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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SECOND SCHOOL ON THE USE OF SYNCHROTRON RADIATION IN SCIENCE AND TECHNOLOGY:
"JOHN FUGGLE MEMORIAL"

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Miramare - Trieste, Italy

Fresnel Based Optics and Microfabrication

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Fresnel Based Optics and Microfabrication

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The lecture scope:

1. Optical properties of the materials in x-ray region.
2. Grazing incidence optics.
3. Fresnel zone plates.
4. Fourier x-ray optics.
5. Multilayer mirrors.
6. Bragg-Fresnel soft x-ray optics.

a) Multilayer gratings

b) Modulated Optics

c) Bragg-Fresnel lenses

d.) Fluorescence microprobe

7. Microfabrication technique.

Optical Properties of Materials in X-ray Region

Complex optical index:

$$n = 1 - \delta + i\beta$$

$$\delta = r_e\lambda^2 N_g f_1/(2\pi) \qquad \beta = r_e\lambda^2 N_g f_2/(2\pi)$$

Where: f_1 and f_2 are atomic scattering factors;
r_e - the classical electron radii,
N_g - the number of atoms in unit volume.

Example:

For SILICON at the wavelength of 0.15 nm:

$$\delta = 7.56\text{x}10^{-6}, \qquad \beta = 1.7\text{x}10^{-7},$$

For TUNGSTEN at the wavelength of 0.15 nm:

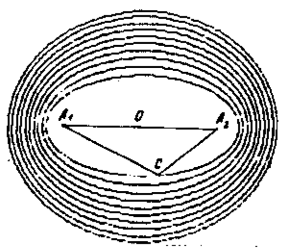
$$\delta = 4.57\text{x}10^{-5}, \qquad \beta = 7.56\text{x}10^{-6},$$

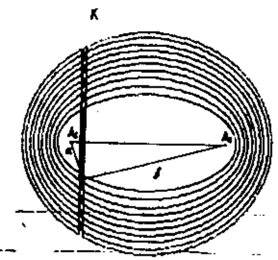
V.V. Aristov, A.I. Erko, V.V. Martinov, 1988

REVUE DE PHYSIQUE APPLIQUÉE N° 10

le I.

	Grazing incidence optics 1952	Fresnel optics 1952	Bragg-Fresnel optics 1986
cal scheme			
	$\varphi_{kp} = \sqrt{\Delta n}$	$f = \frac{r_1^2}{\lambda}$; $r_N = N\lambda f + \frac{N^2\lambda}{4}$; $N - 1 < \frac{[\mathbf{k}_1 \cdot \mathbf{r}]^2}{r_1} + \frac{[\mathbf{k}_2 \cdot \mathbf{r}]^2}{r_2} \leqslant N$	
ɔmatic aberrations	—	λ	none, the image is formed in a reflected wavelength range
iting resolution a_{max}	limiting by strong aberrations at a grazing incidence ~ 1 μm	50 – 100 nm $a_{max} = 2\lambda/(1-n)^{1/2}$	determined by technological possibilities and reaches 10 nm when using bending substrates
imum angular ture φ_{max}	$\varphi_{max} < \varphi_{kp}$	$\varphi_{max} = \frac{1}{2}(1-n)^{1/2}$	determined by technological possibilites
ibility of amp- e and phase ılations	none	none	possible
ibility of hybrid ne fabrication	none	none	switching and controlling of an X-ray signal by electrical and sound signals is possible
bility of fabri- n of different y optical ents	fabrication of focusing and dispersive elements is possible	fabrication of lenses and gratings is possible	fabrication of lenses, modulators and mirrors is possible





— Rotational ellipsoids which represent equal ...

Grazing Incidence Optics. Total External Reflection.

The critical angle value:

$$n = 1 - \delta = \sqrt{1-\theta_c^2}$$

$$\theta_c = 2\delta^2$$

Fresnel reflection coefficients:

$$R_p = \frac{n\sin\theta_1 - \sin\theta_2}{n\sin\theta_1 + \sin\theta_2} \qquad R_t = \frac{\sin\theta_1 - n\sin\theta_2}{\sin\theta_1 + n\sin\theta_2}$$

Applications:

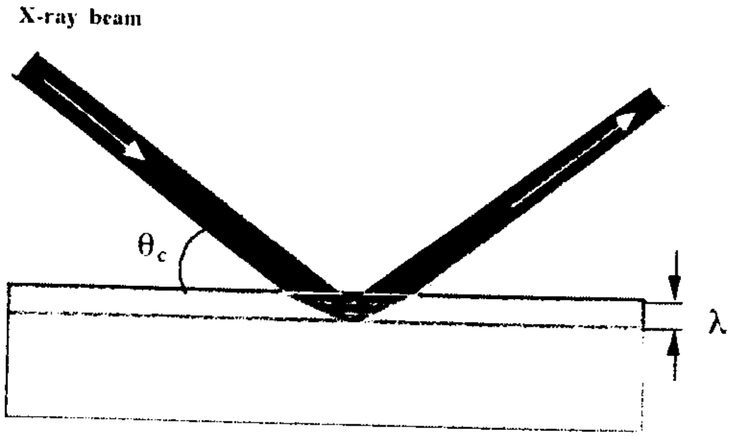
Mirrors,

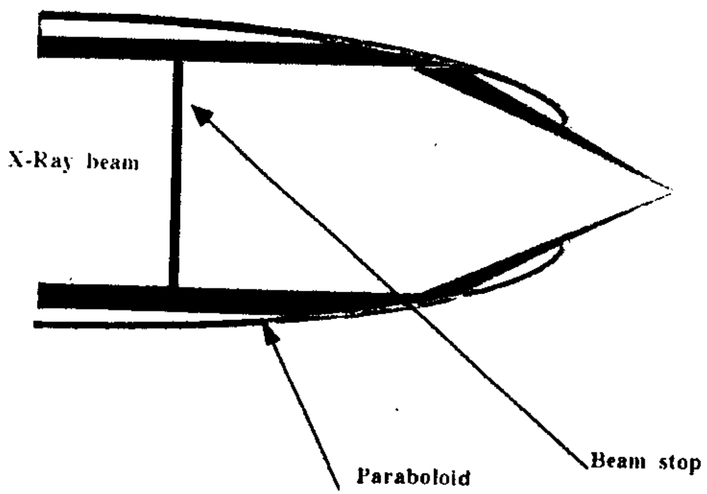
Reflection Gratings,

Focusing devises,

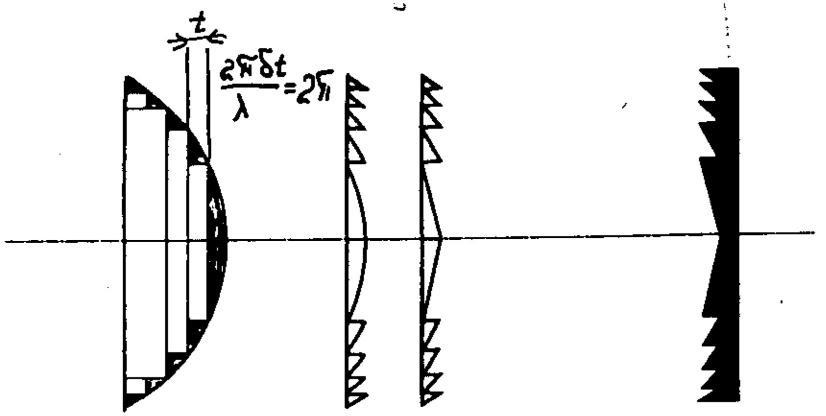
Capillary Optics

Total external reflection optical systems



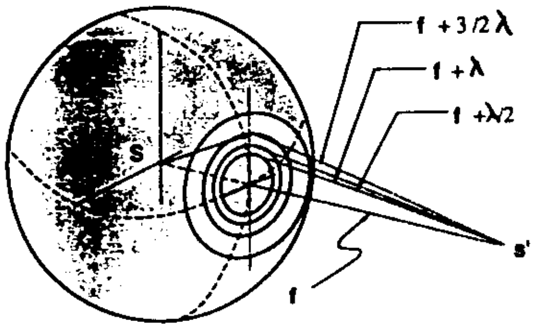


3. Fresnel zone plates.



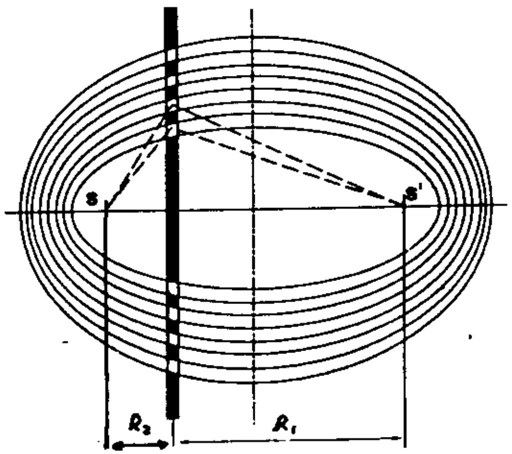
Fresnel's light house lens
(Kinoform)

X-Ray Lens

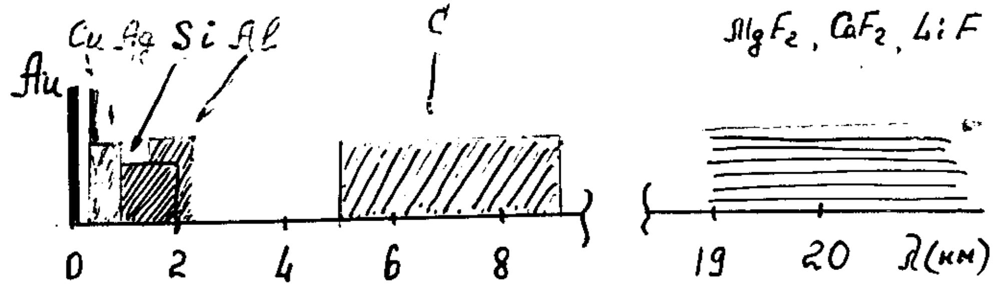


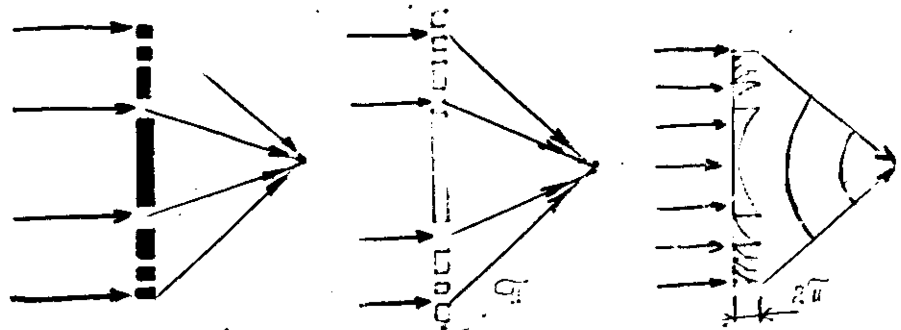
Fresnel's zones

Fresnel's zone lens



$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{F}$$





Amplitude	Phase	Kinoform
$\mathcal{E}_{ff} \leq 10\%$	$\mathcal{E}_{ff} \sim 40\%$	$\mathcal{E}_{ff} \sim 100\%$

Optimal phase shift can be calculated:

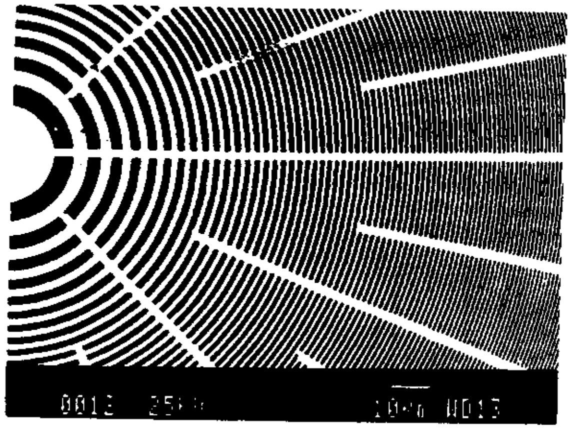
$$2\sin\Delta\varphi_{opt} + 2\chi\cos\Delta\varphi_{opt} = 2\chi\exp\{\chi\Delta\varphi_{opt}\}$$

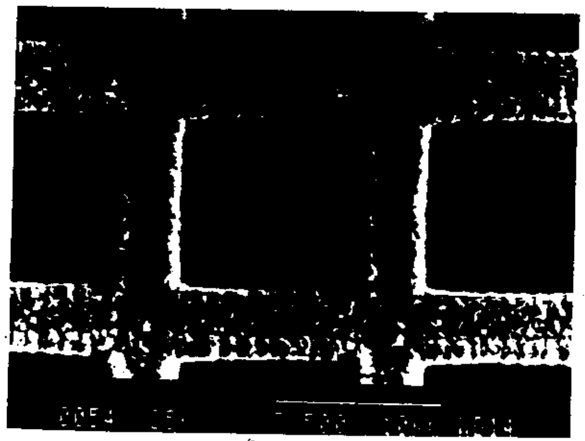
where $\chi = \beta/\delta$

Efficiency:

$$\frac{I_1}{I_0} = \frac{[1 + \exp\{-\chi\}]^2}{\pi^2}$$

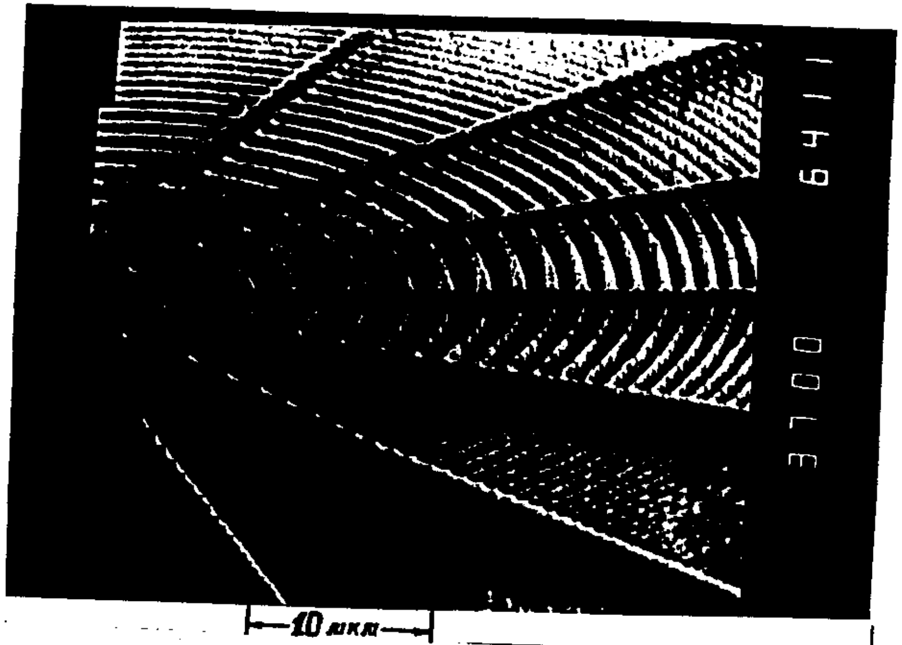
FREE-STANDING GOLD ZONE PLATE





FREE-STANDING GRATING

Made in IMT RAS.



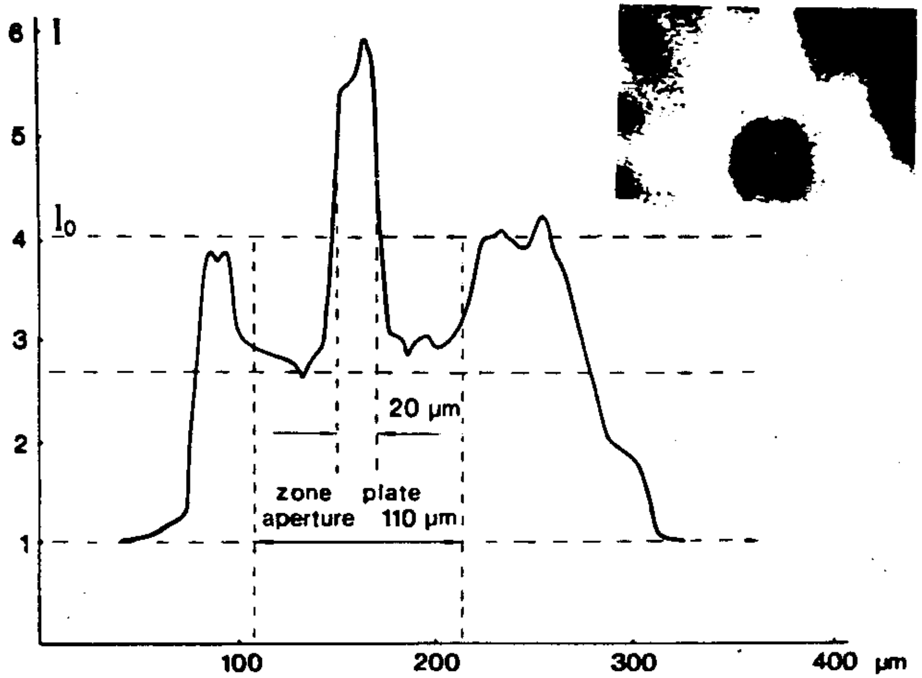
FREE-STANDING CIRCULAR SILICON ZONE PLATE.

THICKNESS - 2.3 μ

FOCAL LENGTH AT 0.834 NM - 5 CM.

Teoretical efficiency - 36% at $\lambda = 8.34$ Å

Made in IMT RAS



. Energy distribution in the image plane of the circular zone plate.

