Mirror Issues for FELs

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Needs for a Laser source?

Coherence
Tunability
High Power
Stability

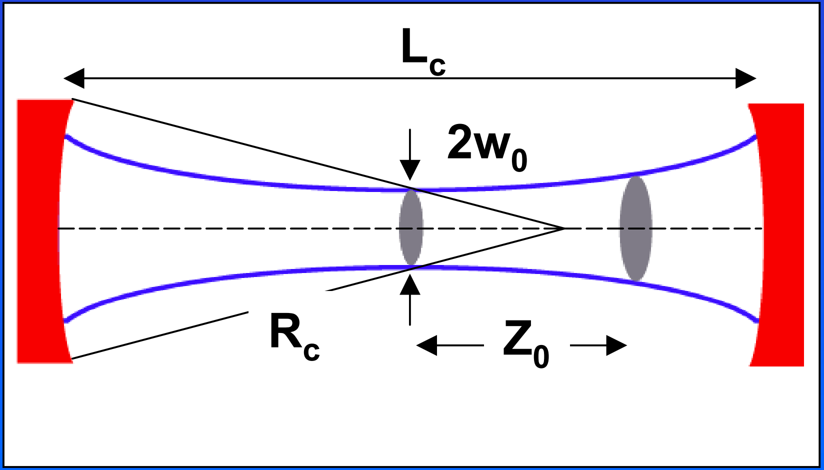
Outline

- Optical Resonators
  - Geometry
  - Mirrors
  - Gain vs. Losses
- Wavelength Range and Tunability
  - Near-Mid IR
  - UV-VUV
- Thermal Load and Stability
  - Synchrotron Radiation
  - High Power FELs
- X-Ray Optics for Resonator-Free Devices
- Conclusions

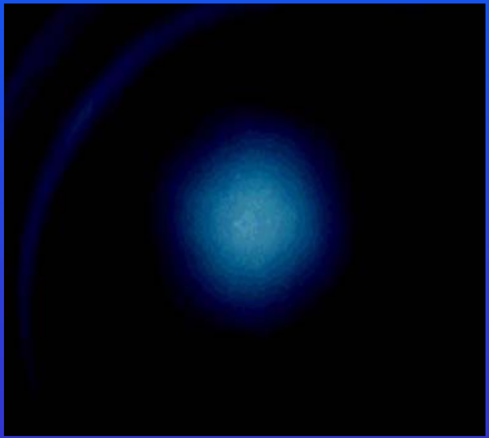
Optical Resonators : Geometry

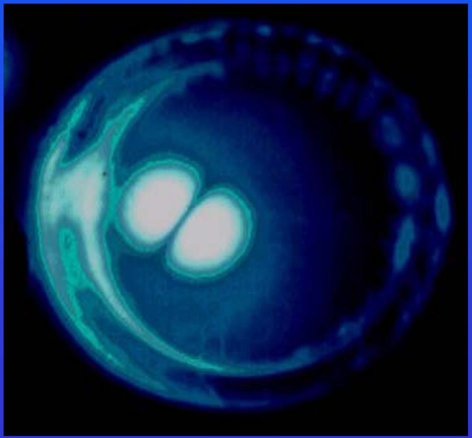
$$w_0 = \frac{\lambda}{2\pi}\sqrt{L_c(2R_c - L_c)}$$

$$Z = \frac{\pi w_0^2}{\lambda}$$



- Gauss-Hermite Modes TEM_{mn}
- Higher order modes are larger





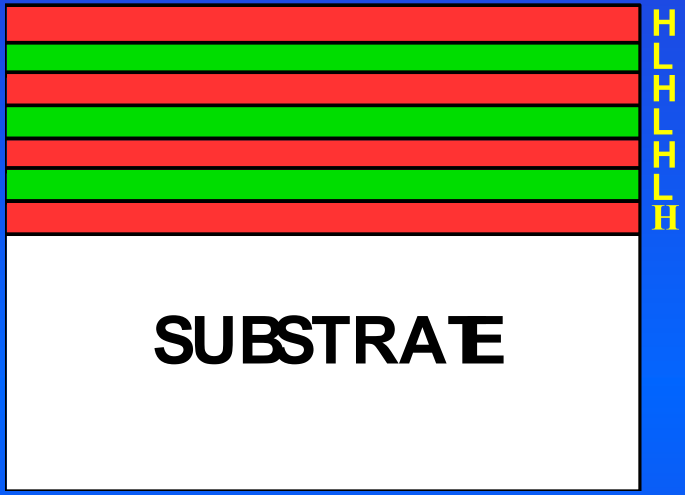
Optical Resonators: Mirrors

IR -> VUV

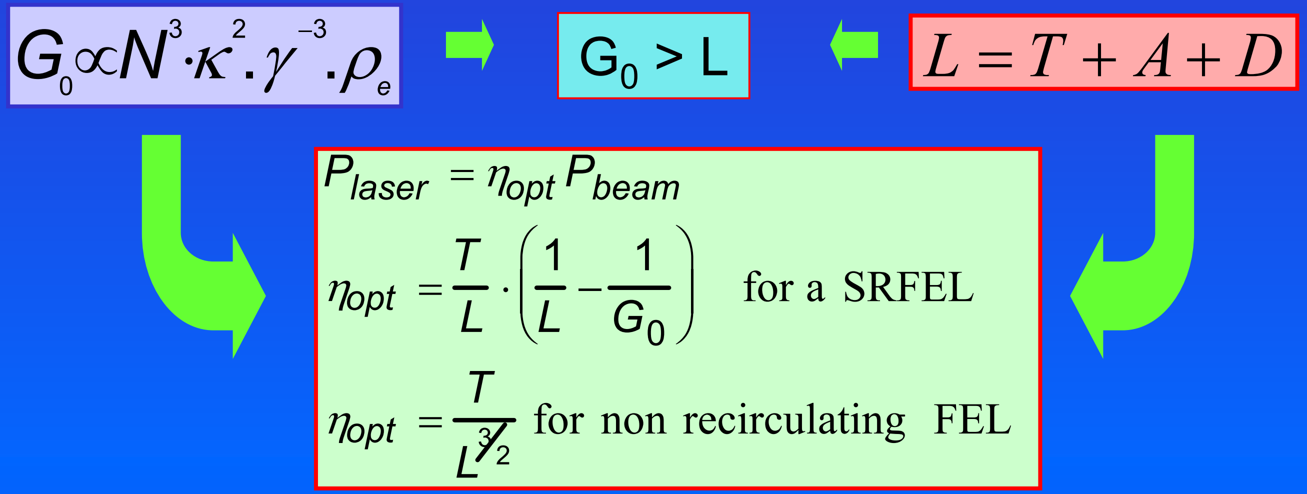
ñ = n + ik = 1.3 … 2.0

- *Substrate +Coated Layers*
- *optical materials:*
  - oxides, fluorides, metals
- *optical losses:*
  - absorption, scattering

