CONSIGLIO NAZIONALE DELLE RICERCHE
Istituto di Fotonica e Nanotecnologie

Studio di ottiche in riflessione e rifrazione per l'ottimizzazione del fascio Thomson

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Geometry of the optical system

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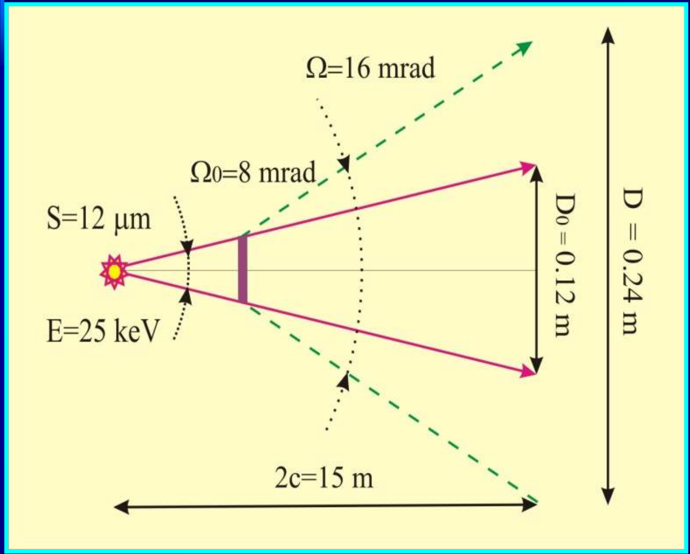

Source

Source: TS

Size of the source: 12 x 12 μm

Wavelength: 0.5 A

Divergence Ω 8 mrad

Distance source – detector: 15 m

Area of illumination 0.12 m

Goal

Increase divergece of the source and therefore the area of illumination up to 0.24 m

X-ray reflective optics basic rules

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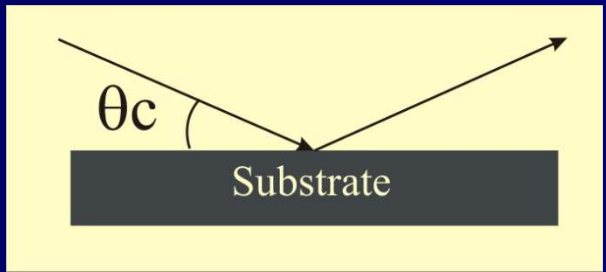
Critical angle