Measured efficiency at λ = 0,84 nm

$$\frac{I_1}{I_0} = 0.18$$

Reference: The best resolution is obtained at BESSY-Göttingen microscope ~ 30nm

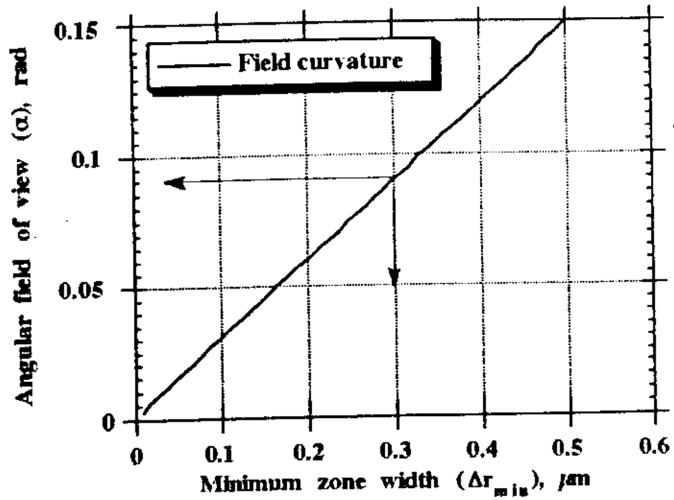
Fresnel zone plates

The main formula:

$$r_n = \sqrt{NF\lambda + \frac{N^2\lambda^2}{4}}$$

The main aberrations:

Field of veiw for transmission zone plate



λ = 1,5 Å
F = 15cm

$$\alpha < 16\,\frac{(\Delta r_{min})^3}{F\lambda^2}$$ - **COMA**

$$\alpha < \Delta r_{min}\sqrt{\frac{4}{F\lambda}}$$ - **ASTIGMATISM AND FIELD CURVATURE**

4. X-Ray Fourier Optics

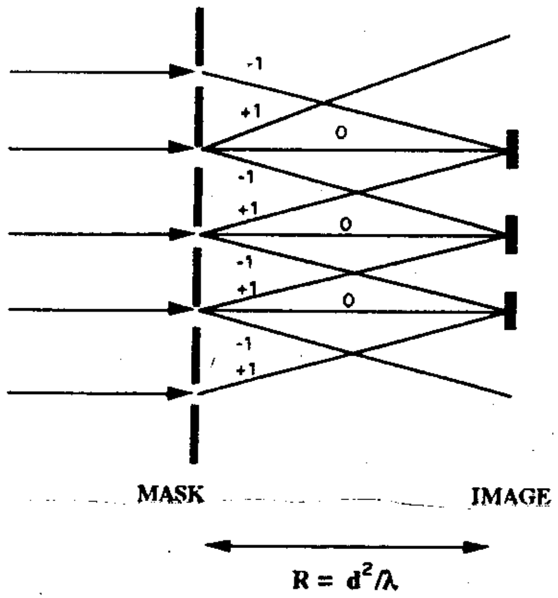
Fresnel-Kirchhoffs Integral.

$$E(u) = \sqrt{\frac{i}{R\lambda}} \int_{-\infty}^{\infty} g(x) \exp\left(-i\frac{\pi x^2}{R\lambda}\right) \exp\left(-i\frac{2\pi u x}{R\lambda}\right) dx$$

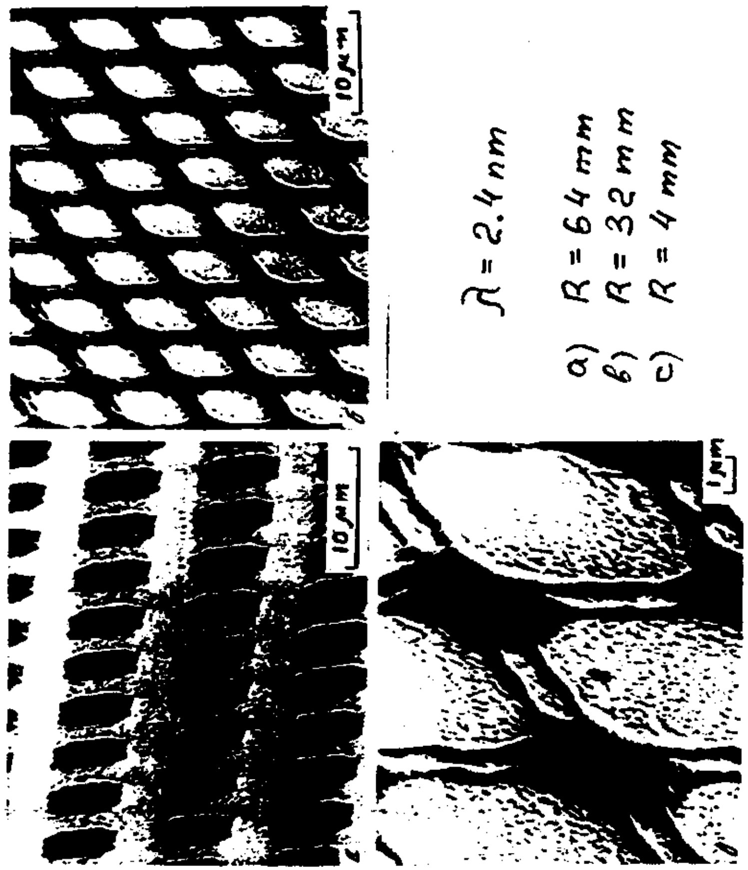
For periodical objects at the distances of

$$R_{n,m} = \frac{md^2}{n\lambda}$$

where d is the mask period, m and n are integer



The Scheme of TALBOT effect or FOURIER imaging



λ = 2.4 nm

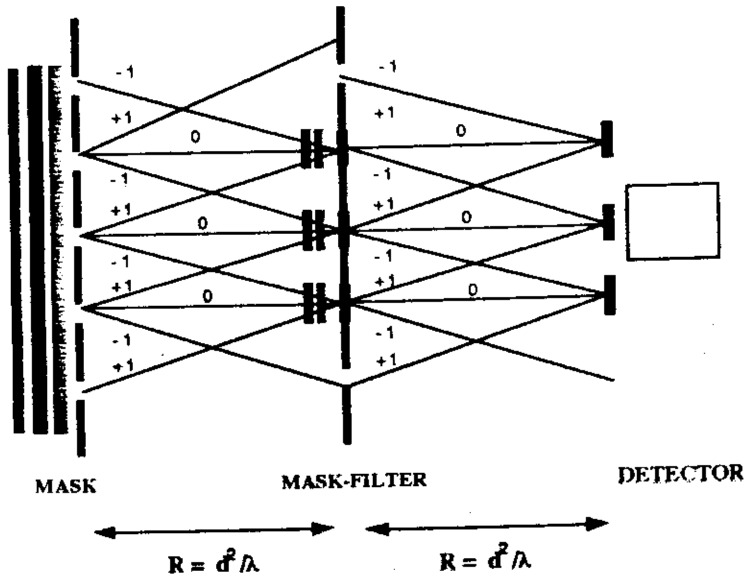
a) R = 64 mm
b) R = 32 mm
c) R = 4 mm

Undulator Beam line. Photon Factory Tsucuba. A. Erko et al. Opt. Comuns. 1985 56, p.223-255

Applications of the Talbot effect:

Periodical imageses transfere

Spectroscopy



The scheme of the Talbot spectrometer

$\frac{\Delta\lambda}{\lambda} = N^{-2}$ - Spec^t^ral resolution of the Talbot spectrometer

↑ Important

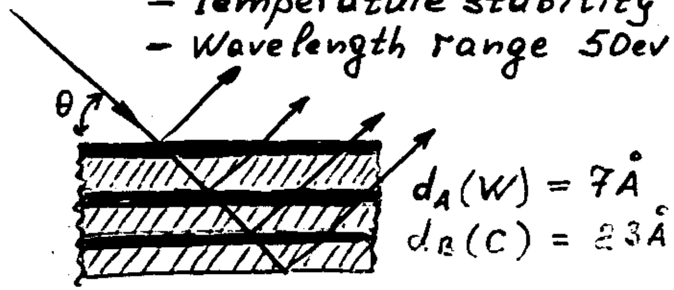
5. Multilayer mirrors

Reflection from the surface at $\theta > \theta_c$
$R \ll 1$ $(\sim 10^{-4} - 10^{-6})$

Only one solution: interference reflection.

a) Natural crystals: High absorbtion, low stability

b) Artificial multilayer structure:
- High reflectivity
- Temperature stability ~ 500°C
- Wavelength range 50ev – 60KeV.



Bragg Law:

$$2(d_A + d_B)\sin\theta = \lambda$$

Examples:

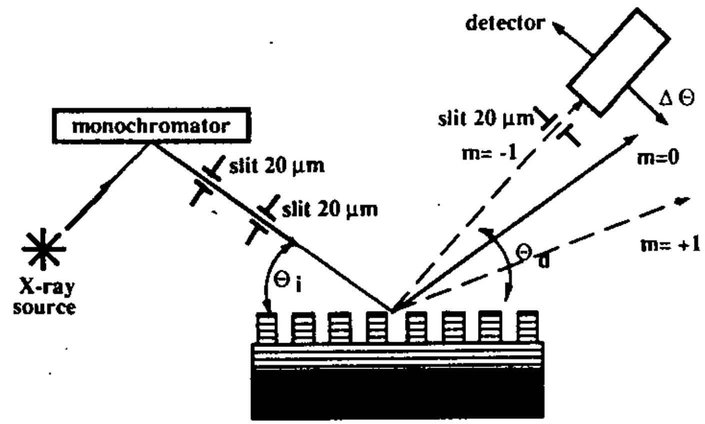
W/Si, 30 Å period, λ = 1 Å, R ≈ 80%
—//— —//— λ = 4 Å, R ≃ 20%
W/C, 32 Å period, λ = 45 Å R ≃ 50%

Spectral resolution $\Delta\lambda/\lambda \simeq 10^{-2}$

6. Bragg-Fresnel soft x-ray optics.

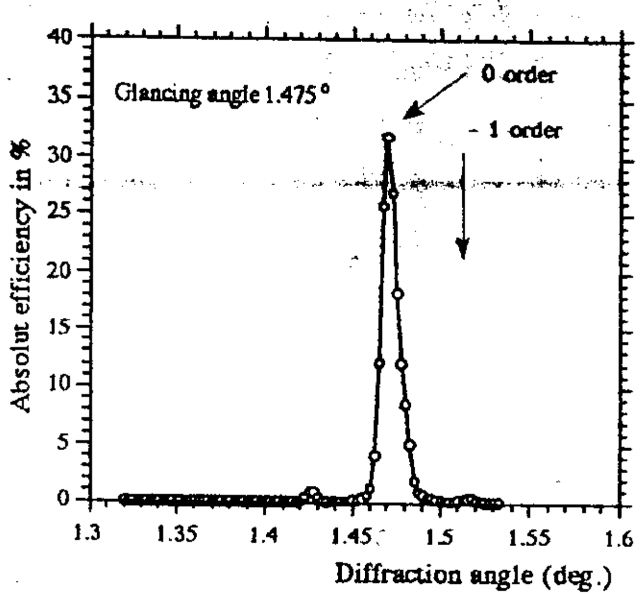
a) Multilayer gratings

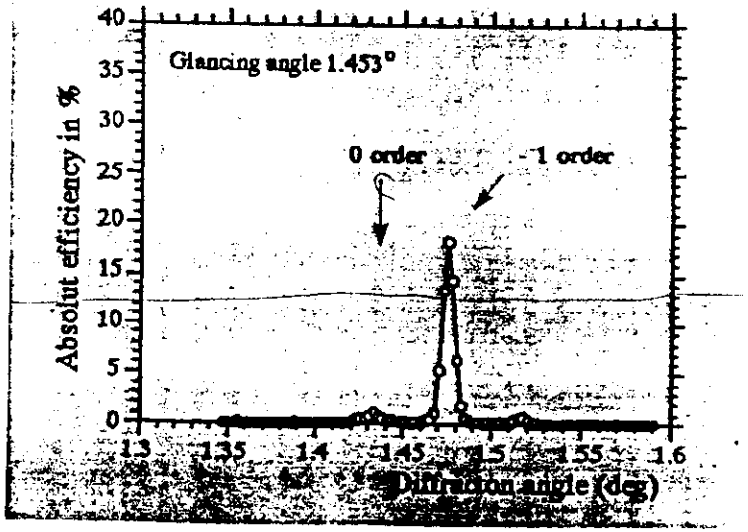
Multilayer graiting test



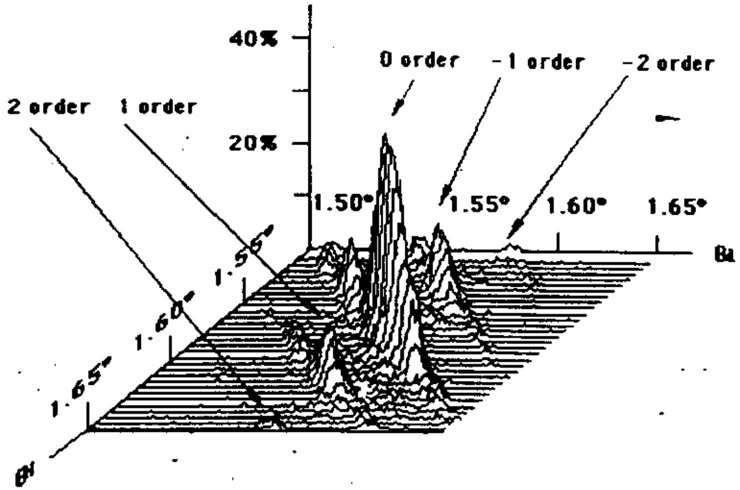
Optical scheme of the experiment.

Multilayer graiting efficiency



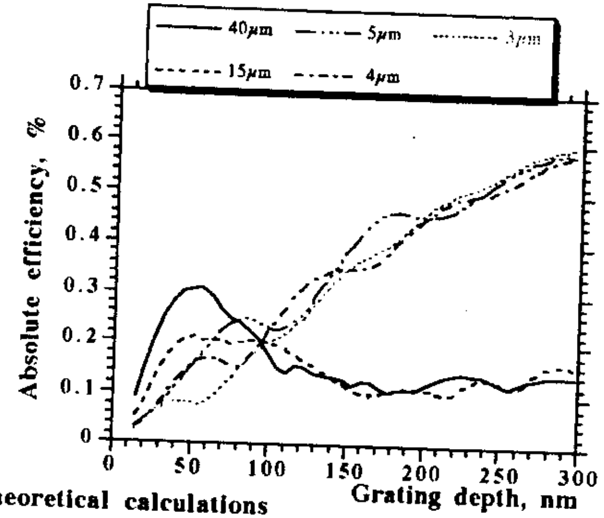


Multilayer graiting test



Detector scan mode for the grating depth 230nm.

Multilayer Grating Efficiency

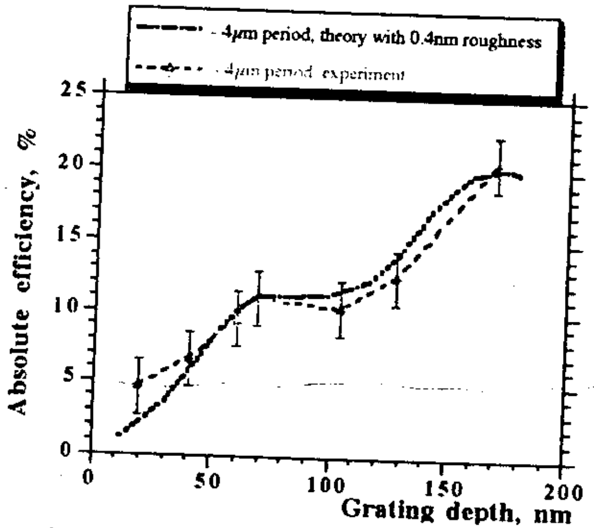


Theoretical calculations

$\lambda = 1.5 \text{Å}$

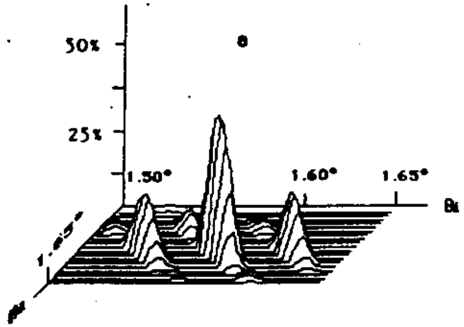
$d = 30 \text{Å}$

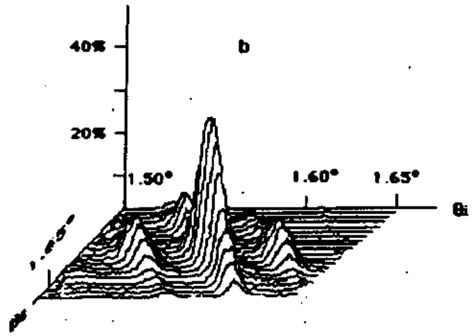
W/Si



Experimental results

Multilayer grating test

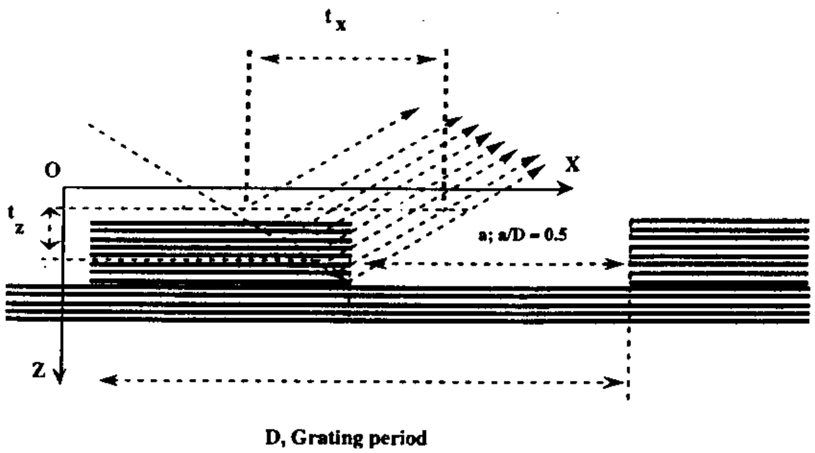




Sample scan mode for the graiting depth 230nm.

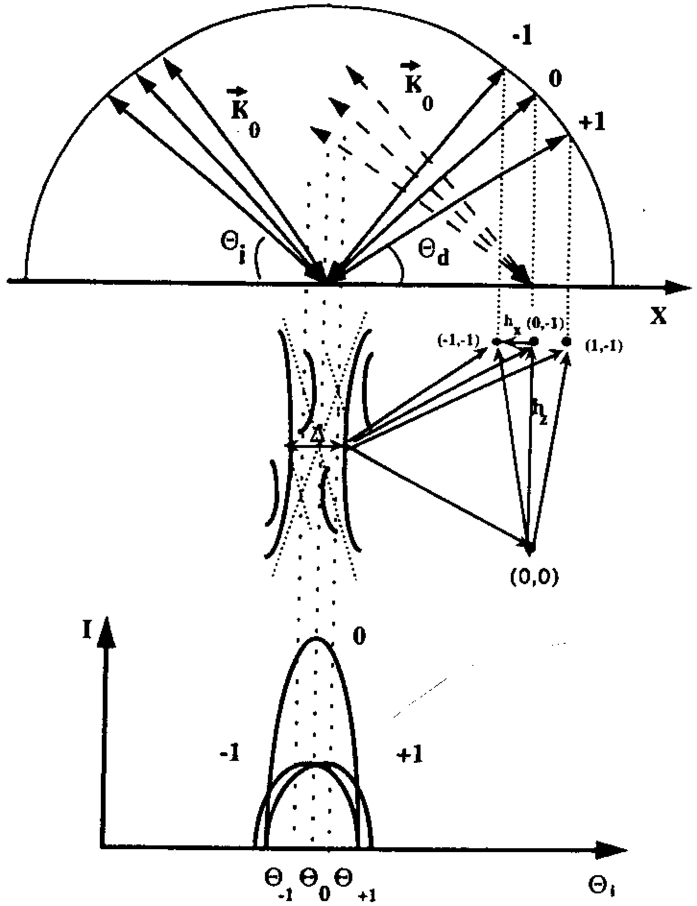
a - calculation using modal theory

b - experimental results.

