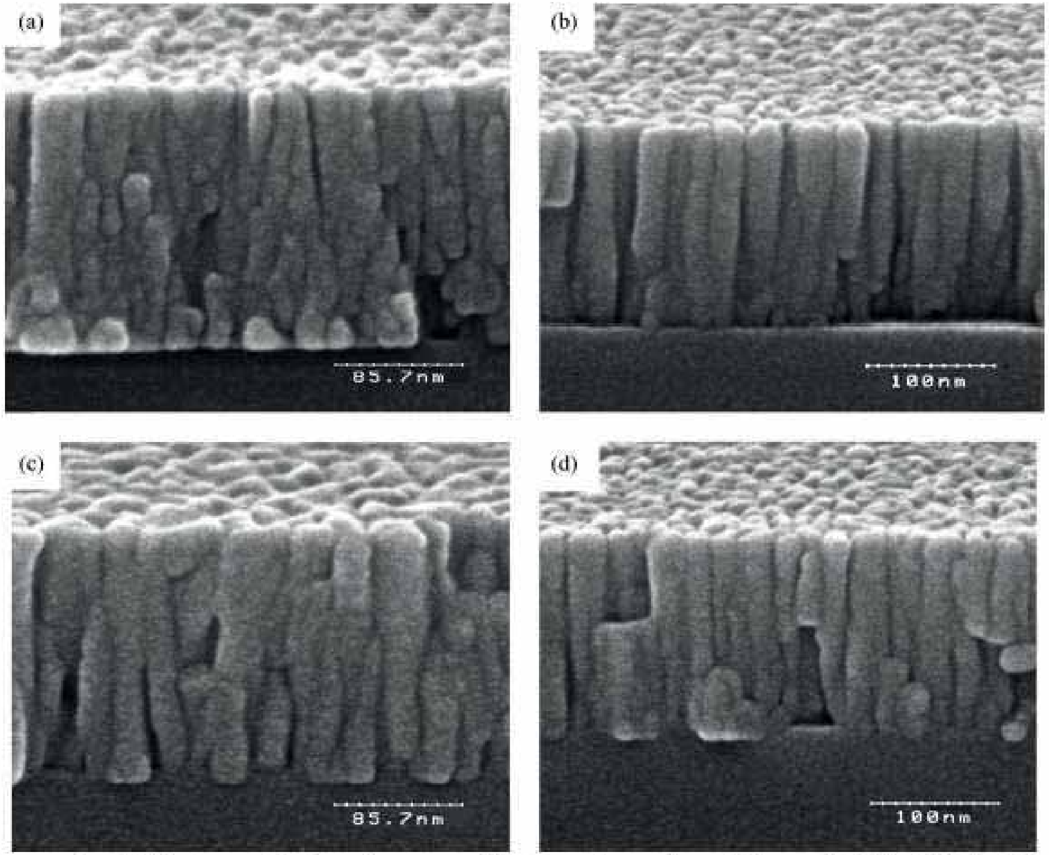


Fig. 2. Cross-sectional SEM micrographs of samples prepared at (a) room temperature at 0.2 nm s^{-1}; (b) T_s = 250 °C at 0.2 nm s^{-1}; (c) T_s = 300 °C at 0.2 nm s^{-1}; (d) T_s = 250 °C at 0.8 nm s^{-1}.