The *index of refraction* for x-ray radiation is

$n=1-\delta-i\gamma \quad \gamma<\delta<<1 \rightarrow Re(n) < 1$

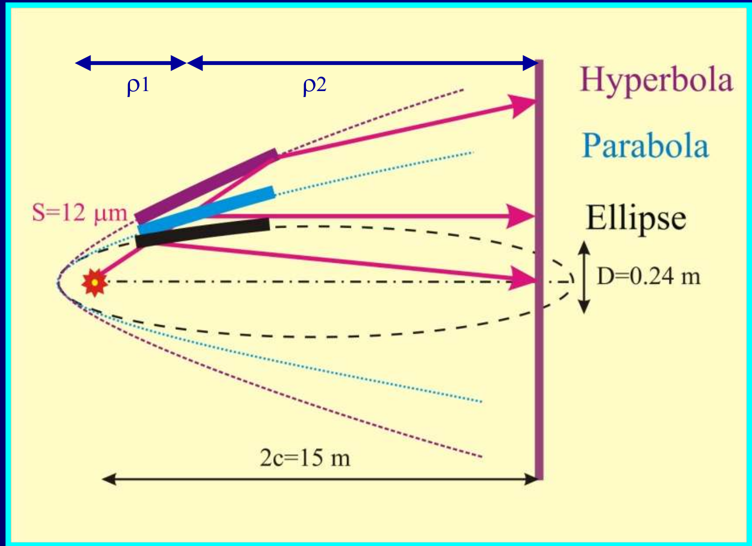
↓

Total reflection below a critical angle

$\theta c = (2\delta)^{1/2} \sim \lambda$

θc (*Pt, λ=0.05 nm*) = 3.4 mrad << Ω=8 mrad

Geometry of grazing incidence optics



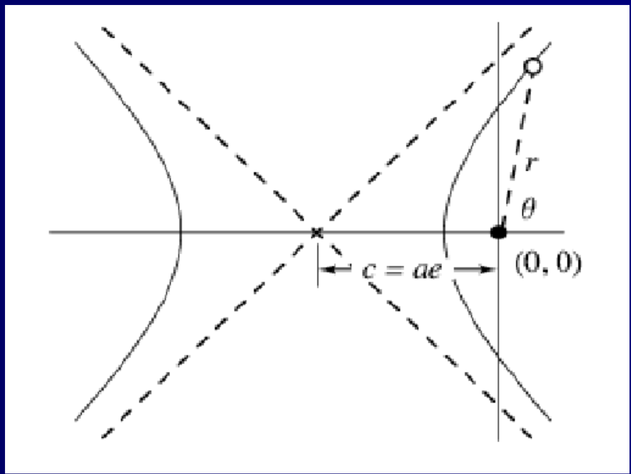
Ellipse

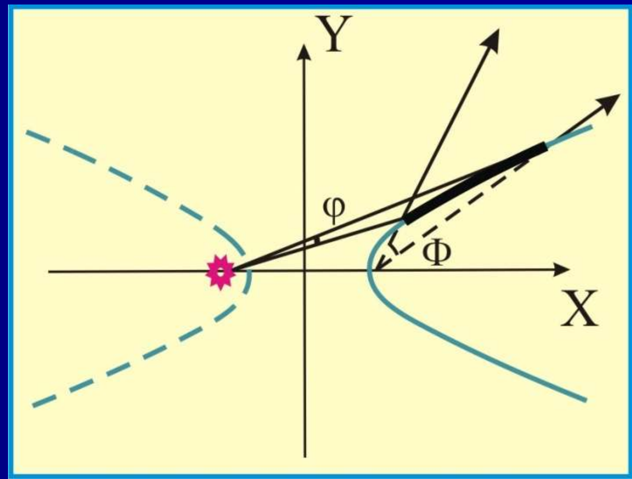
$$M = D/S \approx \rho_2/\rho_1 = 2\cdot 10^4 \quad \Rightarrow \quad \rho_1 \approx 7.5\cdot 10^{-4}\,m$$

Parabola

$$\Phi_{max} = 2\theta_c \approx 7\,mrad$$
$$L >> 1\,m$$

Hyperbolic reflecting mirror



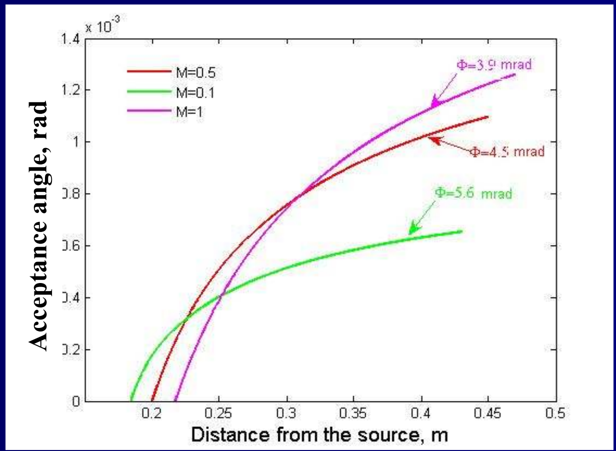


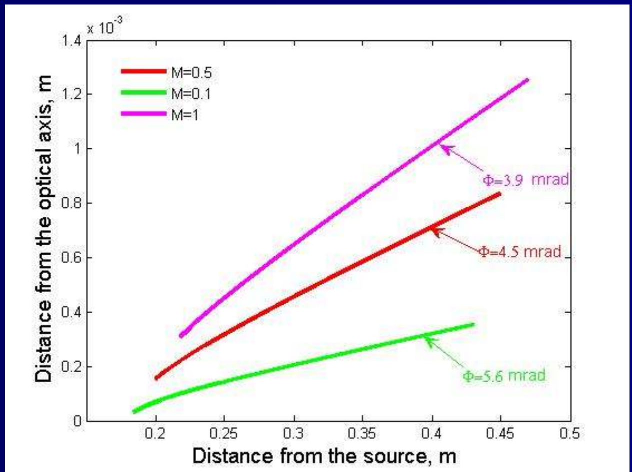
In polar coordinates centered at a focus,

$$r = \frac{a\left(e^2 - 1\right)}{1 - e\cos\theta},$$

All x-rays emitted from the source and reflected from the hyperbolic surface give a divergent beam having a secondary imaginary source

