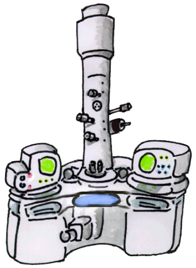
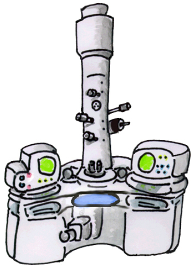


Curriculum Vitae

1949	Born in Yamanashi Prefecture
1949	Osaka
1954	Tokyo (5 year old)
1958	Osaka (9 year old)
1968-1978	Osaka University
1978	Tohoku University
1984-1985	Arizona State University
1990	Tonomura Wave Front Project (JRDC ERATO)
1995	Nagoya University, CIRSE （理工科学総合研究センター）
2002	Nagoya University, Department of electrical Engineering and Communication Science
2007	Nagoya University, EcoTopia Science Institute



With Prof. Hatsujiro Hashimoto

at IMC 2006 (85 year old)

Prof. Keiji Yada at 77 year old party

Young Prof. John Cowley

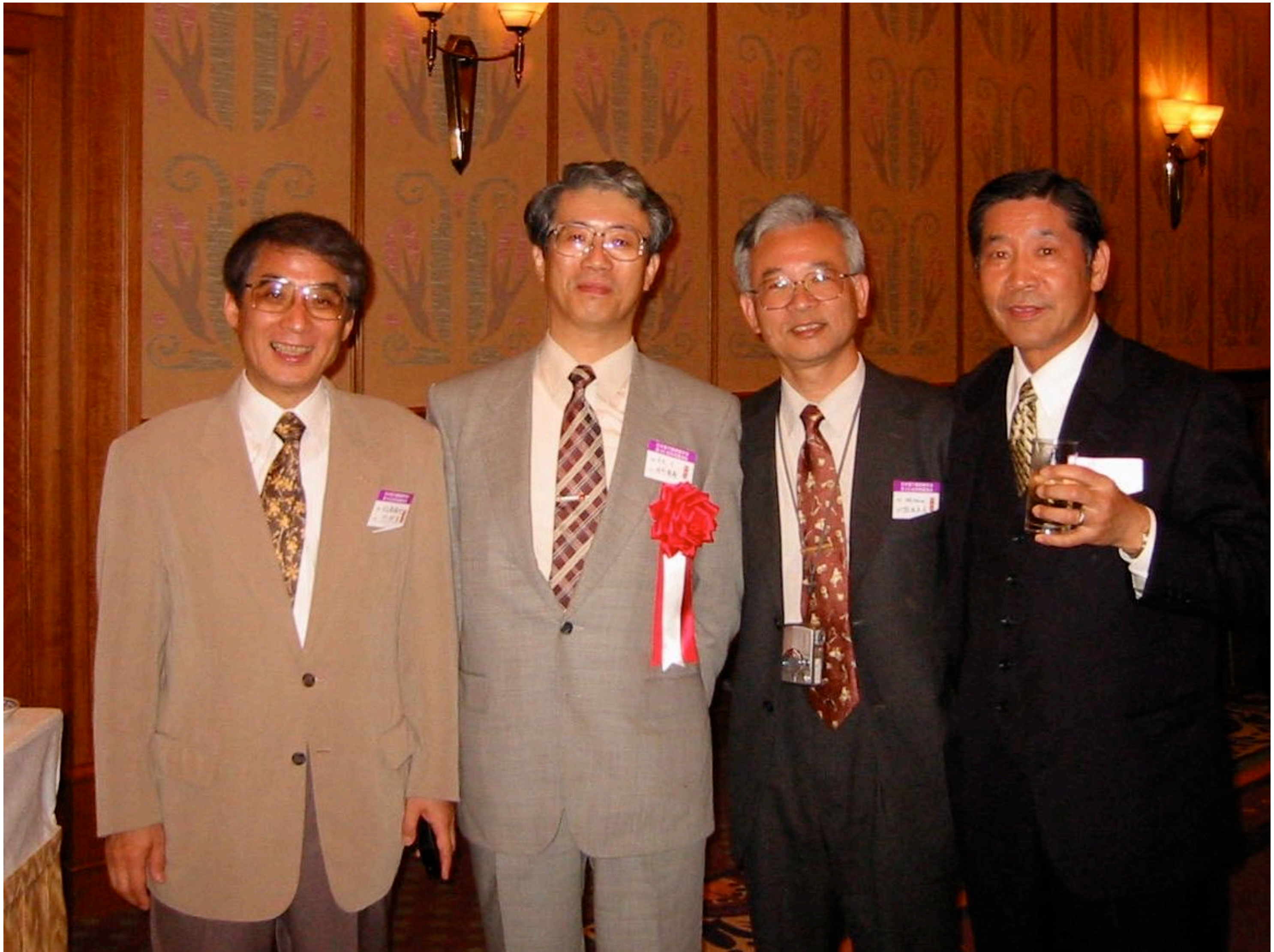
With Prof. John M. Cowley

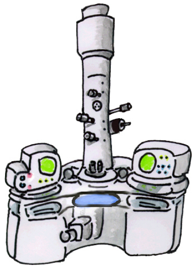
at 80 year old party

Dr. Akira Tanomura

With Akira Tonomura, Sumio Iijima & ・・・・・

With Dr. Akira Tonomura & ・・・





History of Studies

1971-1972 Osaka Univ. BS: Measurements of work functions by photoemission

1972-1978 Osaka Univ. MS & PhD: Optical image processing of high resolution electron microscopic images

1978-1984 Tohoku Univ. Assistant Prof. : High resolution observation of asbestos

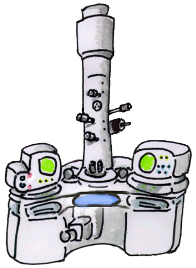
1984-1985 ASU: High resolution observation of the surface profile of MgO

1985-1990 Tohoku Univ. Assistant Prof. & Associate Prof. :

- X-ray diffraction effects on quantitative analysis by EDX
- Scanning image detection system for TEM
- Simulation of electron holography ・・・・・Start of surfing

1990-1995 Tonomura Project , Group Leader:

- High resolution electron holography and observation of magnetics



History of Studies

1995- Nagoya University:

・Precise electron holography (phase shifting EH)

・Differential electron holography 科研費基盤(B)

・Observations of magnetics by EH and Lorentz microscopy 経済産業省「次世代自動車向け高効率モーター用磁性材料技術開発」

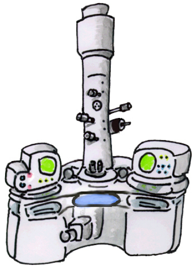
Magnetic nano particles, Magnetic multi layers 科研費基盤(B)、特定A（公募・計画）

・Field emission gun of carbon nano tubes 科研費基盤(B)

・Stereoscopic TEM with TV rate 科研費基盤(A)

・*In situ* observation of SOFC 科研費特定領域(計画)、基盤(A)、文科省「ナノテクノロジーを活用した環境技術開発プログラム」ナノ材料科学環境拠点(GREEN)

・Phase plate using A-B effect 科研費基盤(A)



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1．Introduction

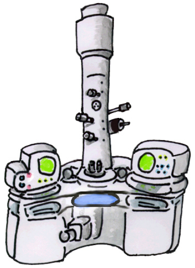
2．Interference of waves

3．Electron holography

- High resolution imaging
- Observation of Magnetic field

5．Stereoscopic TEM

6．Phase plate using A-B effect



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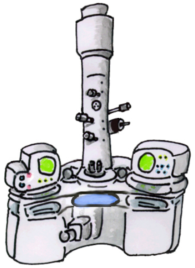
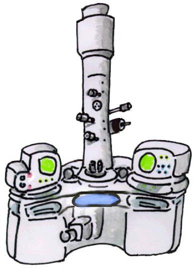


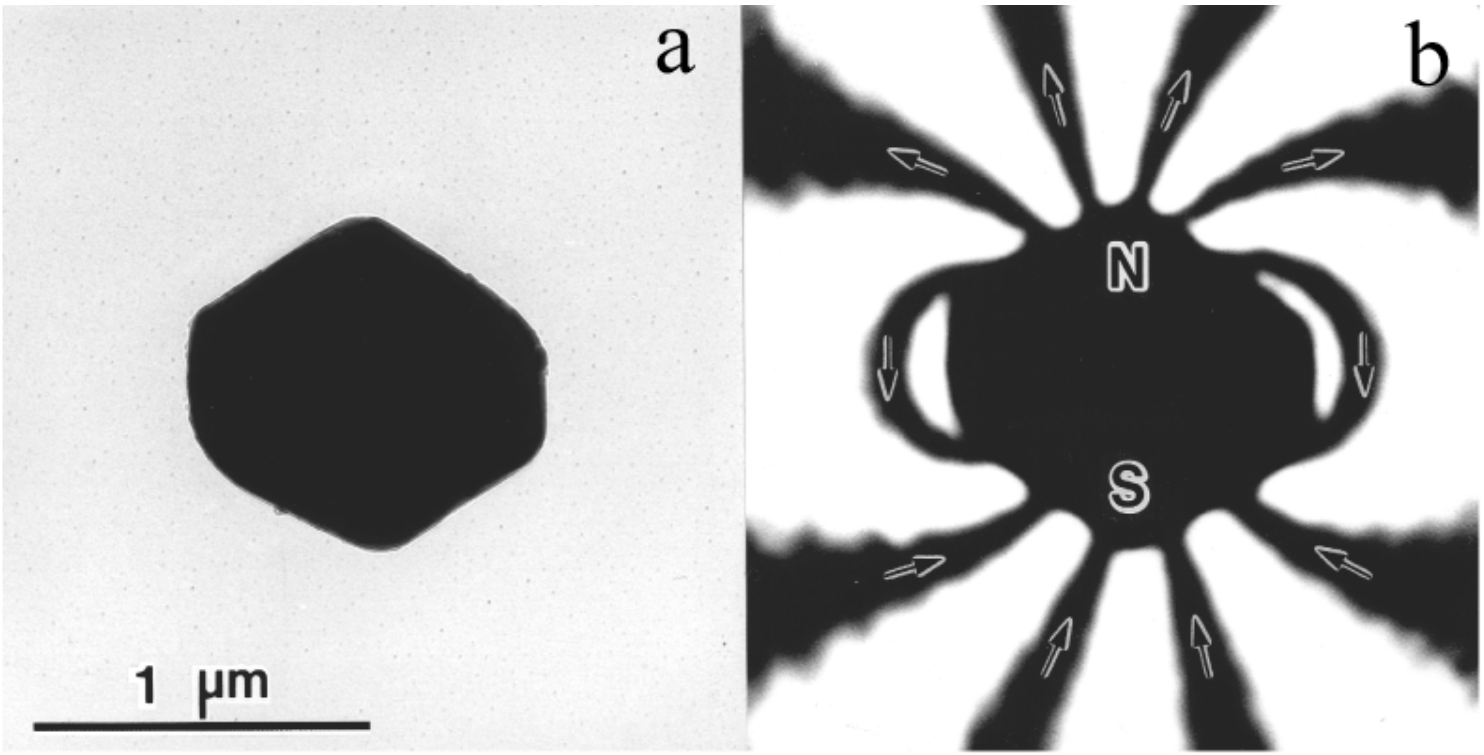
What’s This ?

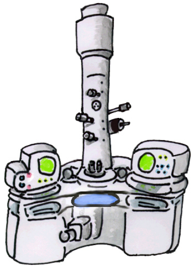
Equipotential Lines

What's This ?

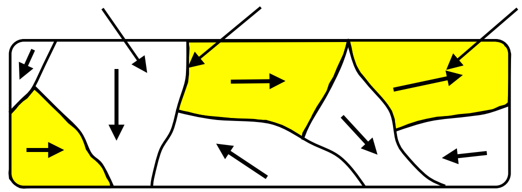


Magnetic Line of Force



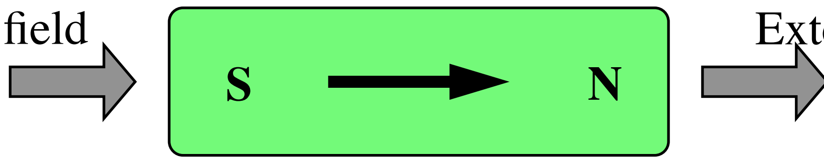


Magnetic Structure of Ferromagnetic



Multi domain structure

External field

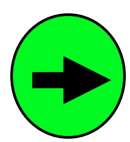


External field

Magnetic energy＝Static energy＋wall energy

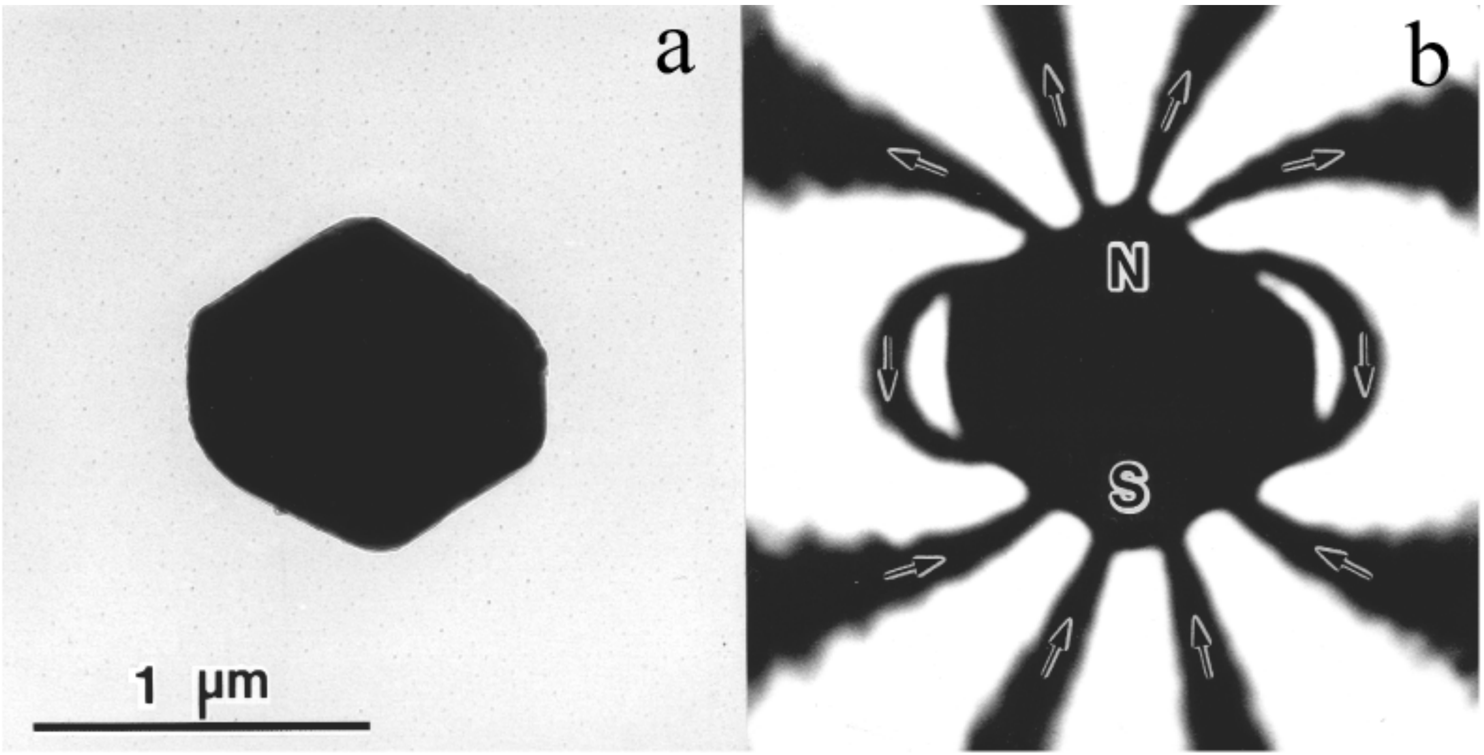
$\propto V \propto d^3$ $\propto S \propto d^2$

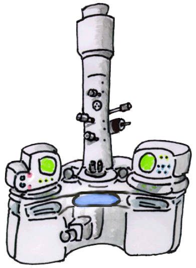
$\phi < \sim 1$mm



Singl magnetic domain particle

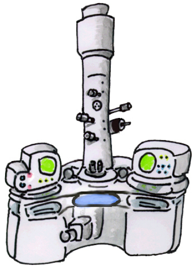
Single Magnetic Domain Particle of Ba-Ferrite



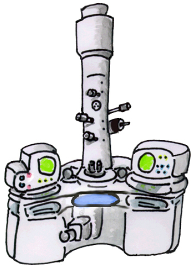


Development of Electron Microscope

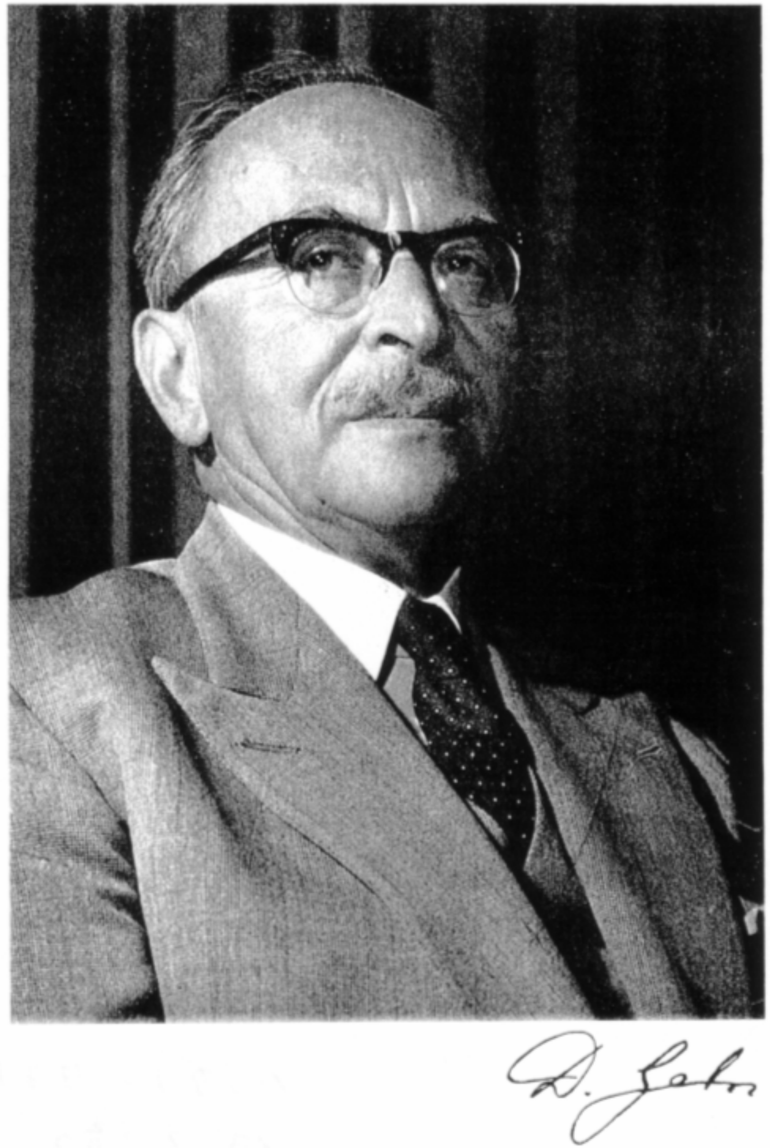
1858	J. Plücker	陰極線の発見
1869	J. W. Hittorf	陰極線の電磁偏向
1874	E. Abbe	顕微鏡の分解能限界
1897	J. J. Thomson	電子の存在を確認
1899	E. Wiechert	軸方向磁界によるスポット径縮小
1924	L. de Broglie	電子の波動性（物質波）
1927	C.J.Davison & L.H.Germer	Ni表面での電子線回折実験
	H. Busch	回転対称磁界のレンズ作用
1931.5.5	R. Rüdenberg	電子顕微鏡の特許申請
6.4	M. Knoll & E. Ruska	電子顕微鏡（磁界型）で最初の像(x17)を発表
1933	B. von Borries & E. Ruska	２段磁界型電顕で光顕を超える(75kV, x12,000, 50nm)
1934	L. Marton	Os染色による生物試料の撮影(x3,900)
	E.Sugata	大阪大学
1935	M. Knoll	走査電子顕微鏡(SEM)
1936	Metropolitan-Vickers社	商用第１号機　EM-1 (20kV, >1μm)
	J.Okubo & T.Hibi	東北大学



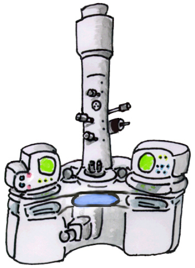
1939	H. Mahl & H. Boersch	静電型電子顕微鏡 AGE社 (8nm)
	Ruska & Borries, Siemens社	UM-100 (100kV, x30,000, 7nm)
	（JSTS） 第37小委員会（Shoji Seto）	
1940	M. V. Ardenne	分解能3nm
	H. Rusk	バクテリアファージの電顕像
	H. Boersch	フレネル縞
	浅尾荘一郎	x100（東芝）
1941	Seimens	UM-220 (220kV, 2nm)
1943	Hitachi	HU-2（名古屋大学）
1946	J. Hillier & E. G. Ramberg	非点収差補正で1.1nm
1948	D. Gabor	ホログラフィ
1949	Japanese Electron Microsocpy Society 日本電子顕微鏡学会設立	
1954	Seimens	Elmiskop I (100kV, <1nm)
1956	J. W. Menter	白金フタロシアニン (1.19nm)
	G. Möllenstedt & H. Düker	電子線バイプリズムの開発
1960	T. H. Maiman	レーザーの発明(ルビーレーザー)
1962	E.N.Leith & J. Upatnieks	二光束(off-axis)ホログラフィーの考案
1968	A. V. Crew et al.	FE-SEM, 単原子像
1979	A. Tonomura et al.	FE-TEM, 電子線ホログラフィ



Dennis Gabor (1900 - 1979)