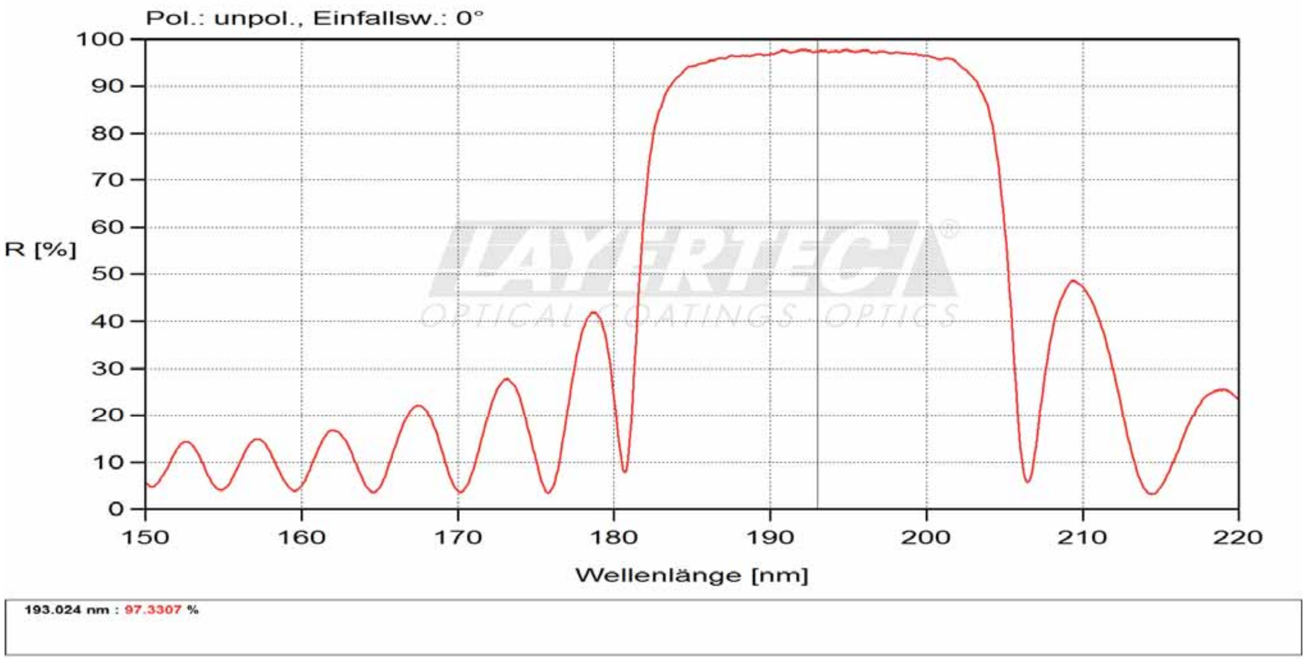
- Columnar structure with large voids (depending on substrate temperature and deposition rate)
- Reason of scattering losses
- Water and hydrocarbons (absorbing in the VUV!) can fill these voids
- Hydrocarbons can be removed by laser conditioning

Liu et al., APPLIED OPTICS / Vol. 45, No. 28 / 1 October 2006

Coating techniques for fluoride layers

Coating technique	Advantages	Disadvantages	remarks
Thermal and E-beam evaporation	Stoichiometry of the molecules remains unchanged Low absorption High LIDT values	Dense films require high temperatures	Most common coating methods
IAD	Dense films possible Low losses at 193nm	Fluorine ! Handling and safety systems necessary! Post treatment necessary	Martin Bischoff Dissertation FSU Jena 2009 (IOF Jena)
IBS	Dense films possible Low scattering losses	NF_3 and Fluorine ! Handling and safety systems necessary ! Absorption losses	M. Schwarz, Veeco Presentation at AK DUV-VUV 2015-10-08, LZH