Hyperbolic reflecting mirror





Length of the mirror **L=0.25 m**
material **Pt**

Critical angle **3.4 mrad**

Eccentricity $$\mathbf{e = 1 + \frac{1}{2}\theta_c^2 M}$$

Acceptance angle increase with increase of the eccentricity e

but

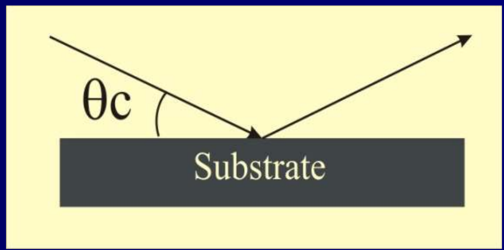
divergence Φ of the reflected beam decrease therefore

$$\mathbf{e_{opt} = 1 + \frac{1}{2}\theta_c^2 M, \quad M = 0.5}$$

Acceptance angle < θc=3.4mrad

β_{max} **~1 mrad << Ω = 8 mrad**

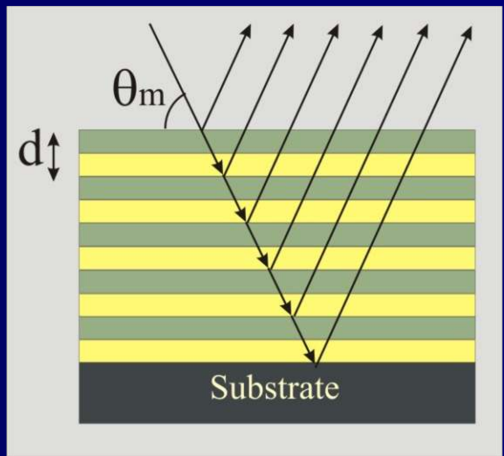
Short-period multilayers



<u>Critical angle</u>

$\theta c = (\delta)^{1/2}$ $\varepsilon = 1 - \delta + i\gamma$ $\gamma << \delta << 1$

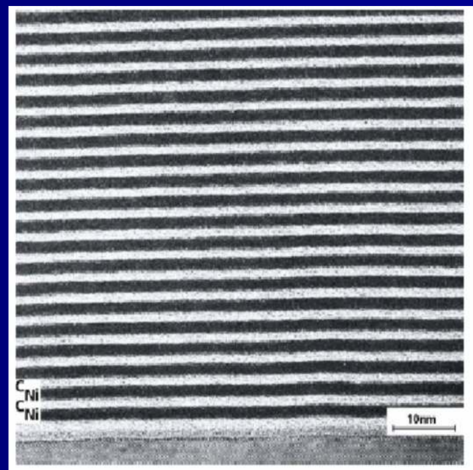
θc (Pt, $\lambda = 0.05$ nm) = 3.4 mrad << Ω = 8 mrad



<u>Multilayer mirror</u>

$2d\mathrm{Sin}(\theta m) = m\lambda$ → d = 2–3 nm

θ_1 = 8-12 mrad



Ni / C d=3.15 nm

R.Dietsh, S.Braun, T.Holz, H.Mai, R.Scholz, L.Brugemann "Multilayer x-ray optics for energy E>8 keV and their application in x-ray analysis" SPIE