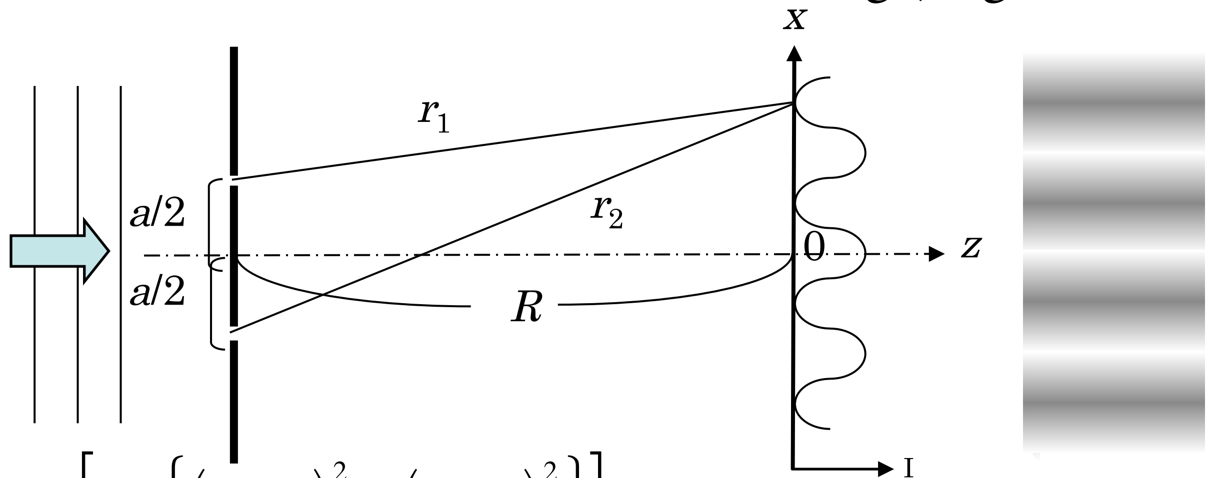
Nature, 1948



Contents

Interference of Light

Interference with double slits　　Thomas Yang (Eng.1773-1829)



$$I = \left[\exp\left(i\frac{2\pi}{\lambda}r_1\right)+\exp\left(i\frac{2\pi}{\lambda}r_2\right)\right]^2$$

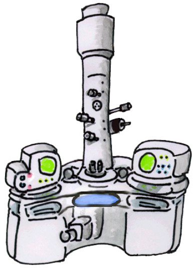
$$= 2+2\cos\left\{\frac{2\pi}{\lambda}\left(r_1-r_2\right)\right\}$$

$$= \cos\left(\frac{2\pi}{\lambda}\left[\left\{\left(x+\frac{a}{2}\right)^2+R^2\right\}^{1/2}-\left\{\left(x-\frac{a}{2}\right)^2+R^2\right\}^{1/2}\right]\right)$$

$$I = \cos\left[\frac{2\pi}{\lambda}\left\{\frac{\left(x+\frac{a}{2}\right)^2}{2R}-\frac{\left(x-\frac{a}{2}\right)^2}{2R}\right\}\right]$$

$$= \cos\left(\frac{2\pi}{\lambda}\frac{ax}{R}\right)$$

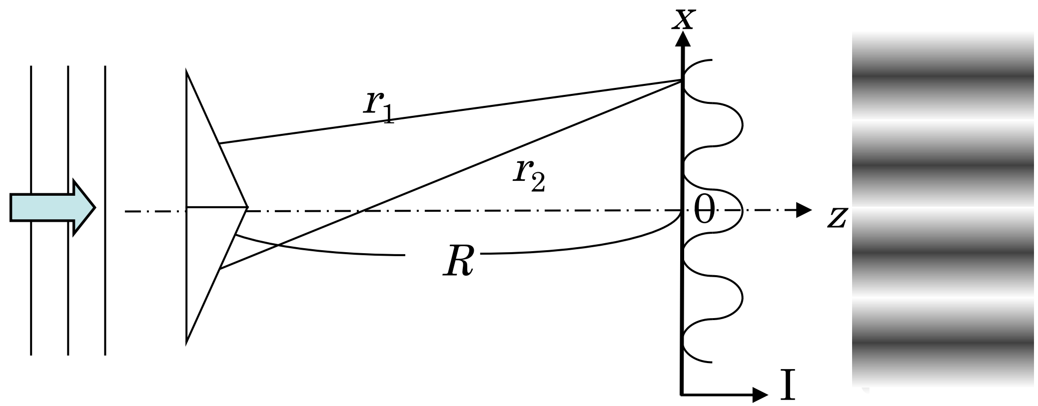
$$= \cos\frac{akx}{R}$$

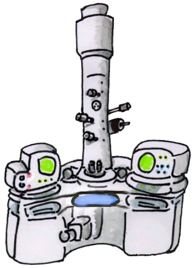


Interference of Light

Fresnel's Biprism (Augustin J. Fresnel:Fr.1788-1827)

Diffraction with a pin hole is not essential for Young's experiment



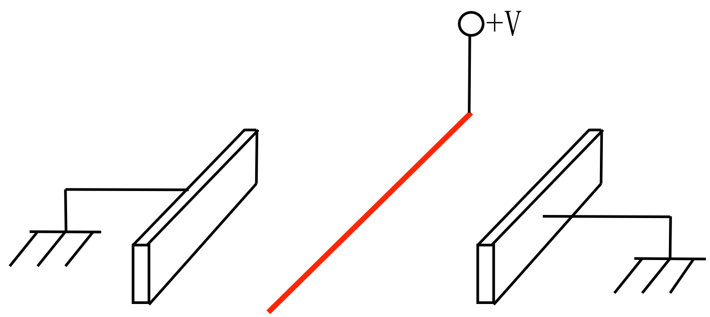


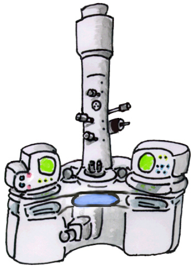
Interference of Electron Wave

Interference experiment with electrons

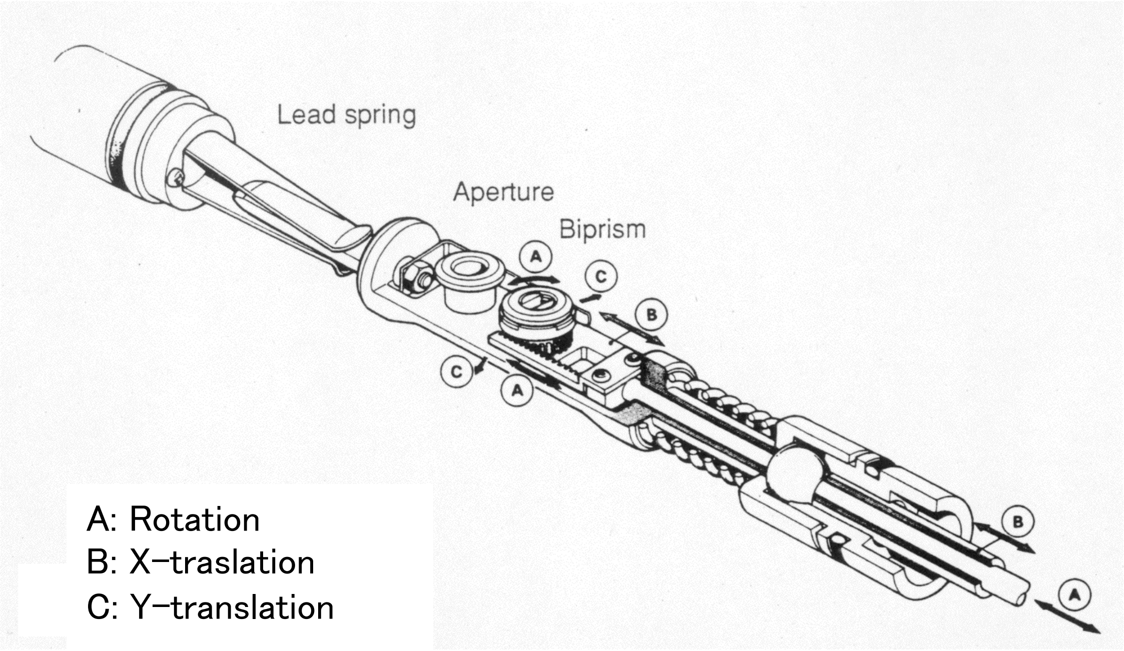
→ The core of quantum mechanics (R.P.Feynman)

Electron Biprism G. Möllenstedt and H. Düker, Z. Phys. **145** (1956) 377.

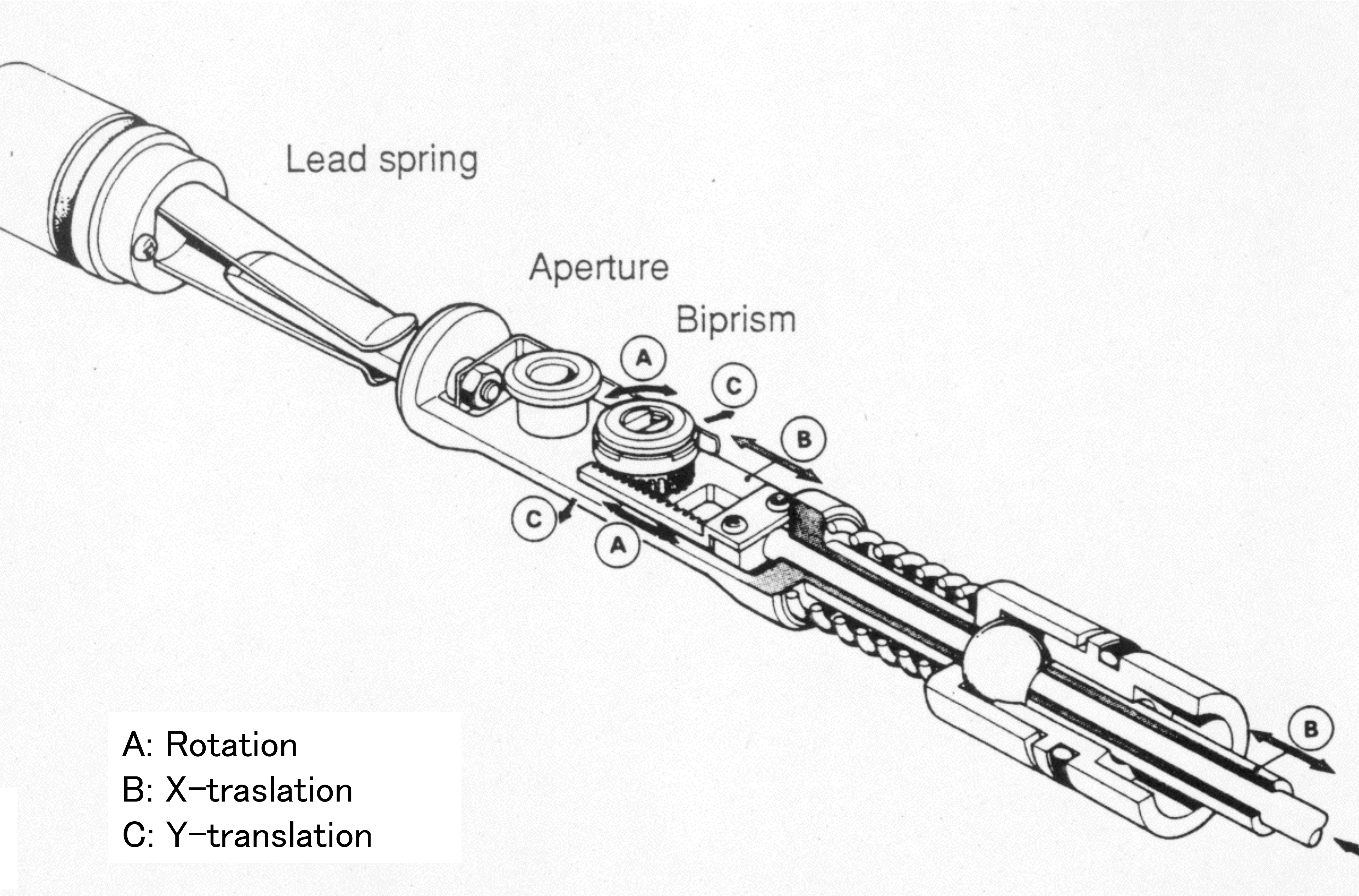




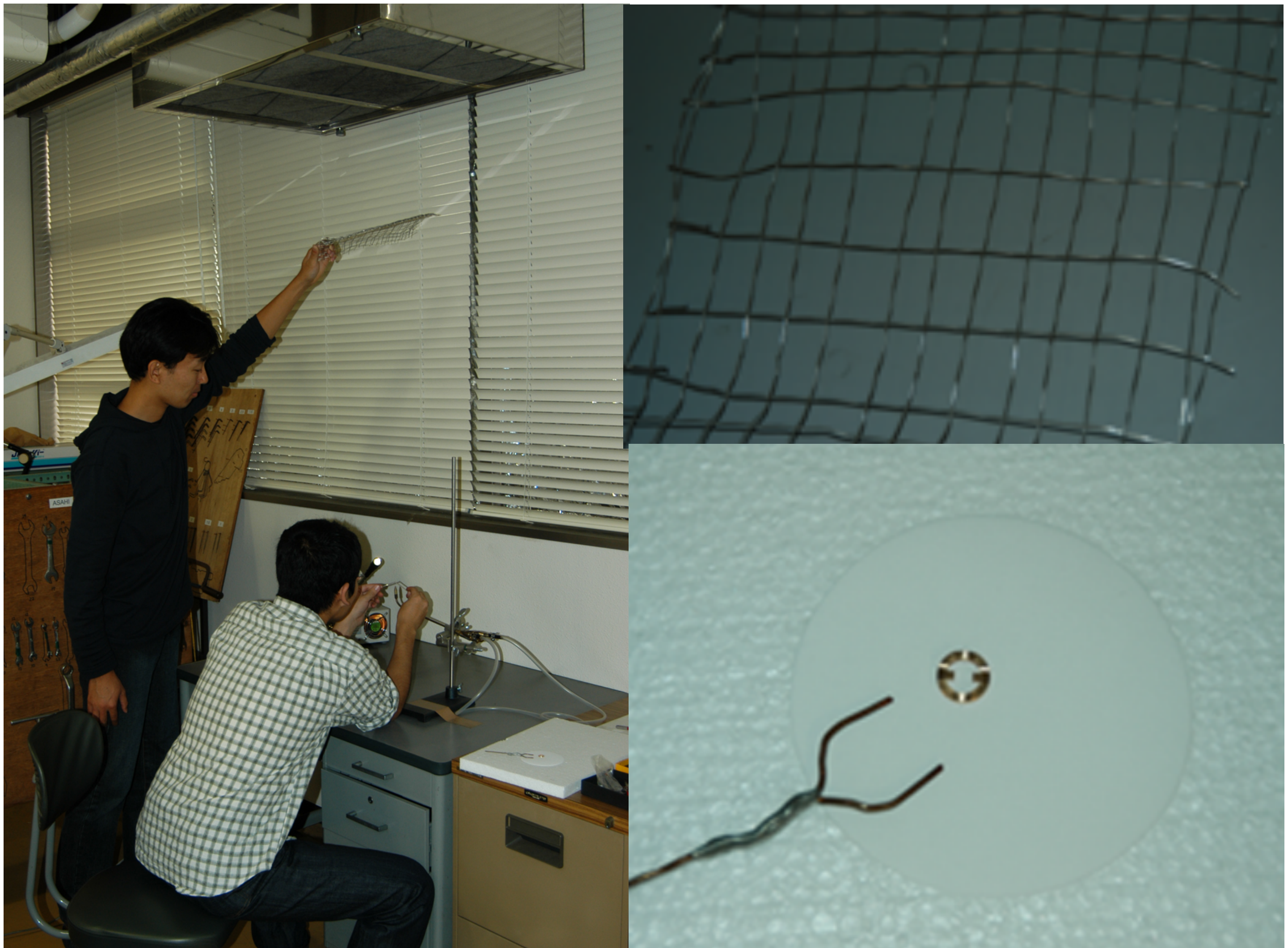
Electron Biprism

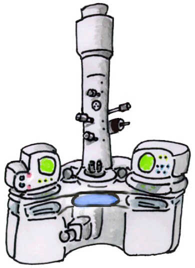


Hitachi


Lead spring
Aperture
Biprism
A
C
B
C
A
B
A: Rotation
B: X–traslation
C: Y–translation

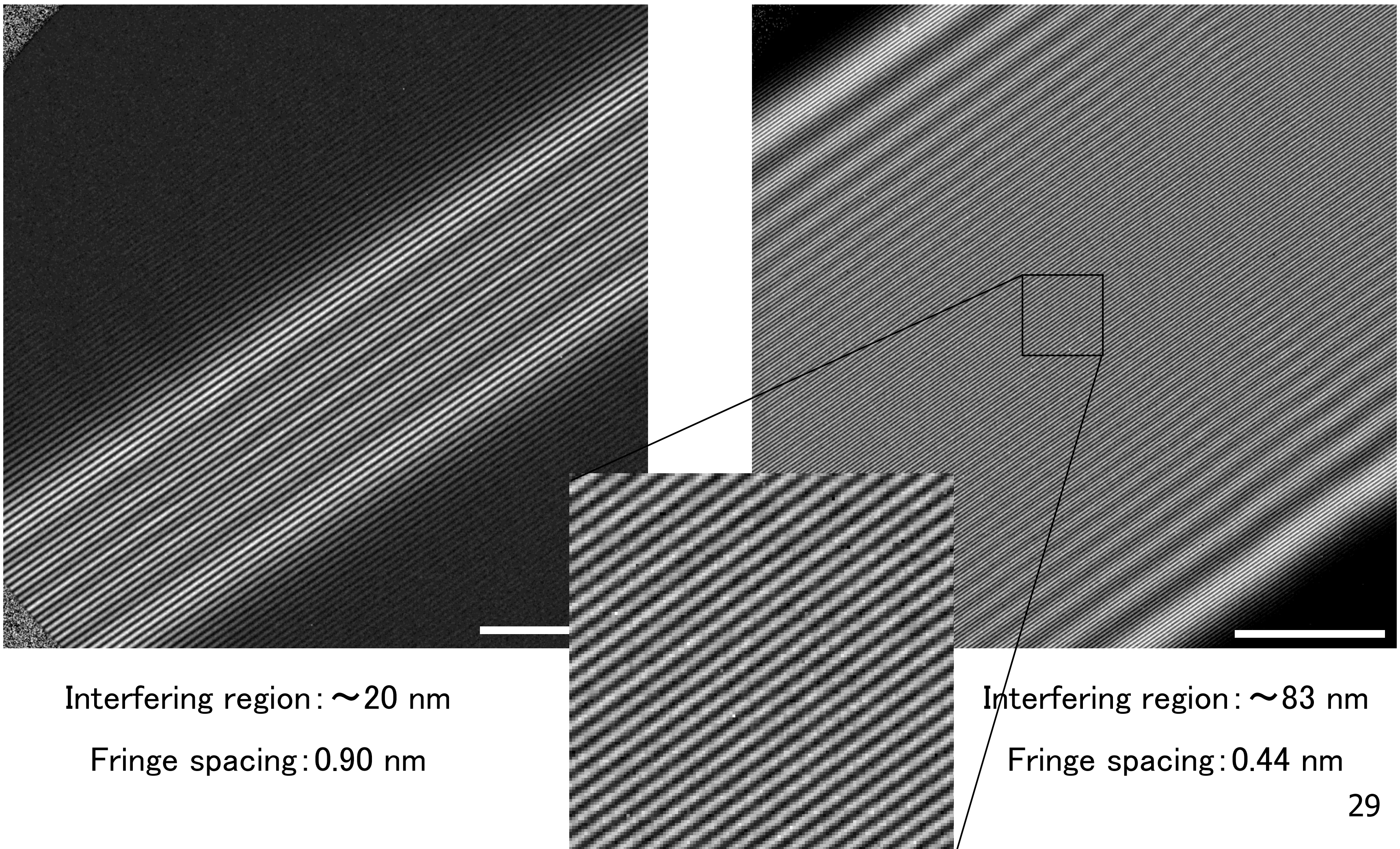
Making Filaments of Biprism





Interference of the Electron Wave

V_f=15 V　　　　V_f=30 V

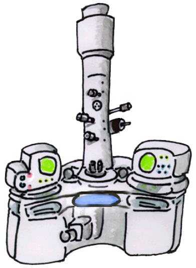


Interfering region : ～20 nm

Fringe spacing : 0.90 nm

Interfering region : ～83 nm

Fringe spacing : 0.44 nm



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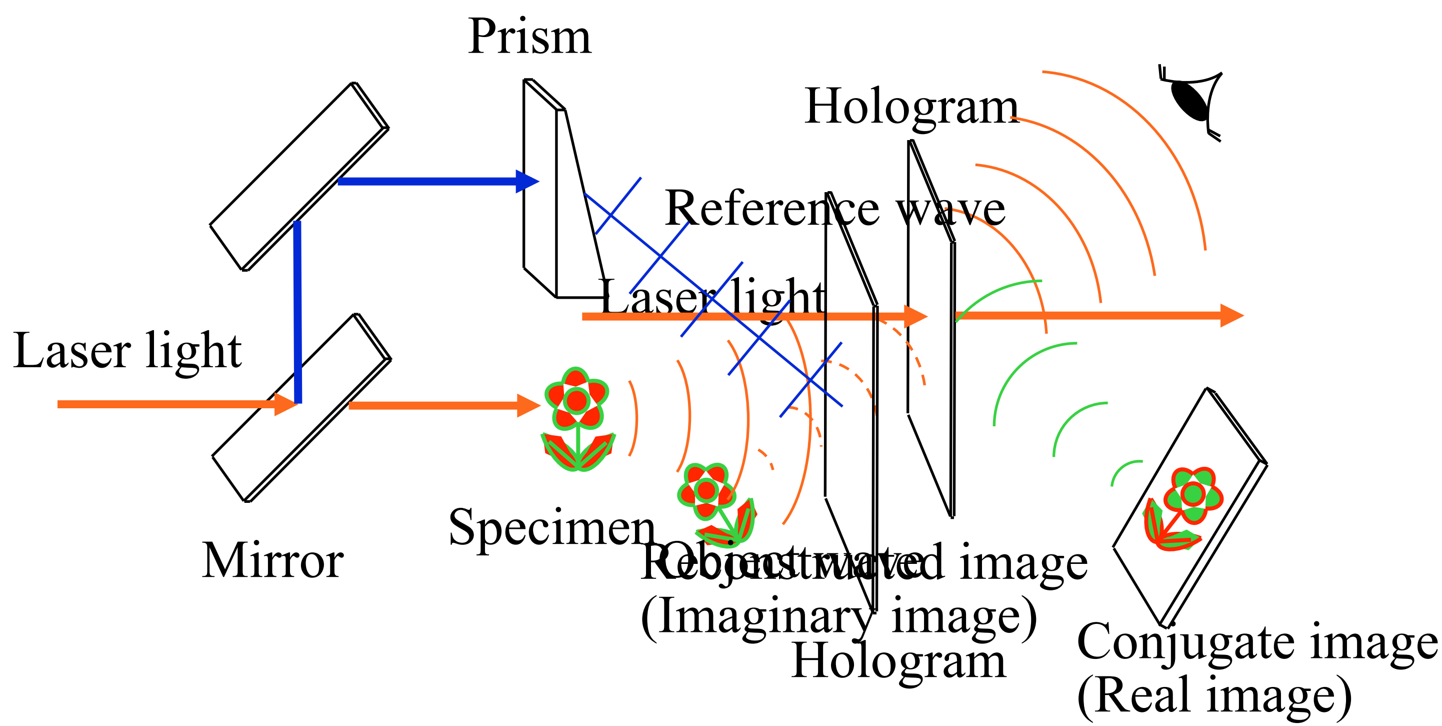
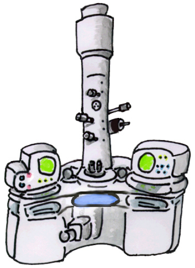
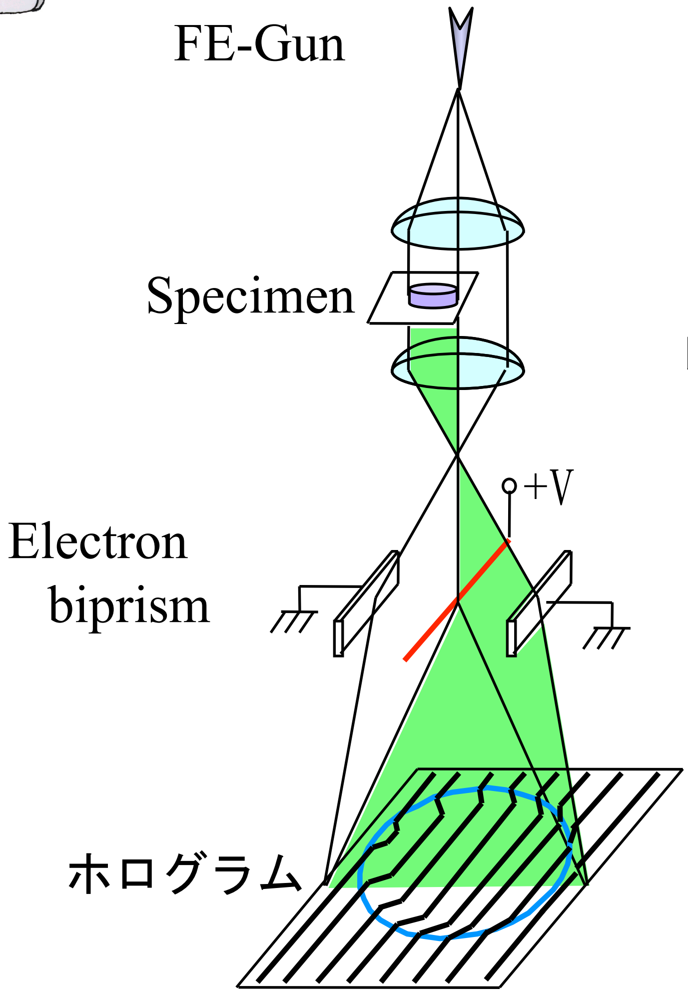
Holography