Optics for excimer lasers: HR mirrors



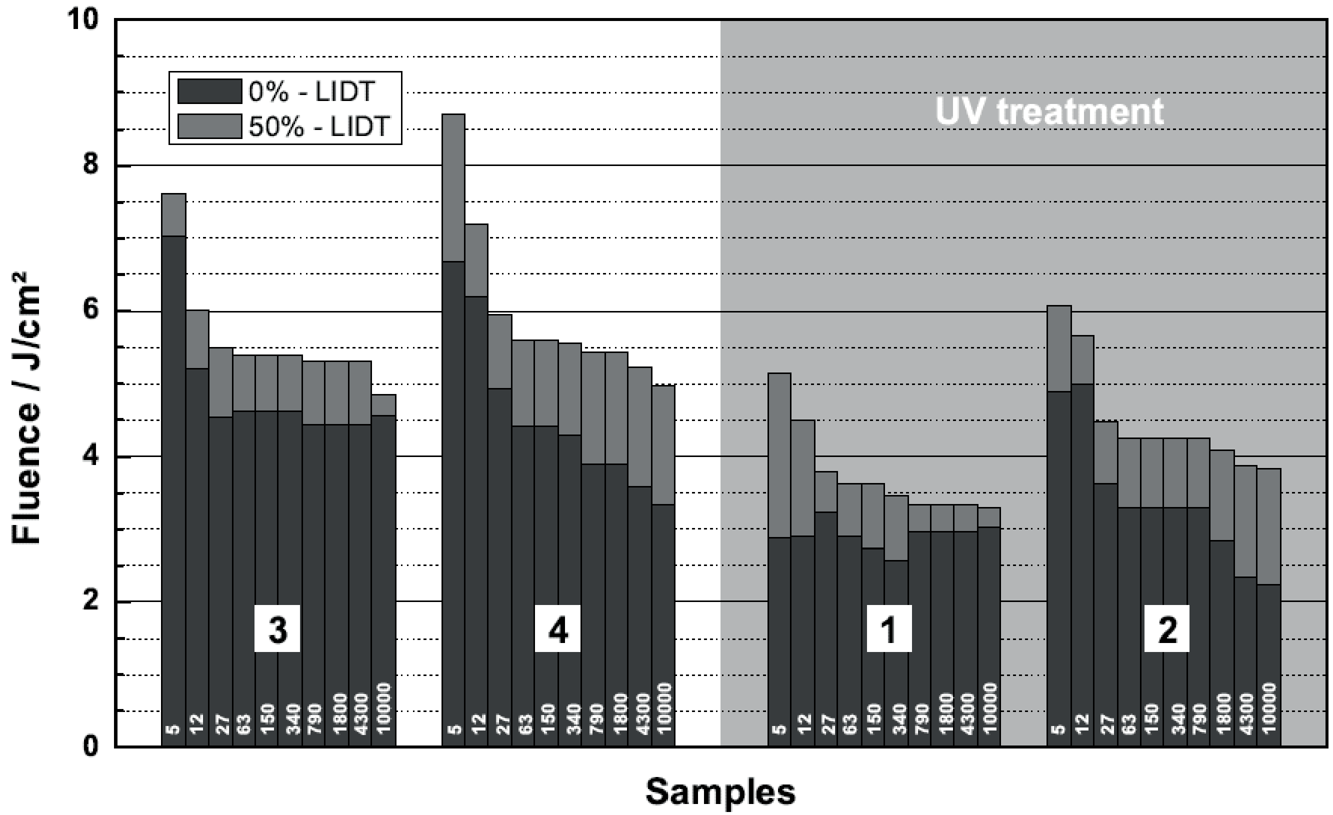
Typical reflectance values:
R>98% at 248nm, 308nm
R>97% at 193nm
R>94% at 157nm

Flourine resistant!

ArF laser mirrors (193nm); results of the German Joined Project „FLUX“, 2011
Lifetime: 10 billions of pulses at 55mJ/cm², 4 billions of pulses at 80mJ/cm²
Lifetime of the optics = lifetime of the laser tube!
LIDT: 2-3 J/cm² (14ns, 10000-on-1), Measured at LZH

LIDT of HR 0° 193nm vs. pulse number

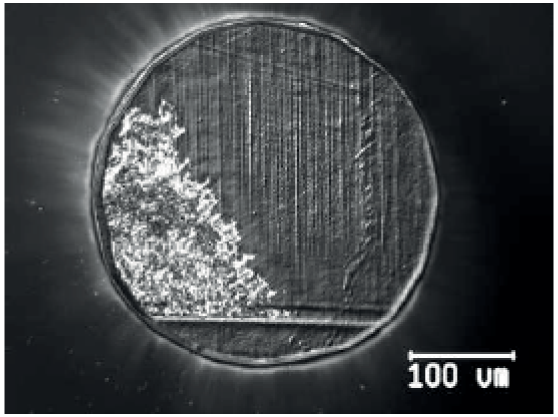
τ=15ns, ø 350µm, 150Hz, with and without UV treatment, measured at LZH, LAYERTEC samples only