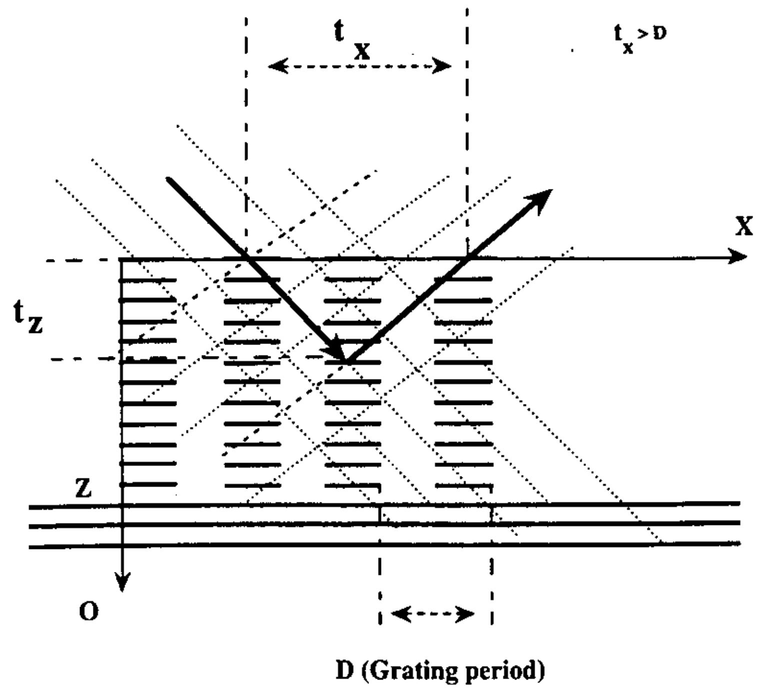


Multilayer Grating scheme showing extinction length; Light path corresponds to the case :

tx <<D

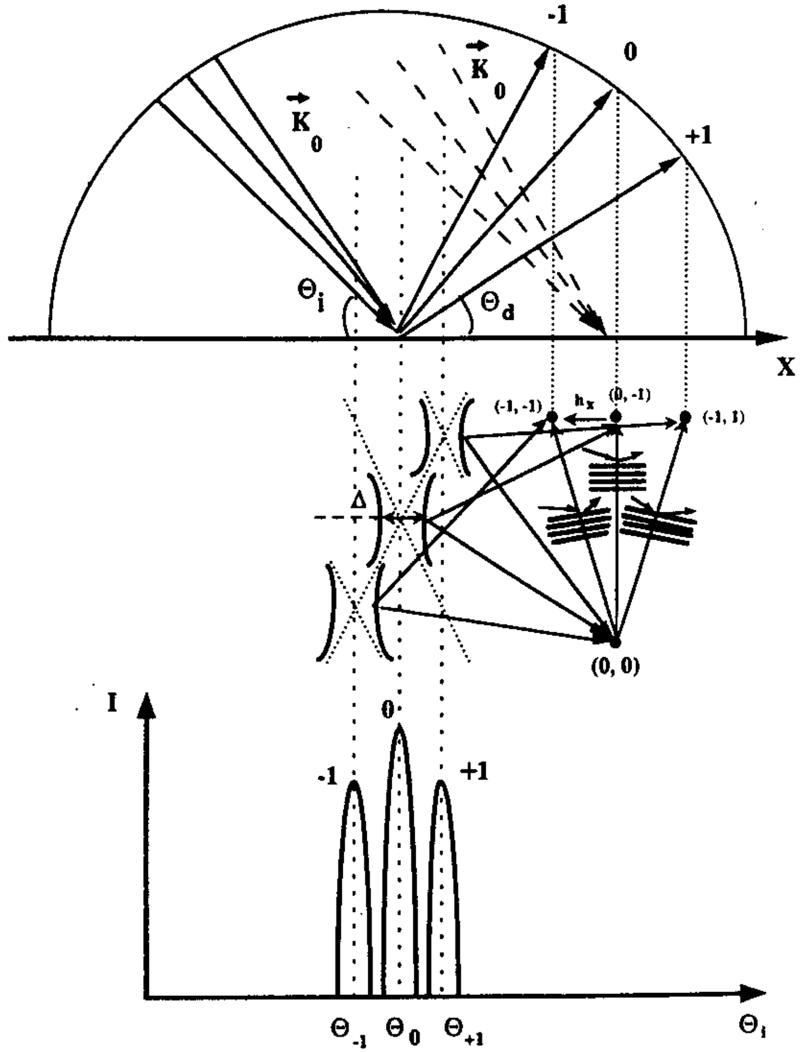


Reciprocal space for large period grating D≈ 20 μ



Multilayer Grating scheme showing extinction length; Light path corresponds to the case :

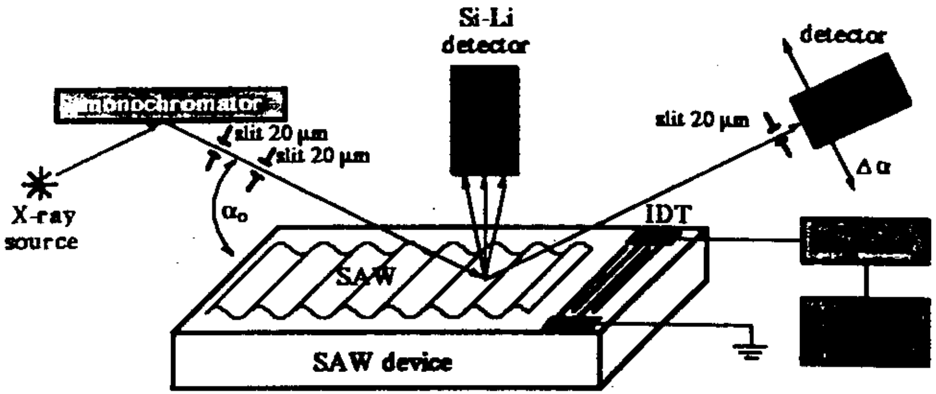
$t_x > D$



Reciprocal space for short period grating $D < 4\mu$

b) Modulated Optics

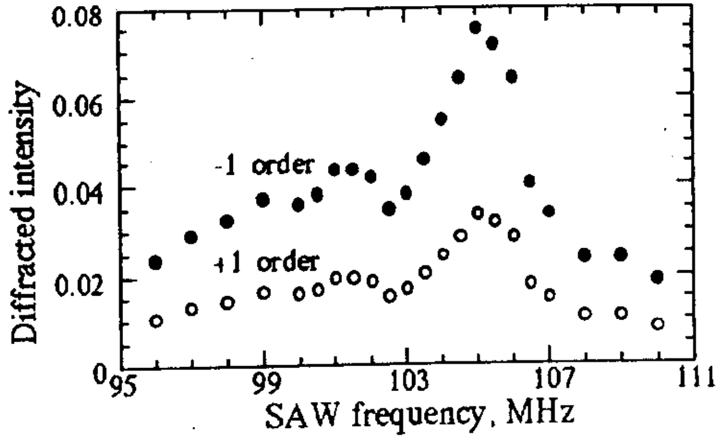
X-RAY SPACE MODULATION BY DIFFRACTION ON AN ULTRASONIC SUPERLATTICE



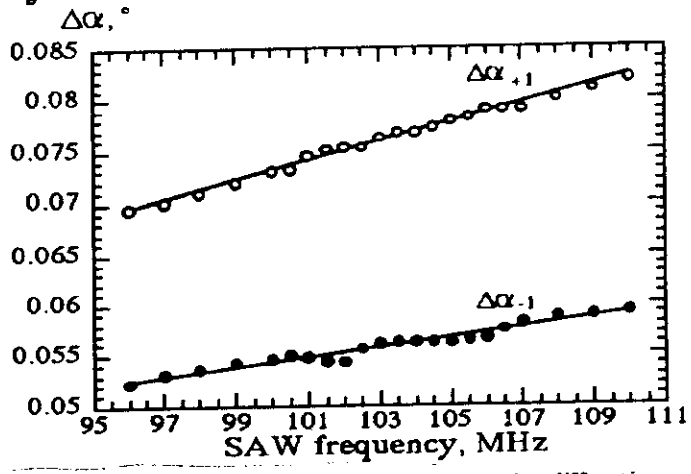
Scheme of the double-crystal X-ray diffractometer

$$k \cos \alpha_m = k \cos \alpha_0 + mK$$

where $k = 2\pi/\lambda$, $K = 2\pi/\Lambda$ and m is the number of the diffraction order



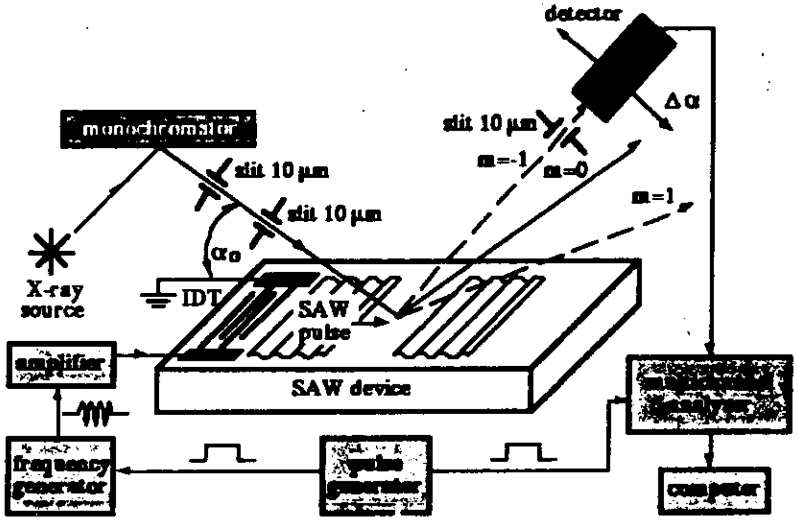
Dependencies of the diffracted X-ray intensities I at different values of the excitation frequency of SAW f=96 110 MHz and amplitude of the input signal U=15 V.



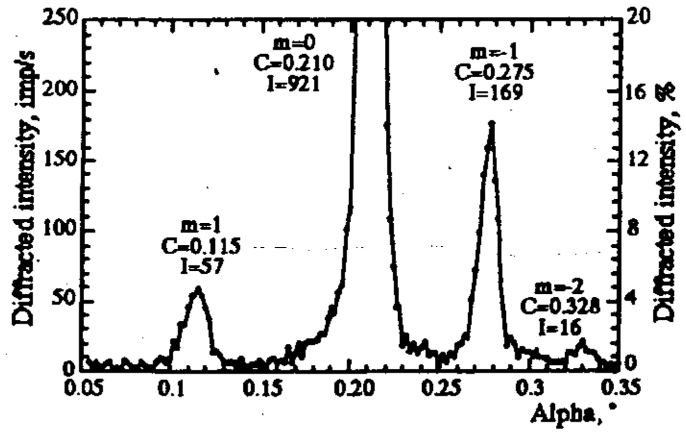
Dependencies of the angular divergences between the diffraction orders $\Delta\alpha_1$, $\Delta\alpha_{-1}$, obtained at different values of the excitation frequency of SAW f=96-110 MHz and amplitude of the input signal U=15 V(the full line shows calculated values).

$\lambda = 1.5$ Å, $F = 10$ cm $\Delta x = 2 \mu m / MHz$

TIME MODULATION OF THE DIFFRACTED X-RAY RADIATION

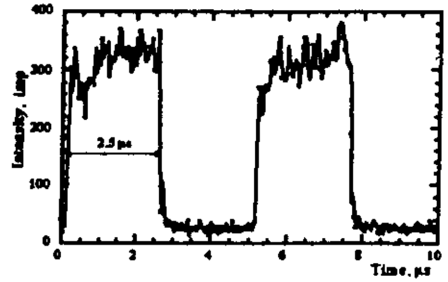


Experimental scheme of the double-crystal X-ray diffractometer

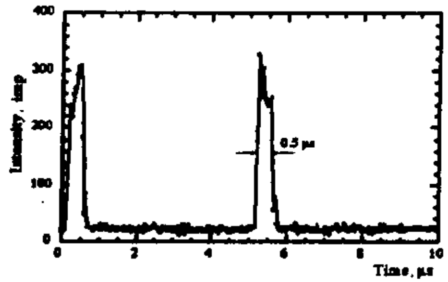


Experimental dependence of the diffracted X-ray intensity as a function of the detector scanning angle $\Delta\alpha$ at incident angle α_0=0.21° (C - gravity centre, I - intensity)

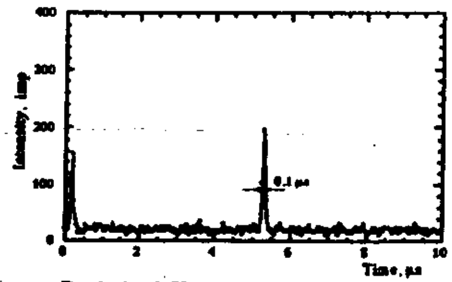
TIME MODULATION OF THE DIFFRACTED X-RAY RADIATION



Period of X-ray pulses T=5 μs
Width of X-ray pulses τ=2.5 μs



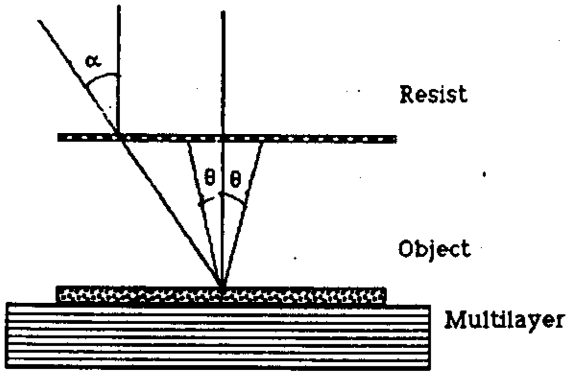
Period of X-ray pulses T=5 μs
Width of X-ray pulses τ=0.5 μs



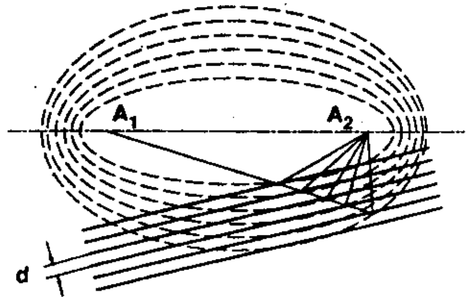
Period of X-ray pulses T=5 μs
Width of X-ray pulses τ=0.1 μs

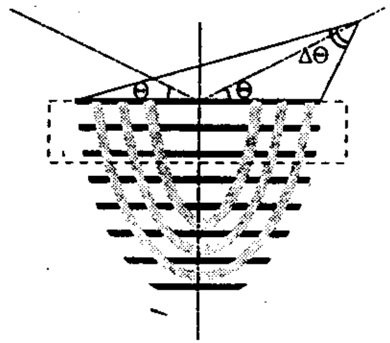
c) Bragg-Fresnel lenses

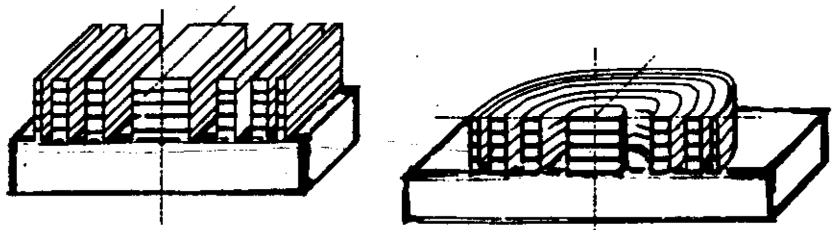
Reflection X-Ray hologram recording scheme.



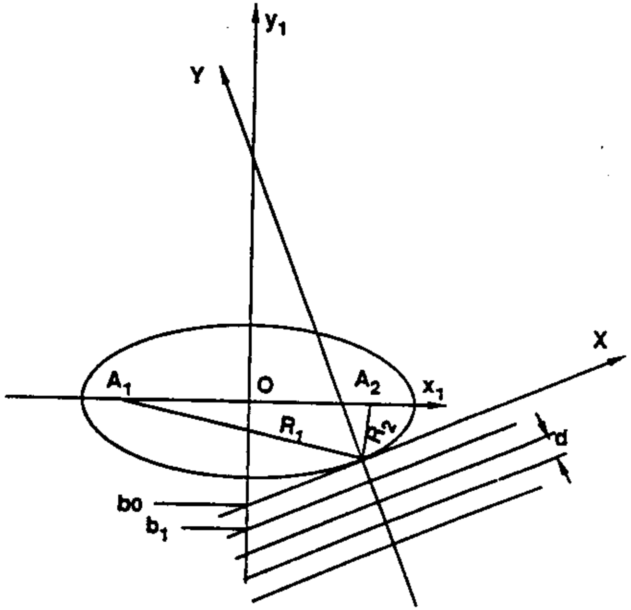
1D and 2D Bragg-Fresnel Grazing Incidence Lenses







Model of Bragg-Fresnel Lens



$$X_n = \frac{1}{\sqrt{1+K^2}}\left[a\,\xi_n\,\nu_n(1+K^2) - b_l K\right] - \frac{Ka^2}{b_l\sqrt{1+K^2}} \qquad [1]$$

$$\xi_0 + 2n\frac{\lambda}{4a} \le \xi_n \le \xi_0 + (2n+1)\frac{\lambda}{4a}$$

- A_1 and A_2 being respectively the object and image point .
- 2a the source-image distance.
- K the slope coefficient.
- b_l the shift parameter of the l-th layer.
- λ the wavelength.
- ξ_n and ν_n the ellipsoidal coordinates , with: $\xi \ge 1$ and $-1 < \nu < 1$).