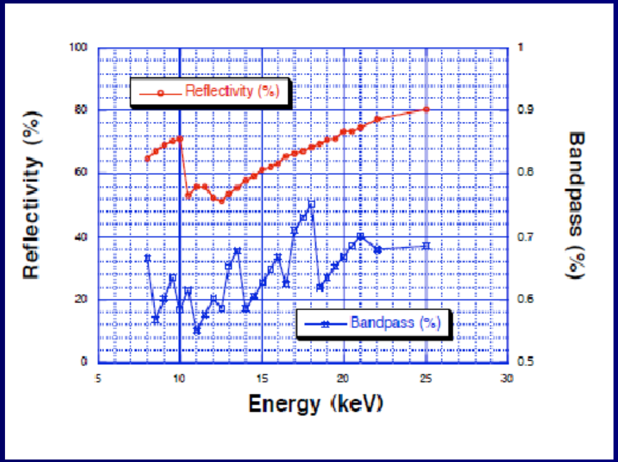
Short-period multilayers

Multilayer (0.965 nm WSi2)/(1.005 nm Si)
d=2 nm

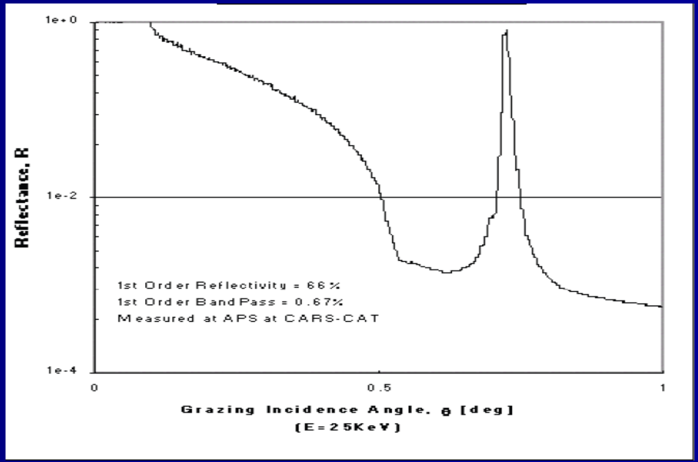
θ_1=12.5 mrad

C.Liu, R.Conley, A.T.Macrander, T.Graber,
Ch.Morawe,C.Borel, E.M.Dufresne,
"Small-d-spacing WSi2/Si narrow bandpass multilayers"
Proc. SPIE, Vol. 5537, 154 (2004)

Advantage of WSi2/Si multilayer
High temperature and radiation load stability

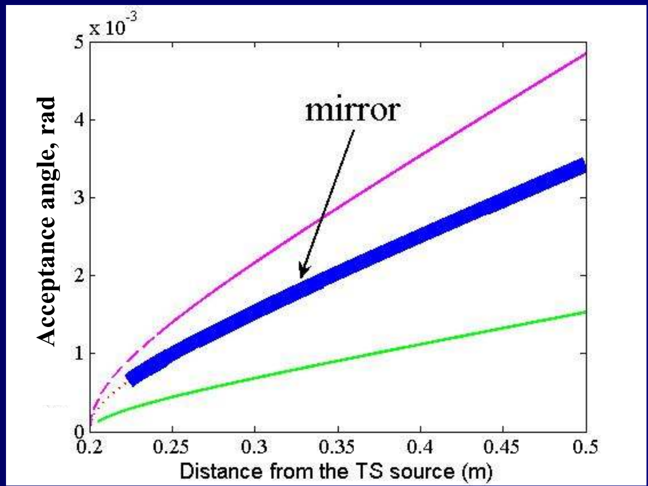


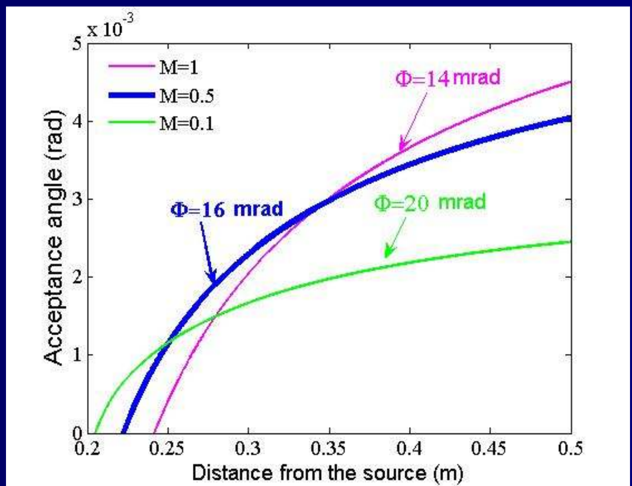
Simulated reflectivity and bandpass for WSi2/Si (d=2 nm) x 300 multilayer
R (E=25 keV) = 80 %



Reflectivity scan carried out at the ChemMatCARS-CAT of the APS at 25 keV
R(E=25keV)=66%, bandpass 0.67%