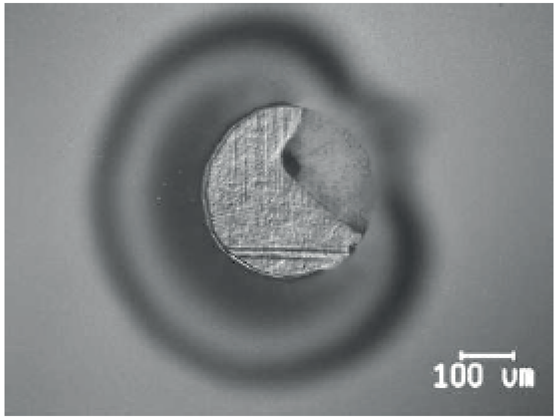


LIDT = 2 – 3 J/cm², relatively constant even at large pulse numbers

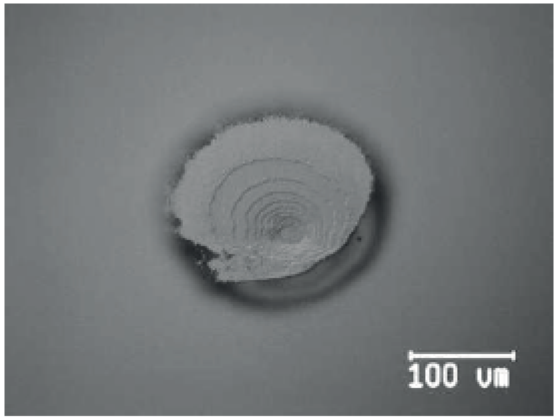
H.Blaschke, D.Ristau, W.Riggers, S.Schippel, „Influence of pre-treatment conditions on the resistivity of fluoride multilayers", Proc. SPIE, Vol.7132, in series: Laser-Induced Damage in Optical Materials, Editors: G.J. Exarhos, D.Ristau, M.J.Soileau, C.J. Stolz, pp 713201 (2008)