transmission, reflection optics



Gain, Mirror Losses and Laser power



$G_0 \propto N^3 \cdot \kappa^2 . \gamma^{-3} . \rho_e$

$G_0 > L$

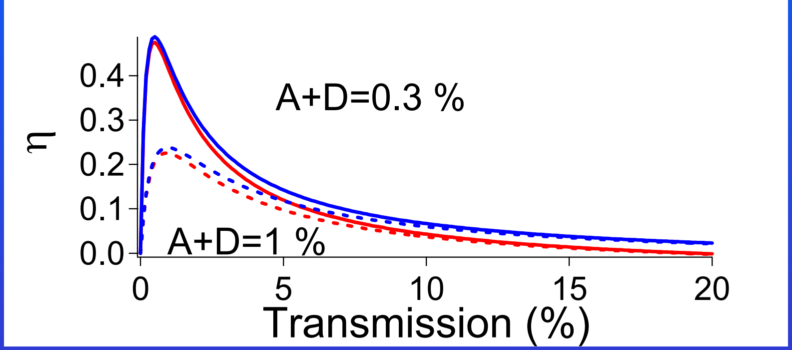
$L = T + A + D$

$$P_{laser} = \eta_{opt} P_{beam}$$

$$\eta_{opt} = \frac{T}{L} \cdot \left(\frac{1}{L} - \frac{1}{G_0} \right) \quad \text{for a SRFEL}$$

$$\eta_{opt} = \frac{T}{L^{3/2}} \quad \text{for non recirculating FEL}$$

- **Too large transmission reduces intracavity power, thus killing the amplification process**
- **The amplification and the losses determine the optimal value for the transmission.**



Wavelength Range and tunability

The IR range

-In the near IR range, gain values overpass the 50-100 %

-Metal Coated Mirrors (Au) or oxyde multilayers guarantee very high reflectivities

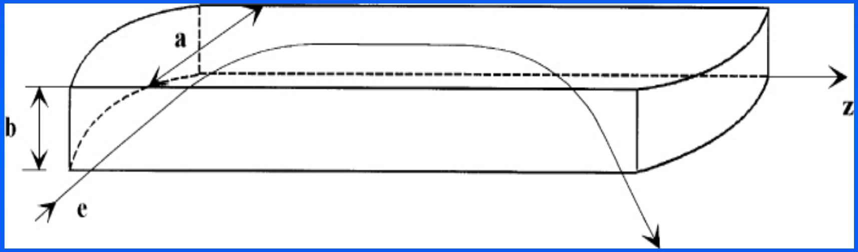
☞How the IR FELs extended their capabilities towards the long wavelength range?

☞Is Output Coupling a crucial factor for increase the extracted Power ?

Free Space-Waveguide Coupling

Optical Range : Free Space modes small compared
to the Finite Aperture

Long Wavelengths Range : Diffraction Losses increase



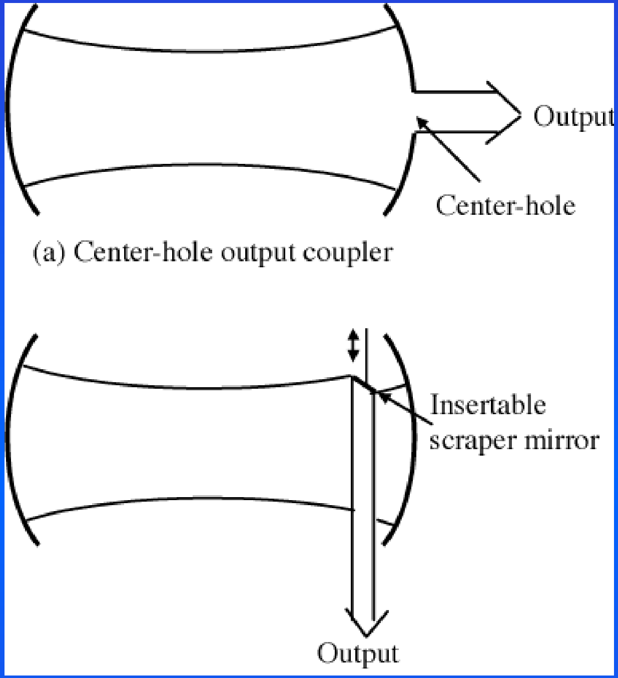
$w_0/a=0.352$

- ➢Hybrid waveguides resonators : partial waveguiding of the optical mode
  high efficient TEM_{00}-TE_{10} coupling
- ➢Toroidal Mirror are used
- ➢High order modes are almost suppressed

A. Doria, G. Gallerano, Opt. Com 85 (1991) 500-507

K. Berryman, T. Smith, NIM A 318 (1992) 147-151

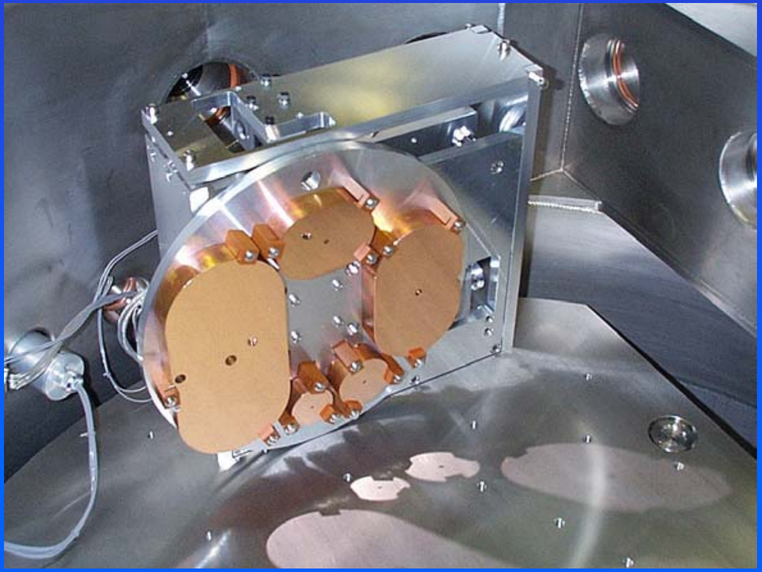
Output Coupling and Versatility



Output coupling system in JAERI FEL
For the mid-IR range.