Hyperbolic reflecting mirror





Length of the mirror L=0.25 m

WSi2/Si multilayer

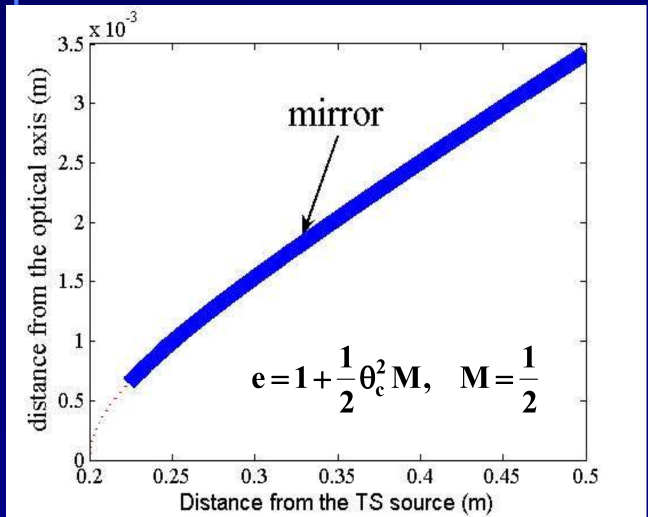
θ_1=12.5 mrad

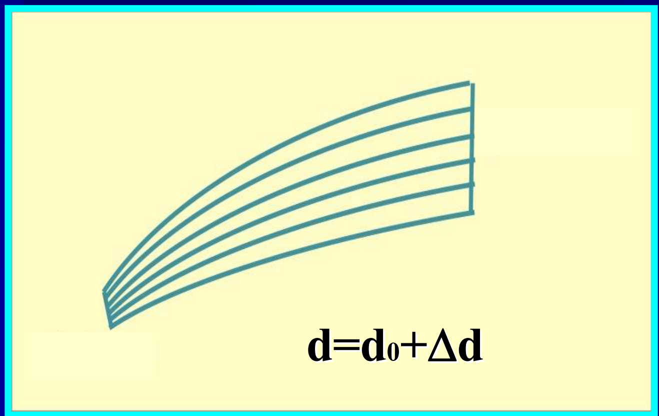
Eccentricity $e = 1 + \frac{1}{2}\theta_1^2 M \,, \quad M = 0.5$

Acceptance angle

βmax ~ 4 mrad = $\Omega/2$

Hyperbolic reflecting mirror



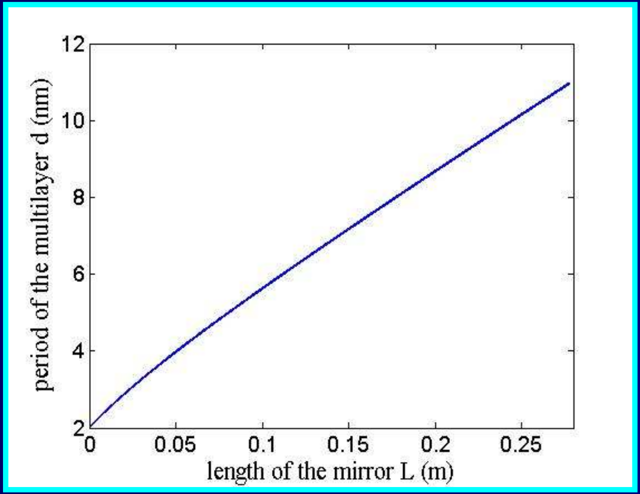


Optical system (hyperbolic)

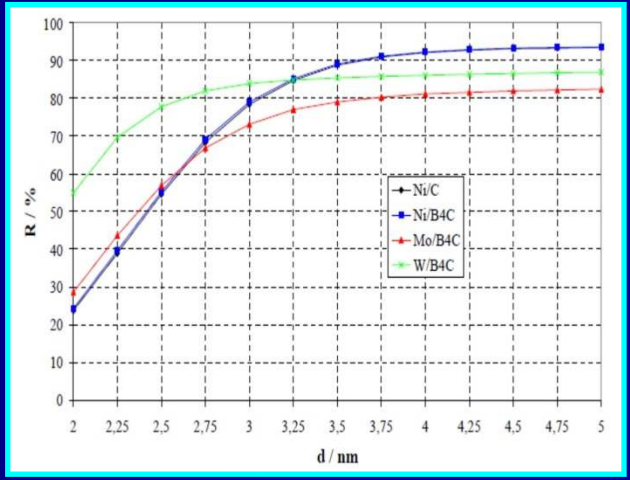
Crytical angle (multilayer):	8-12.5 mrad
Distance source – mirror:	0.2 m
Length of mirrors:	0.25 m
Divergence Φ	16.4 mrad = 2W
Area of illumination	0.24 m
Acceptance angle:	4 mrad