Damage Morphology



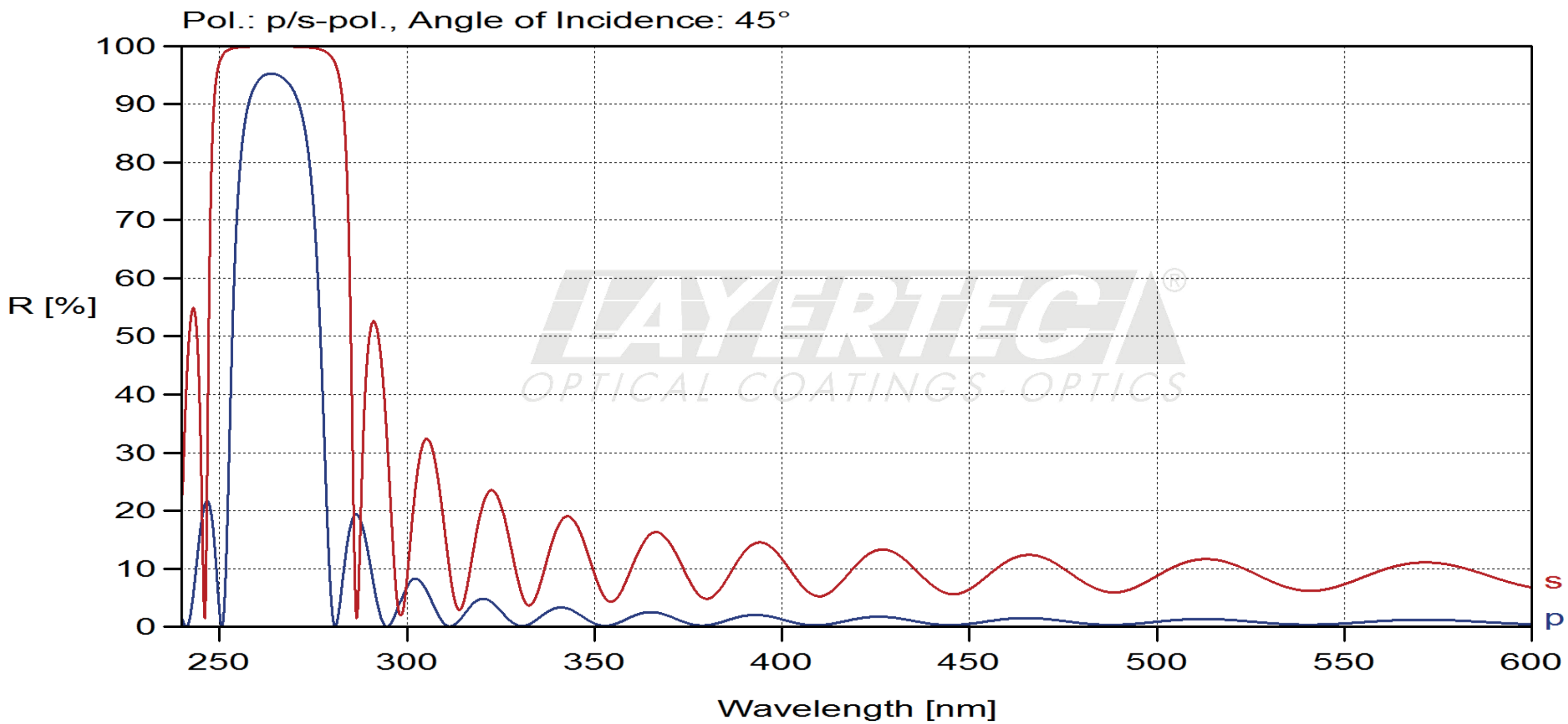


High LIDT values:
Delamination;
Damage of „the coating itself"



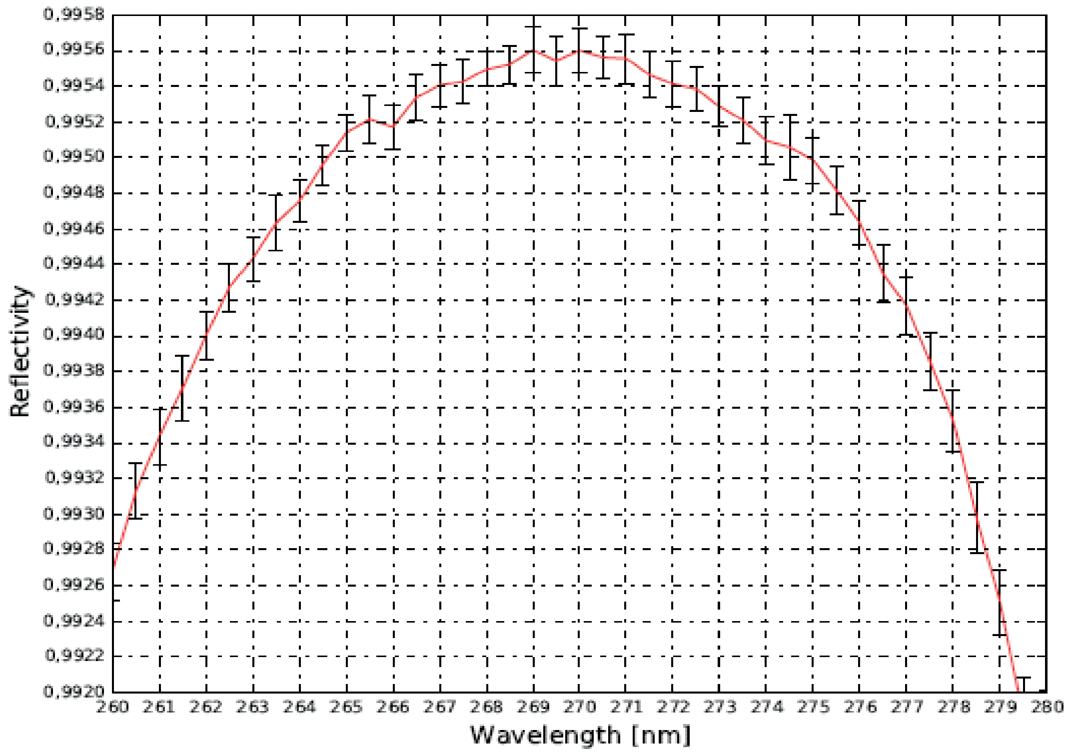
Low LIDT values:
Craterlike structure;
Driven by defects in the coating