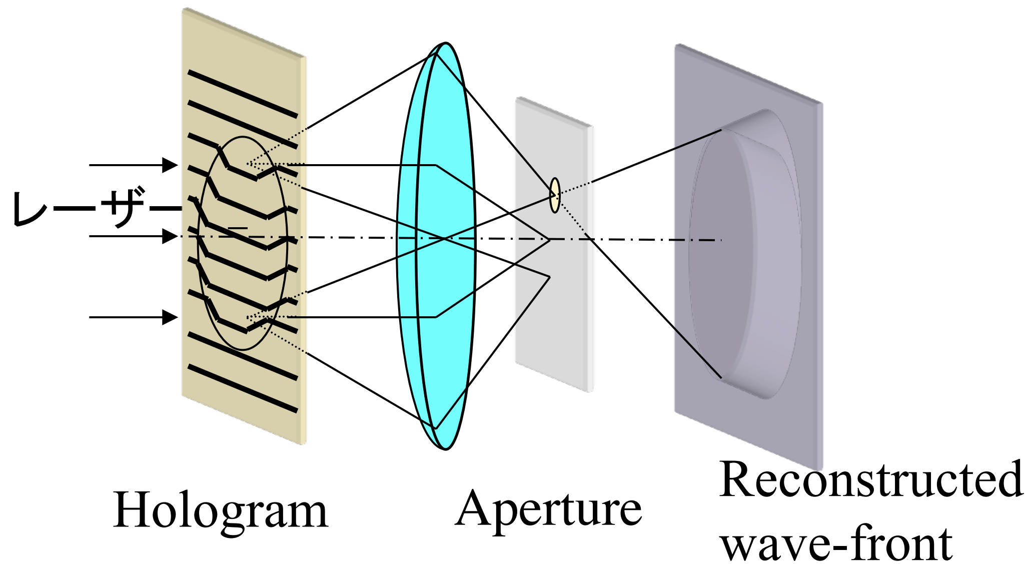

Prism
Hologram
Reference wave
Laser light
Laser light
Mirror
Specimen
Object wave
Reconstructed image
(Imaginary image)
Hologram
Conjugate image
(Real image)



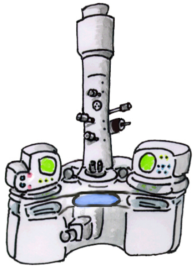
Electron Holography



Recording of a hologram

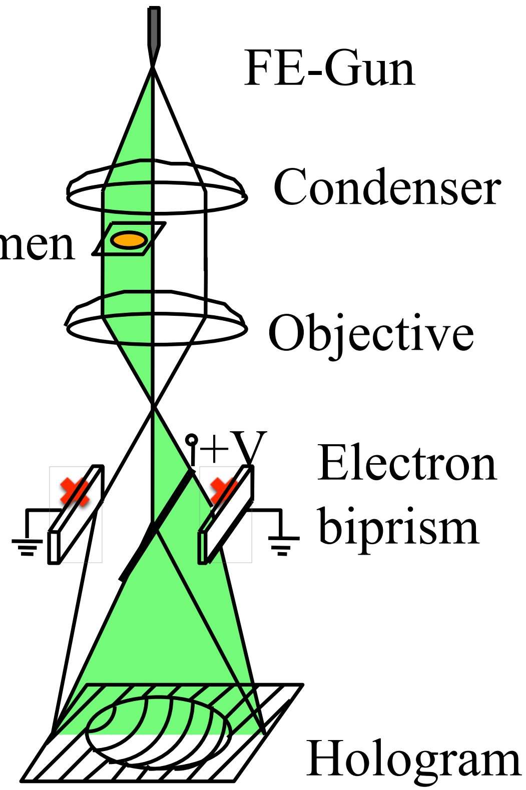


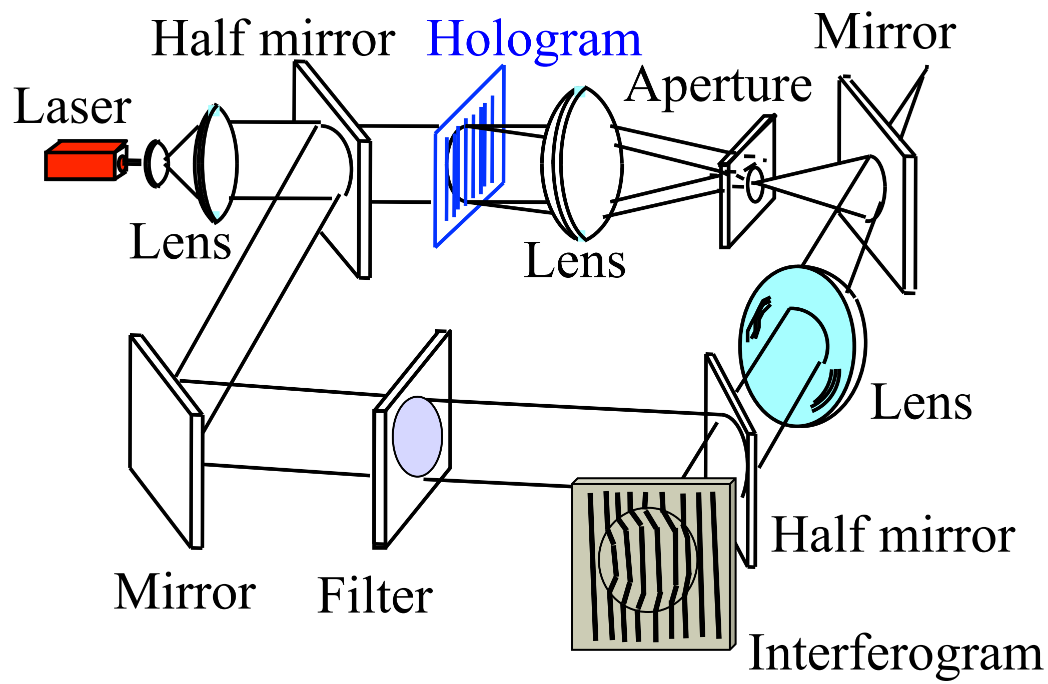
Reconstructed optics



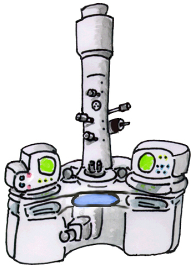
Interference Microscopy

(Machzender Interferometer)

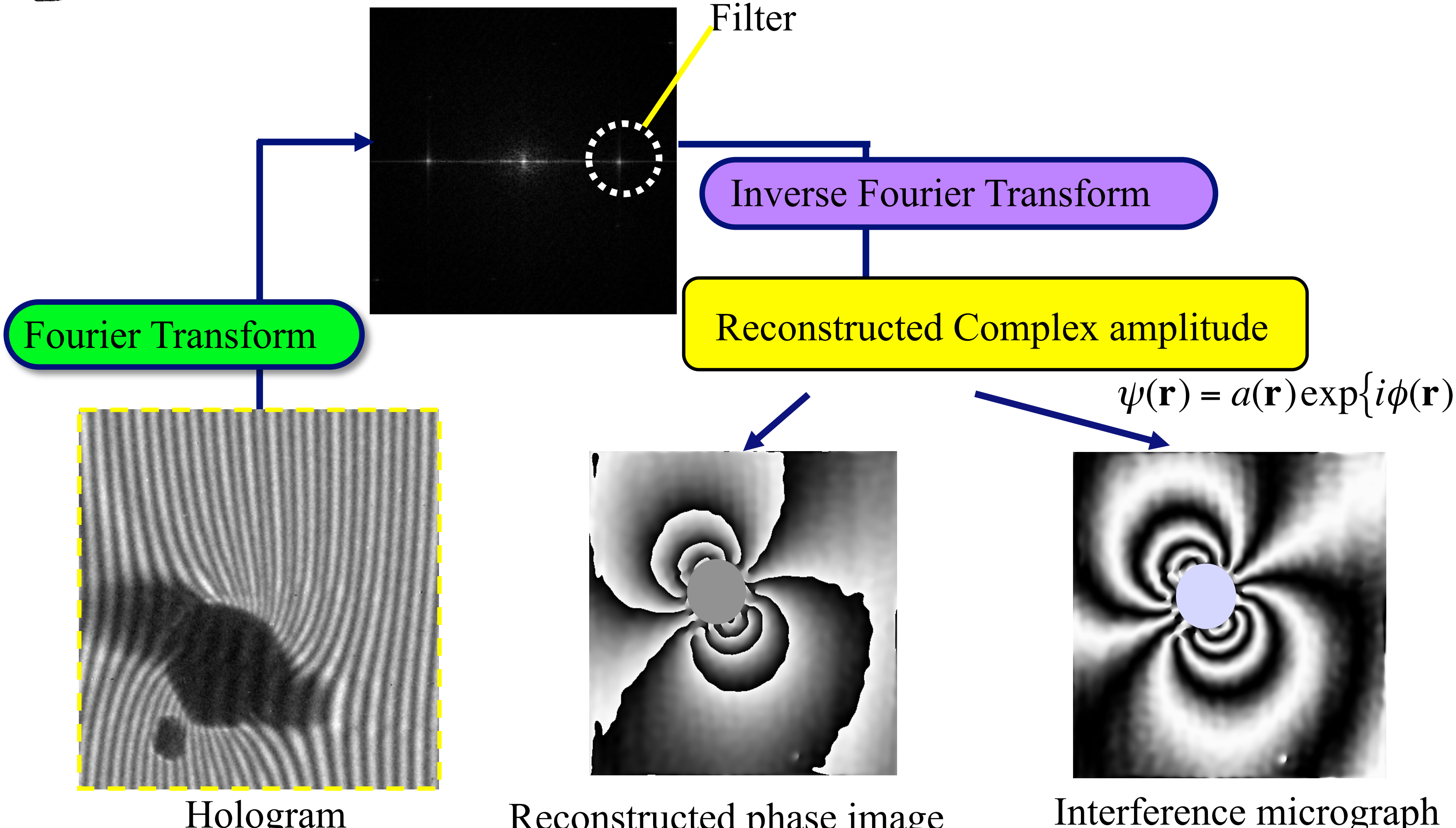




Interference micrograph



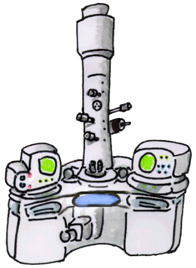
Digital Reconstruction



$$\psi(\mathbf{r}) = a(\mathbf{r})\exp\{i\phi(\mathbf{r})\}$$

$$\phi(\mathbf{r}) = \mathrm{Tan}^{-1}\left\{\frac{\mathrm{Im}\,\psi(\mathbf{r})}{\mathrm{Re}\,\psi(\mathbf{r})}\right\}$$

$$I(\mathbf{r}) = \mathrm{Re}\,\psi(r)$$



Phase Shift of Electrons by the Electromagnetic Field

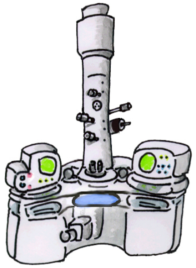
Schrödinger Eq.
$$\left(\frac{\hbar}{i}grad + e\mathbf{A}\right)^2 \Psi - 2m\left(E - eV\right)\Psi = 0$$

▪WKB applrox. & $E<<eV$

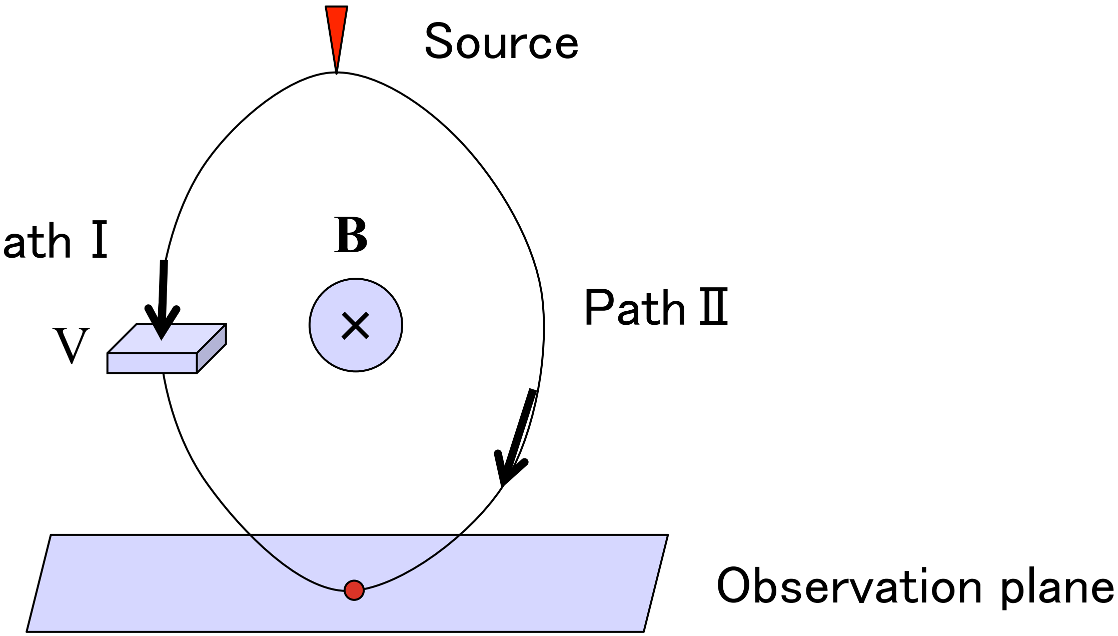
if
$$\Psi(\mathbf{r}) = a(\mathbf{r})\exp\left\{i\phi(\mathbf{r})\right\}\exp\left\{i(\omega t - \mathbf{k}\cdot\mathbf{r})\right\}$$

Phase shift by an electrostatic potential
$$\Delta\phi = \frac{\pi}{\lambda E}\int_z V(x,y,z)dz$$

Phase shift by a magnetic field
$$\Delta\phi = -\frac{e}{\hbar}\int_S \boldsymbol{B}(x,y,z)\cdot d\boldsymbol{S}$$



Phase Shift of Electrons by the Electromagnetic Field

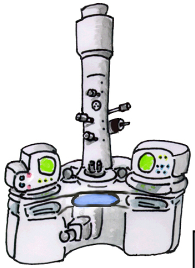


Phase shift by an electrostatic potential

$$\Delta\phi = \frac{\pi}{\lambda E}\int_z V(x,y,z)dz$$

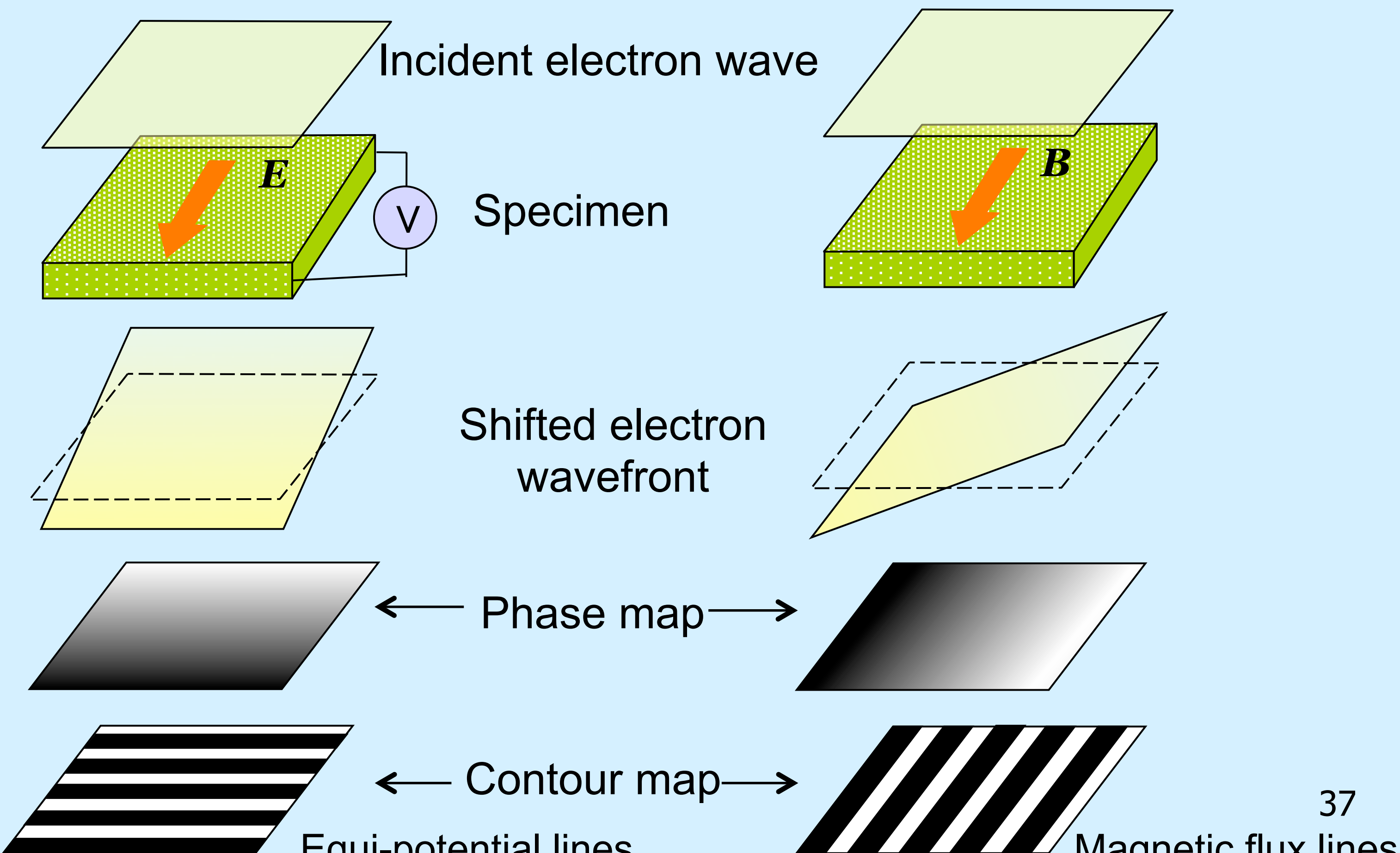
Phase shift by a magnetic field

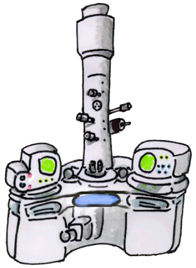
$$\Delta\phi = -\frac{e}{\hbar}\int_S \boldsymbol{B}(x,y,z)\cdot d\boldsymbol{S}$$