APPROXIMATED EQUATIONS

Approximated equation in cartesian coordinates:

$$\left[X + \frac{Ka^2\sqrt{a^2+b_l^2}\,\frac{n\lambda}{2}}{b_l^3 + \rho\, b_l\frac{n\lambda}{2}\sqrt{a^2+b_l^2}}\right]^2 = \left[\frac{a^2+b^2+\rho\frac{n\lambda}{2}\sqrt{a^2+b_l^2}}{b^2+\rho\frac{n\lambda}{2}\sqrt{a^2+b_l^2}}\right] \times \left[\frac{b_l - a k^2}{a^2\rho^2}\right]$$

$$\times\left[\frac{a^2\rho\frac{n\lambda}{2}\sqrt{a^2+b_l^2}}{b_l^2+\rho\frac{n\lambda}{2}\sqrt{a^2+b_l^2}}\right] \qquad [2]$$

Focal distance :

$$F = \frac{\sqrt{a^2+b_l^2}}{2\sqrt{K^2+1}}\;\frac{b_l^2 - a^2K^2}{b_l^2} \qquad [3]$$

b_0 is dependent to the magnification ratio M and to the slope parameter K as:

$$b_0 = aK\frac{M+1}{M-1} = aKm \qquad [4]$$

$$d = \frac{\lambda}{2\rho}\frac{b_0}{\sqrt{a^2+b_0^2}} \qquad [5]$$

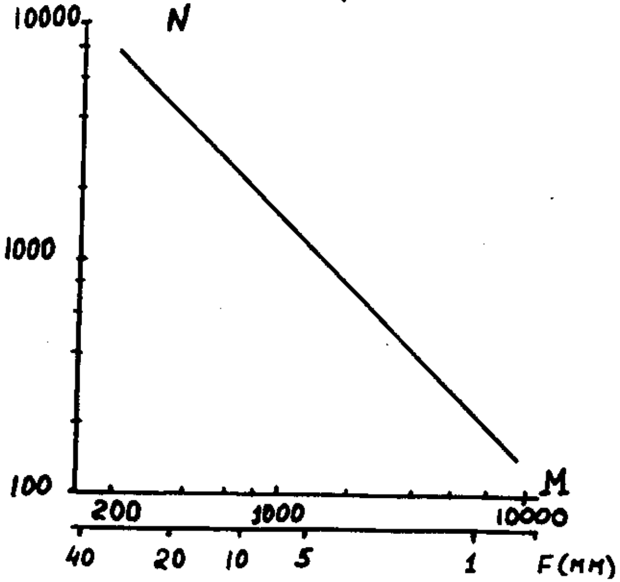
Relation between the Bragg angle Θ, the slope coefficient K and the magnification factor m :

$$\sin\Theta = \frac{Km}{2\rho\sqrt{a^2+b_0^2}} \qquad [6]$$

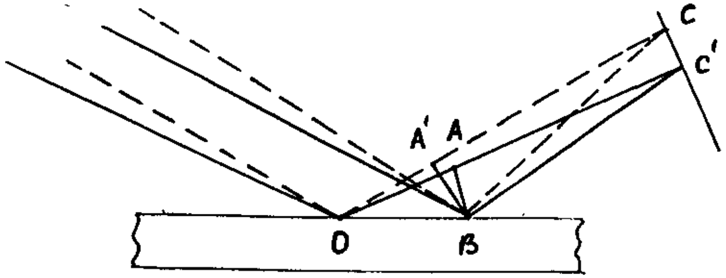
Spherical aberration

$$F_q = a\frac{(q^2-k^2)\sqrt{1+q^2}}{2q^2\sqrt{k^2+1}}$$

$$N \leq \frac{\sqrt{F_0}}{4(\sqrt{F_0}-\sqrt{F_{q\ell}})}$$



Off-axis aberrations



$$\Delta L = BC' - A'C'$$

$$\Delta L = r^2/2F_1 +$$

Coma $\alpha[r^3F/(2F_1^3) + rf/F_1] -$

$$-\alpha^2[3r^2F^2/(4F_1^3) + Ff/F_1]$$

Astigmatism and Field Curvature

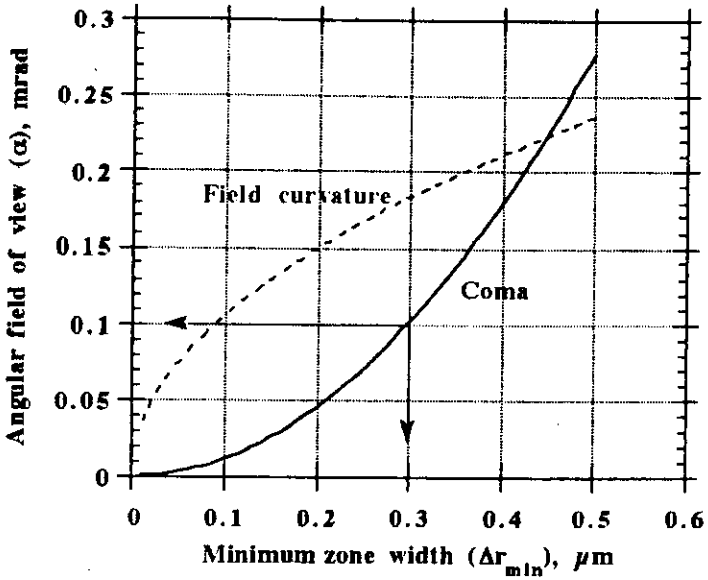
Coma dominate, and

$$\alpha_{max} \simeq \tan\theta/2N$$

$\lambda = 5Å$, $d = 30Å$, $N = 100$

$$\alpha_{max} \simeq 5\cdot 10^{-4}\ \text{rad}$$

Off-axis aberrations



$$\alpha < \frac{(\Delta r_{min})^2}{2dF\cos\theta_B} \quad \text{- COMA}$$

$$\alpha < \sqrt{\frac{\lambda\, \Delta r_{min}}{2dF\cos\theta_B}} \quad \text{- FIELD CURVATURE}$$

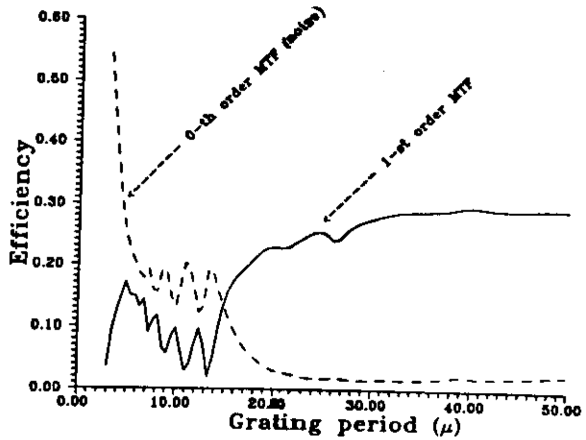
Calculation parameters:

Wavelength (λ) = 0.1 nm (12.4 KeV)

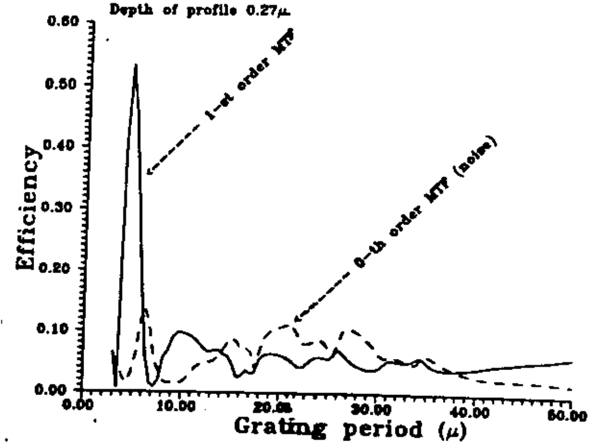
Multilayer period (d) = 3 nm

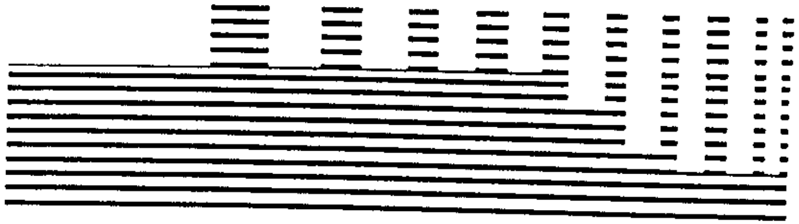
Focal distance (F) = 15 cm

Modulation Transfer Function (MTF) for the Multilayer Bragg-Fresnel Lens. Depth of profile 0.06μ. W/C multilayer with period 3.38nm. Multilayer substrate - 100 bilayers. Wavelength 0.154nm.



Depth of profile 0.27μ.





Bragg–Fresnel Lens with optimal profile.

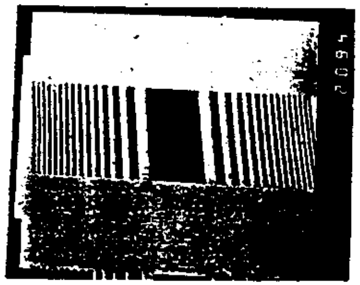


FIG. 1. Profile of the surface of a multilayer mirror.

radiation. The profile of the surface is shown in Fig. 1. As the original multilayer mirror we used a Ni–C structure.

As the x-ray source we used an x-ray tube with a linear focus and an Fe anode. The radiation from the tube is collimated with a standard slit collimator; the size of each slit is 50 μm. A mirror with a shaped surface is installed in the goniometric head 18 cm from the collimator. With a 180-μm central relief zone and angle of incidence at the mirror surface in the range 2°–2.2°, the reduced slit image is situated 1.7 cm from the focusing element. As the detector we used "Mikrat LOI-2" holographic plates with a 0.2-μm intrinsic resolution.

Figure 2 shows the images of an x-ray wave front in the region of a typical FeKα spectral line obtained by (a) modulating the amplitude by forming a profile in the mirror and (b) modulating the phase by depositing ~300-Å-thick layer of gold on the mirror surface in the Fresnel zones. The slit image corresponds in size (~6 μm) to that obtained by scaling down the optical apparatus of the experiment.

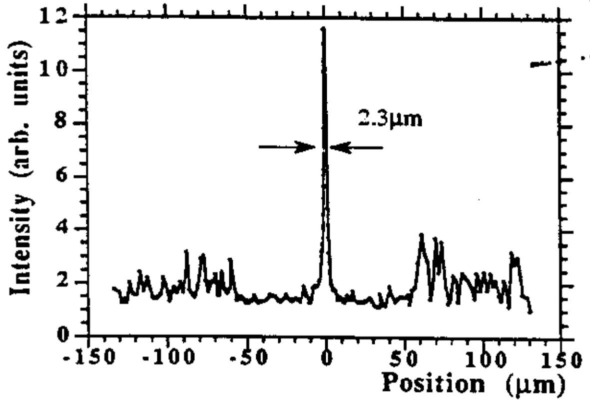
a b

FIG. 2. (a) Image in the focal plane produced by modulating the amplitude of an x-ray wave front; (b) image in the focal plane produced by modulating the phase of an x-ray wave front. The arrow indicates the position of the focal line.

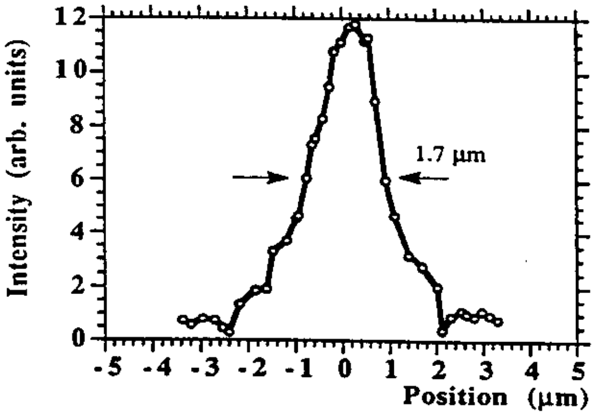
Photographic resolution test.

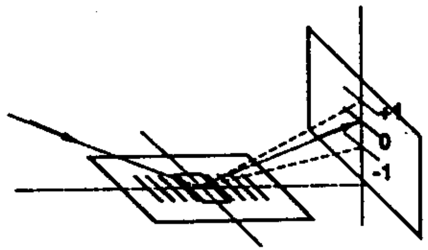
(experiment)

Intensity variation along the vertical focus at 0.12nm

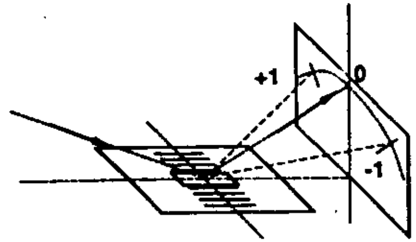


Intensity variation along the vertical focus at 0.084nm

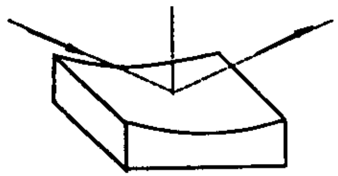


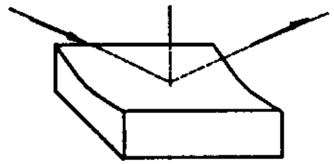


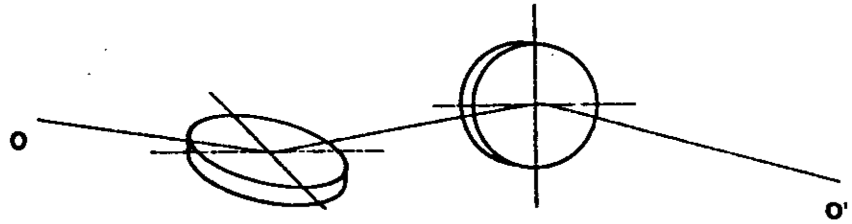
Classical diffraction grating (meridional)



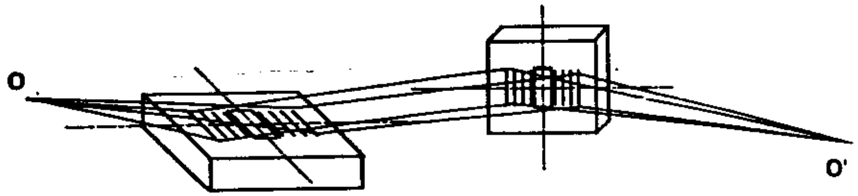
Conical diffraction grating (saggitae)