Optical extraction efficiency doubles
with respect to the hole coupling

R. Nagai et al., NIM A 475 (1992) 147-151



Mirrors Carrousel on the FELIX facility
Wavelength Range : 25-300 μm

UV-VUV Optics I

- 1983 : ACO oscillates @ 635 nm with G<0.5 %
- 1987 : ACO @ 463 nm with G~0.2 %
- 1988 : VEPP3 OK-4 @ 240-690 nm with G=4-10 %

- 1992: Super ACO at high E=800 MeV @ 350 nm G ~2 % P~100's of mW

- 1997: UVSOR Helical OK @ <239 nm
- 1998: Duke OK-4 and NIJI-IV @ 212-226 nm 2 % < G < 13%
- 1999: Duke OK-4 @193.7-209
- 2001: ELETTRA @ 190 nm G ~20 %

- 2001: UVSOR user experiment @ 570nm but P~1.2 W!
- 2002: ELETTRA E= 1.5 GeV @ 207 nm P~0.2 W.

UV-VUV Optics II

✓**Coatings**

- Reduced number of transparent materials

- Scattering and absorption losses increased

- Contamination, environment and lifetime problems

✓**Components**

- Coating substrates with strong different thermal expansion coefficients

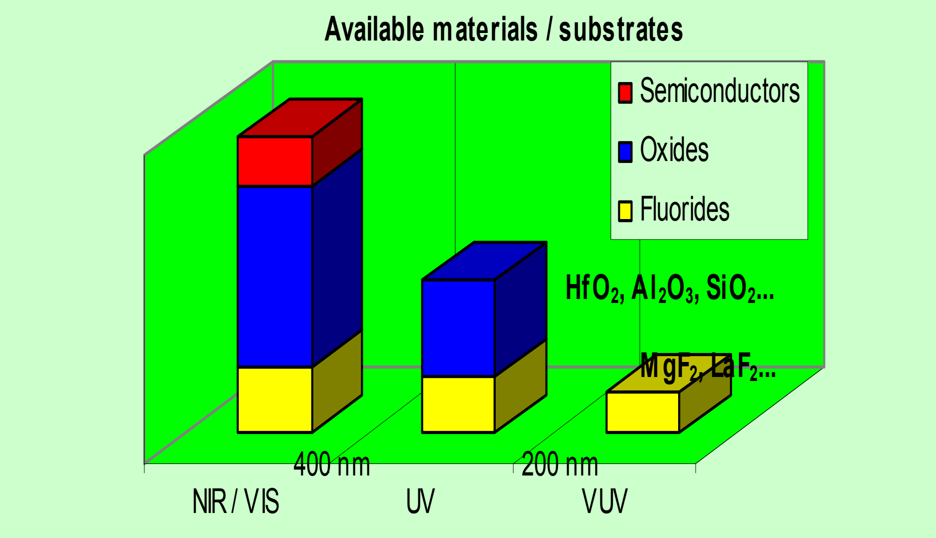
-Transparency (Output Coupling)

✓**General**

- No commercial metrology tools available, must be developed too.

UV-VUV Mirrors : Available materials

- Available technologies :
- - Ultra low loss PVD
- - Advanced Plasma Source (PIAD)
- - Ion Assisted Deposition (IAD)
- - Ion Beam Sputtering (IBS)



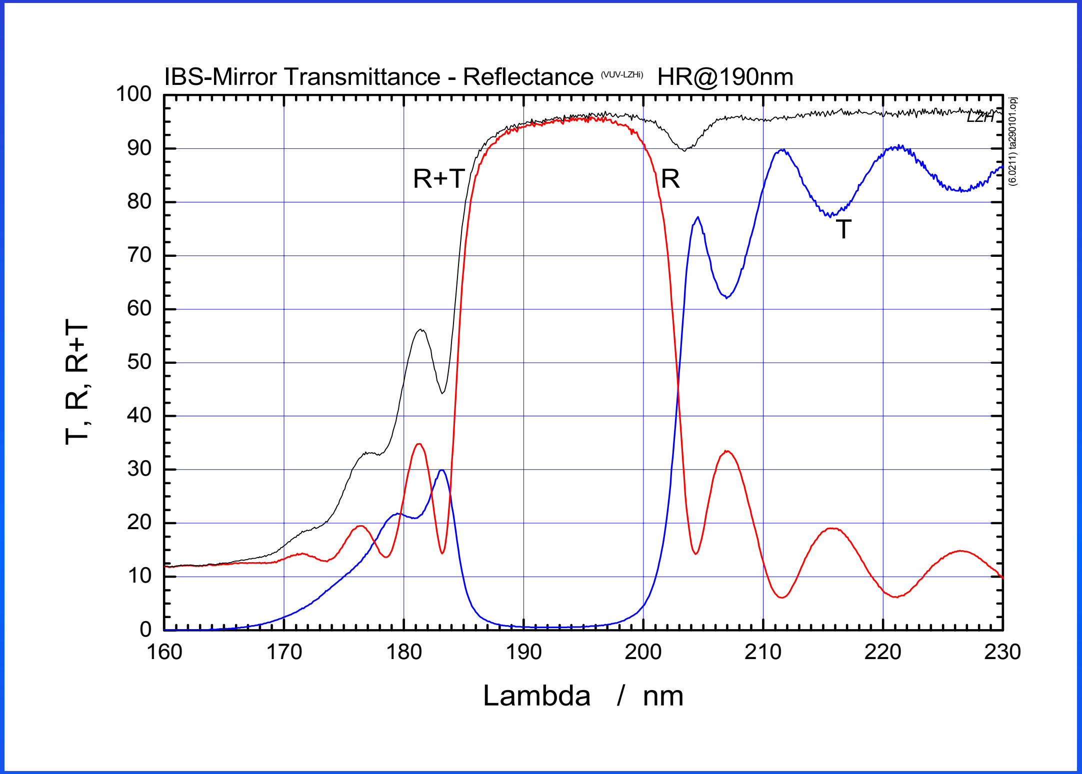
	248 nm	193 nm	157 nm
Fused silica	+	+	
Sapphire	+	--	--
CaF_2	+	+	+
MgF_2	+	+	+