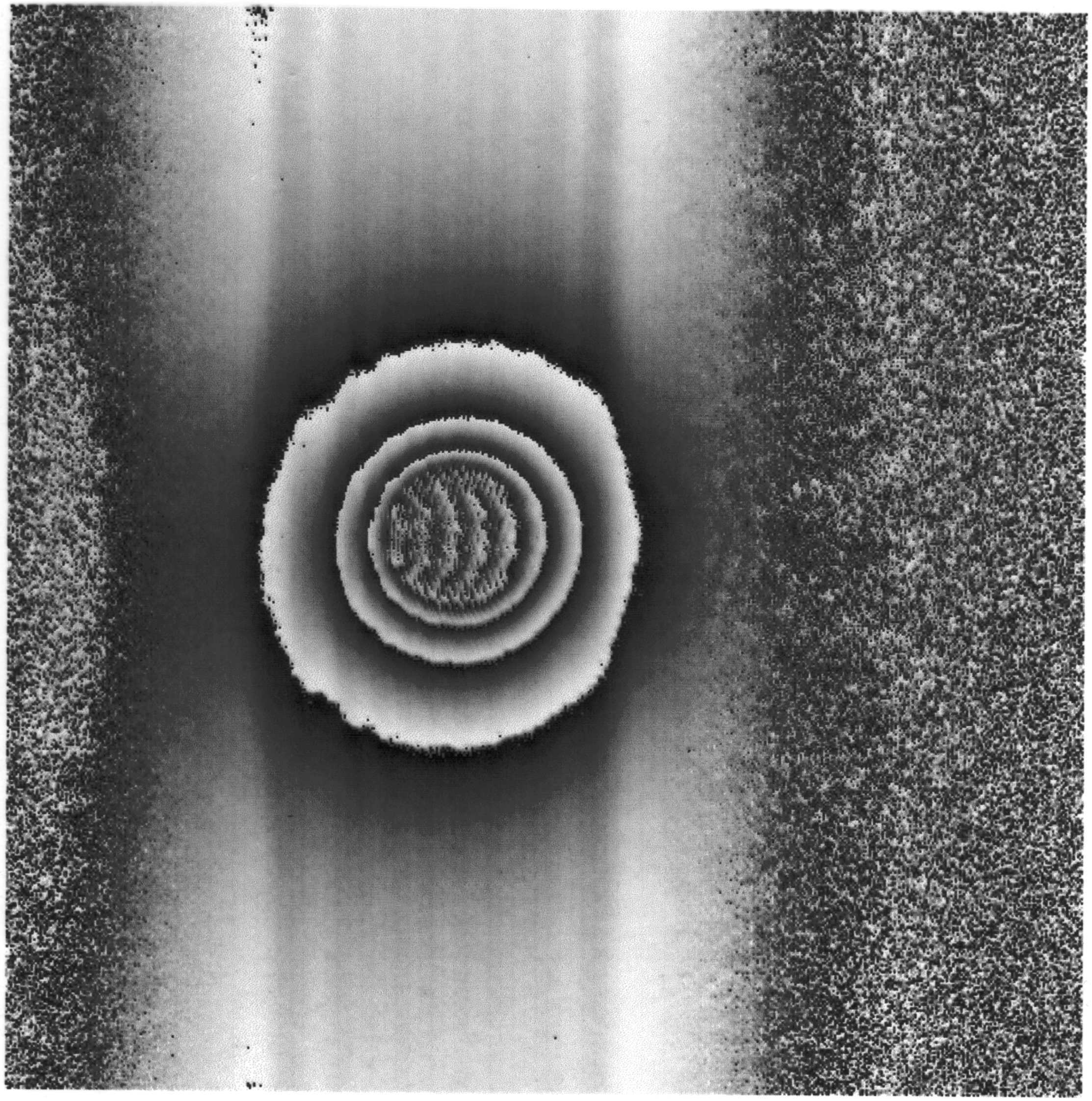
Phase Shift of Electrons by the Electromagnetic Field

Electric field	Magnetic field
$\Delta\phi = \frac{\pi}{\lambda E}\int_z V(x,y,z)\,dz$	$\Delta\phi = -\frac{e}{\hbar}\int_S \boldsymbol{B}(x,y,z)\cdot d\boldsymbol{S}$

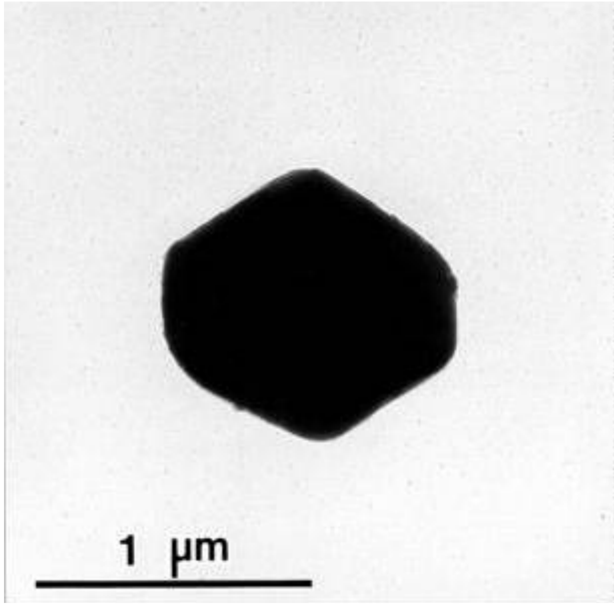


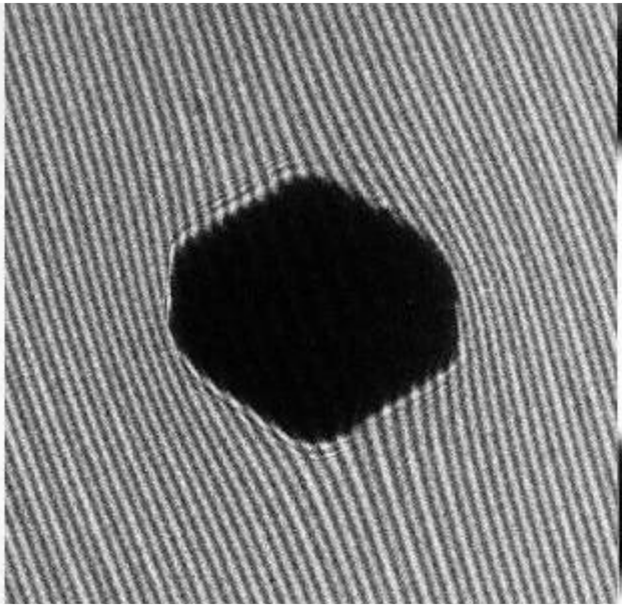


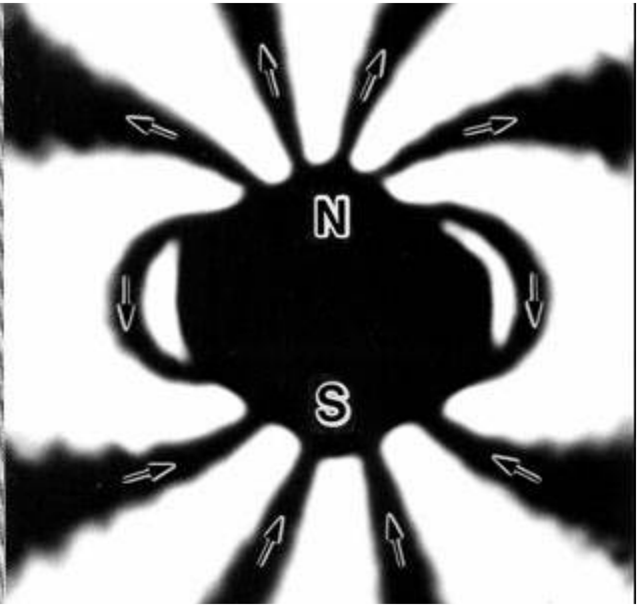
Latex Particle Charged Up



Single Magnetic Domain Particle of Ba-Ferrite



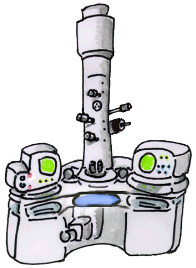




TEM Image

Hologram

Interference image



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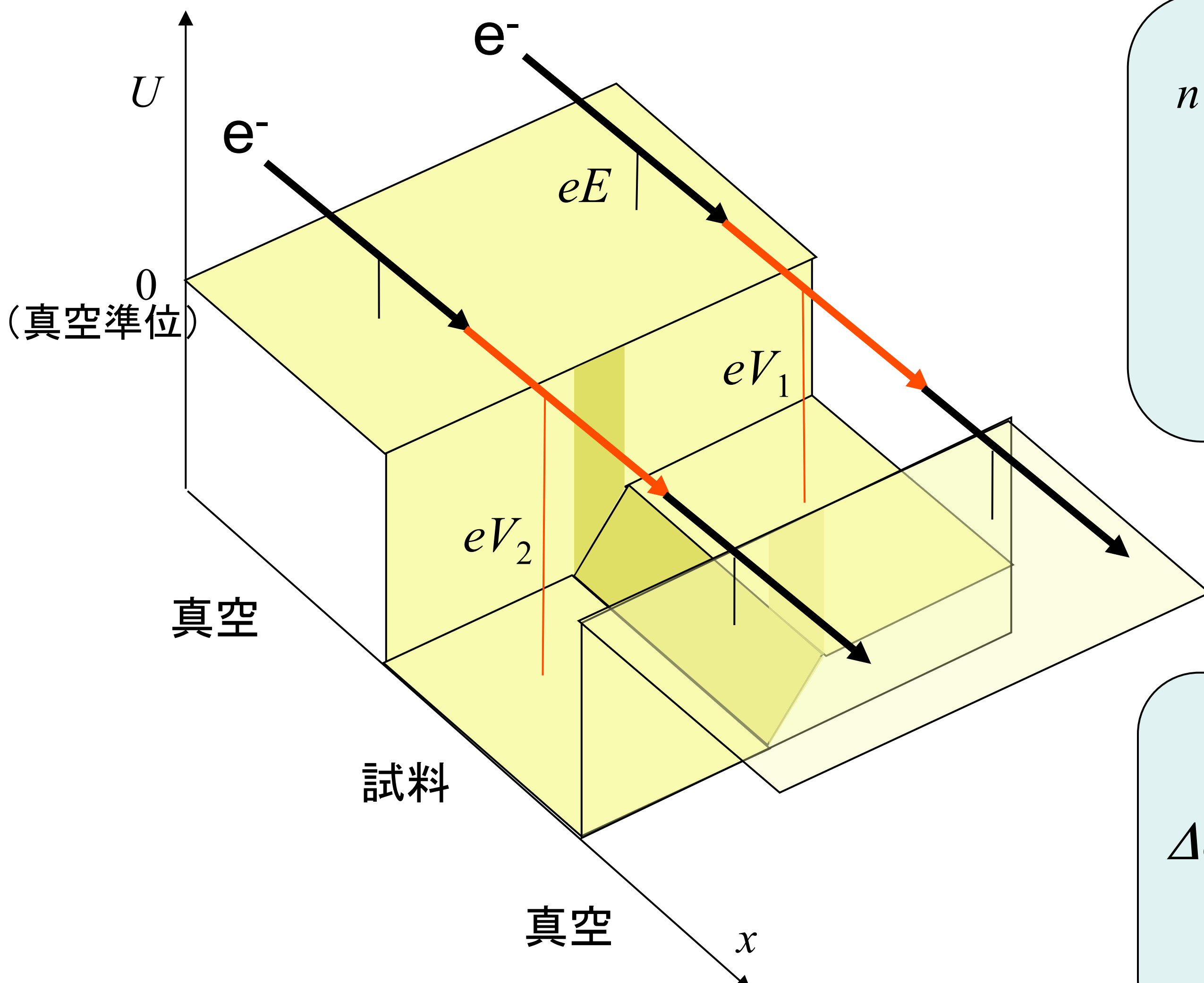
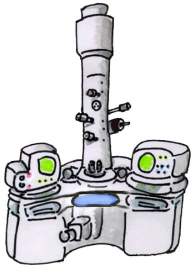
内部電位による電子の位相変化

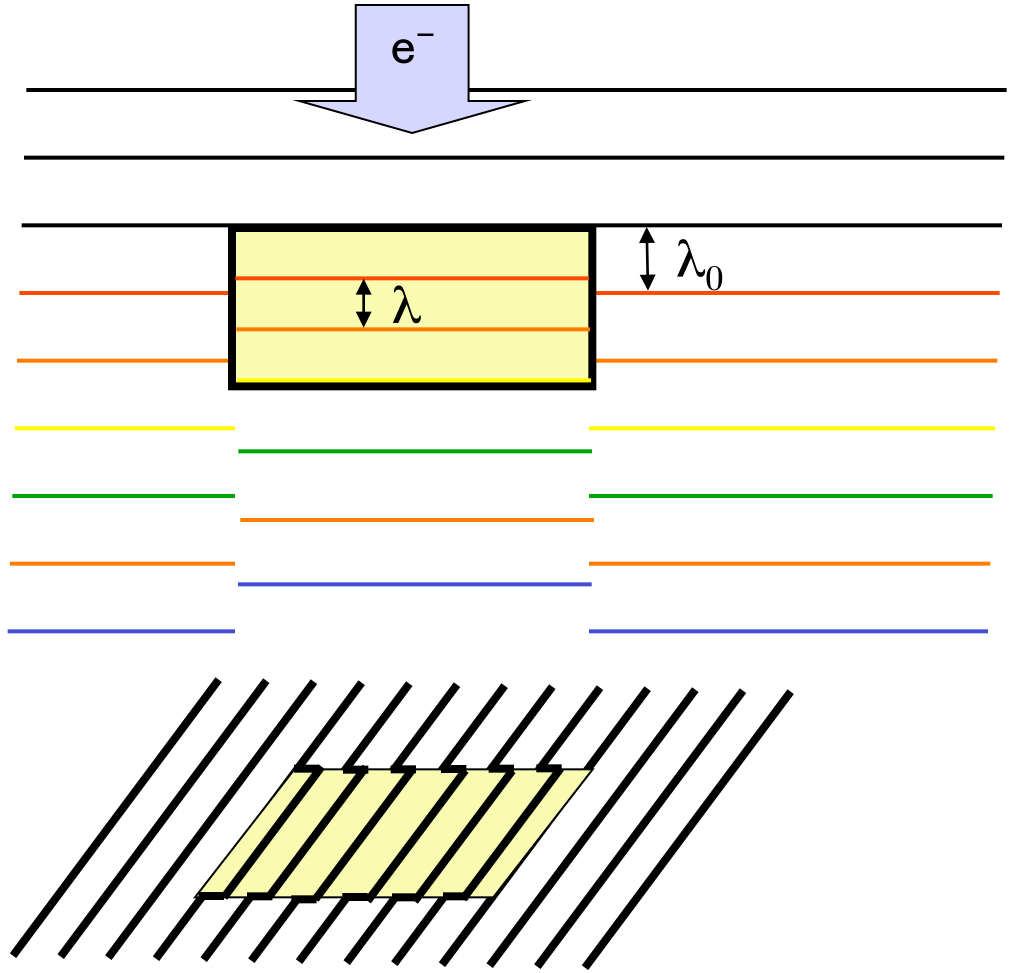


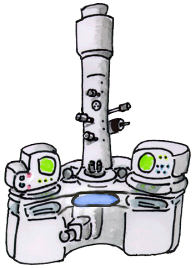
$$n = \frac{\lambda_0}{\lambda_1} = \sqrt{\frac{e(E+V)^*}{eE^*}} = 1 + \frac{V}{2E}\left(\frac{1+\dfrac{eE}{mc^2}}{1+\dfrac{eE}{2mc^2}}\right)$$

$$\Delta\phi = \frac{2\pi kVd}{2E}\left(\frac{1+\dfrac{eE}{mc^2}}{1+\dfrac{eE}{2mc^2}}\right)$$