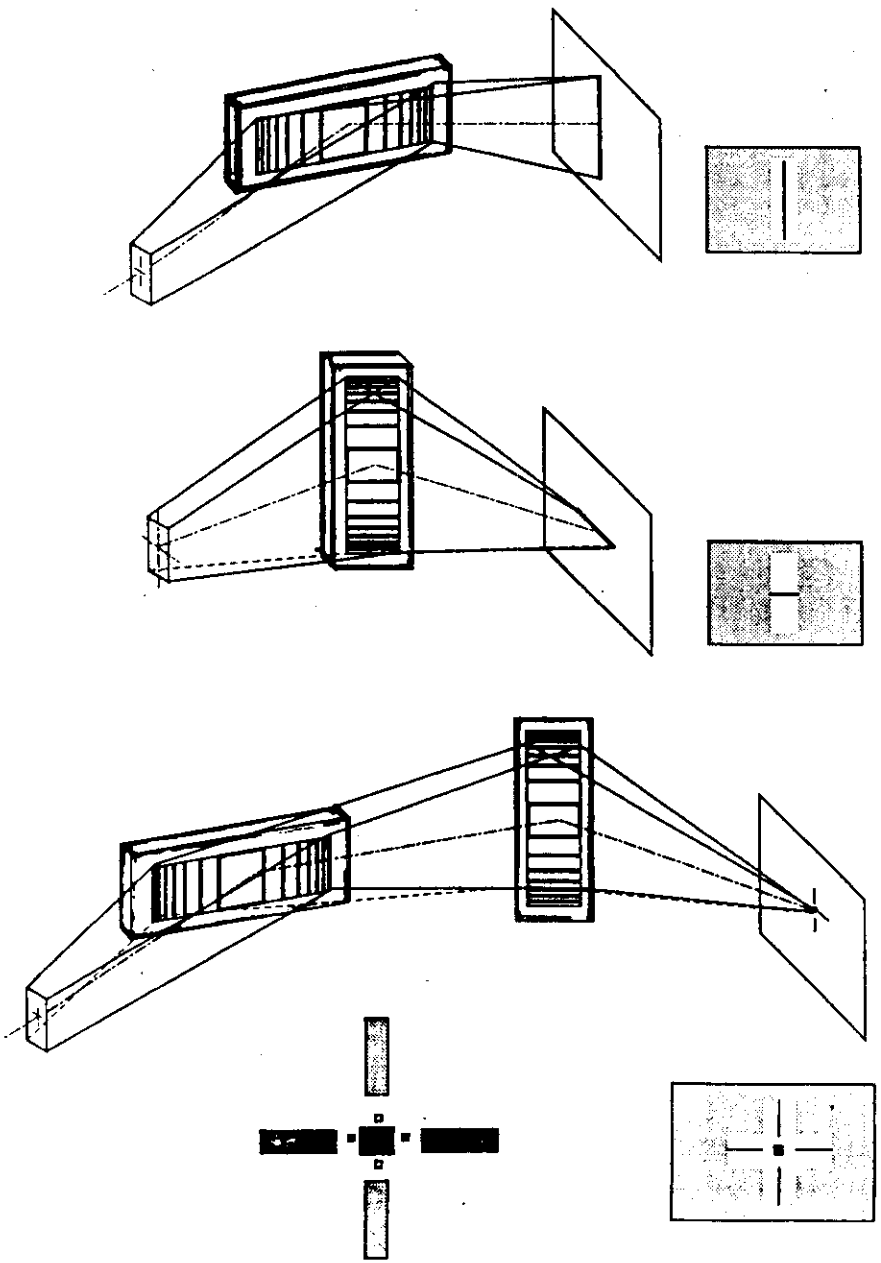


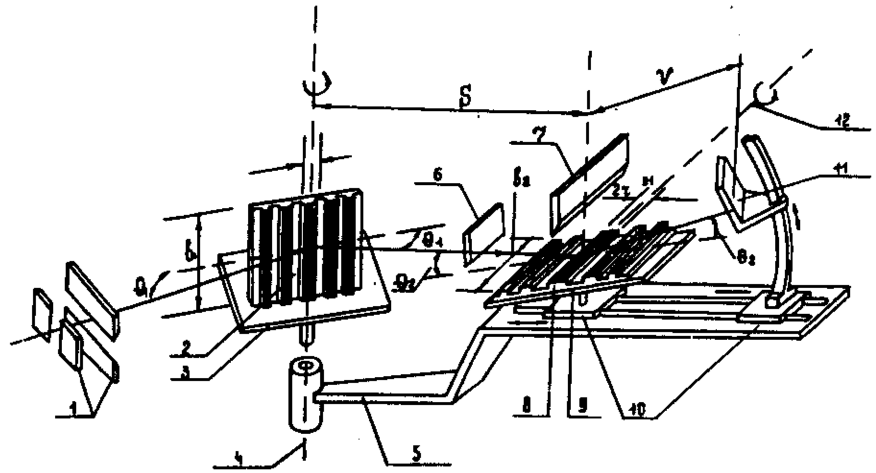


Kirkpatrick-Baez Focusing Optic Scheme



Kirpatrik-Baez Bragg-Fresnel Optic Principle





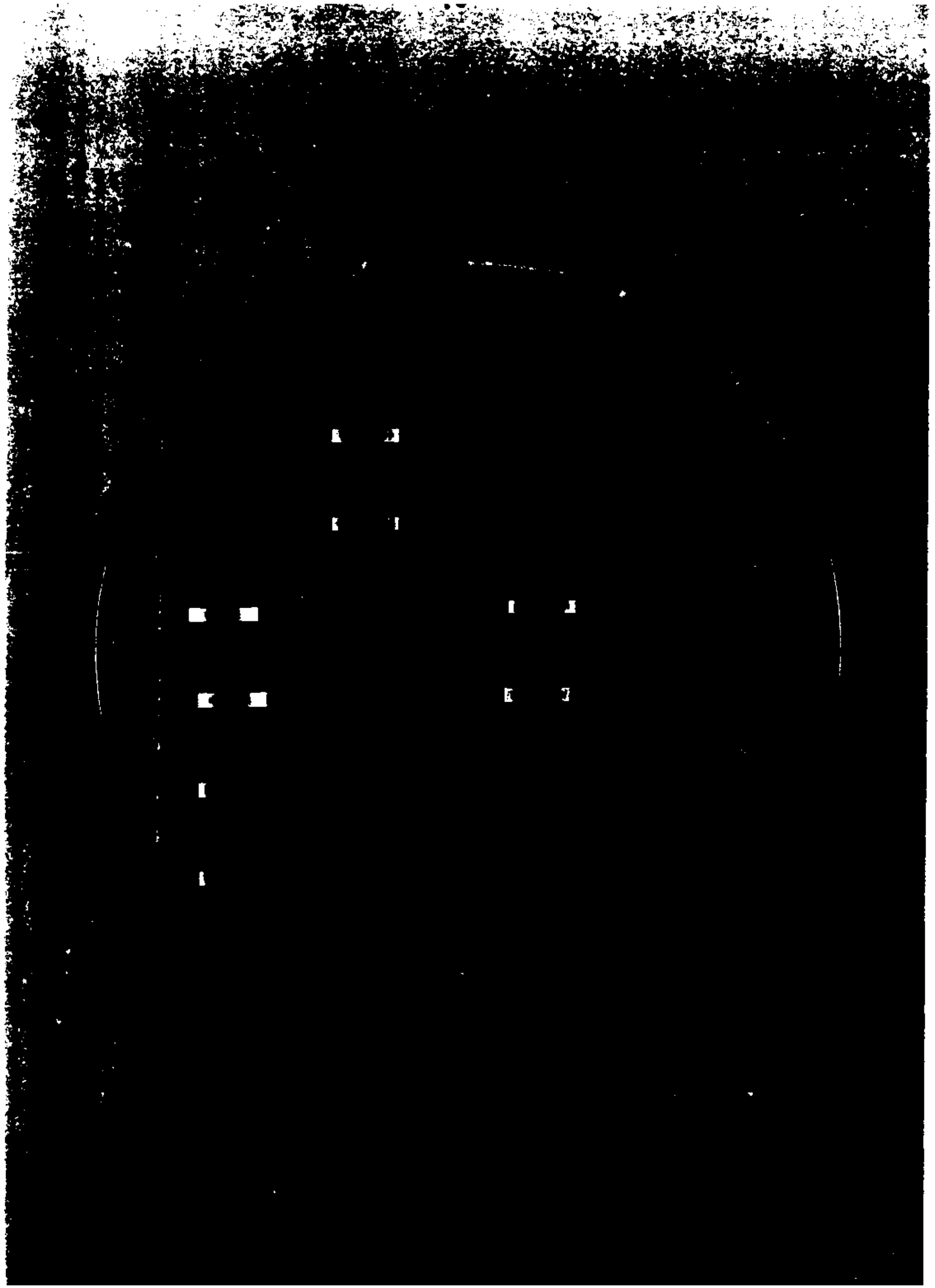
The scheme of diffraction Kirkpatrik- Baez microscope .

1 - Input slit,
2 - BFL - 1
3 - Stage for BFL - 1
4 - Axis of rotation,
5 - Ganiometer,
6 , 7 - Slits
8 - BFL -2,
9, 10 - Stage for BFL - 2,
11 - Recording plate.

Resolution of 2-3 μm was reached!

Best resolution until now without BFL : 5 μm

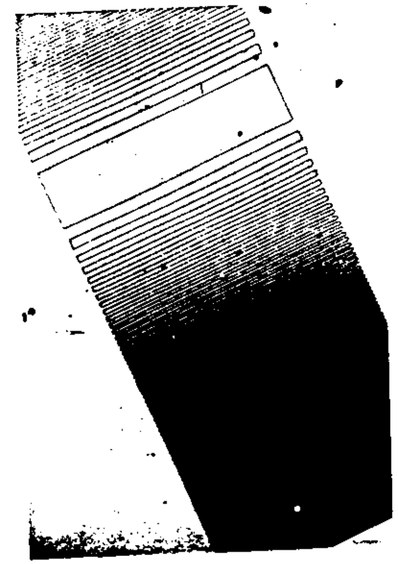
Possible : < 1 μm



BRAGG - FRESNEL LINEAR ZONE PLATE

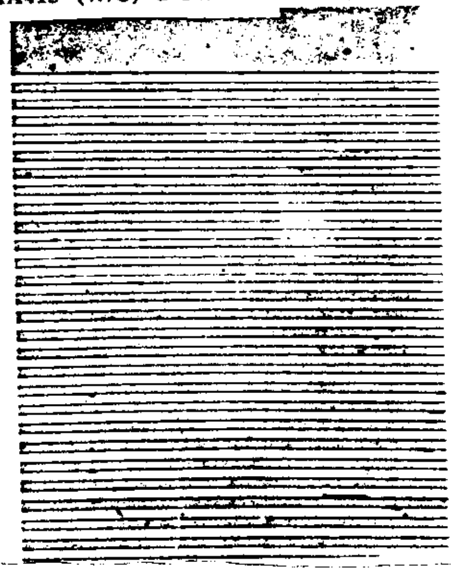
APERTURE	1mm X 3mm
OUTER ZONE WIDTH	3.5 μ
FOCAL LENGTH AT WAVELENGTH 1.5 A	6.08 cm

MA415 (W/C) d=34.4 A



200μ

MA415 (W/C) d=34.4 A



25 μ

TWO - DIMENTIONAL FOCUSING
IN DUBLE - MULTILAYER KIRKPATRIK-BAEZ SCHEME
WITH BRAGG-FRESNEL LENSES

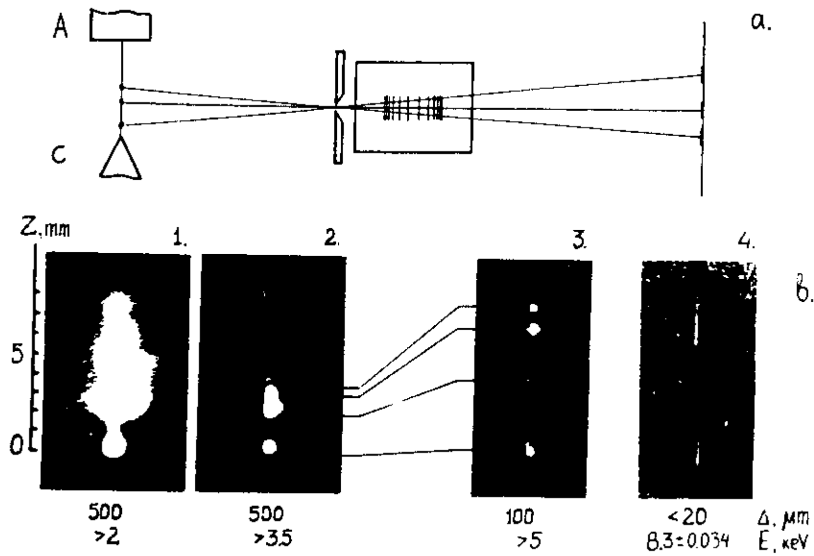
Wavelength	**1.24 A**
Focal distance	**7 cm and 5.8 cm**

Si 160B (W/Si) d=29 A

200μ

Si 160B (W/Si) d=29 A

10 μ



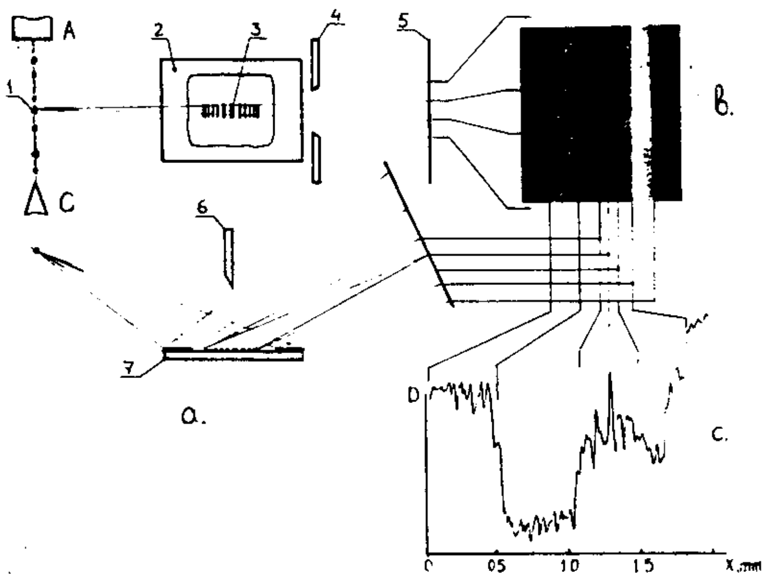
a) The scheme of lens operation in emission of λ = 0.15nm

b) experimental results: 1, 2, 3, - pinhole camera images,

4 - lens obtained images,

E_i - filter cut-off energy in pinhole camera

D - real spatial resolution of pinhole camera.



a) Scheme of lens operation in emission with a wavelength of $3\lambda_0$ = 0.45nm.

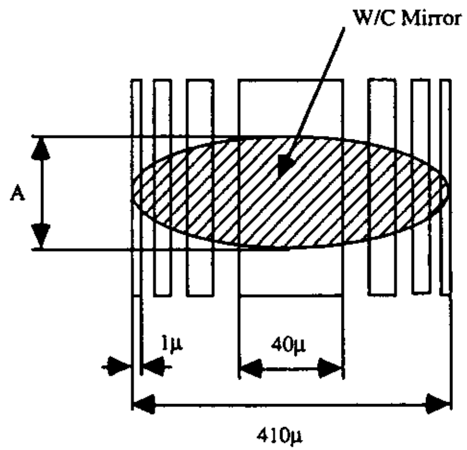
1 - plasma "hot point" of explosion wire;
2 - Bragg structure;
3 - Fresnel lens structure;
4, 6 - limited apertures stops;
5 - photographic film;
7 - Si substrate;
A - anode, K - cathode of high-current diode.

b) plasma image photographs in the 1st and 3d diffraction orders.

c) plasma image dencitogram.

R&D Center ROMT, Russia

Lenses for Plasma Imaging System (PIMS)



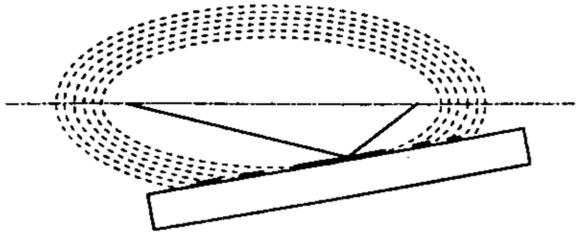
The multilayer Bragg-Fresnel lenses, designed for two-dimensional imaging of a plasma X-ray sources.

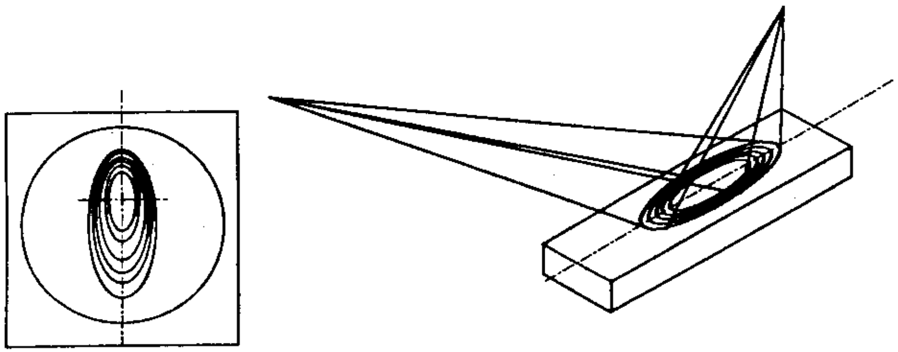
- **Spectral bandwidth $\delta\lambda/\lambda = 2\ 10^{-2}$.**
- **Spatial resolution better than 10 µ**

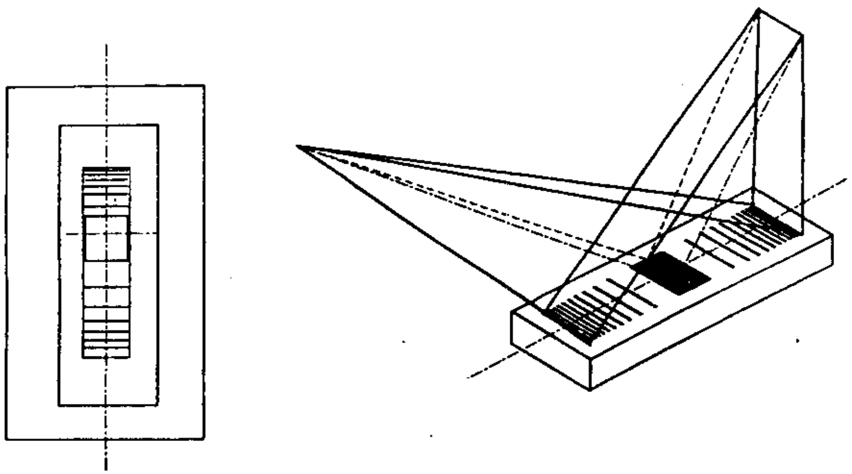
***Efficiency of each multilayer were tested at 8.3 KeV beam energy.**

Specimen	Multilayer period, nm	Multilayer efficiency*, %	Photon energy range, KeV	Focal length, cm
Ellipse 1	2.95	64	0.5 - 1.5 (A=73µm)	32.26 at 1KeV
Ellipse 2	3.11	60.3	1.5 - 2.5 (A=146µm)	64.5 at 2KeV
Ellipse 3	2.86	54	2.5 - 3.5 (A=218µm)	100 at 3KeV
Ellipse 4	3.17	58	4.5 - 5.5 (A=363µm)	161.25 at 5KeV

1D and 2D FOCUSING GRATINGS







Elliptical Bragg-Fresnel Multilayer Lenses.

Wavelength range 0.45nm - 3.5nm.
Aperture - 0.35mm x 0.5mm.
-Minimum zone width - 0.25μm.
-Absolute efficiency - 10% at the 0.45nm wavelength.
Spacing resolution less than 1μm.

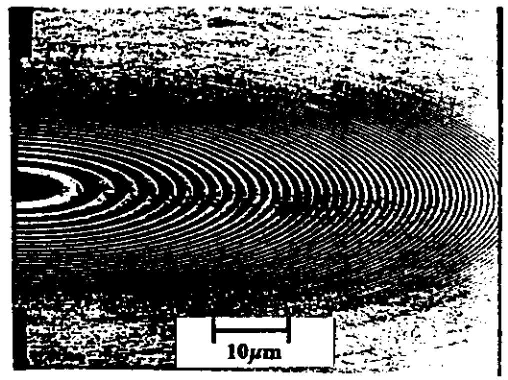


Fig.7. Bragg-Fresnel elliptical lens-polarizer for the wavelength 4.5nm. Aperture 355μm x 500μm.

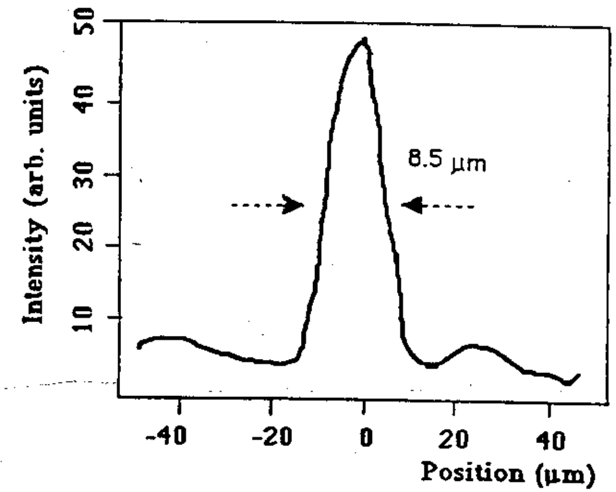


Fig.8 Intensity distribution in the focal plane of the BFML. Wavelength 4.5nm. (Experiment)

LURE-IMT Fluorescence Microprobe

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FRANCE

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Laboratoire d'optique électromagnétique, Université de Marseille
FRANCE

I. Our Main Constraints on the DCI Beam Line.

*** Quite low brightness source (4 meters depth) at 24 meters:**

σ_x: 2.7 mm σ'_x: 0.53 mrad

σ_z: 1.5 mm σ'_x: 0.26 mrad

*** Build a probe having:**

- 1 or 2 microns spot size.
- Flux usable for practical applications on this beam line.

*** Choose a technology able to work:**

- from C_K(0.3 KeV) on SuperACO
- up to Zr_K (20 KeV) on DCI

II. Our Choices.

* Keep open the possibility to reach
  sub micron spot size in the future

  ==>> No curved mirrors optics.

* Choose a technology to compensate our low brightness
  - as large as possible collecting aperture.
  - possibility to have phase gratings
    over the considered energy range.

    ==>> No transmitting Fresnel zones.

  - large band pass.

    ==>> No crystal optics.

* Take advantage of our knowledge in multilayer X ray mirrors
  and our collaboration with IPMT Chernogolovka.

  ==>> Bragg Fresnel lenses on multilayers.

III. Minimum Spot size useful for fluorescence studies around 10 KeV?

* Penetration depth versus element to detect and matrix.
* Emitting volume versus element to detect and matrix.
* Minimum sample thickness to limit volume effect.

IV. Tested optics since 1989.

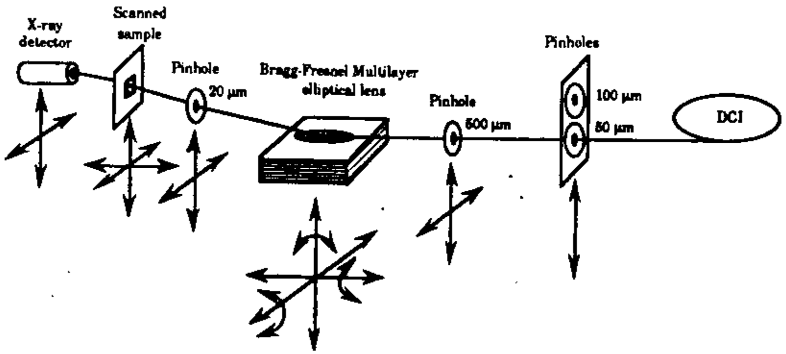
* ***May 1990:*** First Kirpatrick-Baez optic
  with 2 linear Bragg Fresnel lenses
  and "home made" manual goniometer.