UV-VUV Optics II: State of the Art

HR @ 193 nm
Al_2O_3/SiO_2 deposited by IBS

lasing at
189.95 nm – 200.3 nm

10 mW @ 26 mA

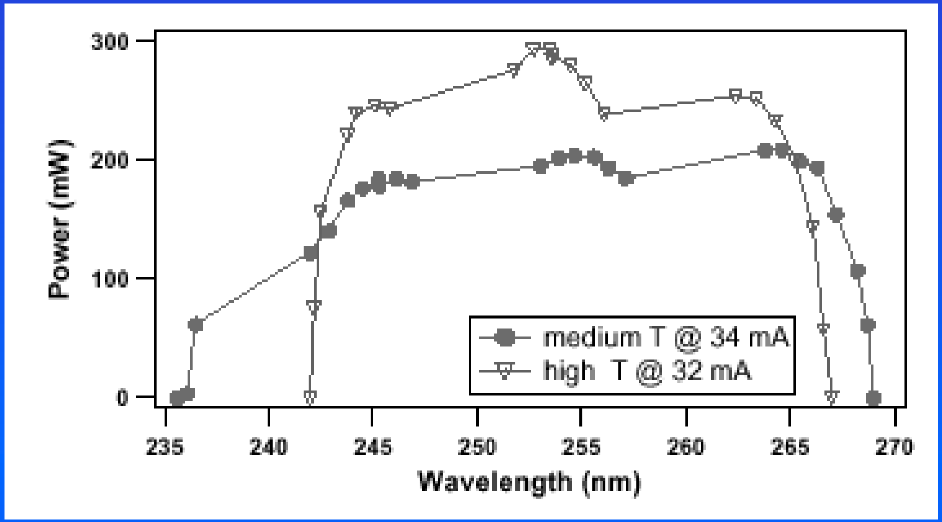


By courtesy of A. Gatto and S. Gunster

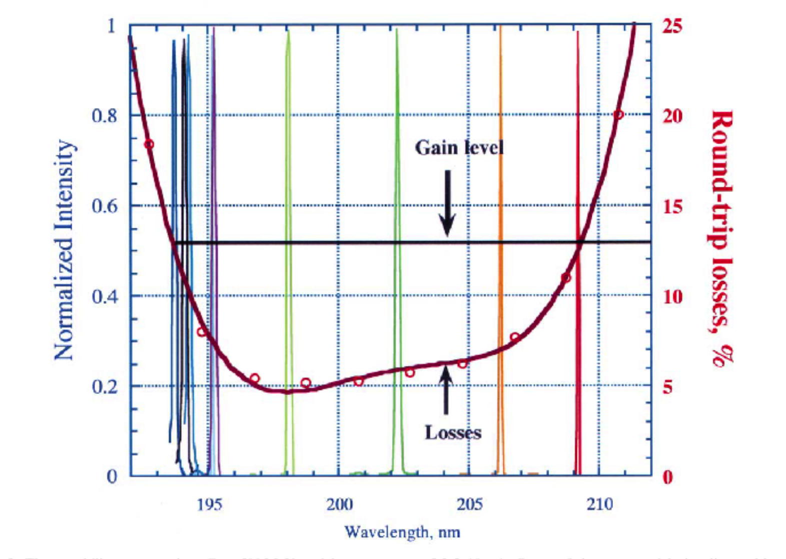
Laser Zentrum Hannover e.V.