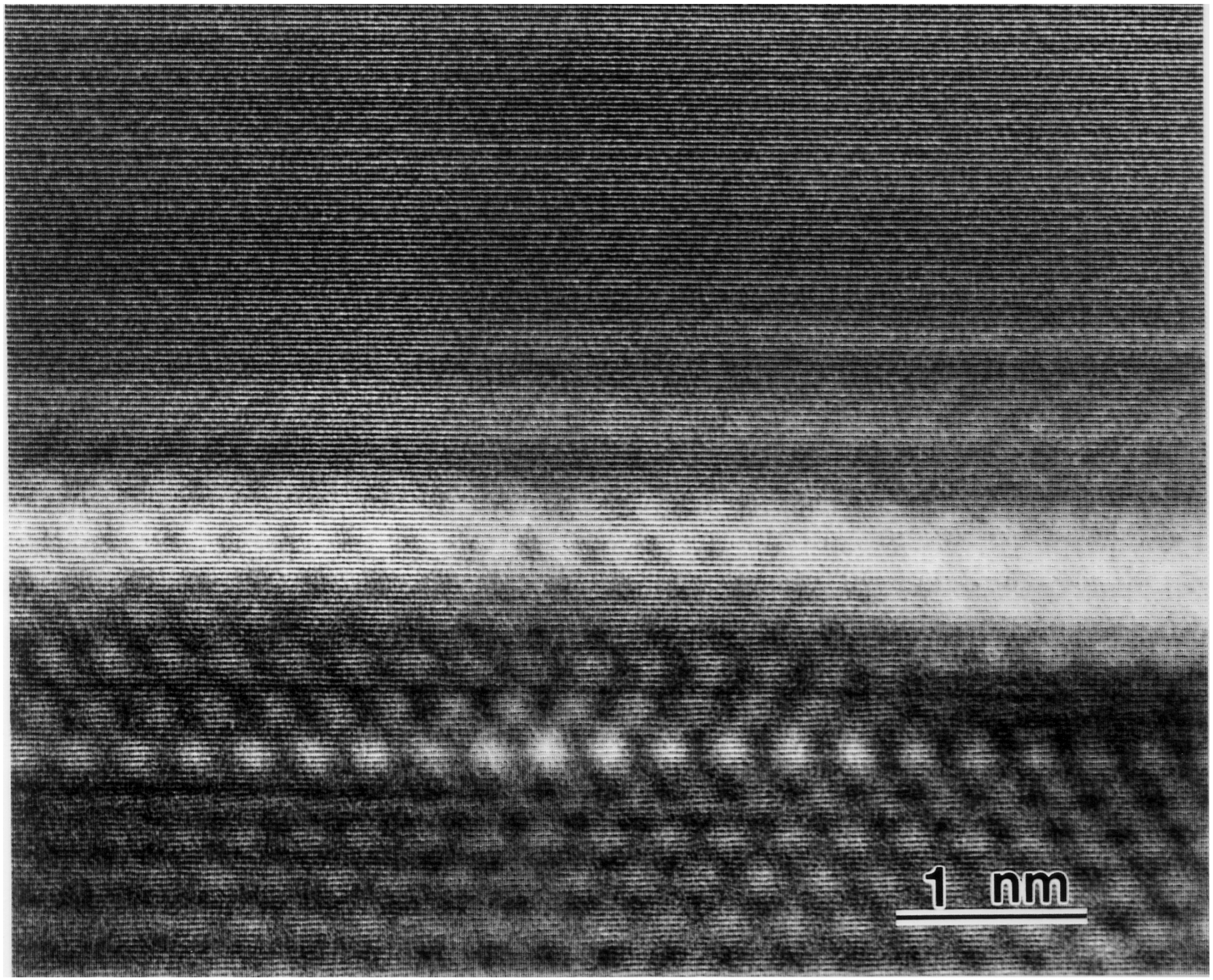


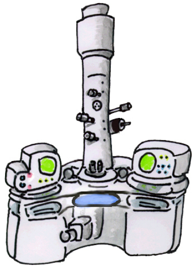
波長の変化とホログラム



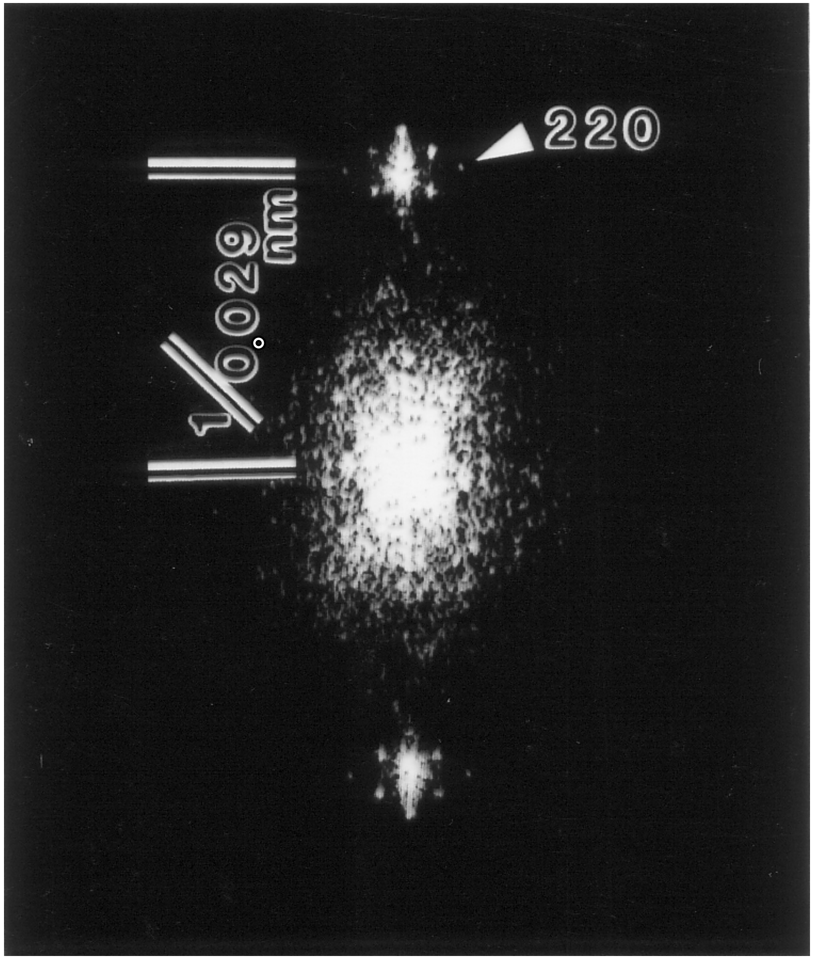


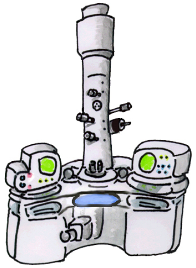
Electron Hologram of MgO



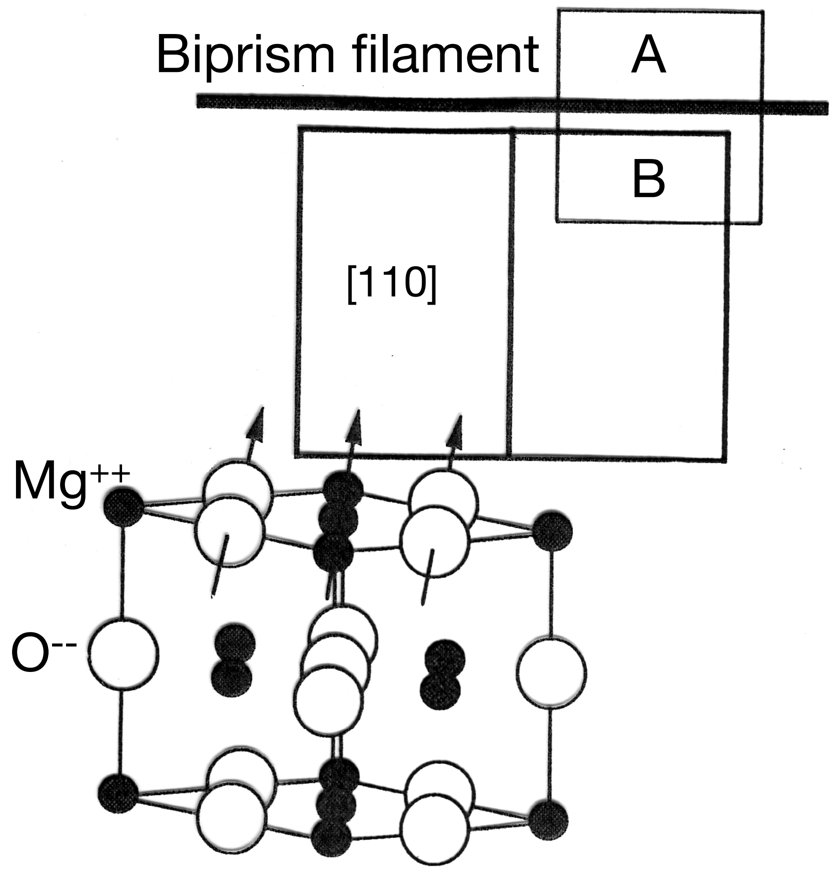


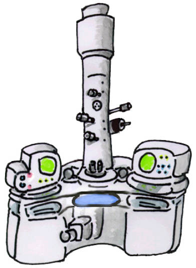
MgOホログラムのFourier変換像



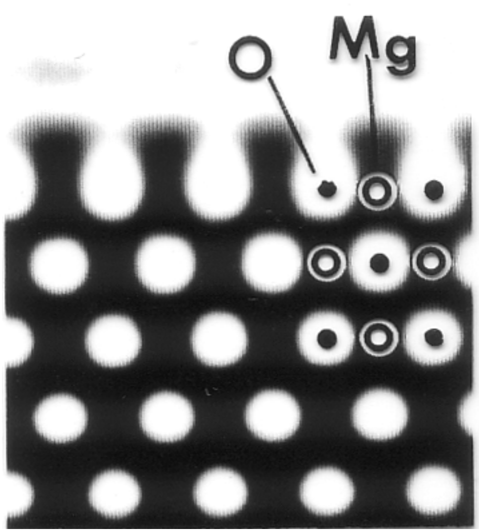


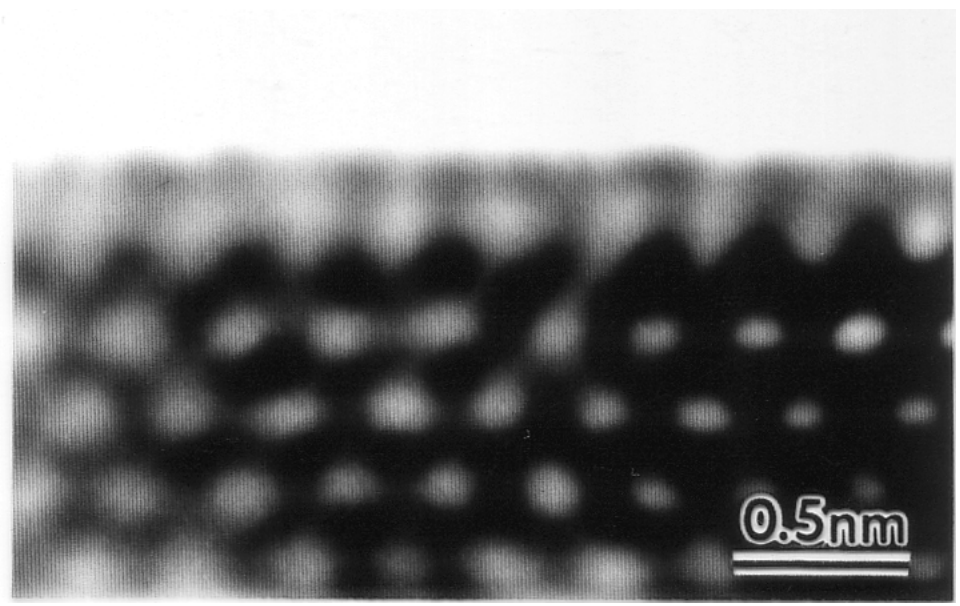
MgO [110] 表面の電子線ホログラフィー





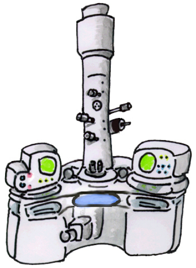
MgO (001) 表面



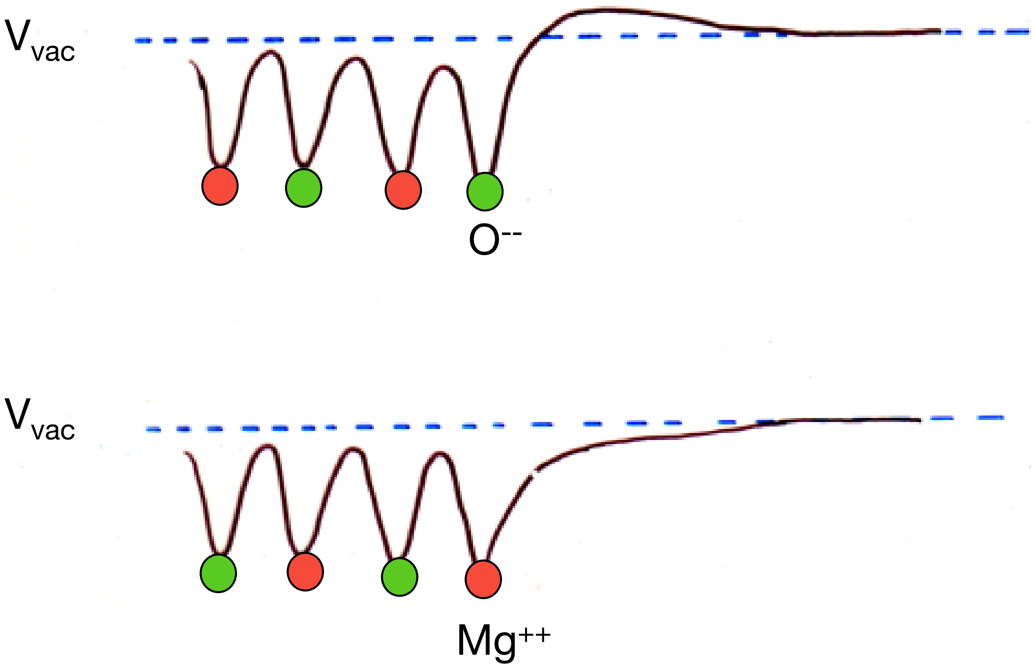


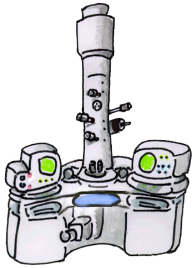
Simulation t=10nm

Reconstructed Phase



MgO (001) の表面ポテンシャル





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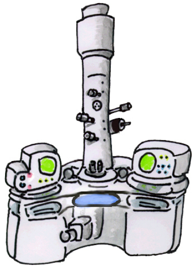
２. Interference of waves

３. Electron holography

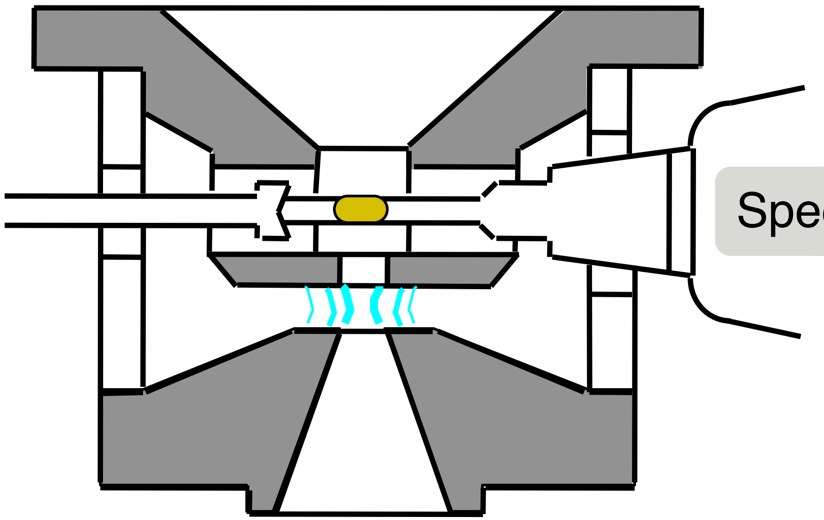
- High resolution imaging
- Observation of magnetic field

５. Stereoscopic TEM

６. Phase plate using A-B effect

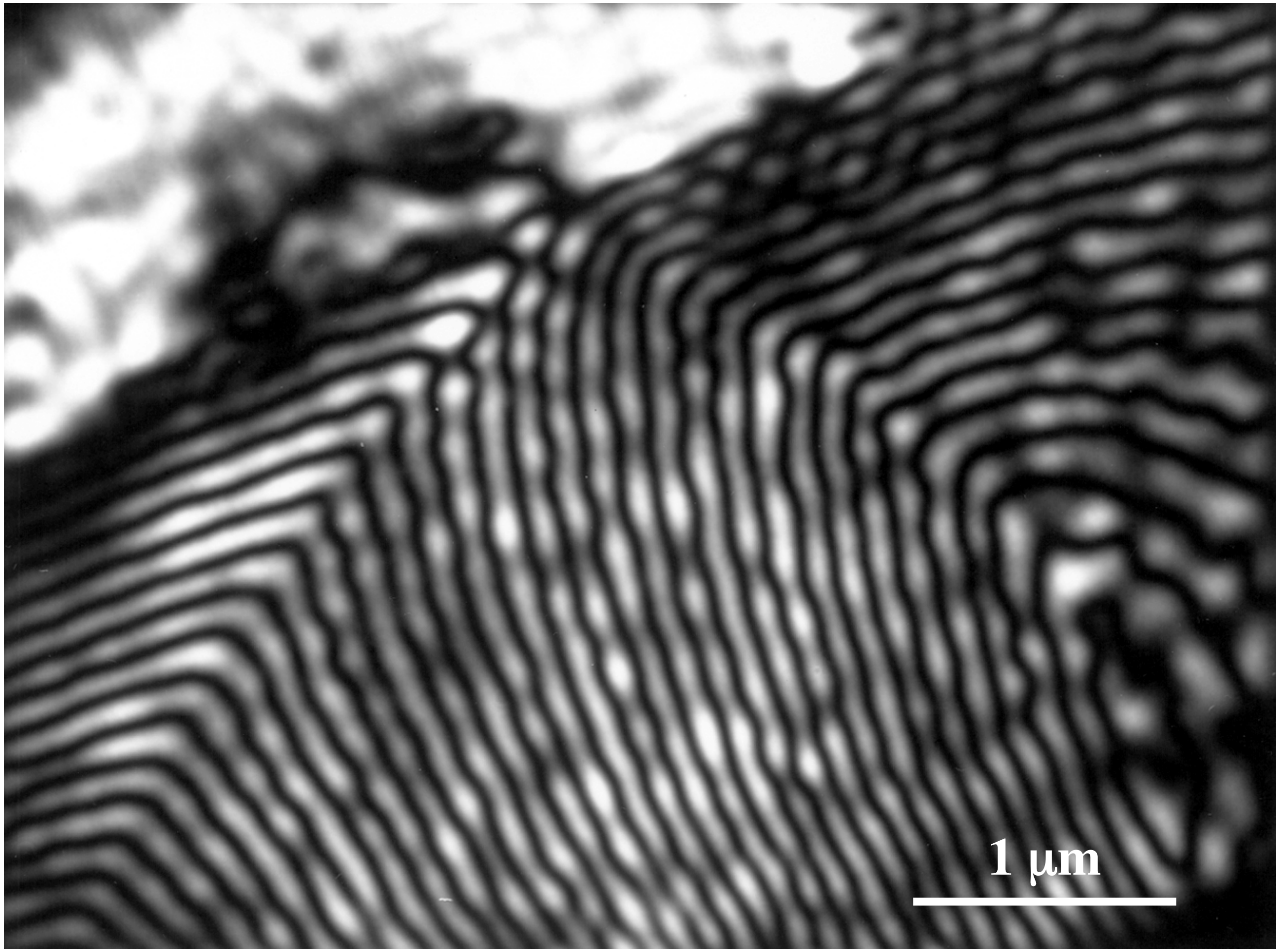


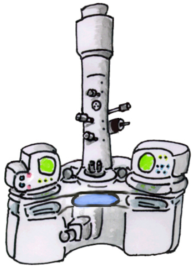
Low-Magnetic-Field Objective Lens



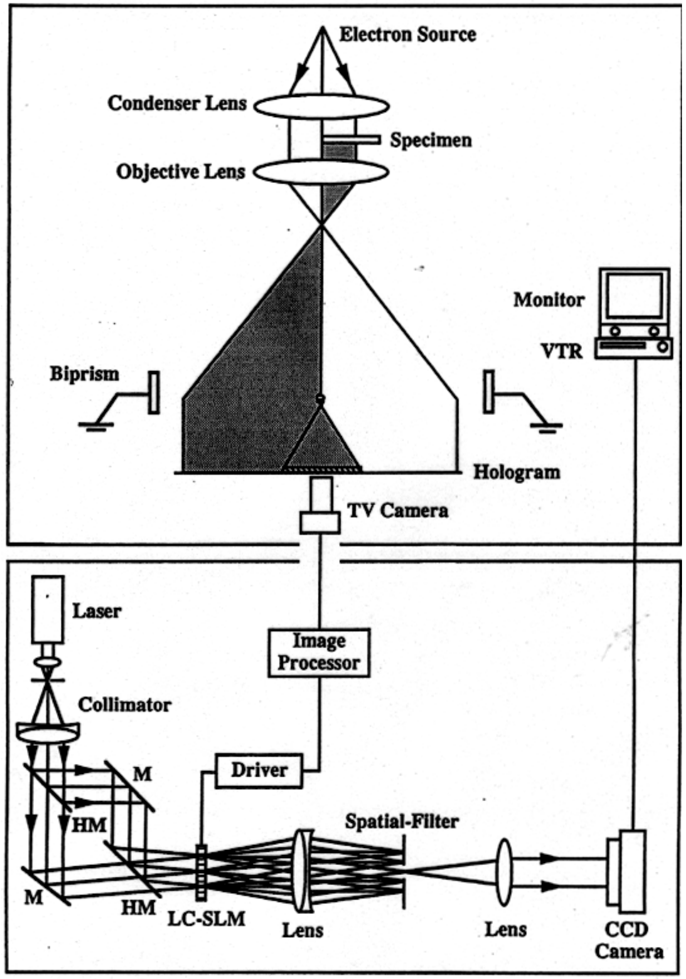
B > 1T T, x 1K~500K

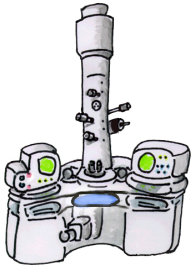
Magnetic Domain in a Permalloy Thin Film



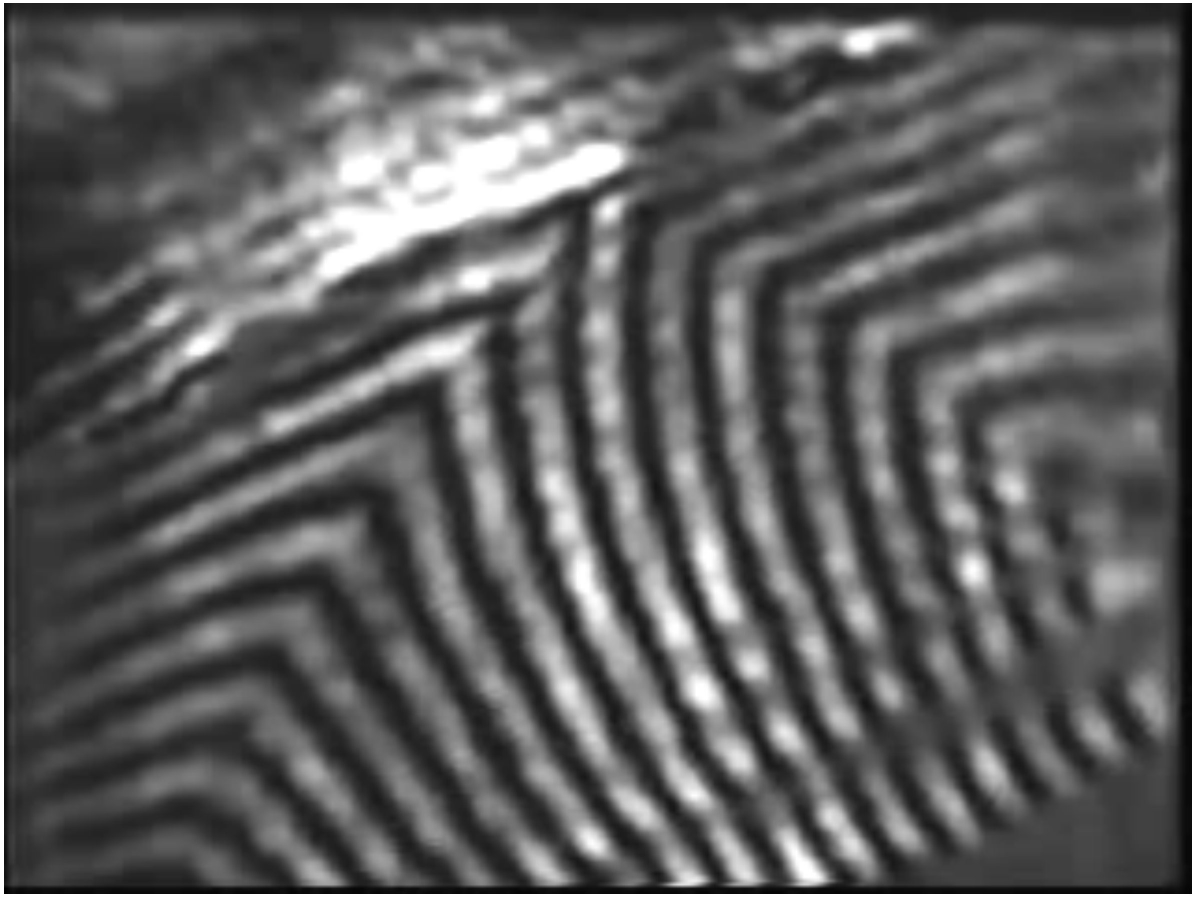


Real-Time electron Holography

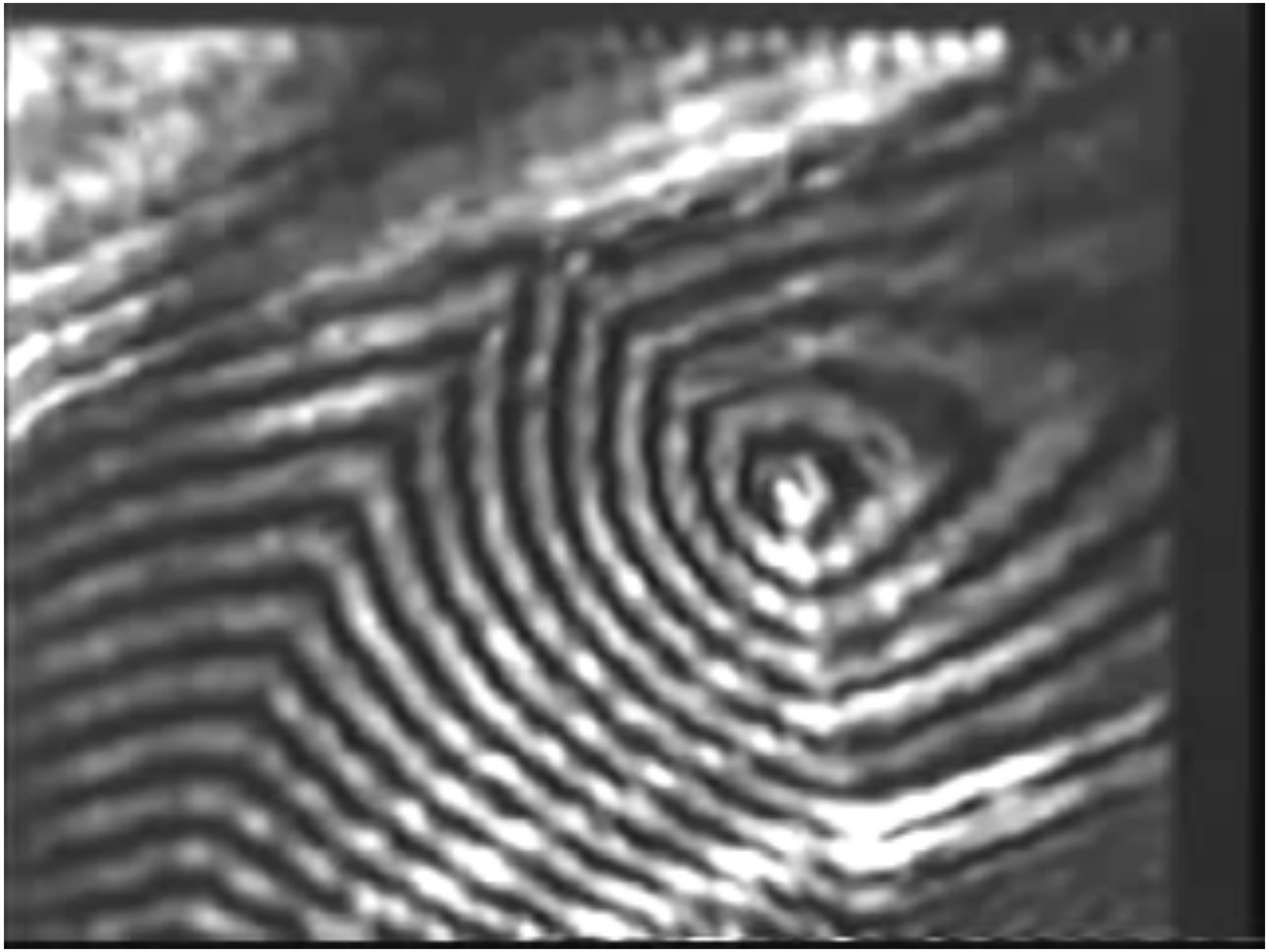




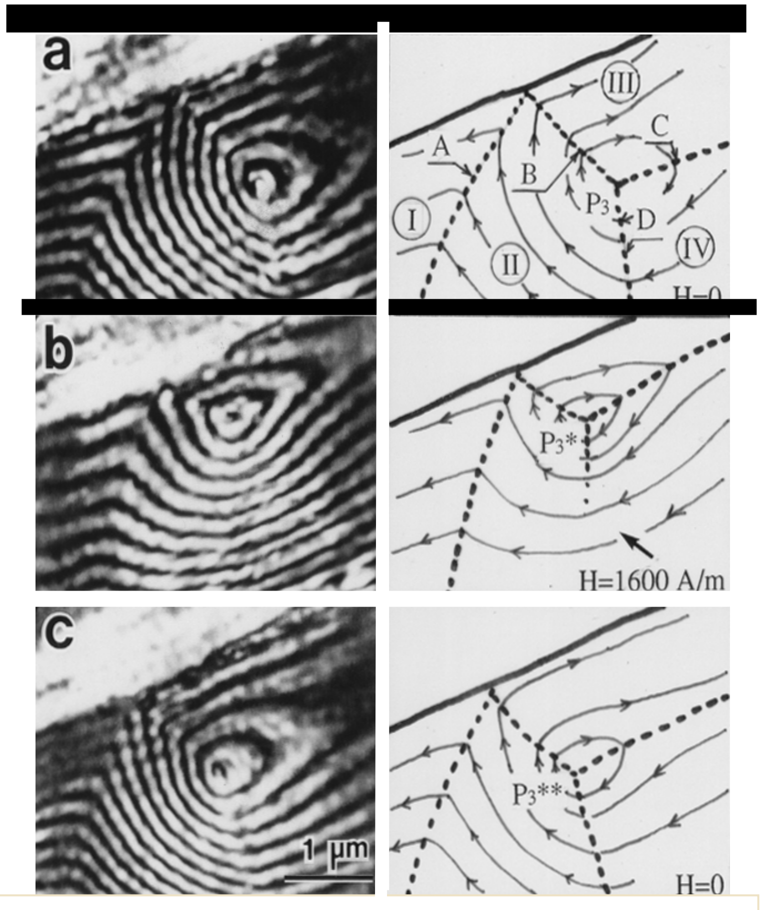
Rea-time Observation of Magnetic Domain

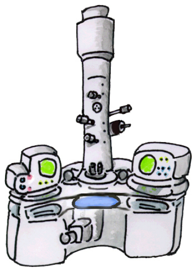


Rea-time Observation of Magnetic Domain



Magnetic Structure in a Permalloy Thin Film





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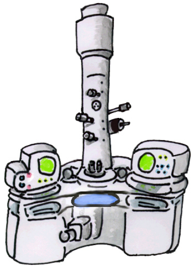