* ***June 1991:*** Second Kirpatrick-Baez optic
  with 2 linear Bragg Fresnel lenses
  and new automatic goniometer.

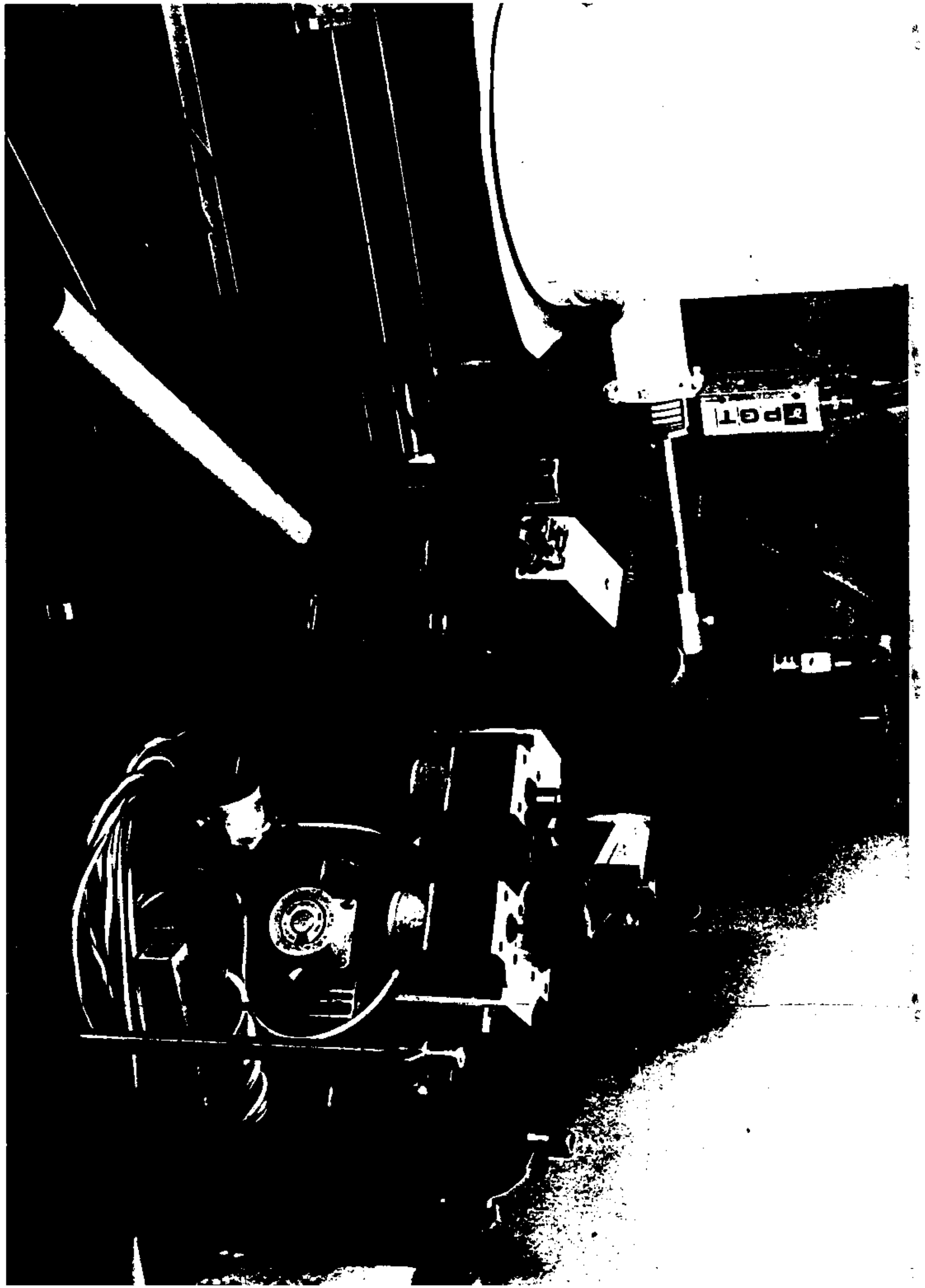
  => 10^4 to 10^5 ph/sec in the multilayer band pass.

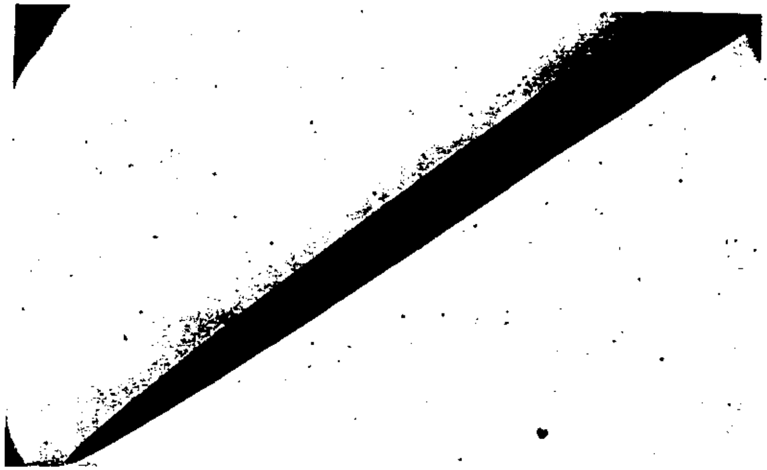
* ***Dec. 1992:*** First 2D focusing optic
  with a single elliptical Bragg Fresnel lens
  and visible microscope with zoom
  for on line identification.

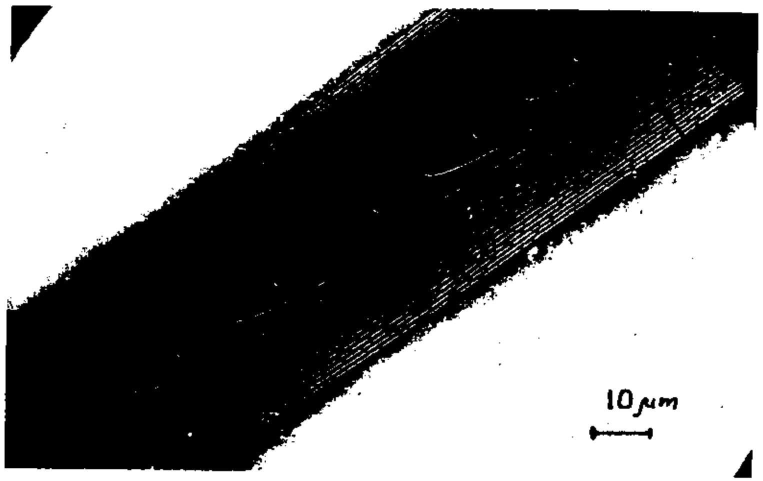
* June 1993 1 μm Focal spot was achived
  10^5 ph/sec
  First 2D mapping of the
  micro meteorite sample



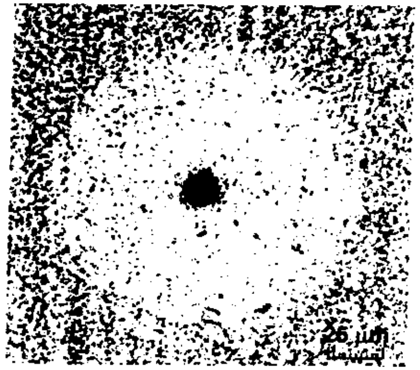
LURE - IMT RAS MICROPROBE



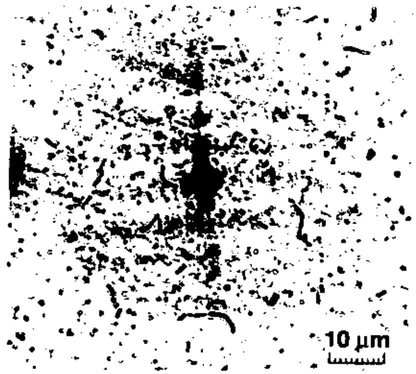




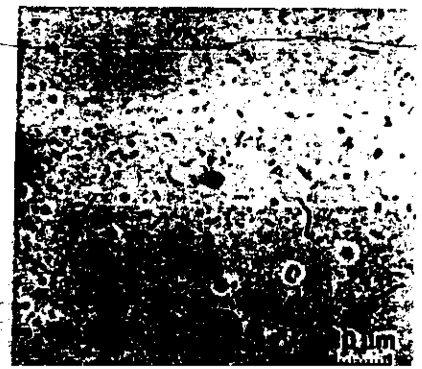
Bragg-Fresnel lens
λ = 1 Å, F = 15cm
W/C multilayer 30 Å period
Aperture 59 µm × 2478 µm



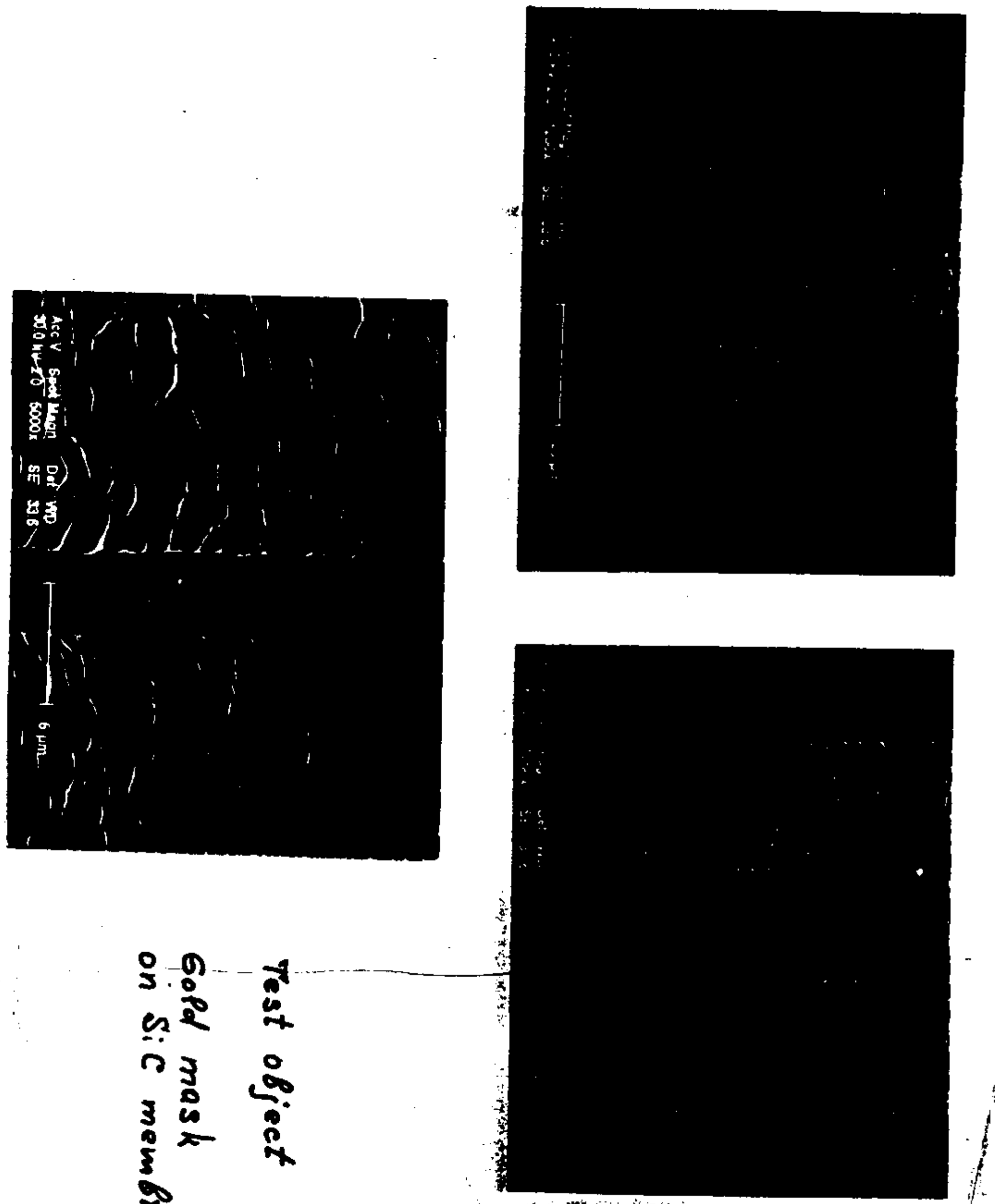
Focal spot at 1.5 Å
X-Ray tube



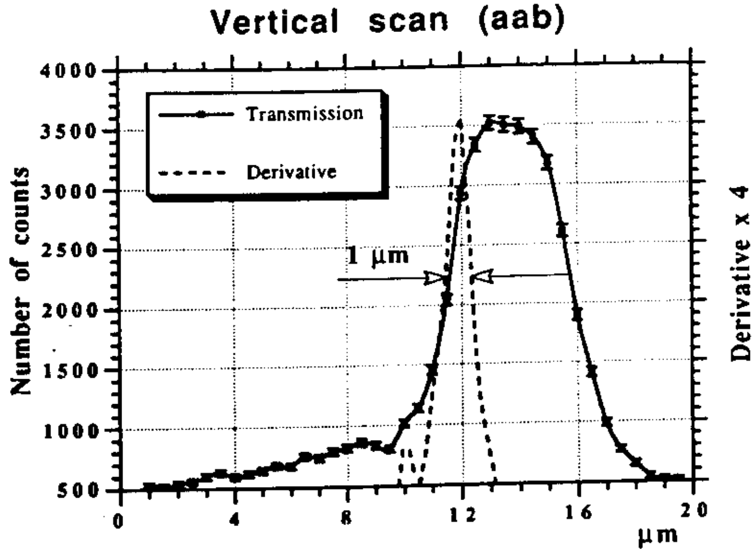
Focal spot at 1 Å
Input pinhole 50 µm
Synchrotron source