Fluoride Coatings for solid state lasers: Separator HRs 45° 266nm + HT 45° 532nm



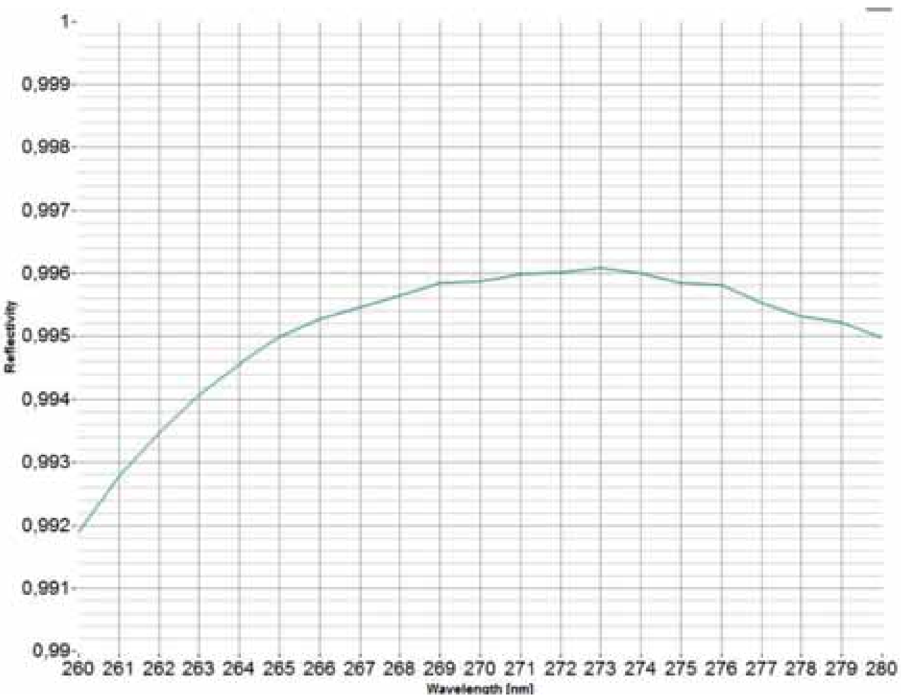
- Bandwith of HRs is sufficient for spectral production tolerance of ±3%
- Very low reflectance in the transmittance range

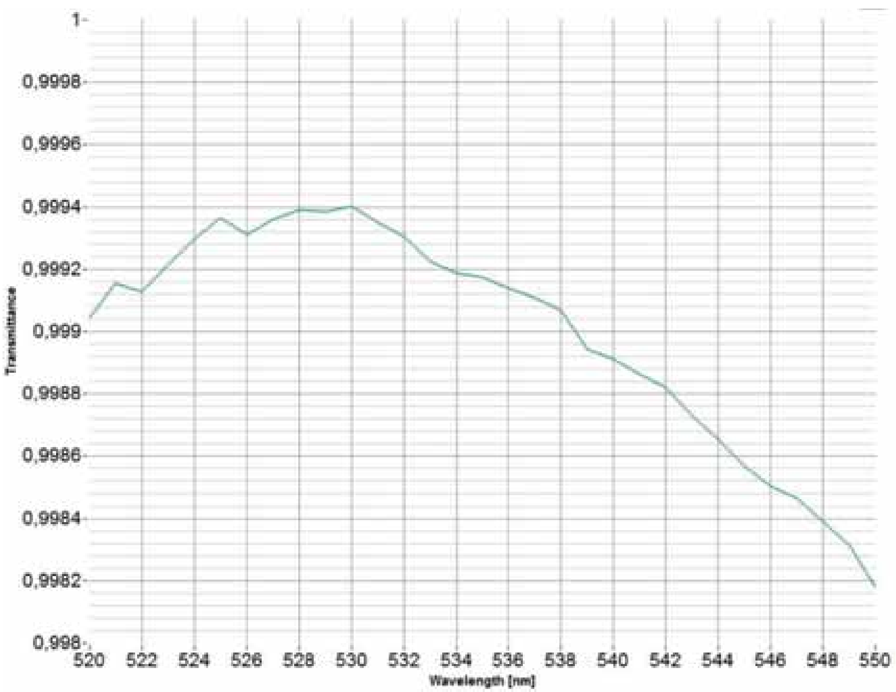
Fluoride Coatings for solid state lasers: Separator HRs 45° 266nm + HT 45° 532nm



- Reflectance measurement by CRDS: Rs>99.5% (LAYERTEC specifies Rs>98%)
- A (266 nm) ≤ 110 ppm (measured by LID at IPHT Jena)
- A (532 nm) = 3 ppm ! (~2µm of coating material + interface!)