Development of a Real-Time Stereo Transmission Electron Microscope

- Real-Time Observation: Deformation, Crystal growth, Dislocation
- 3D Observation: Defect, Radiation damage, Cell

→ Stereoscopy, Computer Tomography

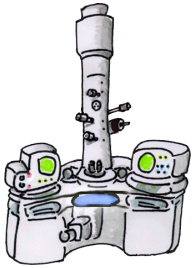
~~Recording time,~~ ~~Computation time~~ for RT

↓

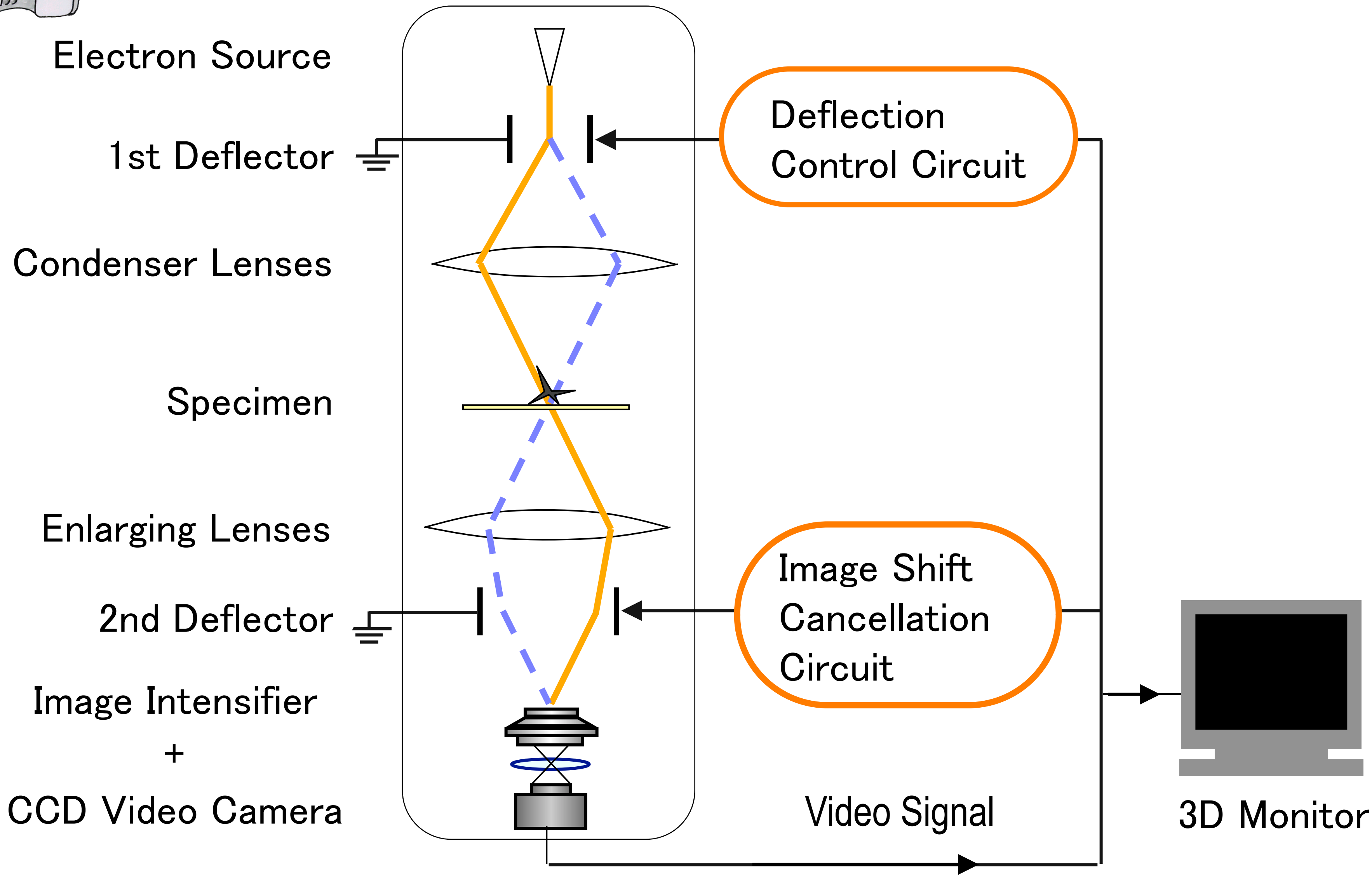
Real−Time 3D TEM

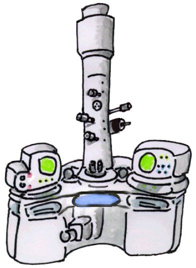
→ Tilted Illumination Stereo Microscopy

・D.Typke et al. Proc. 6th EUREM (1976) 334.
・J.M.Pawley Proc. 6ht Int. Conf. on HVEM 4 (1980) 58.
・P.F.M.Teunis et al. J. Microscopy, 168 (1992) 275.
・G.Fan and M.H.Ellisman Ultramicroscopy 55 (1994) 155.

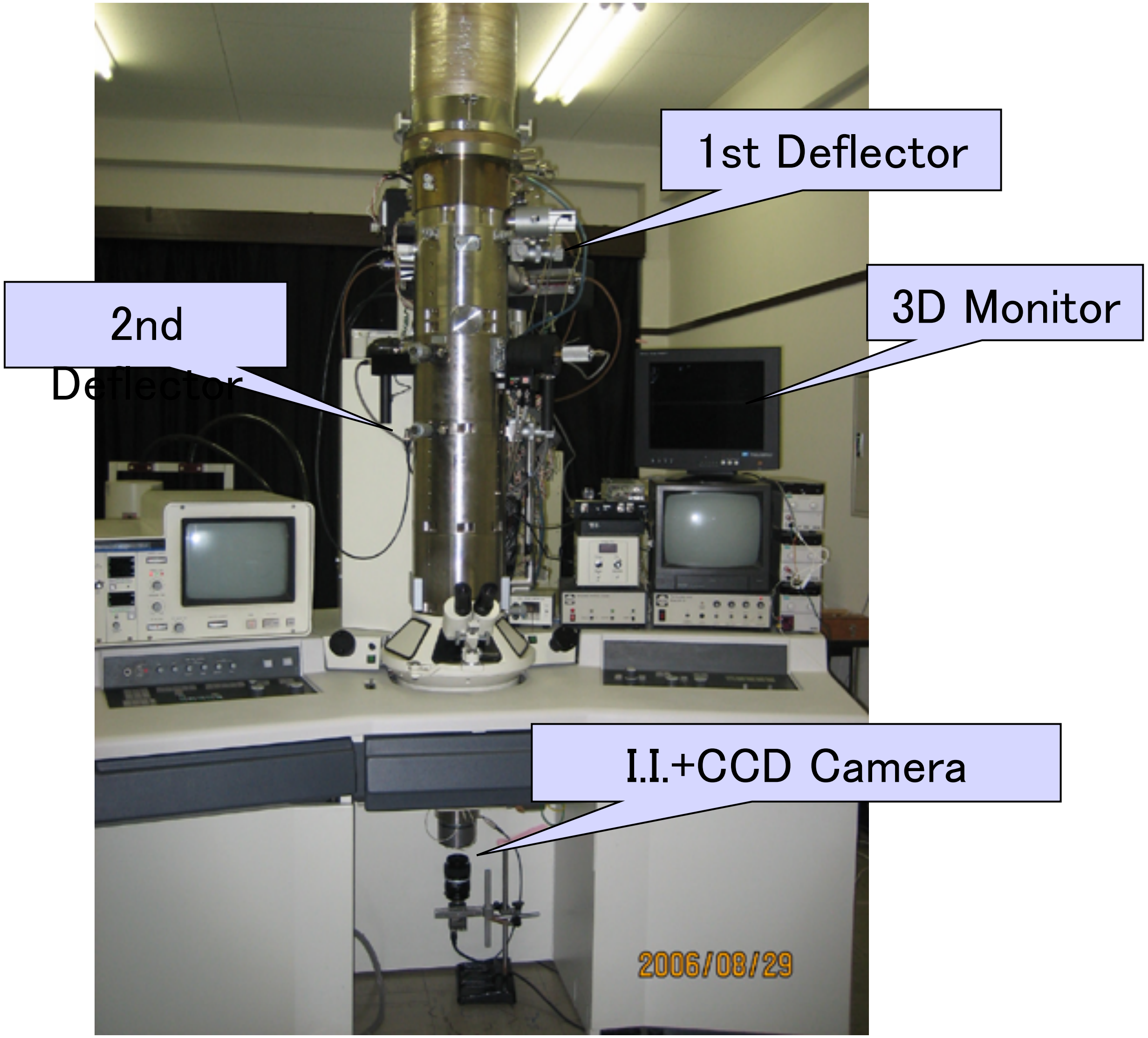


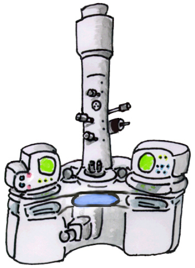
Real-Time Stereo TEM



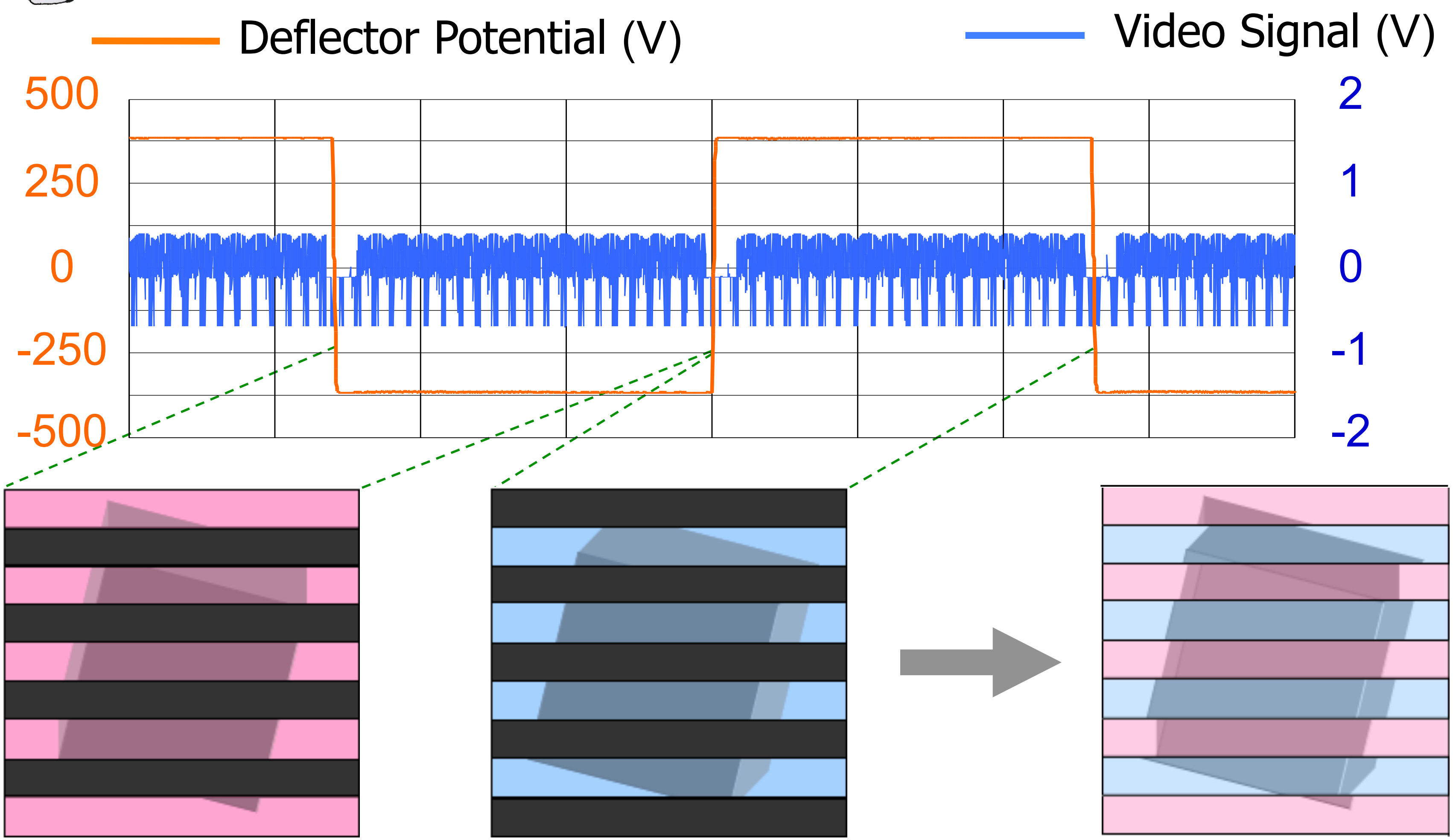


Real-Time Stereo TEM (HF-2000)





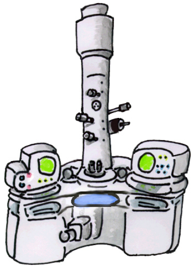
Video Signal and Deflector Potential



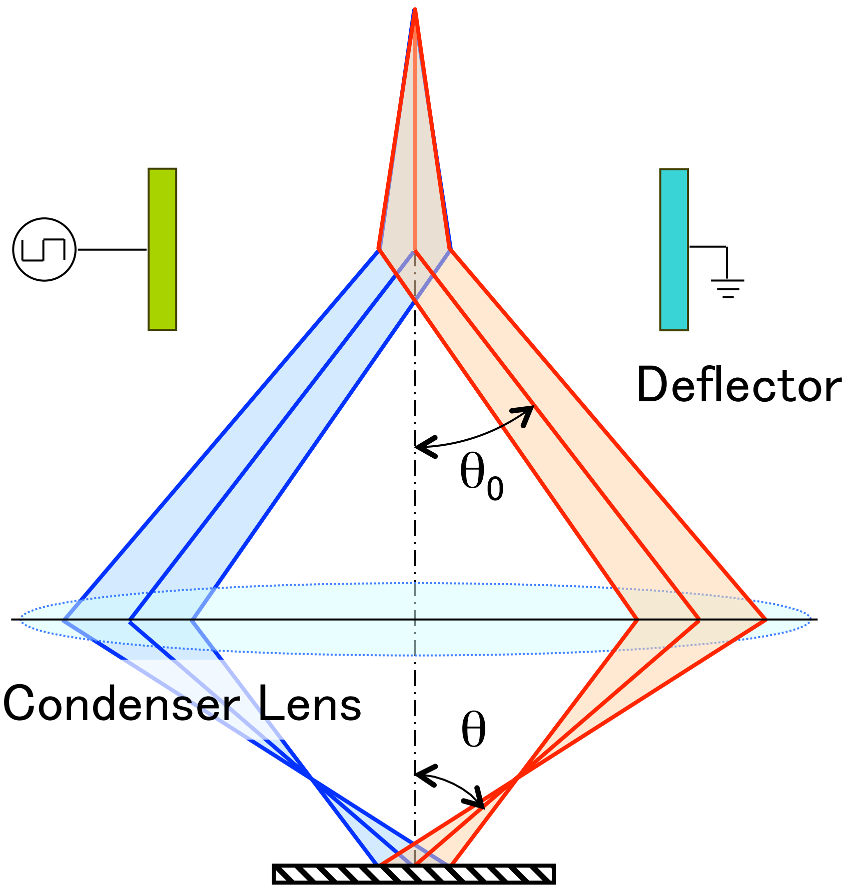
Odd Field (Left image)

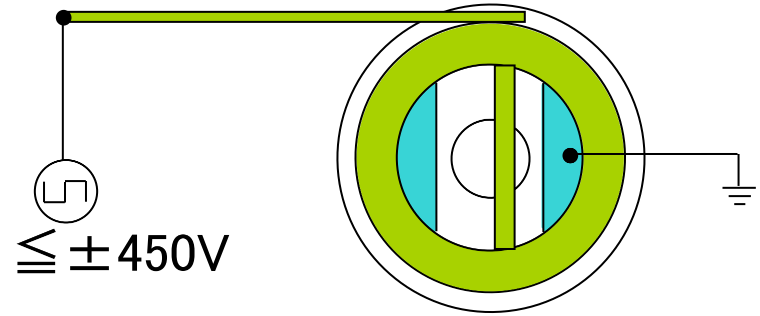
Even Field (Right image)

1Frame (Output image)



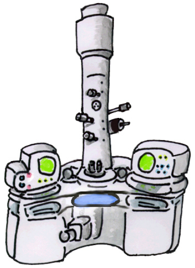
Illumination System



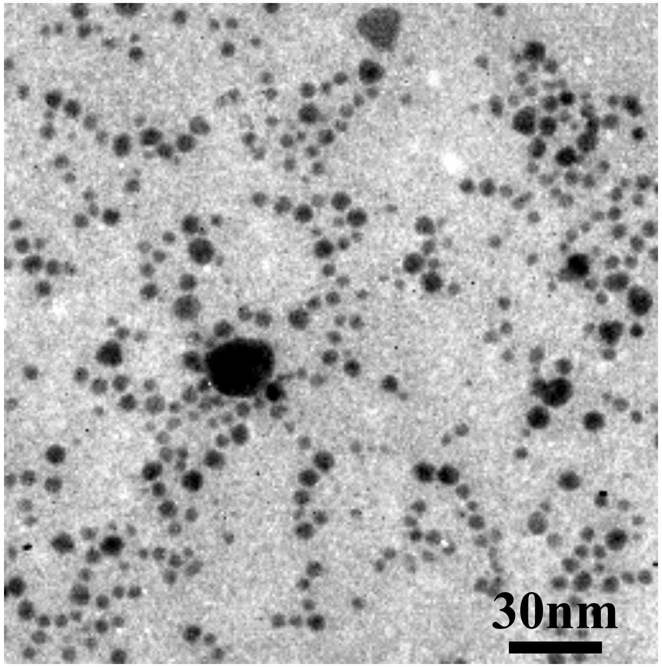


Max. Angle 0.081° (1.4mrad)
Required Angle : θ >2°
Need Angle Mag. : x 25
Image Mag. : x 1/25

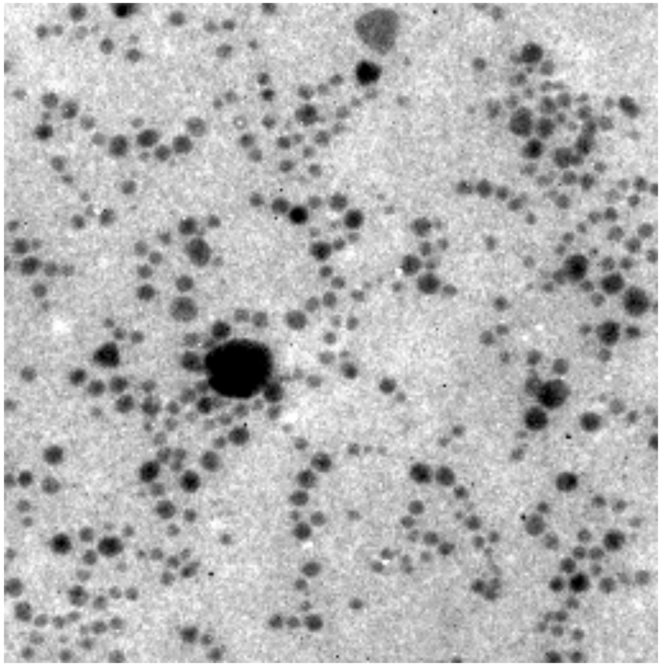
Use condenser lenses in a reduction mode.
→ ±2.3°
Deflector and Specimen plane should be conjugate.