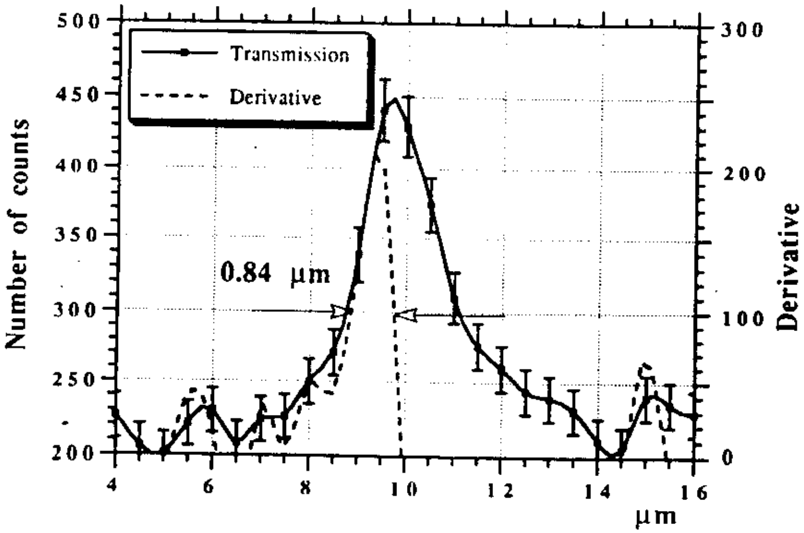
Input pinhole 100 µm

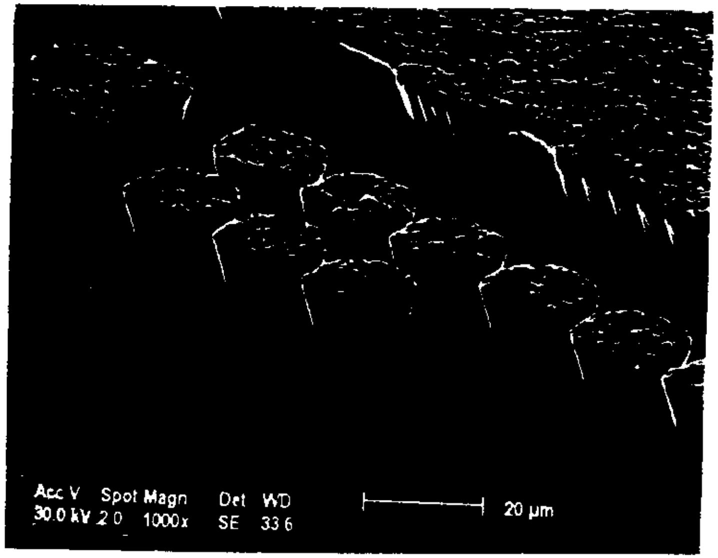


Test object
Gold mask
on SiC membrane

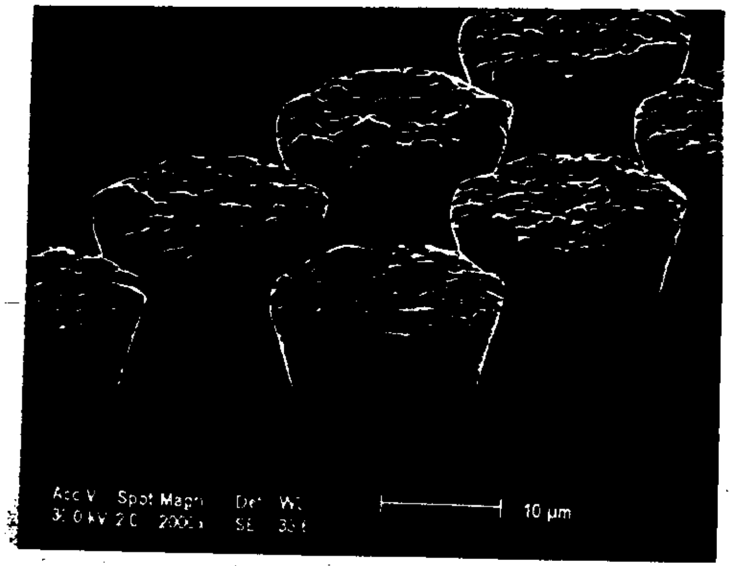


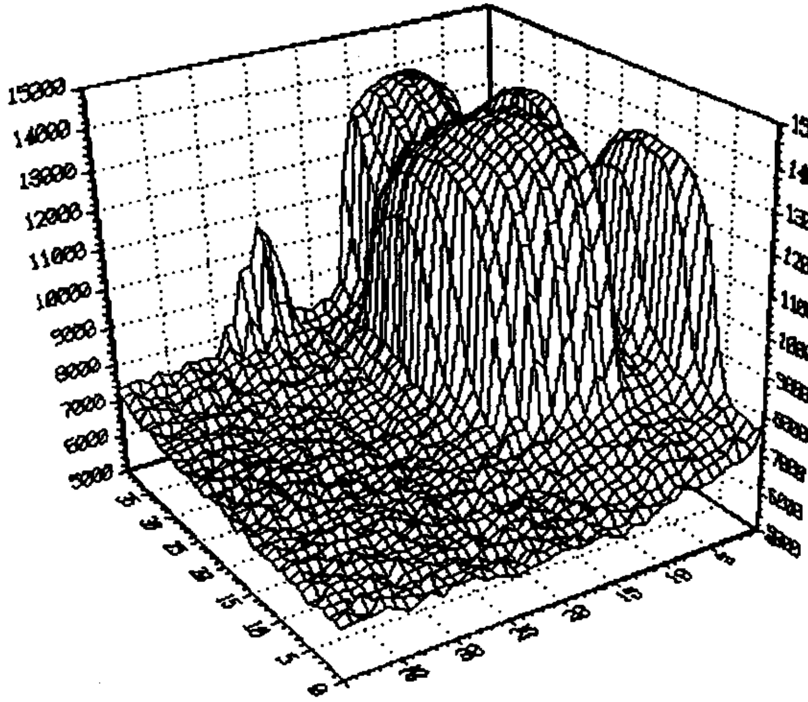
Vertical scan 2μm line





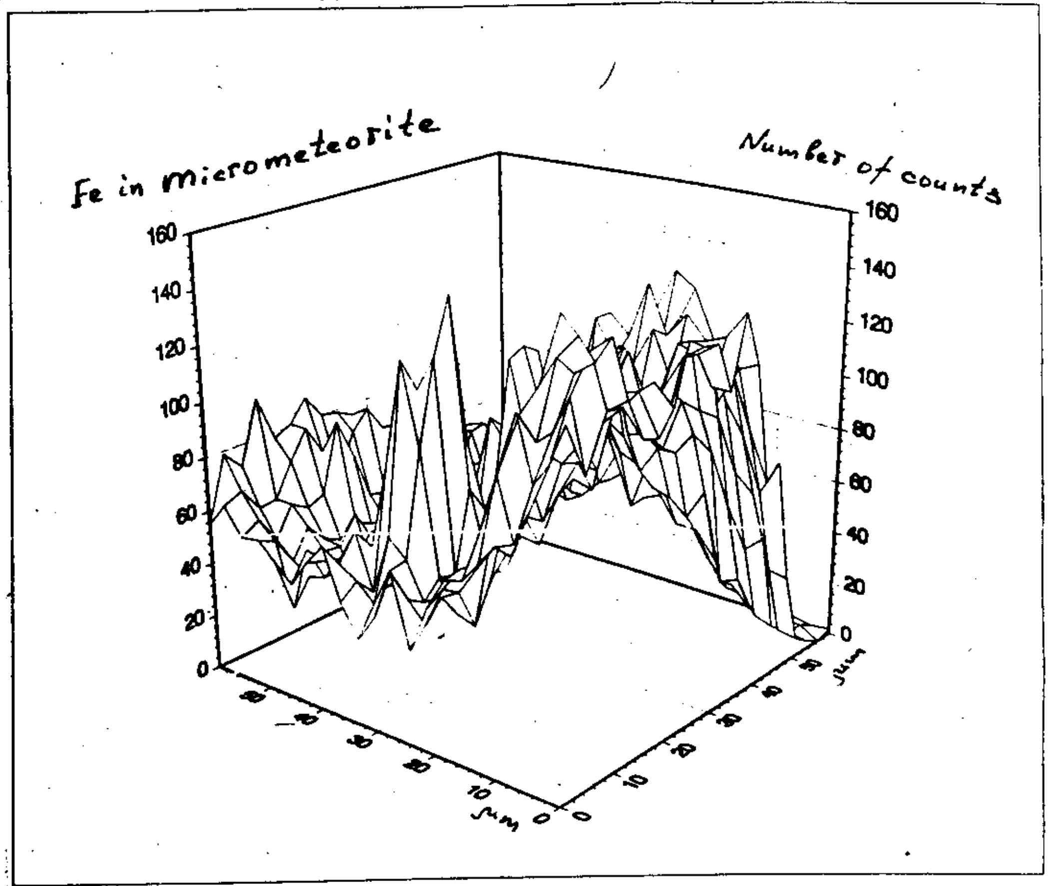
Test object. Gold mask on SiC membrane





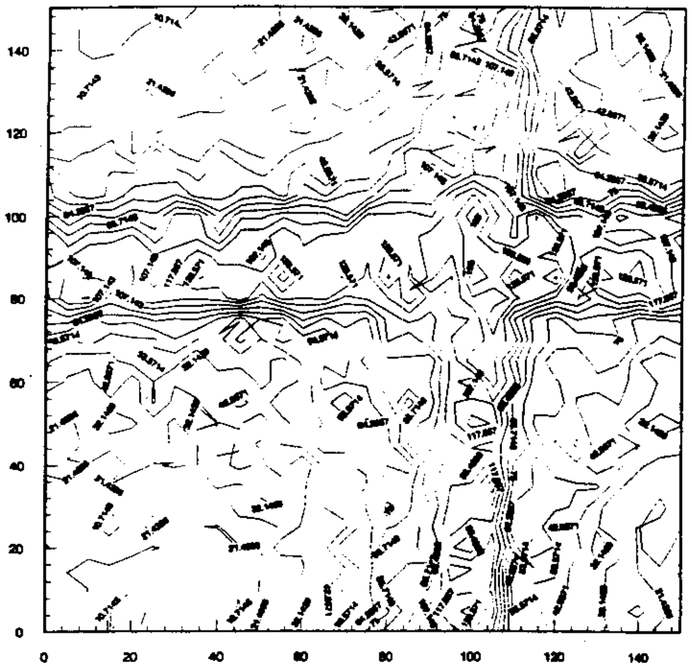
3D Intensity plot

Micrometeorite sample



Iron distribution in micro meteorite

cross of two 20 microns wire in fluorescence
with the 1 A lens setted at 13.8 keV



LURE - IMT RAS MICROPROBE

Specifications:

- Wavelength range: 0.8 - 1.5Å (8 - 15KeV)
- *Spatial resolution:*

  ZOOM: in Fluorescence mode:

  20 μm in diameter, fast scan;

  3μm x 3μm (0.5μm x 0.5μm in the future), slow scan;

  1μm x 1μm (0.1μm x 0.1μm in the future), point analysis

- Energy resolution : $\Delta E/E \approx 10^{-2}$ (Band pass 100 eV at 8 KeV)
- Minimum step size: 0.1μm.
- Photon flux in focal spot > 7.10^5 photon/sec. (3 x 3 μm^2 focal spot)
- *Basic optical scheme*: Single lens system with demagnification of 42.

  Bragg - Fresnel Multilayer Lens:

  Elliptical type, focal length 15cm.

  Aperture 3mm x 50μm

  C/W multilayers with period 3nm.

  Minimum zone width of 0.3μm.

- Mechanical scanning.
- Detector: Si(Li) solid state detector with dedicated computer system.

Future plans

I. Combination of 1st - 3d order diffraction in one lens (Michette - type lens) will led to increasing:

- Efficiency in 10 times
- Resolution in 2 times

II. Application of Surface Acoustic Waves scanning devices in X-Ray microscopy will led to:

Positioning accuracy in order of 0.01 µm

III. Combination of the lens and scanning device in one element.

IV. Ray-tracing of Bragg-Fresnel elements

Wavelength range 0.08nm - 0.2nm.

-Apperture - 0.15mm x 10mm.
-Minimum zone width - 0.25µm.
-Absolute efficiency - 20% at the 0.1nm wavelength.
Spacial resolution less than 1µm.

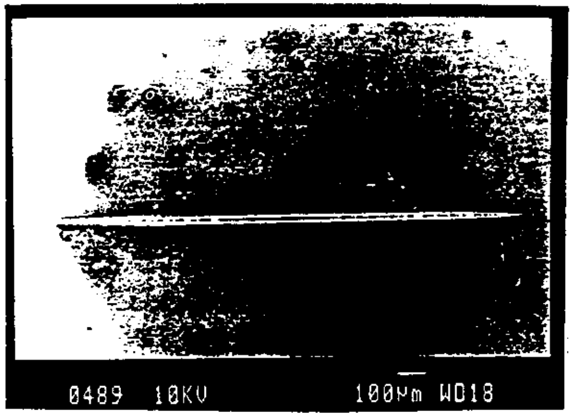


Fig.9 General vew of the Bragg-Fresnel elliptical lens for the 0.154nm wavelength.
Apperture 50µm x 2mm.

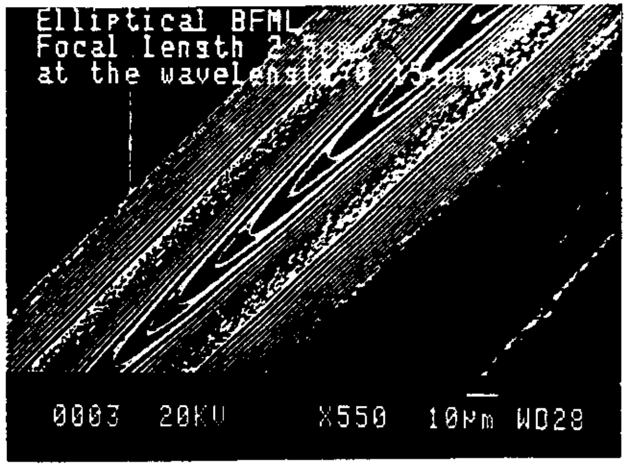
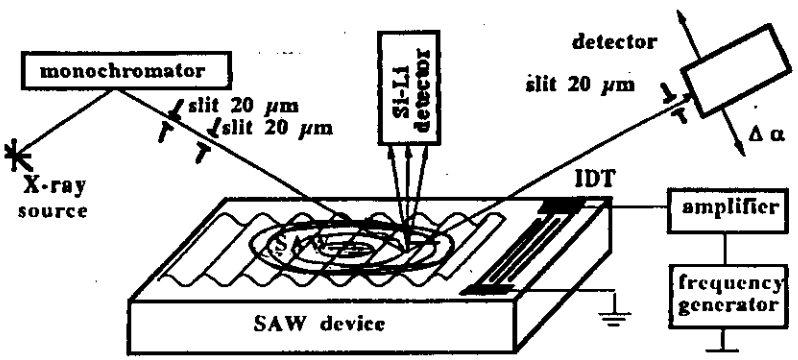


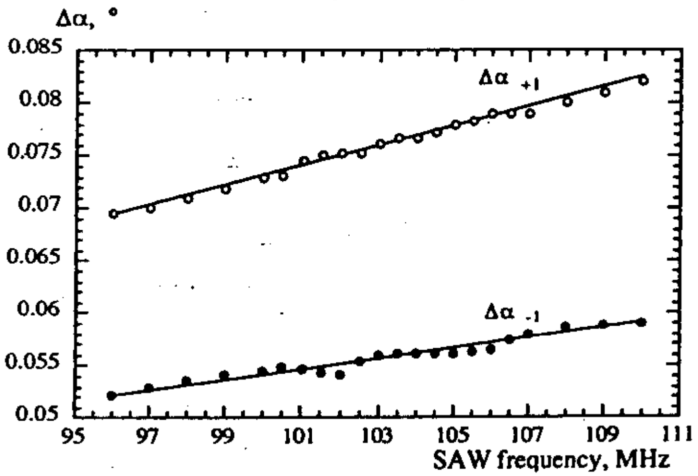
Fig 10 The central part of the same elliptical BFML.

R&D Centre "ROMT"

X-RAY SPACE MODULATION BY DIFFRACTION ON AN ULTRASONIC SUPERLATTICE



Scheme of the double-crystal X-ray diffractometer



Dependencies of the angular divergences between the diffraction orders $\Delta\alpha_1$, $\Delta\alpha_{-1}$, obtained at different values of the excitation frequency of SAW f=96-110 MHz and amplitude of the input signal U=15 V(the full line shows calculated values).

Microelectronics technology for X-ray optics:

- Submicron (subnanometer) resolution,
- Large (10mm x 10mm) fields with topology precision < 0.1μm,
- Nonlinear structures, discribed by 2 -nd order curves,
- Thin films, consists from monoatom layers (thickness in order of 0.5nm-1nm).
- Surface roughness in order of 0.1nm - 0.3nm

Instrumentation:

Electron-beam lithography:

ZRM-12 with "GASMAL" control system

Electron beam energy	30 KeV
Spot size	50nm
Minimum line width	0.3μm
Field size	1mm x 1mm
Wafer size	102mm x 102mm
Alignment accuracy -	0.2μm

JEOL 840A with "GASMAL" control system

Electron beam energy -	40 KeV
Spot size	5nm
Minimum line width	0.1μm
Scan field size	2mm x 2mm
Wafer size	10mm x 10mm
Alignment accuracy	1μm

Ion sputtering, etching:

Argon ion gun (IMT)

Ion energy	100eV - 3 Kev
Beam size	2cm
Wafer size -	20mm x 20mm
Etching speed	15nm/min

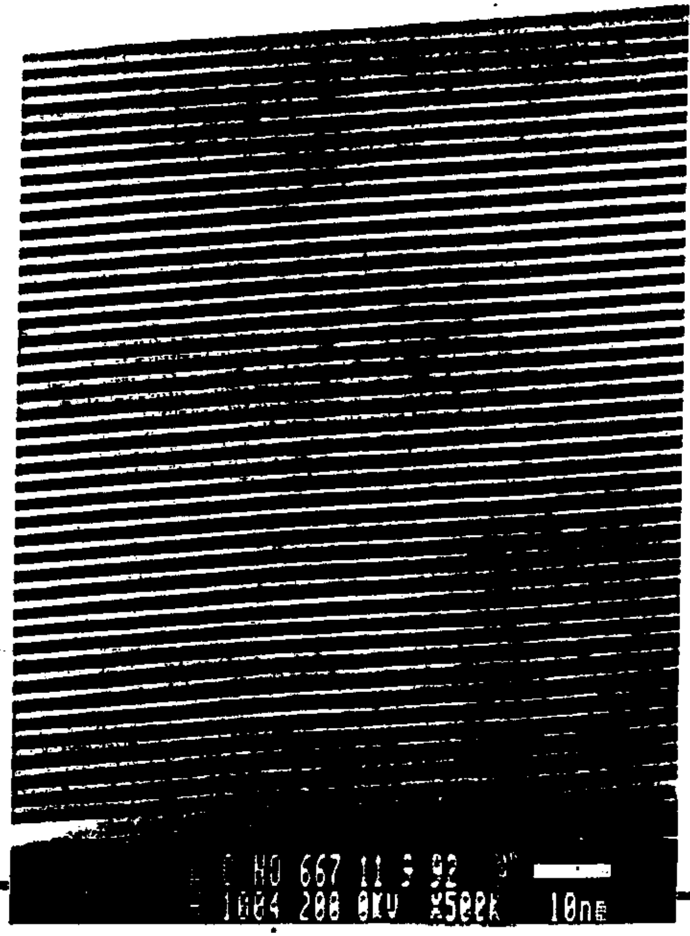
Magnetron sputtering:

SCM-651 (ALCATEL)

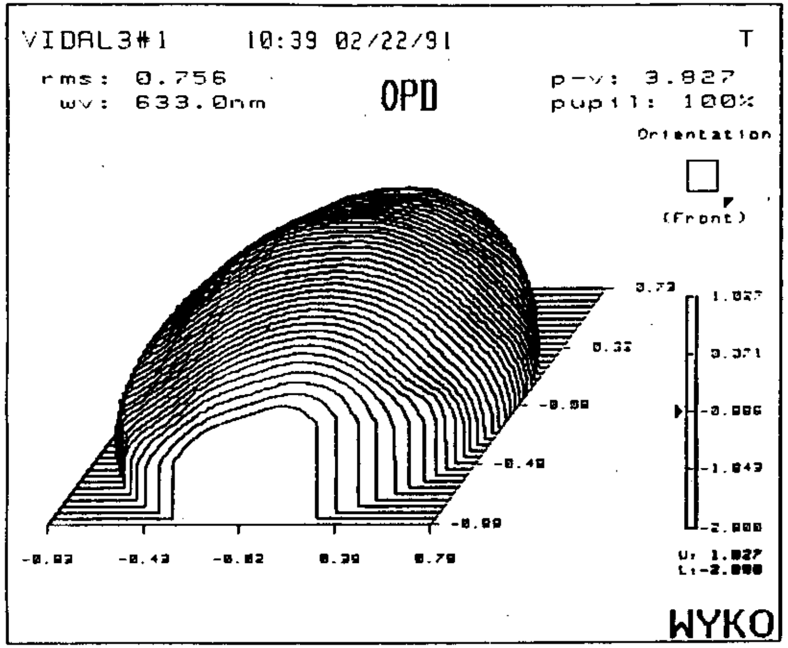
RF magnetrons	2 x 600 W
Wafer size	250mm x 100mm
Target materials	C, W, Si, Ni, B_4C, AlN.