Fraunhofer
IOF
Institut
Angewandte Optik
und Feinmechanik

UV Tunability



ELETTRA

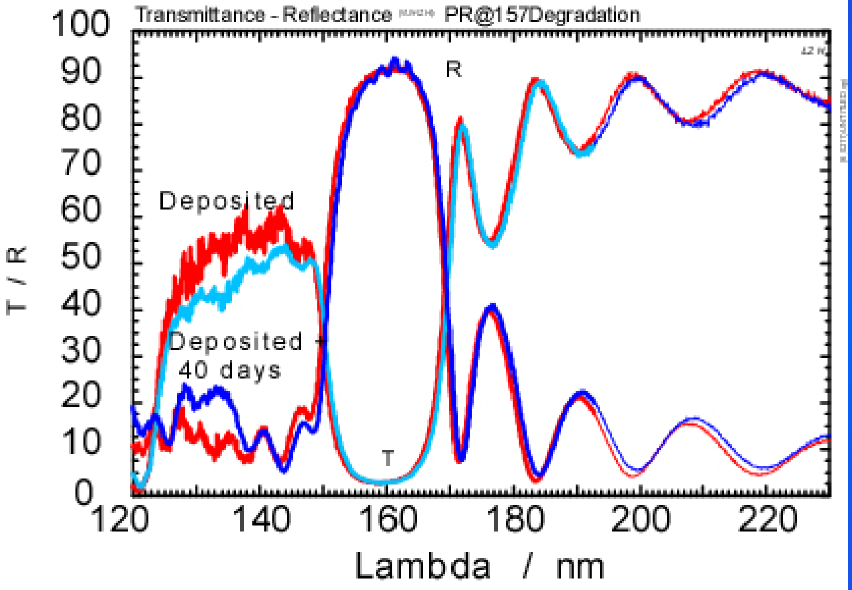


DUKE

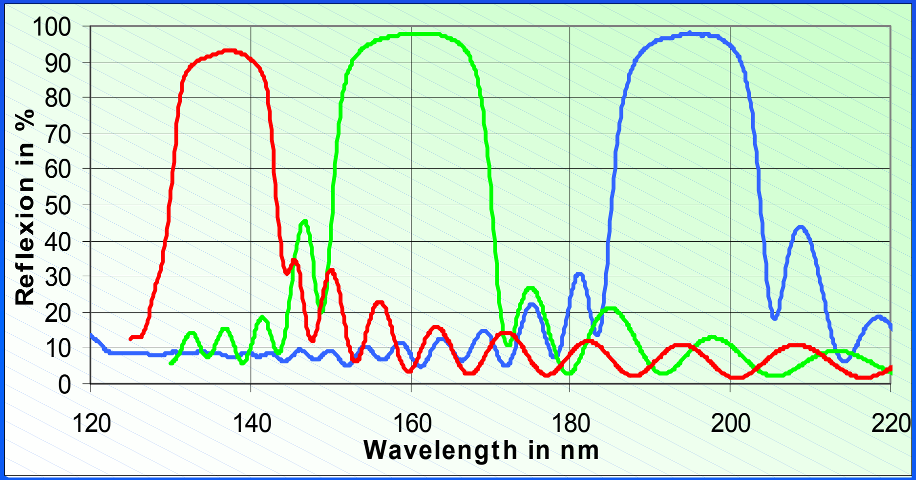
☞G.Swift, V. Litvinenko, Tu-P-18

Towards shorter Wavelengths I

IBS Al_20_3/SiO_2 multilayer



Optical indices based Calculations



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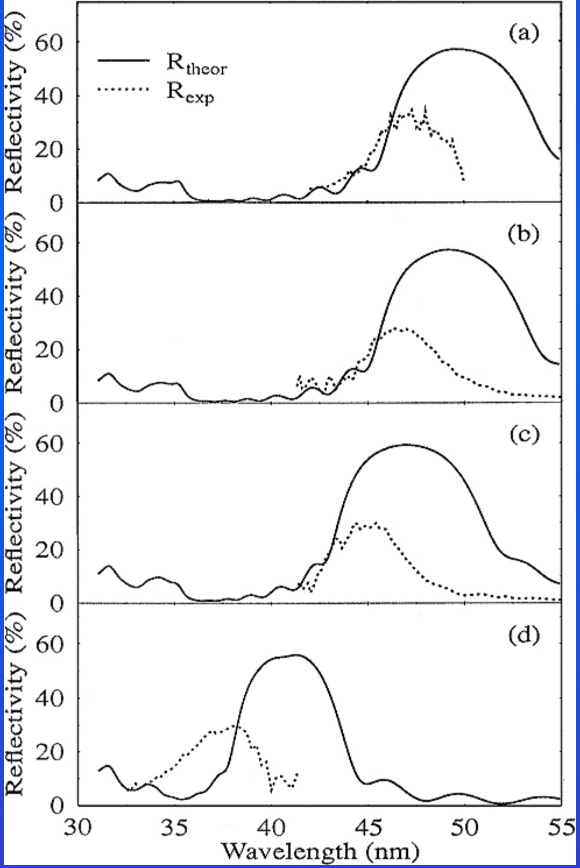
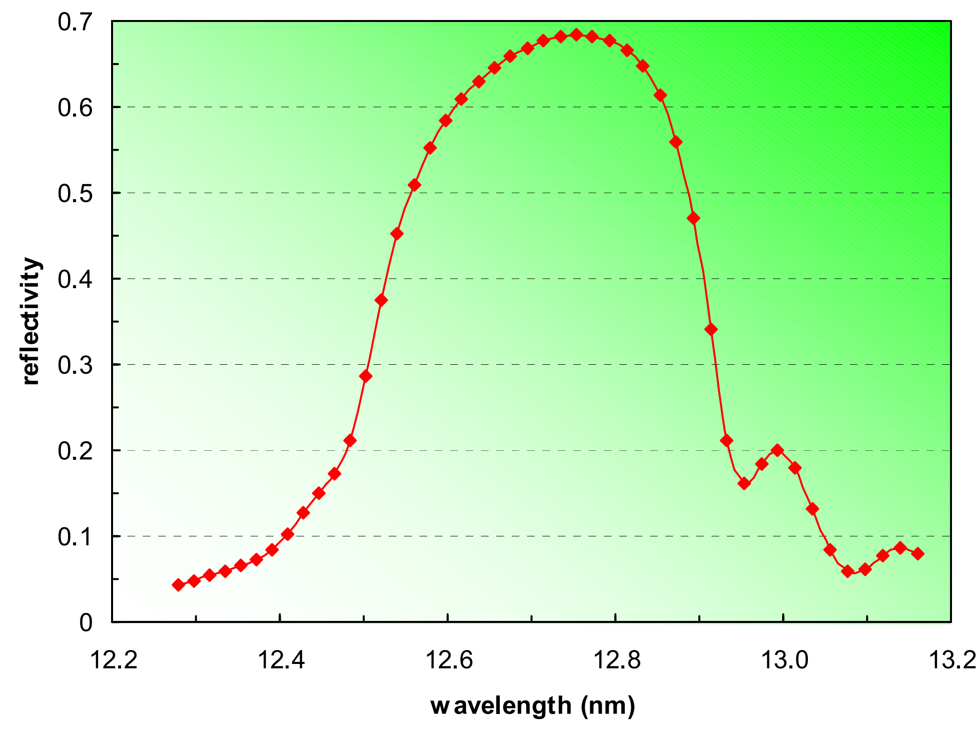
Towards shorter Wavelengths II

Sc-Si multilayer



Uspenkij et al. NIM A 448 (2000) 147-151

Mo-Si multilayer



By courtesy of A.Gatto

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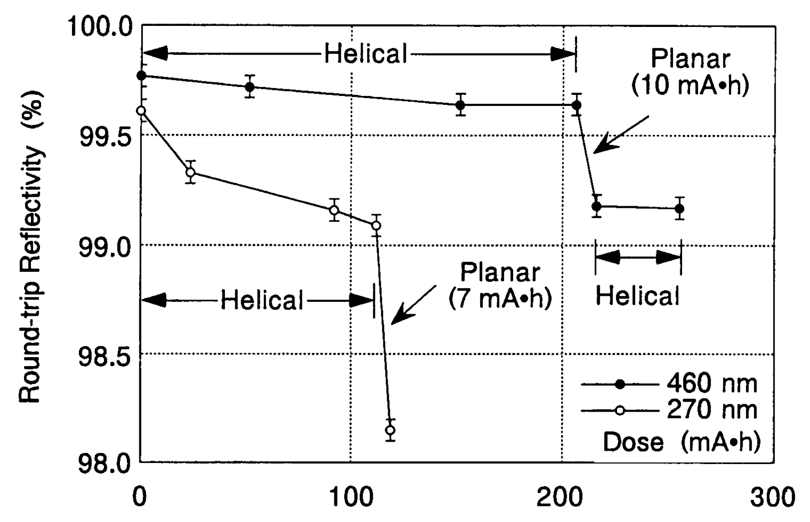
Mirrors Degradation

- ➢Surface Degradation
  - -Residual Hydrocarbon Gases
  - -VUV Harmonics from the undulator
- ➢Volume degradation
  - -Non stoichiometry
  - -X-rays activation



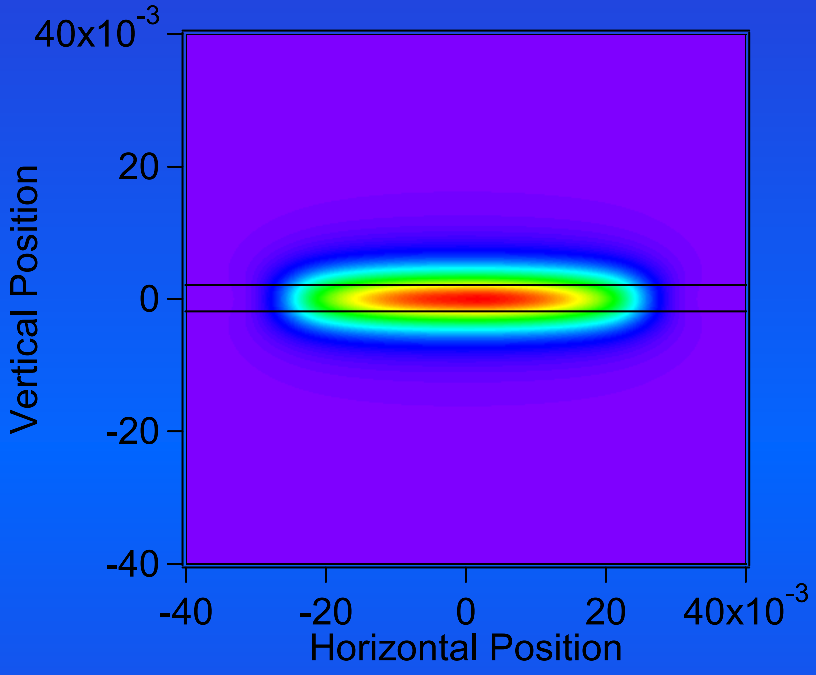
K. Yamada et al, NIM A (1995)