Stereo Pair of Au Particles



Right Image

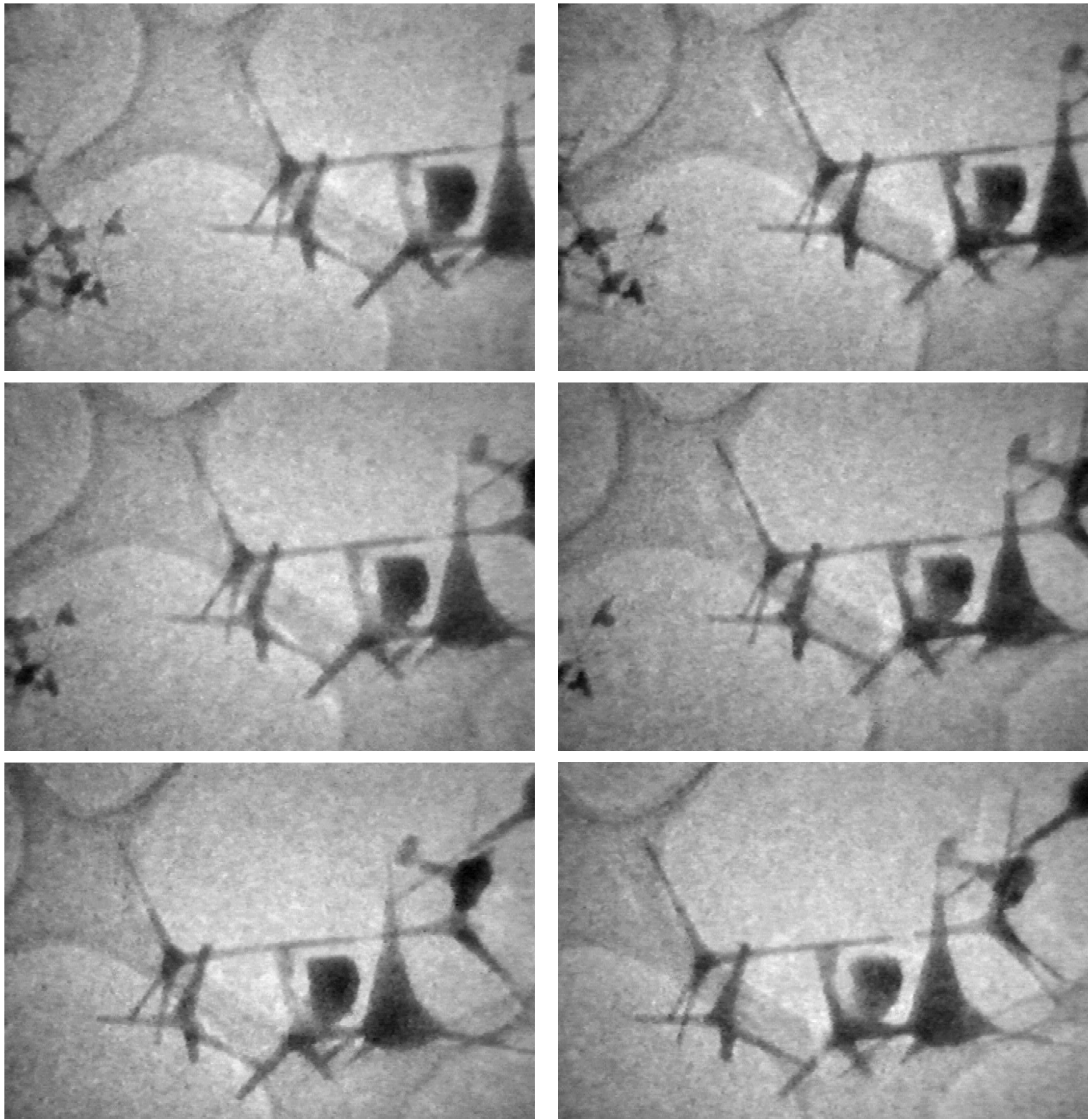


Left Image

Lateral Resolution: ~1 nm

Depth Resolution: ~13 nm

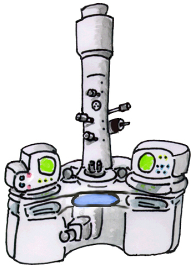
Real-Time Stereo Observation of ZnO



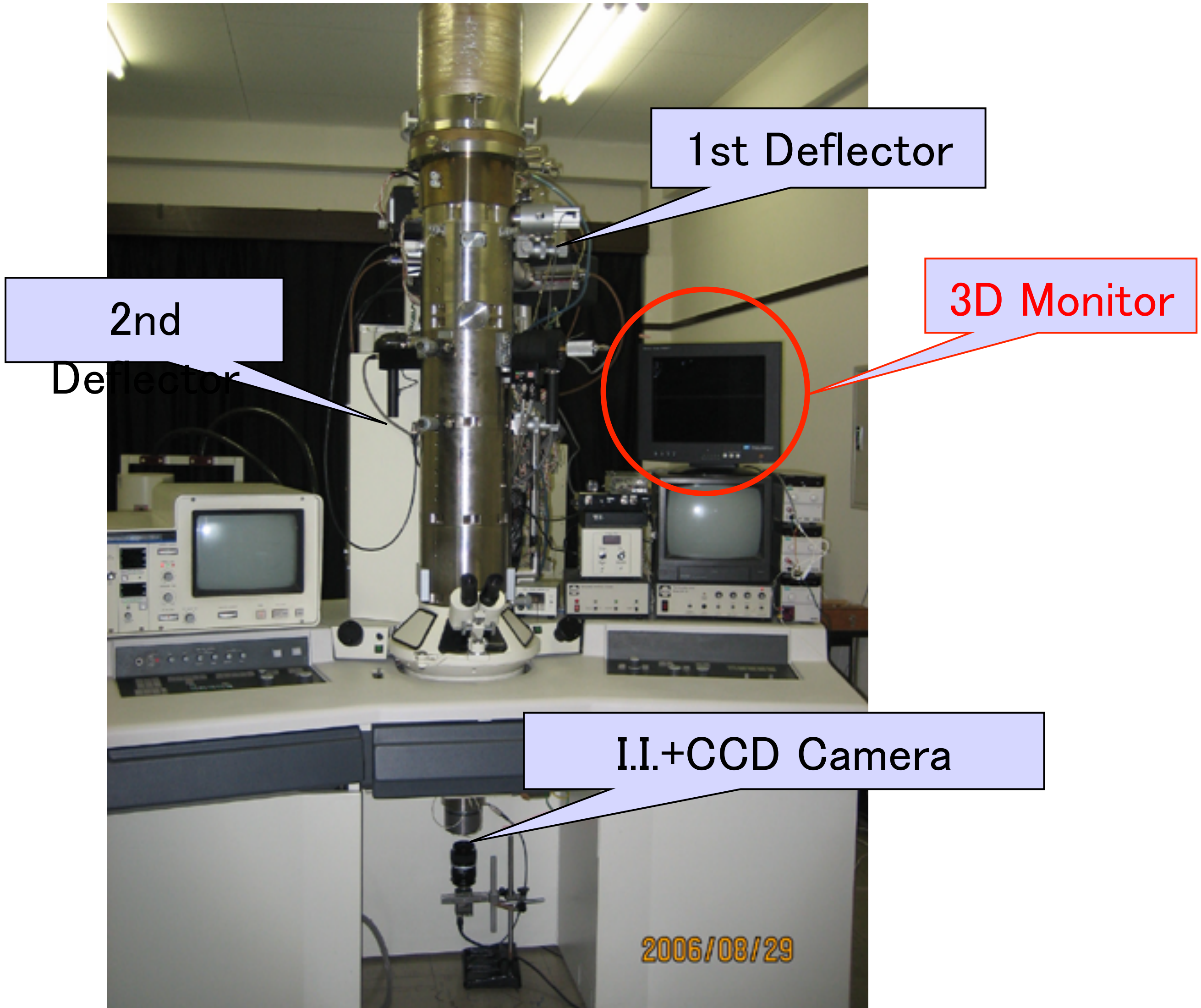
0.00 sec

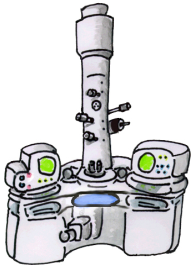
0.06 sec

0.28 sec

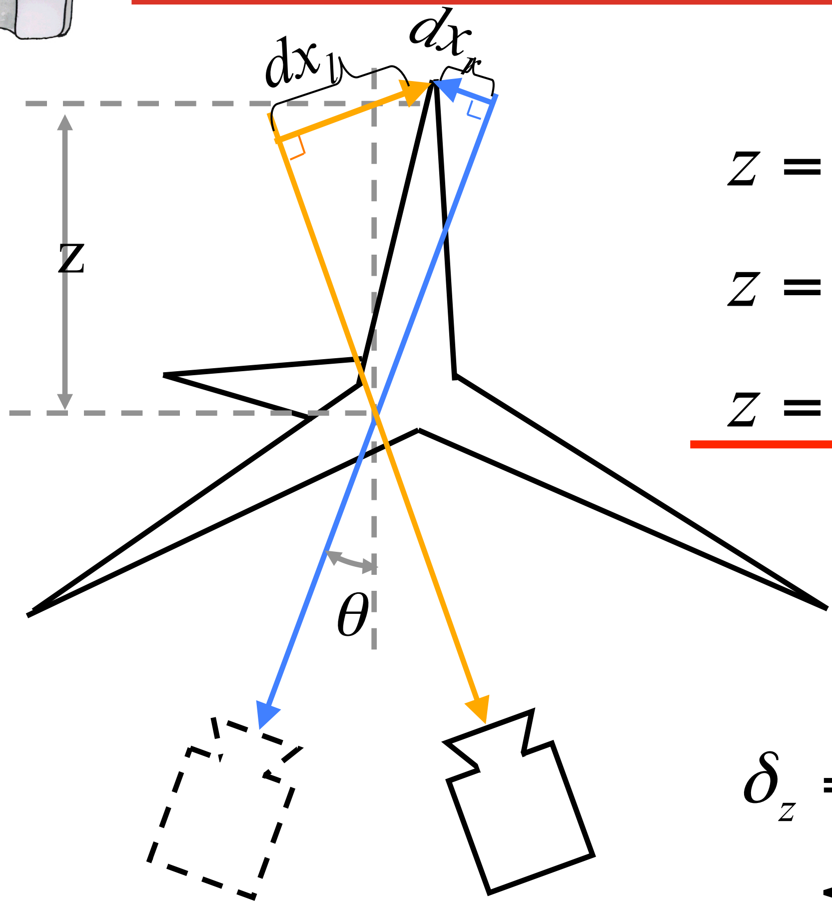


Real-Time Stereo TEM (HF-2000)





Depth Measurement



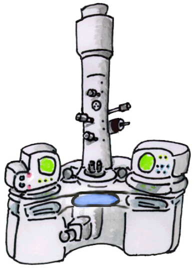
$$z = (dx_r / \sin\theta + dx_l / \sin\theta) / 2$$

$$z = (dx_r + dx_l)/2\sin\theta$$

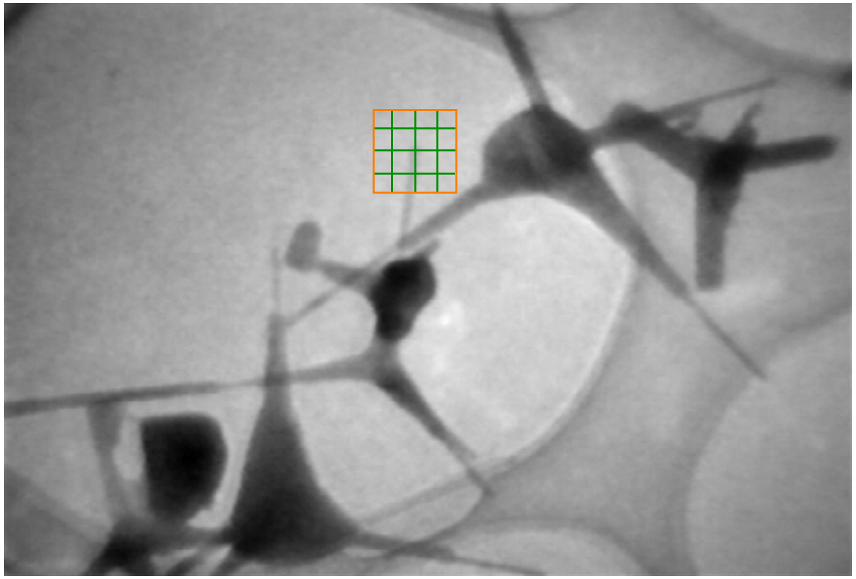
$$z = dx/2\sin\theta$$

$$\delta_z = \delta_x / 2\sin 2.3^\circ$$

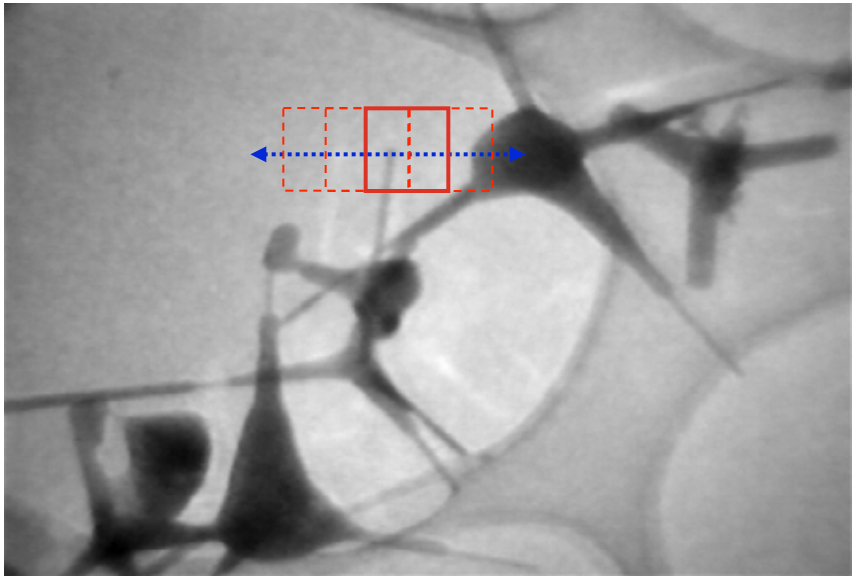
$$\leq 13\,\mathrm{nm} \qquad (\delta_x = 1\,\mathrm{nm})$$



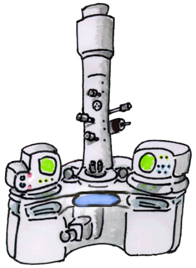
Detection of corresponding points



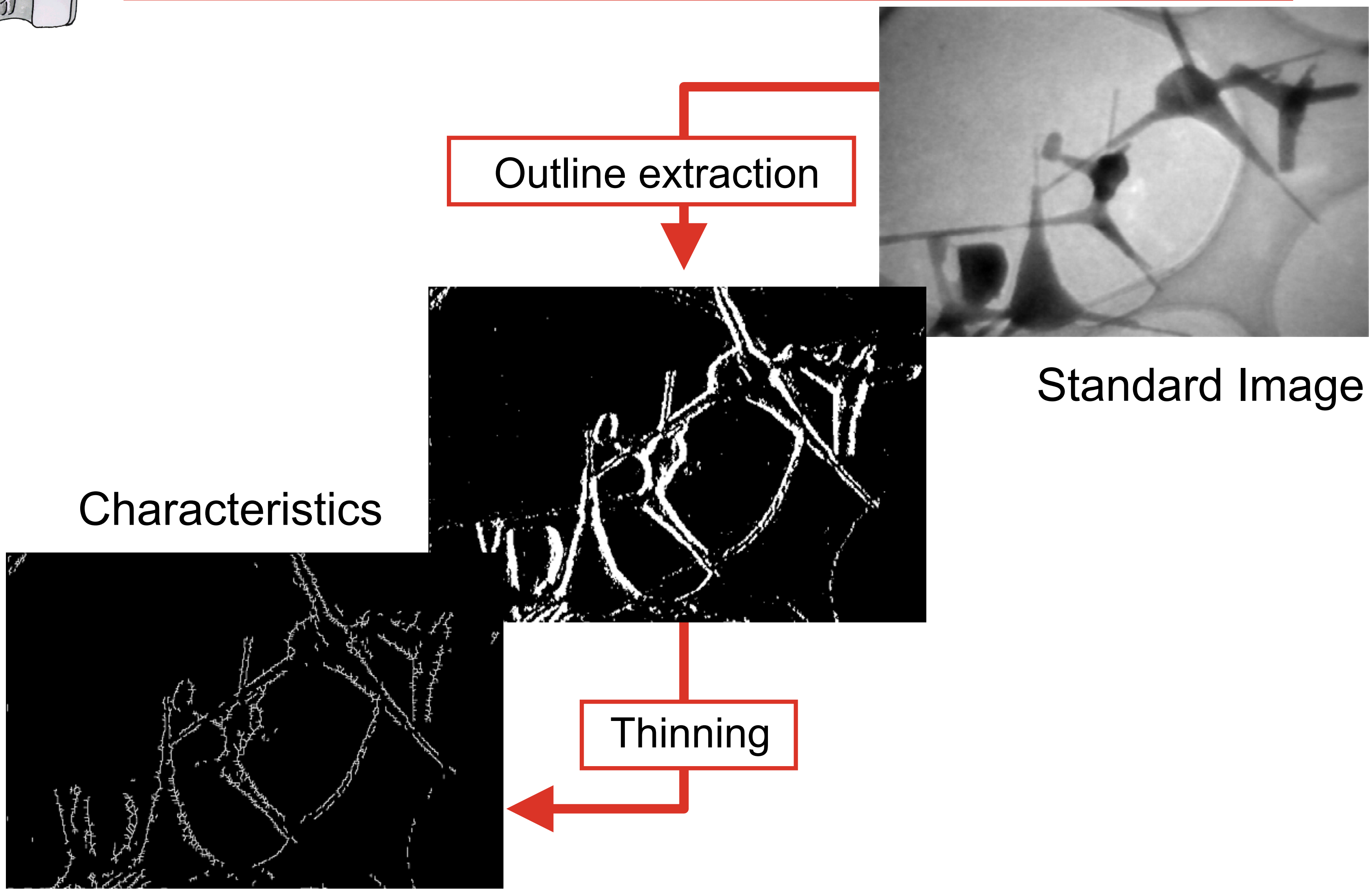
Right Image (standard)



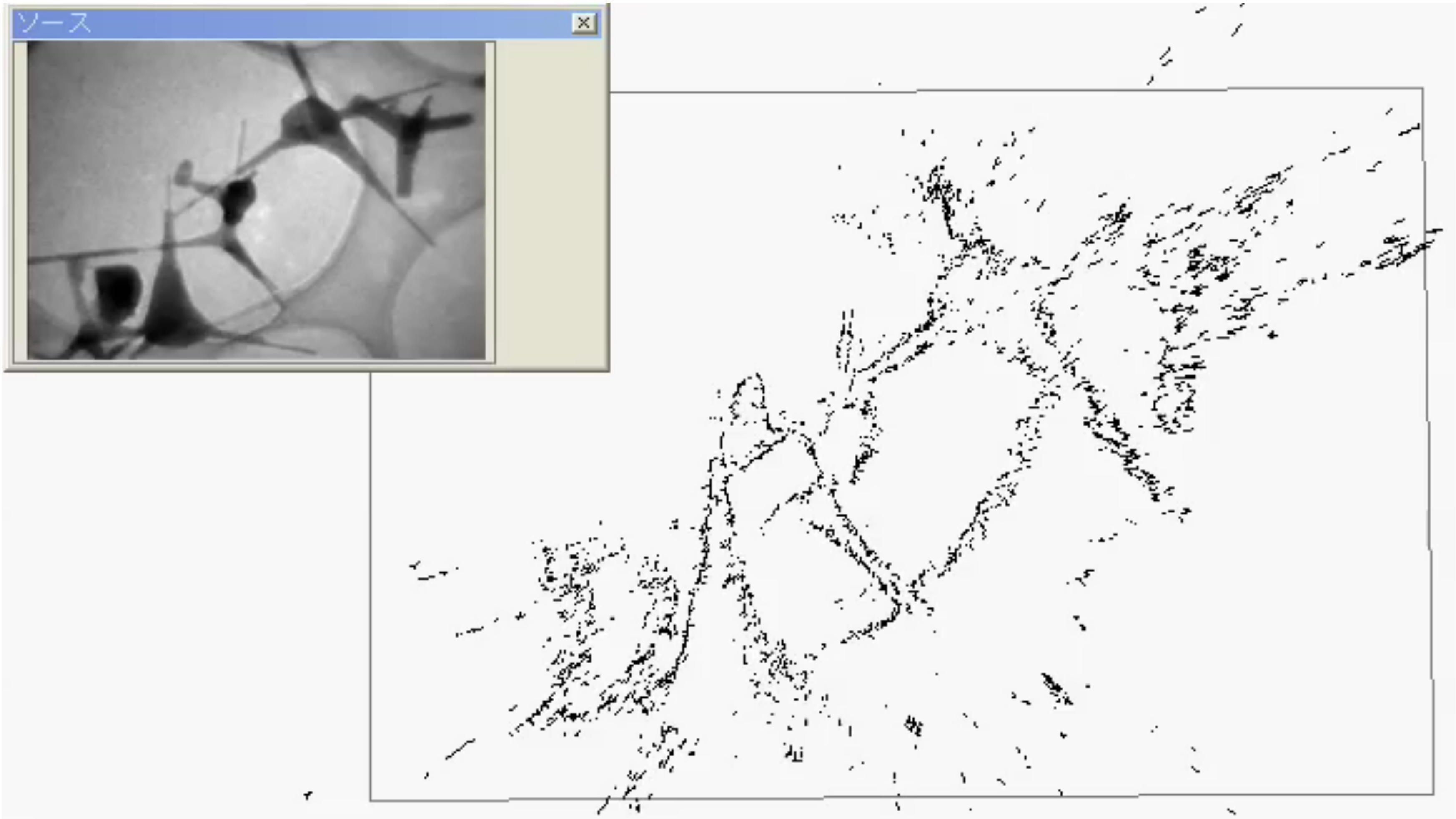
Left Image



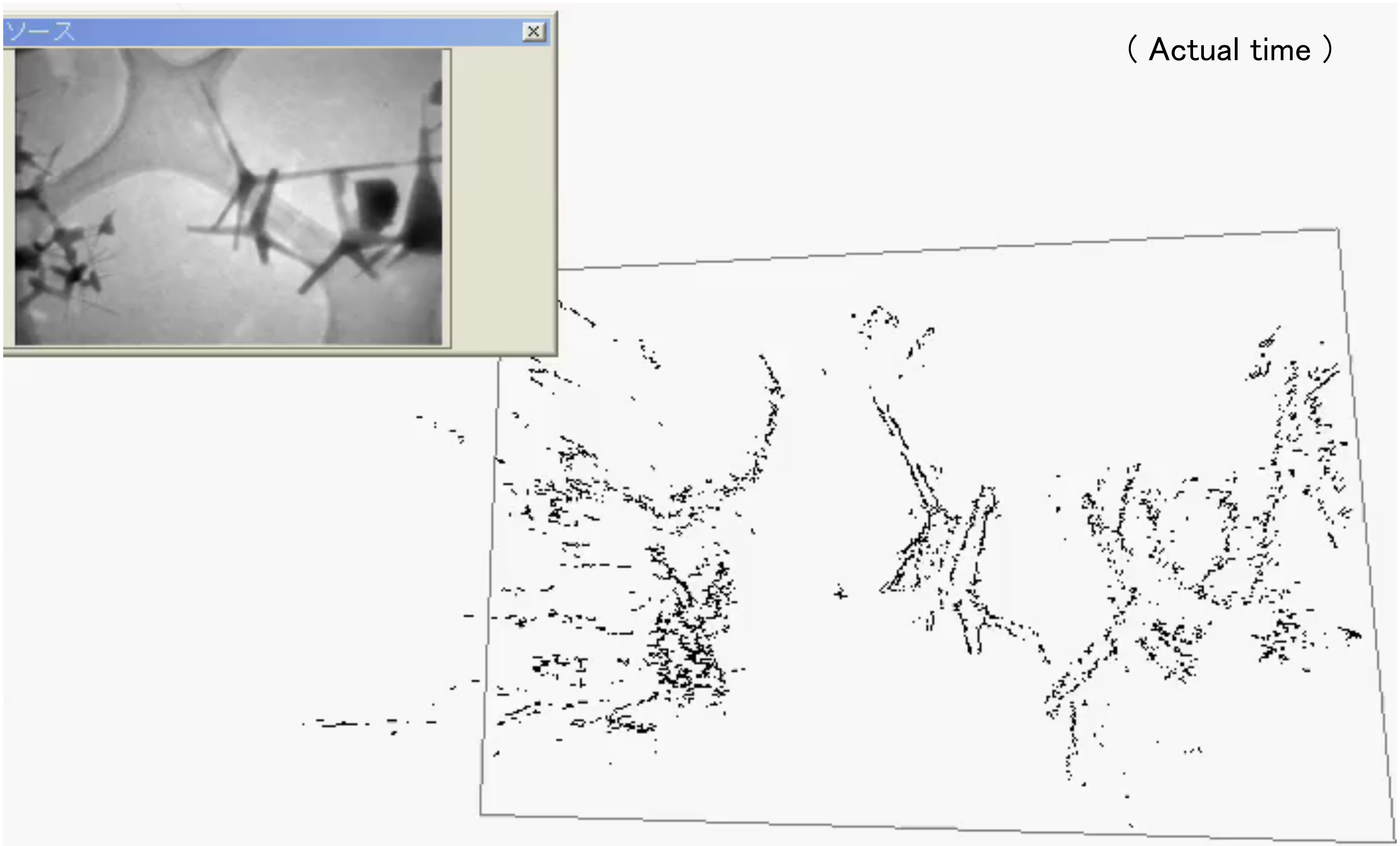
Detection of corresponding points

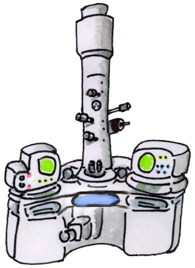


3-D Reconstruction and Plot



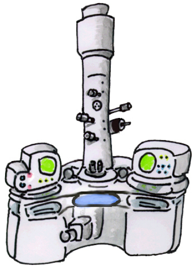
Continuous Observation by 3D Plot





Summary of the Real-Time 3D-TEM

- Developed a real-time stereo TEM
  - Introduced electrostatic deflectors and a 3D-Monitor
  - Spatial resolution: ~ 1 nm lateral; ~13 nm longitudinal
  - Temporal resolution 33 msec (TV rate); <5ms expectable
- Developed an on-line 3D plot application
  - Extract characteristics and find corresponding points
  - Temporal resolution 2-8 sec TV frame
  - Spatial resolution: ~18 px longitudinal (estimation)