Surface of the mirror is covered by laterally graded multilayers

Laterally graded multilayers

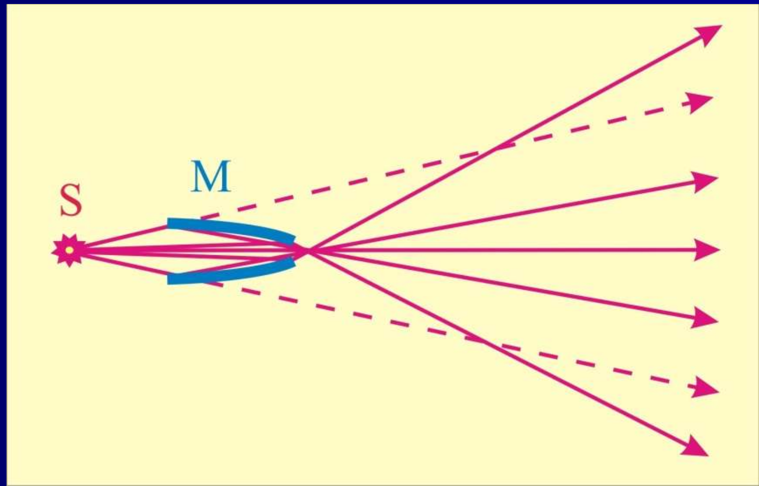


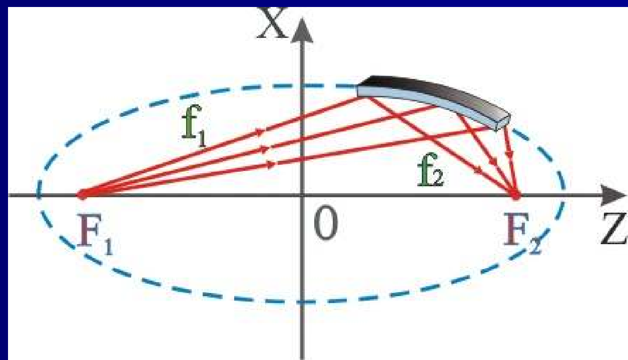
Period of the multilayer increase



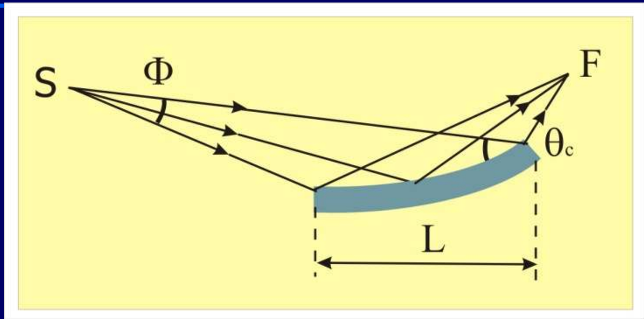
Simulation of the reflectivities of Ni/C, Ni/B4C, Mo/B4C, and W/B4C multilayer systems with 75 periods for E=30 keV radiation
R(d>3.5 nm)->80-90 %