H. Hama et al, NIM A (1997)

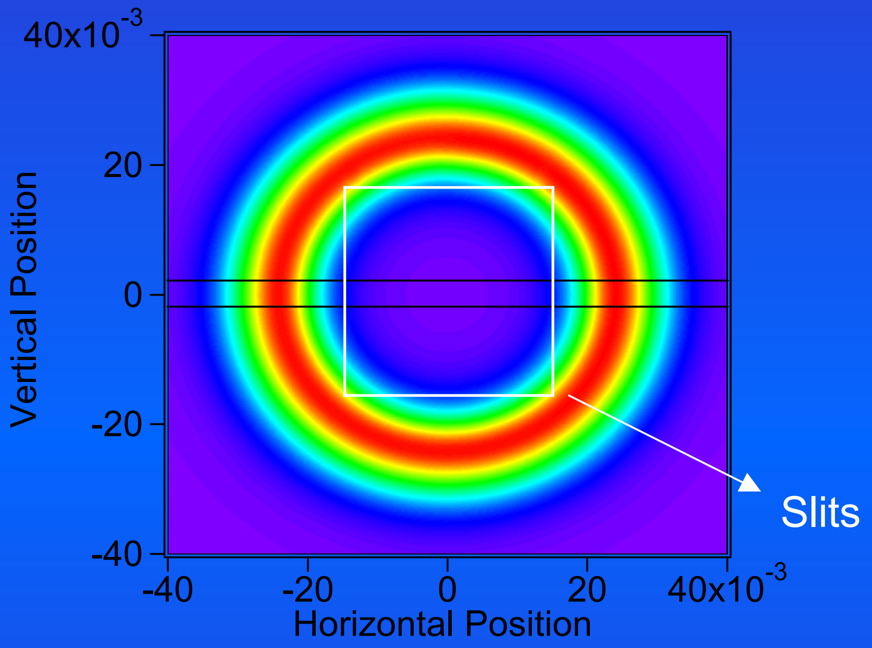
D. Garzella et al, NIM A (1996)

A. Gatto et al, NIM A 484 (2002)

Synchrotron Radiation



Planar Optical Klystron

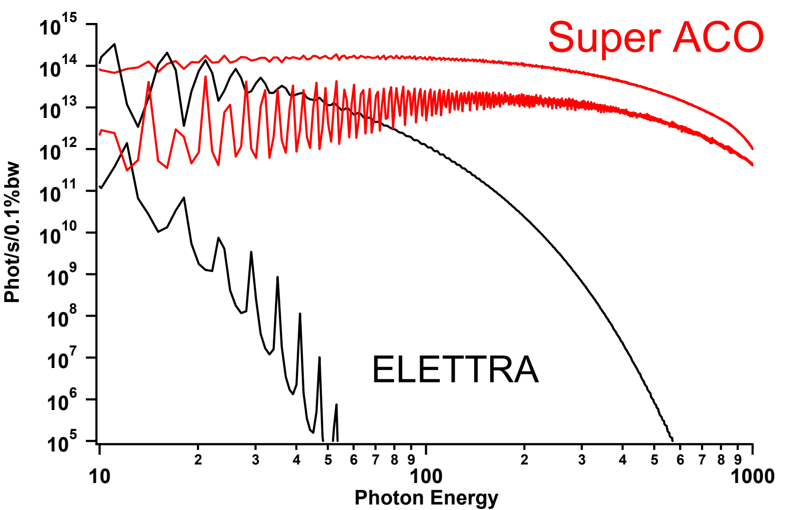


Variable Polarization Optical Klystron

Calculations performed with the SRW code (by P. Elleaume and O. Chobar)

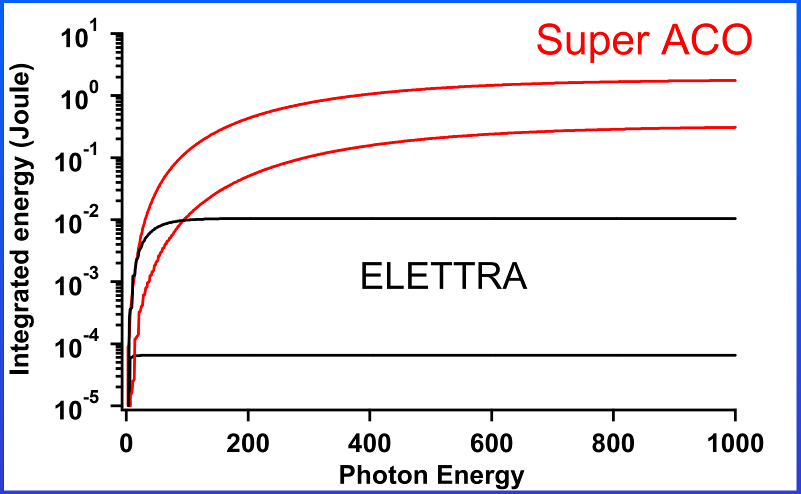
Mirrors Degradation

Synchrotron Radiation
spectral content



Investigated Areas :5 x 5 mm
20 x 20 mm

Total energy deposited
on the Surface



Has Irradiated Dose (mAh)
a meaning anymore?