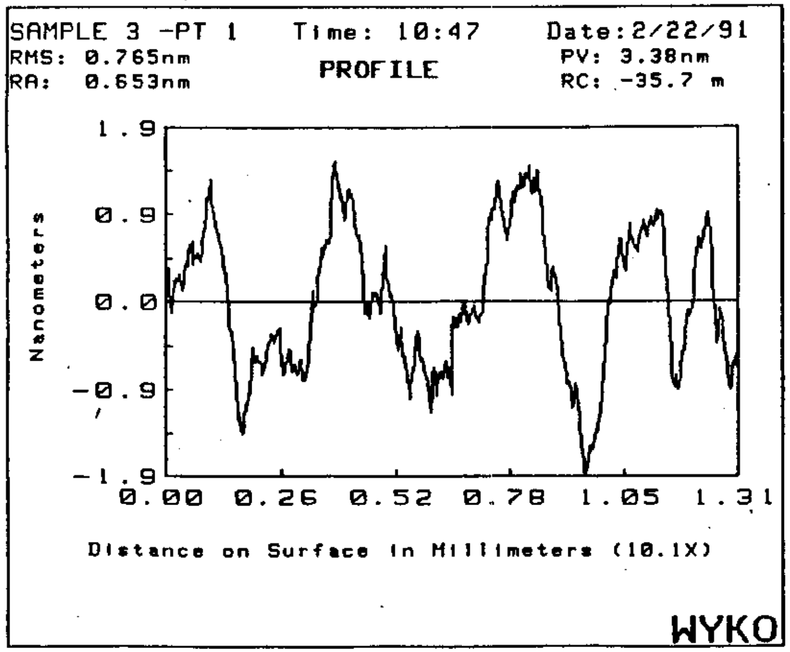
Cross-section of Mutilayer X-Ray Mirror fabricated by magnetron sputtering method in the SCM-651 "ALCATEL" system. (with participation of LOE, Marseille)

Multilayer materials: C and W,
Multilayer period: 3.15nm,
Number of bilayers: 76,
Efficiency at 0.154nm: 63%

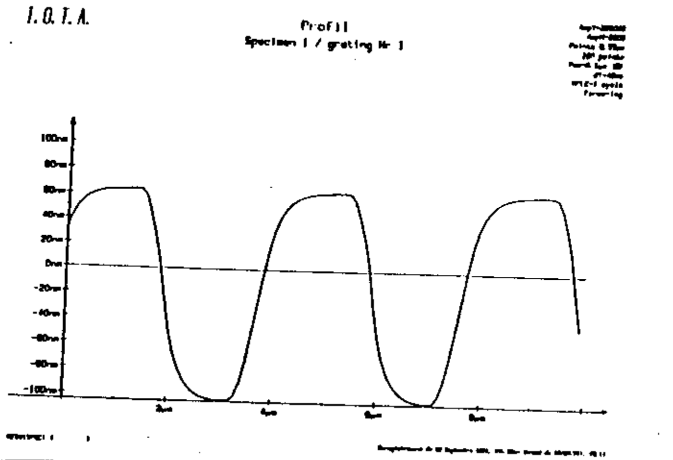


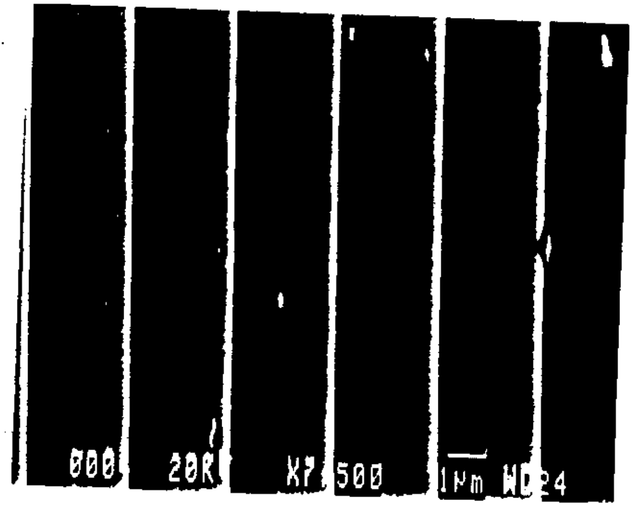
Substrate testing





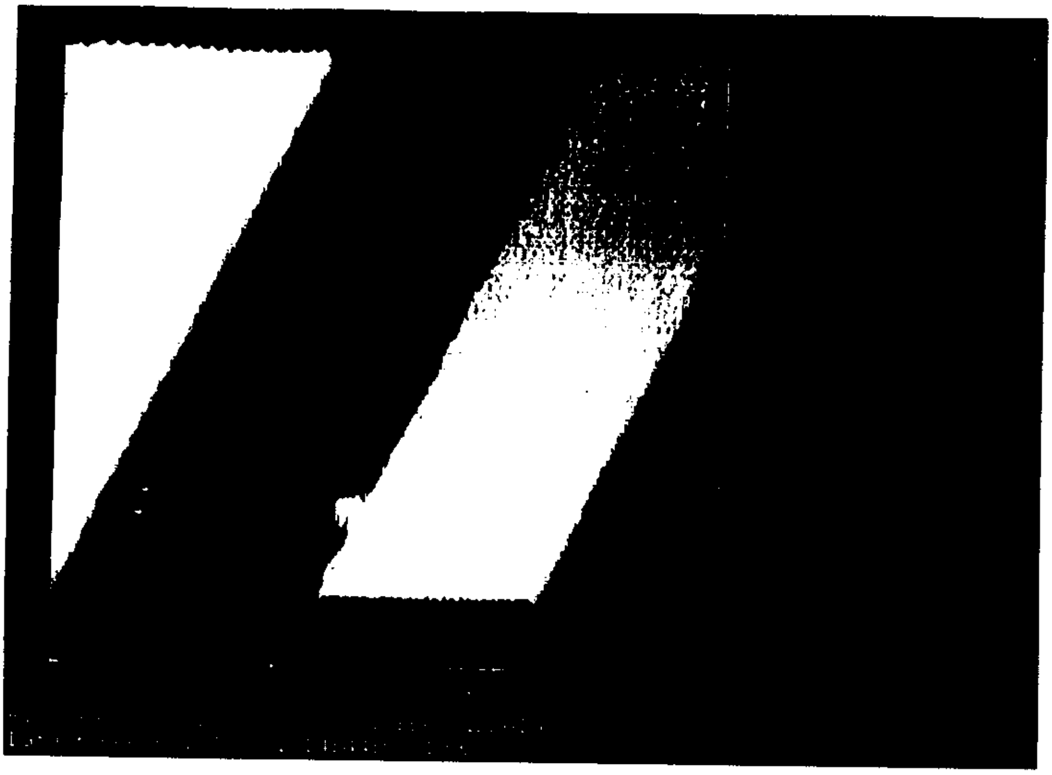
Tally-step measurements

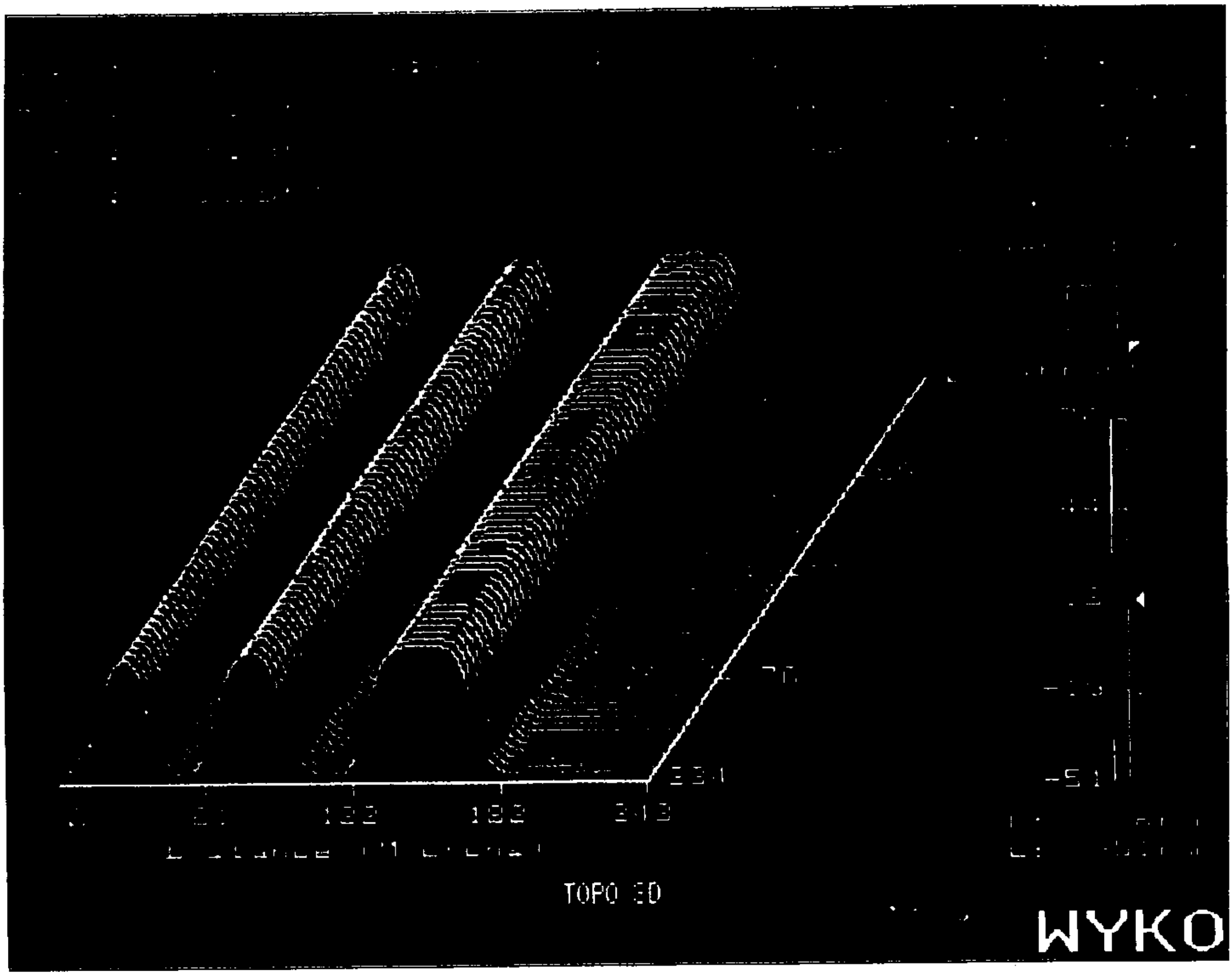




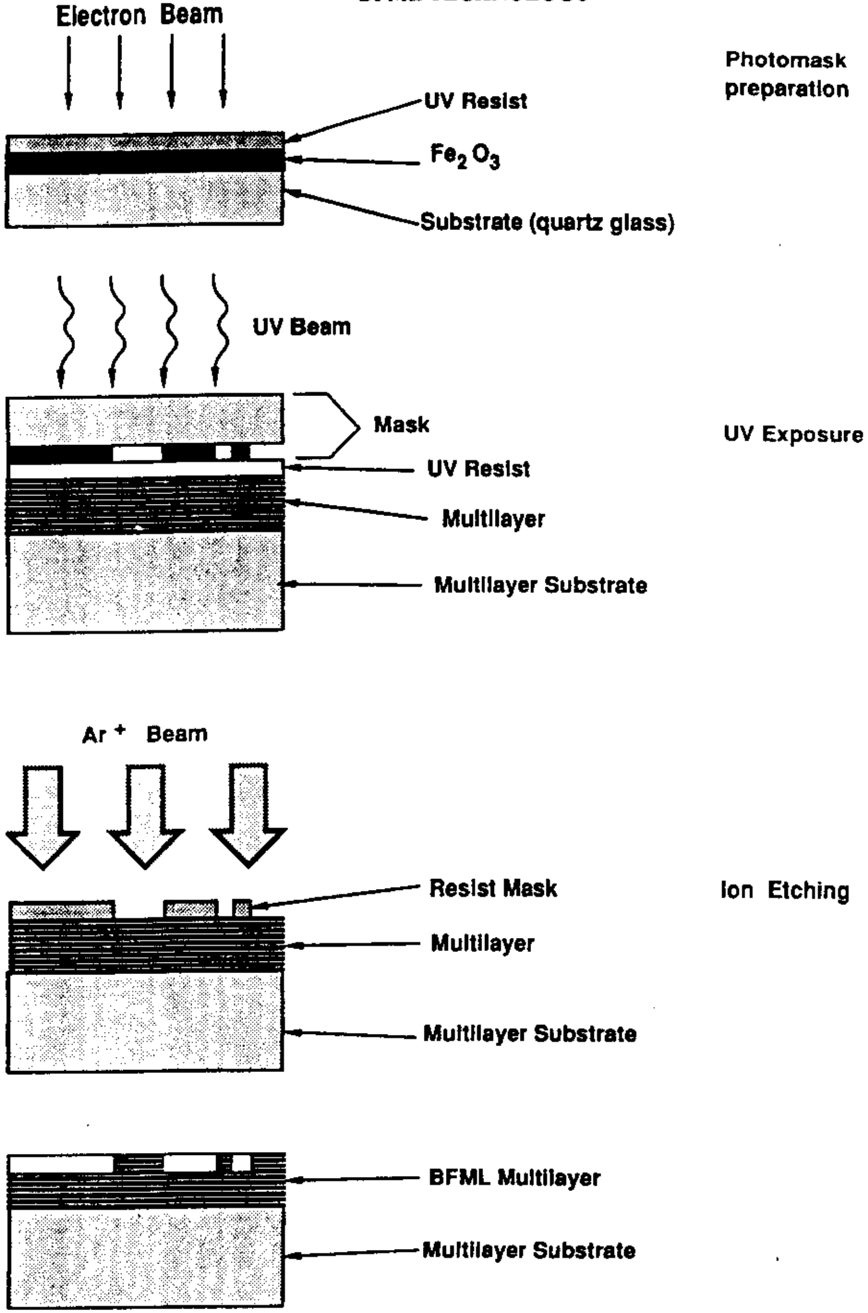
Microphotograph of LGM with period 4 μm.
Made in scanning electron microscope.

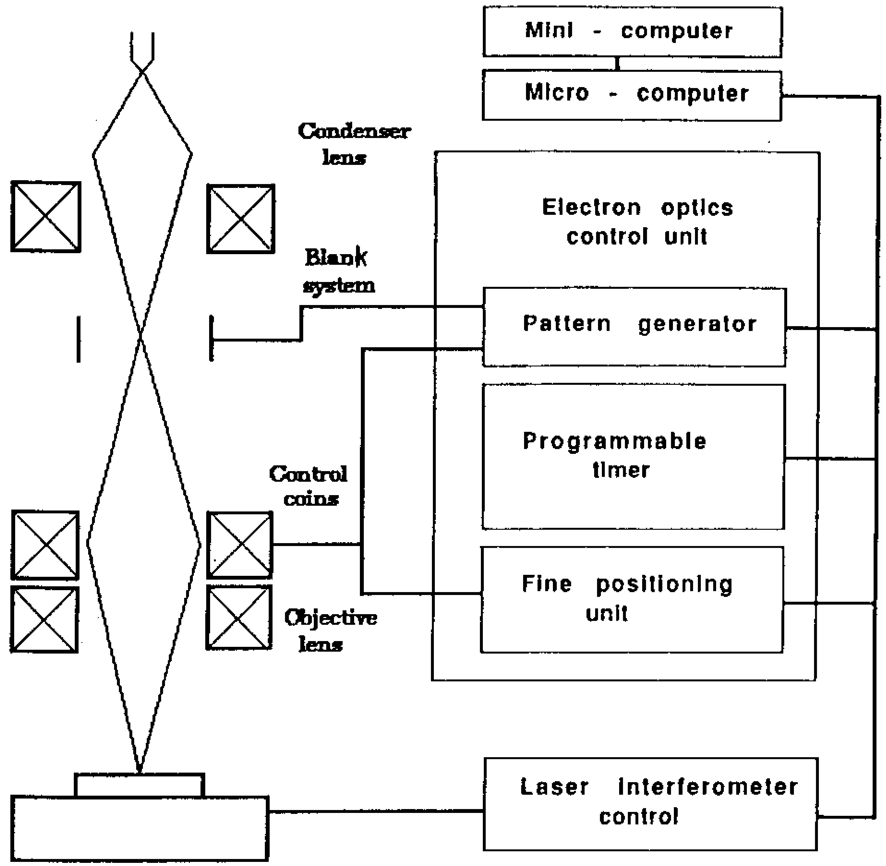
Atomic-force microscopy



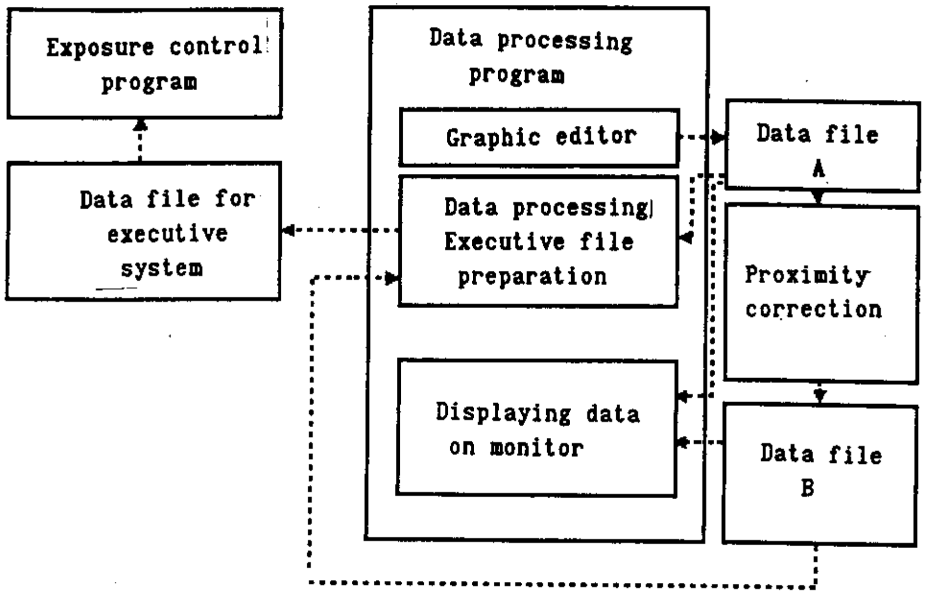


BFML TECHNOLOGY

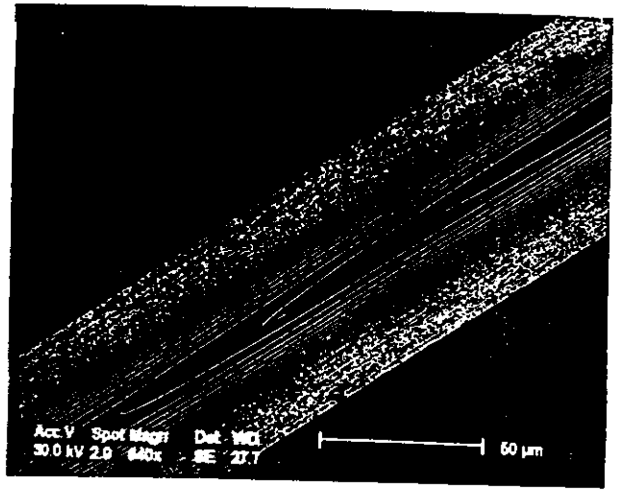


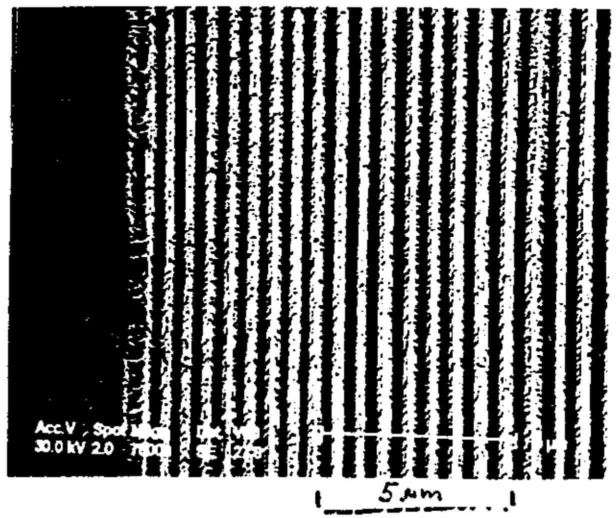


Electron-Beam Lithography system



Data processing program structure





Minimum line width [illegible]

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