Elliptical focusing mirrors





Elliptical focusing mirrors



$$e_{opt} = 1 - \frac{1}{2}\theta_c^2 M \qquad M = \frac{1}{2}$$

$$\Phi_{opt} \approx 5/6\,\theta_c\,M$$

$$L_{opt} \approx 2c\left(1 - \frac{2-\sqrt{1+M}}{1+M}\right)$$

2 mirror or ellipsoid

Divergence ~16 mrad

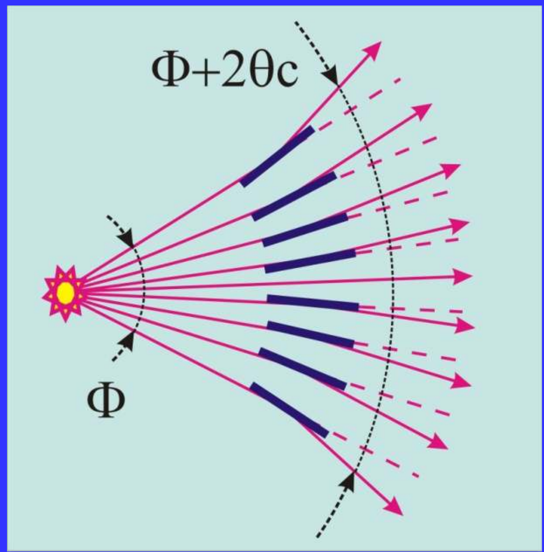
Material Pt

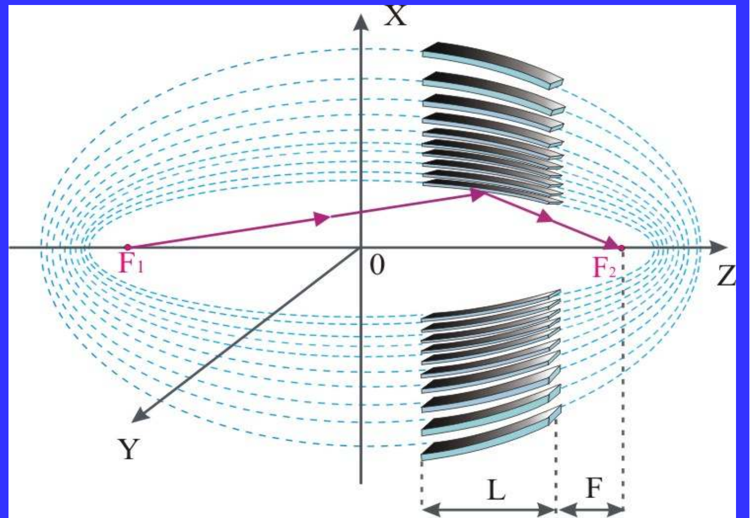
Distance source –mirror:	1 m
Critical angle:	3.4 mrad
Acceptance angle (Φopt)	1.4 mrad
Length of the mirrors:	~1 m
Divergence	~ 3mrad
Distance	0.2 m
Acceptance angle	1.4 mrad
Length of the mirror	~0.2m
Divergence	~ 3mrad

Multilayer

Resonance angle (θ_1)	8-12.4 mrad
Acceptance angle (Φopt)	4.6 mrad
Distance	1m
Length of the mirror	0.97 m
Divergence	~ 8-10 mrad
Distance	0.2 m
Acceptance angle (Φopt)	4.6 mrad
Length of the mirror	~0.2 m
Divergence	~ 8-10 mrad

Multiple mirrors





$\theta c(Pt)=3.4$ mrad $\Phi_0=\Phi+4\theta \sim 16$ mrad
$D \sim 15m*16mrad \sim 0.24$ m

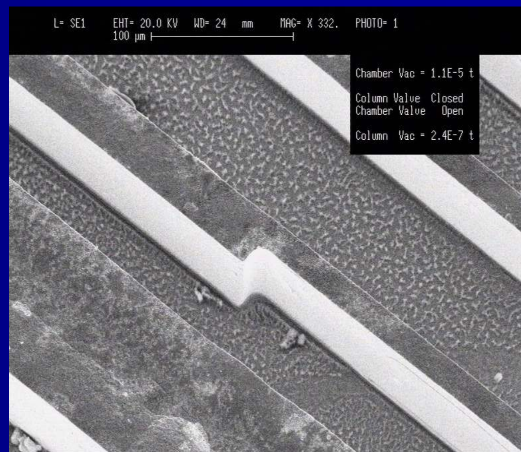
*I.Bukreeva, A.Gerardino, A.Surpi, A.Cedola, S.Dabagov, S.Lagomarsino, Design and simulation of nested x-ray mirrors, Proc. SPIE, vol. **5974** (2005).*

*I.Bukreeva, A. Surpi, A. Gerardino, S.Lagomarsino, F. Perennes, M. Altissimo, S. Cabrini,A. Carpentiero, A. Vicenzo and P. Cavallotti, Multiple micro mirrors for X-ray focusing and collimation, Optics Communications, **259**, 366- 372, (2006).*

Experimental results with deep X-ray lithography

- **4 mirror system for synchrotron radiation**

- **Mirrors in Ni grown by electrochemical deposition**



Experimental results with SU8

- **Few-centimeter long self-standing mirrors**
- **No enlargement in the process**