High damage Threshold

LIDT scales as 1/λ and decrease with pulse length

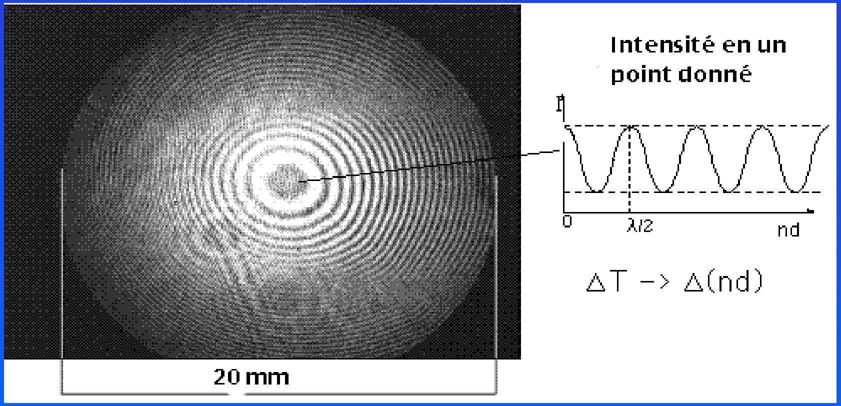
Wavelength (nm)	Coating	Pulse width	LIDT (J/cm²)	**Scaled 248 nm LIDT (J/cm²)**
355	Fluoride	3 ns	12	0.2
355	Oxide	3 ns	12	0.2
248	Oxide	30 ns	16	0.1
248	Oxide	20 ns	2.5	0.02
193	Oxide	30 ns	0.5	0.003
193	Fluoride	30 ns	6.7	0.04
800	Oxide	100 fs	0.4	0.1