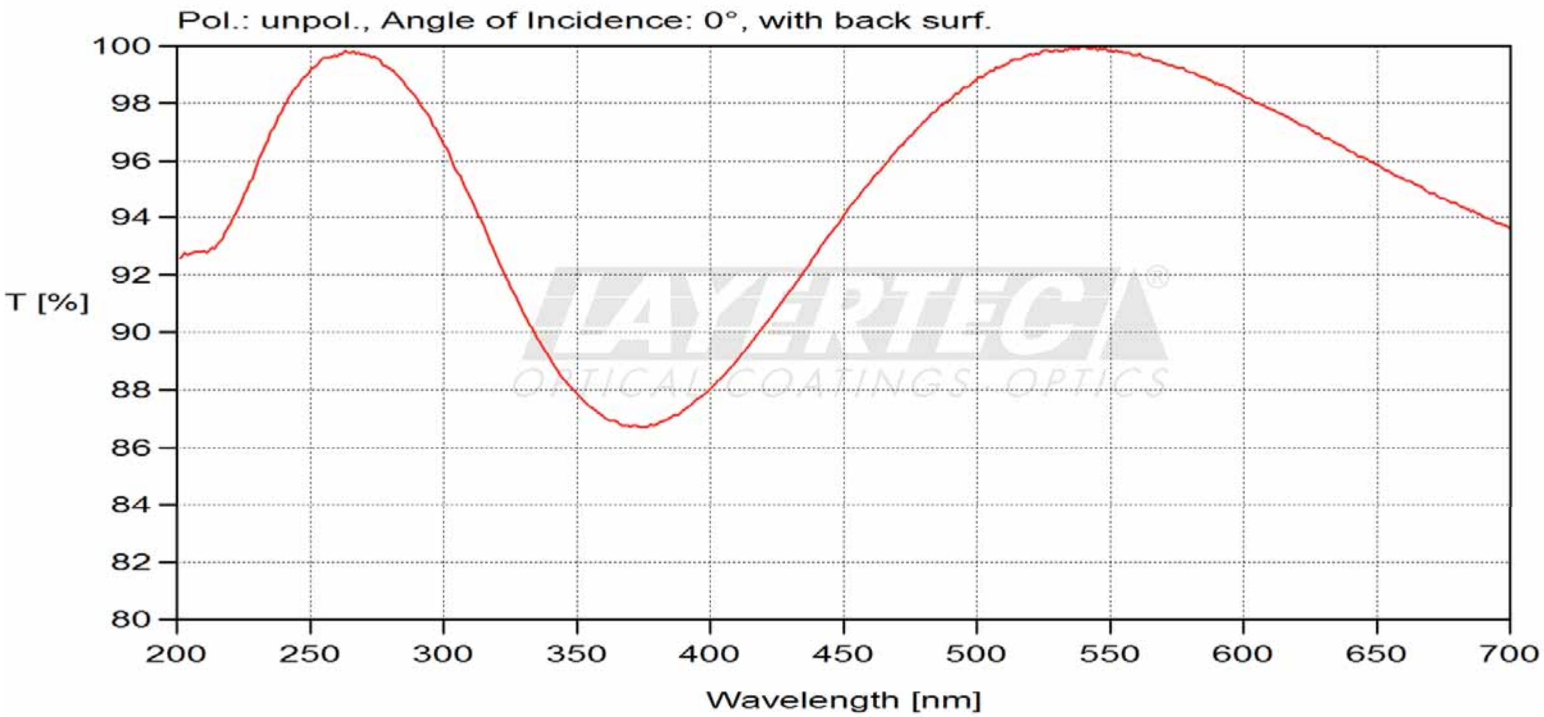
Fluoride Coatings for solid state lasers: Separator HRs 55° 266nm + HTp 55° 532nm





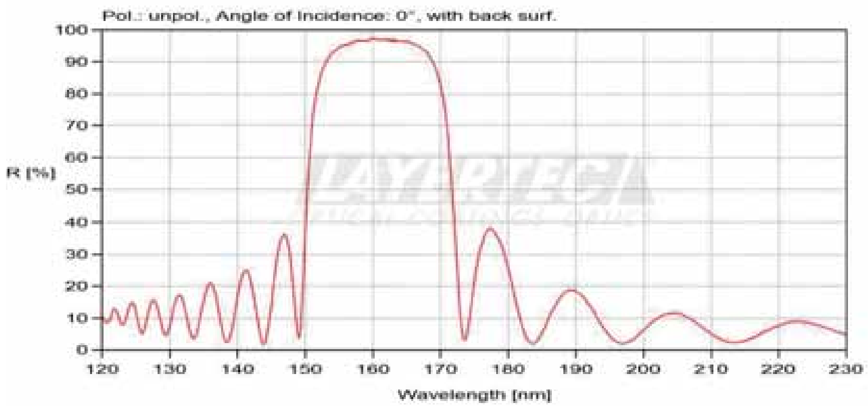
- 1-T at Brewster´s angle is a nearly direct measure of the losses
- Tp (55°, 532 nm) > 99.9% $\Rightarrow$ very low scattering losses
- Reflectance measurement by CRDS: Rs(55°, 266nm)>99.5%

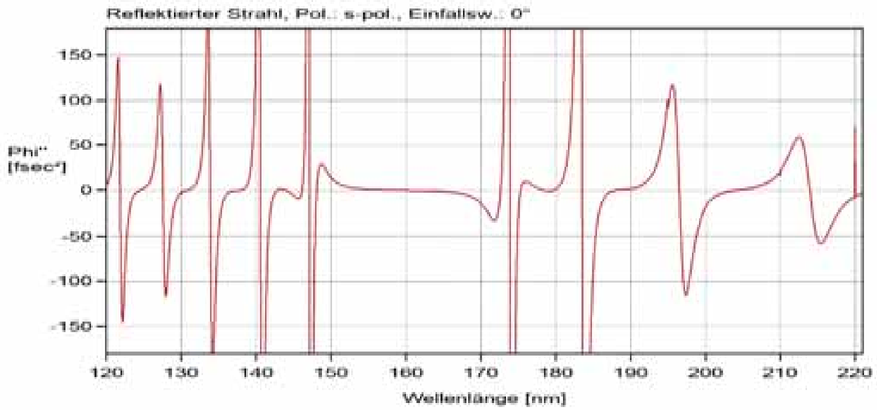
Fluoride Coatings for solid state lasers: DAR 0° 266nm + 532nm

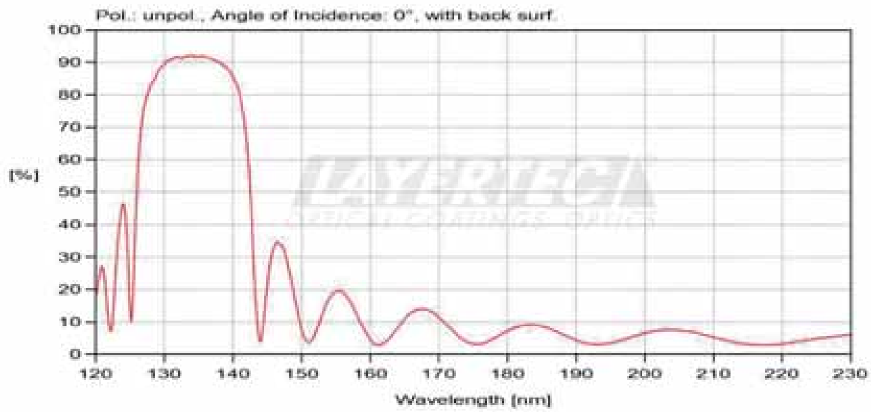


- Transmittance of a window coated on both sides: T>99.7% (LAYERTEC specifies T>99%)
- A (266 nm) = 370 ppm (measured by LID at IPHT Jena)
- A (532 nm) < 2.5 ppm

Ultrafast mirrors for the VUV-range: higher harmonics of the Ti:Sapphir laser at 160nm and 133nm







- |GDD|<20fs² in the reflectance band
- Ru>90% (typically >94%) at 160nm
- Ru>85% (typically >90%) at 133nm
- Mirrors and separators for AOI=45° are also possible
- Separators with Rs<10% Rp<2% at 800nm / 400nm / 266nm / 200nm

Summary

- Fluorides are the only materials for the production of laser optics for the DUV / VUV range
- Fluoride coatings for the NUV / DUV range compete with oxide coatings
  - Advantages:
    - longer lifetime
    - lower absorption losses
  - Disadvantages:
    - higher scattering losses
    - coatings are soft an can be scratched easily

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