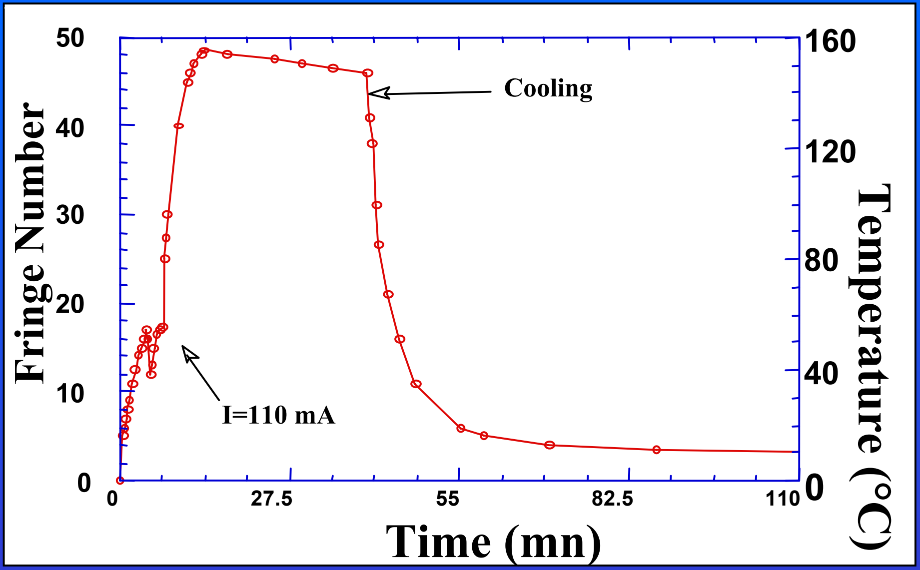
By courtesy of M. Shinn

Thermal Load and Stability

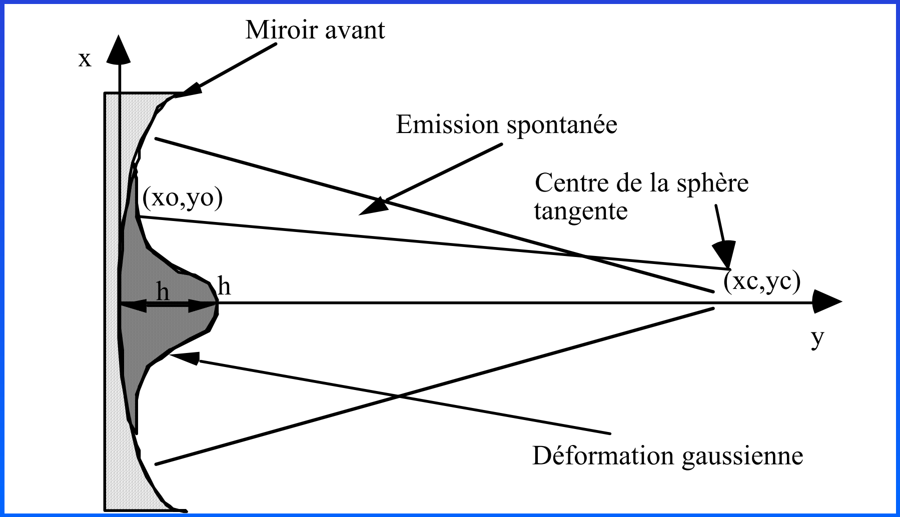
Synchrotron Power

$$P(W) = 7.28\,E^{2}(GeV)\,N\,I(A)\,\frac{K^{2}}{\lambda_{0}(cm)}$$



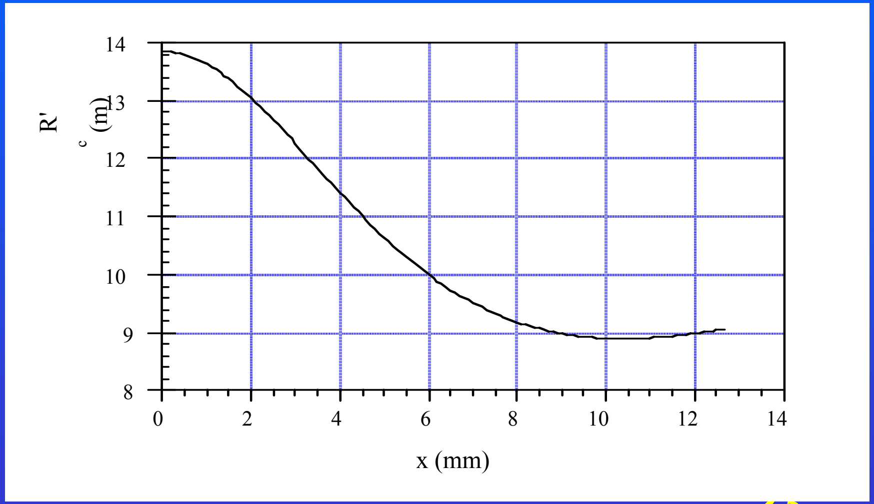


Synchrotron Power



$$y(x) = \frac{x^2}{2R_c} + h_{Th}\, e^{-\frac{x^2}{2\sigma_{Th}^2}}$$

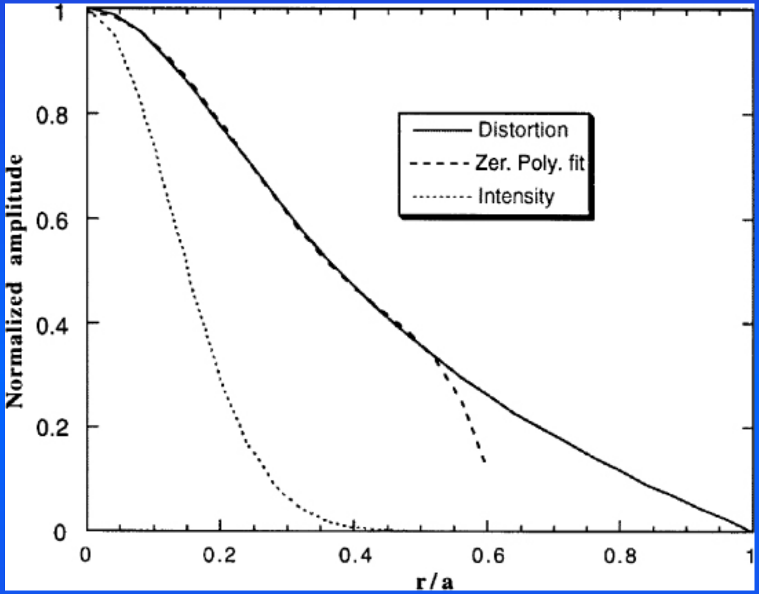
$$\frac{1}{R_c} - \frac{h_{Th}}{\sigma_{Th}^2}\, e^{-\frac{x_o^2}{2\sigma_{Th}^2}} \left(1 - \frac{x_o^2}{\sigma_{Th}^2}\right) = \frac{1}{R'_c}$$



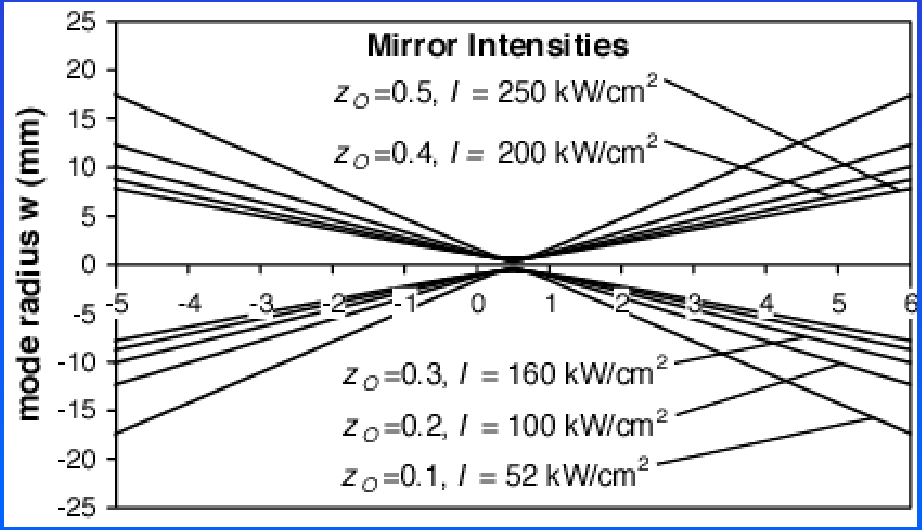
High Power FEL Operation

Non negligible amount of FEL power is absorbed (10’s of W)

Transient and steady-state mode distortion has been observed



High Power FEL Operation



-Thermal Load is reduced by shortening the Rayleigh Length

-Concentric Resonator configuration (more unstable)?

☞M. D. Shinn Tu-O-06

X-Ray Optics I : Reflective Optics

Spatial Coherence, High Brilliance ⟺ Imaging
Interferometry
Non linear Optics

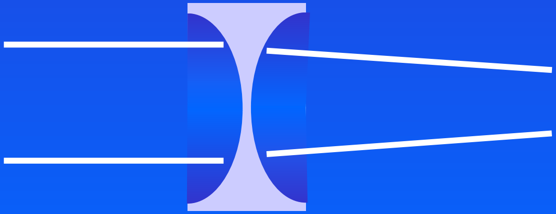
- ➢Surface State
  - Roughness << 1nm
  - Figure Errors < λ
- ➢Thermal constraints
- ➢Damage Thresholds

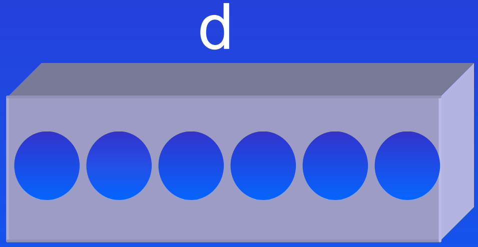
☞J. Kuba Th-O-04

☞B. Steeg Tu-P-30

X-Ray optics II : Refractive Optics

$$\mathrm{Re}(n) = 1 - \delta \qquad \delta \approx 10^{-4} - 10^{-6}$$



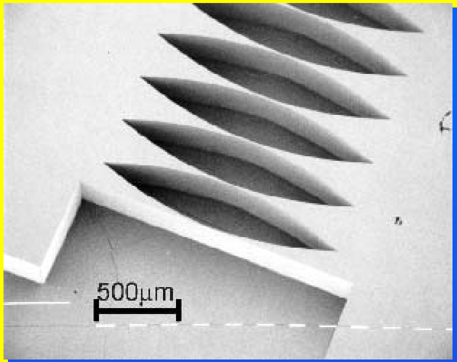


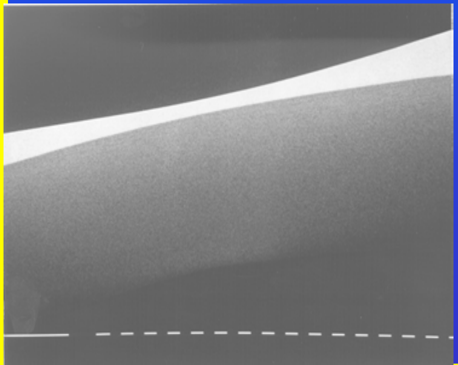
$$f \cong \frac{r}{2N\delta} \qquad N \approx 50 - 100$$

$$f \cong \frac{r}{2\delta} \qquad r \approx 100\ \mu m - few\ mm$$

δ (Al) 2.8 10^{-6} λ= 0.9 Å

$$f \cong 200\ m!!$$





LIGA process on PMMA

r=1-2 mm
d= 10 mm
δ =1.6 $10^{-6}\,\lambda^2$
N=100
f≈ few mm

By courtesy of R. Kupka

Conclusions

- Optical Resonator development is linked to the extension of user applications domain.
- High Damage threshold studies in the UV and mirror degradation by Synchrotron Radiation (cf. Fluorides) are still major issues.
- Research & Development in UV-VUV Optics for FEL still has a large interest, provided that improvement of the gain progresses as well.

Acknowledgments
M.E. Couprie and the Super ACO FEL team
The ELETTRA FEL Team
M. Shinn and S. Benson
A.Gatto, T. Feigl and S. Gunster