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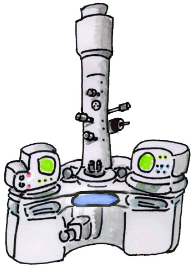
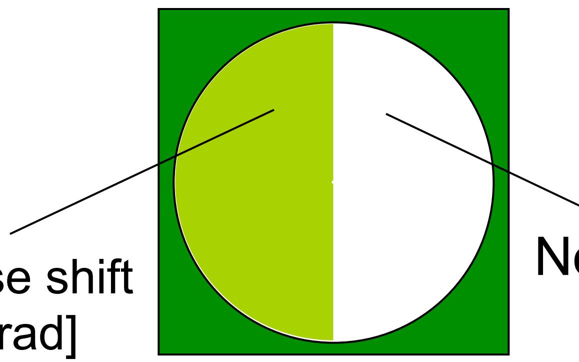
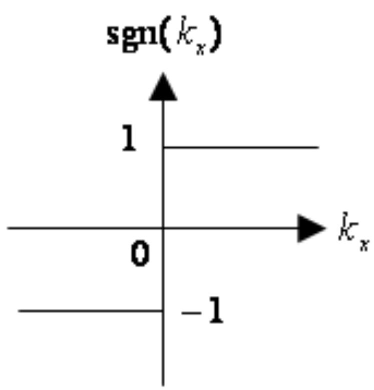


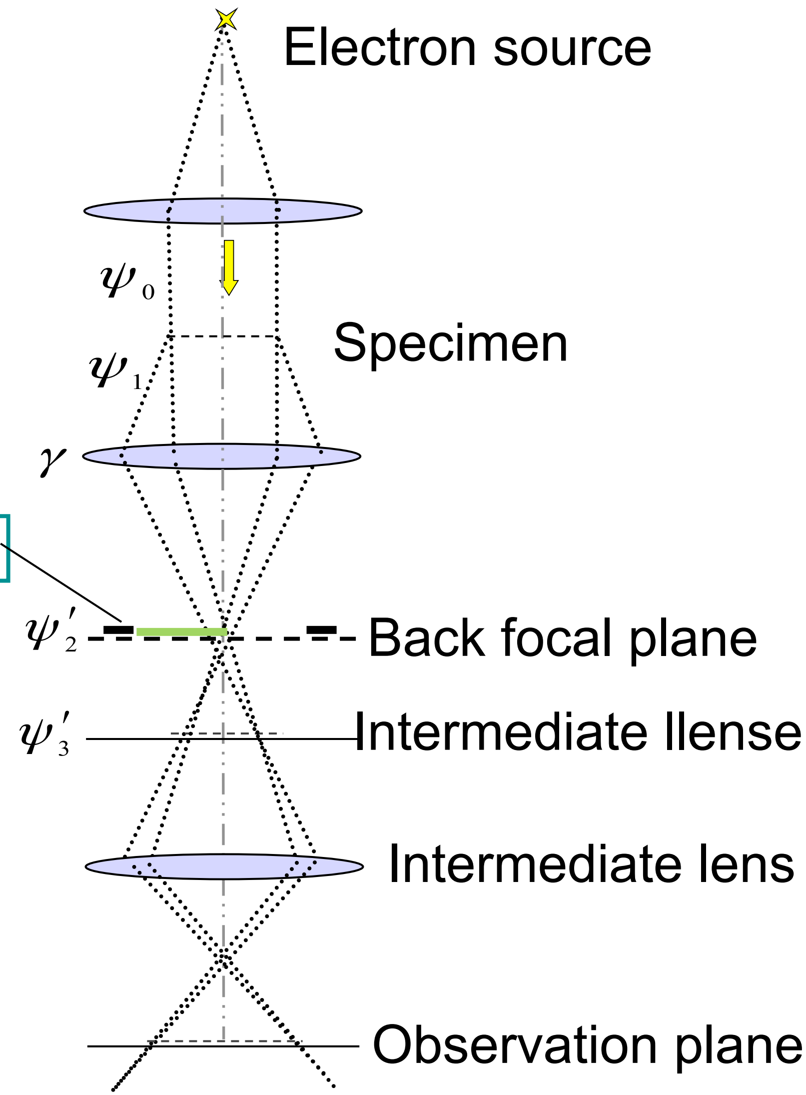
Hilbert Phase Plate for TEM

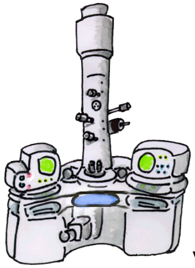
Thin film type Hilbert phase plate



sgn function

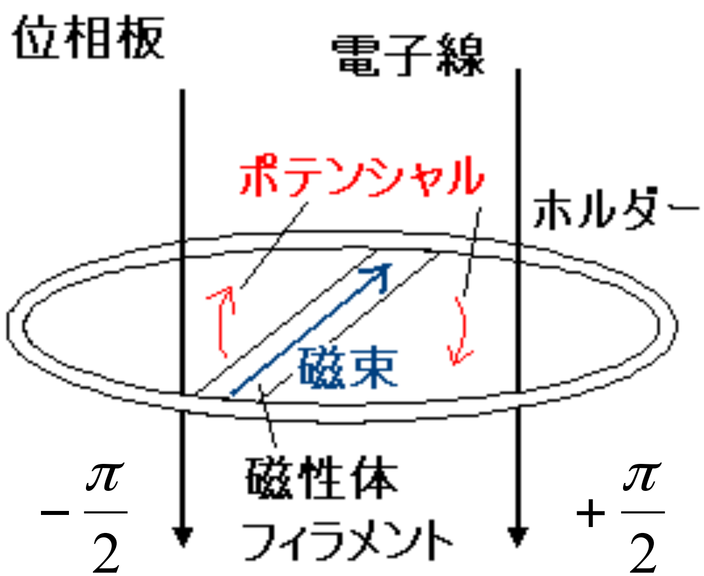


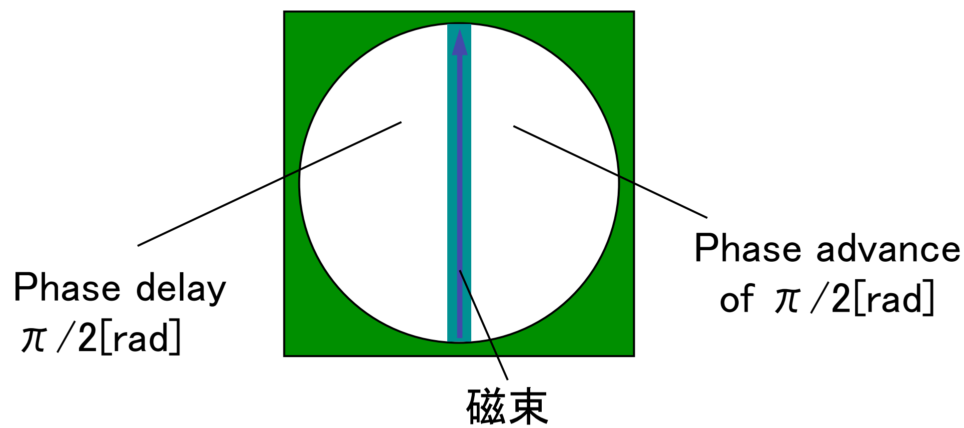


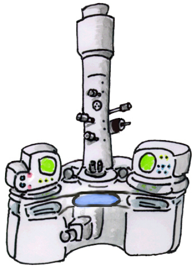


A-B Effect Phase Plate

Vector potential appearing with the magnetic flux inside the filament causes the phase shift of the electron wave pass through the both sides of the filament

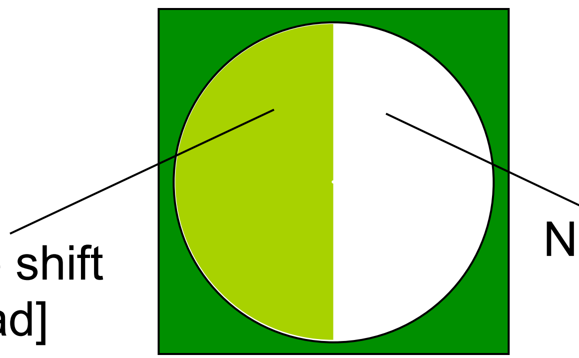




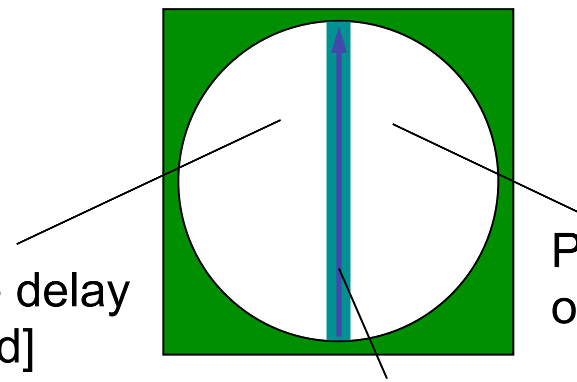


Phase Plate

Thin film type phase plate



A-B effect phase plate



・Damage

・Short life time

・Degradation of image quality

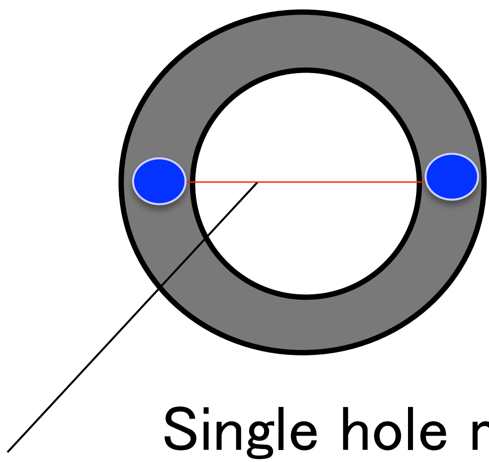
・Clean

・long life time

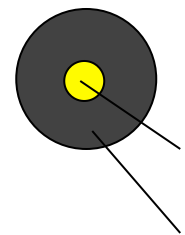
・Keeping image quality

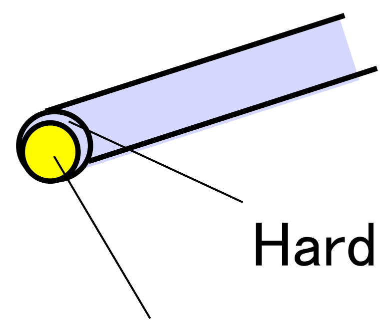
・Cannot centered

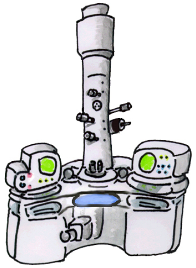
Phase Plate



Cross section of Wollaston wire

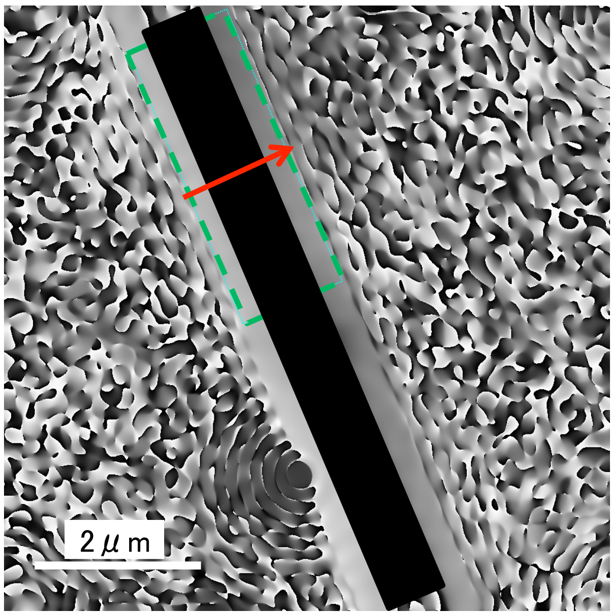


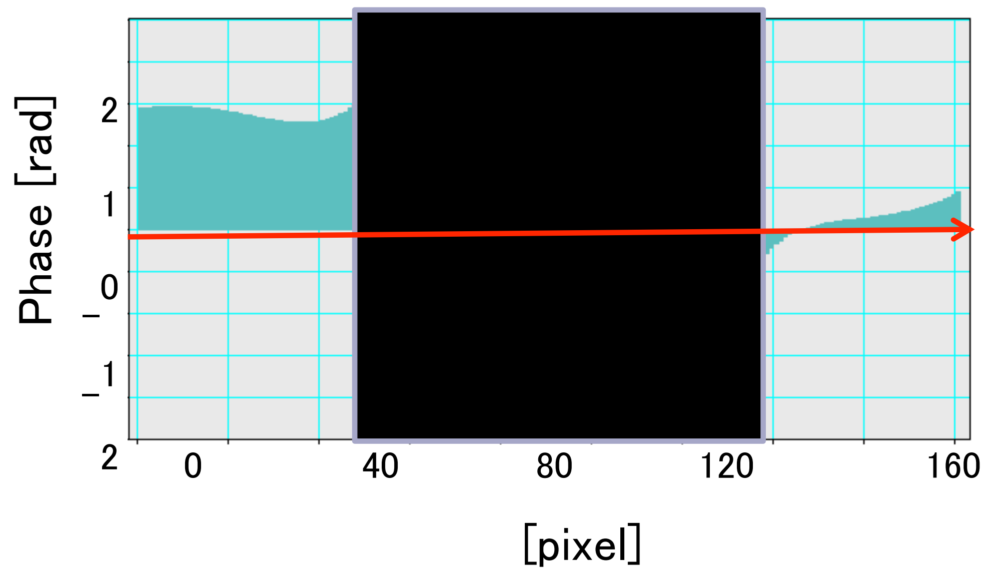




Phase Shift by A-B Effect

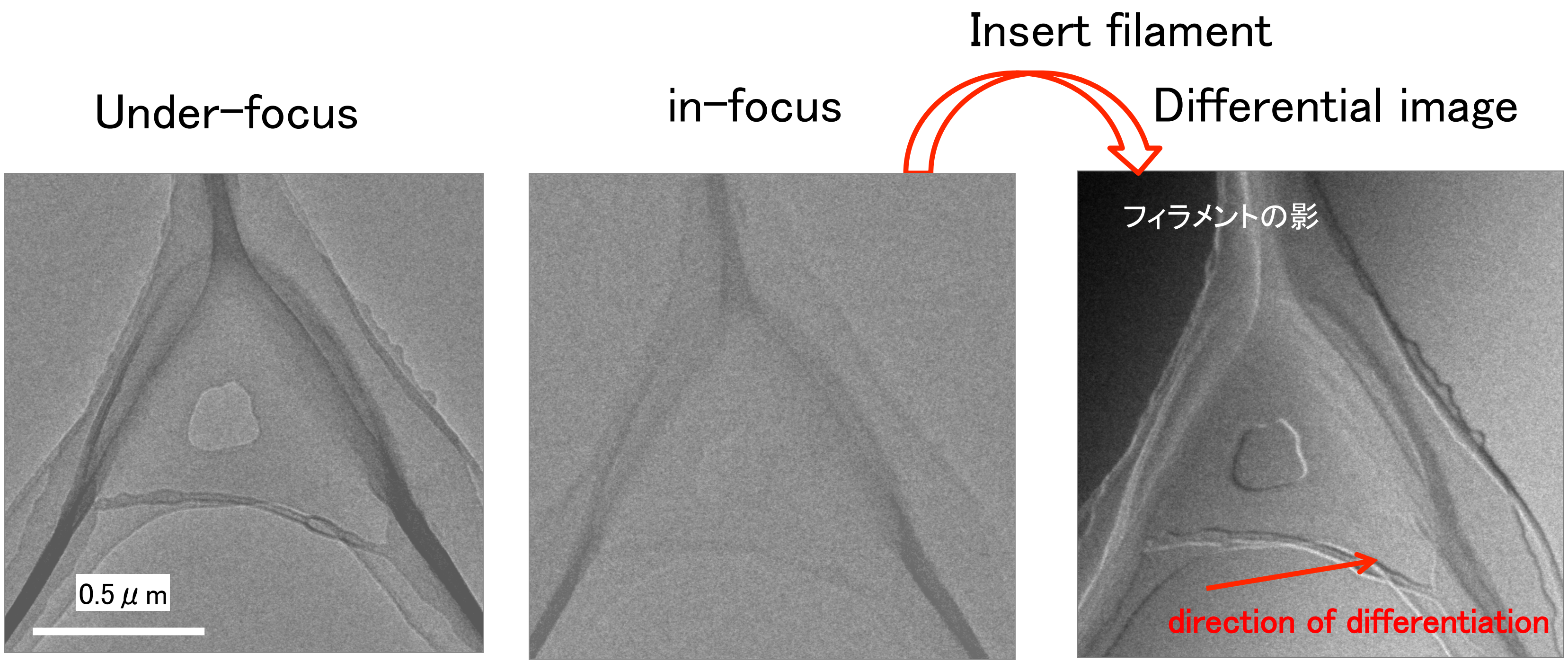
Reconstructed phase



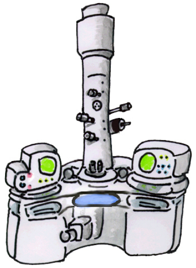


phase shift of ～1.5rad

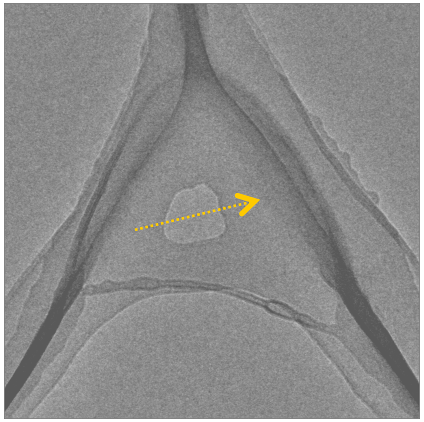
Differential Image of Holly C Film



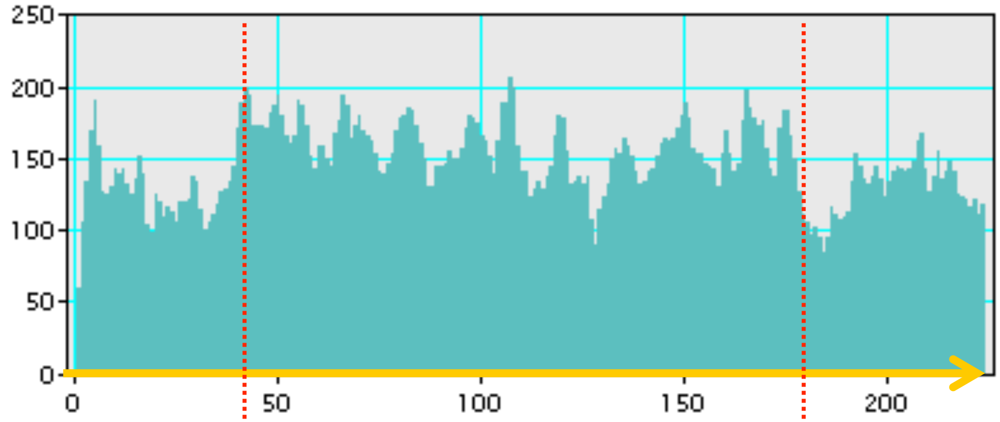
Obtain in-focus → Higher resolution



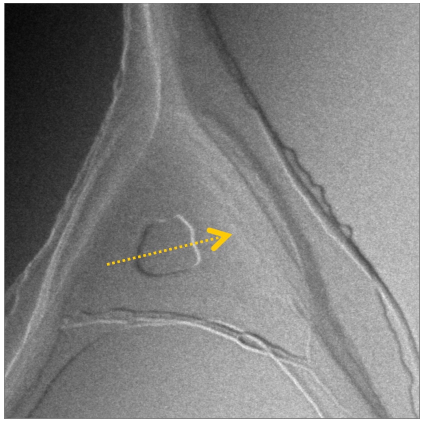
Differential Effect



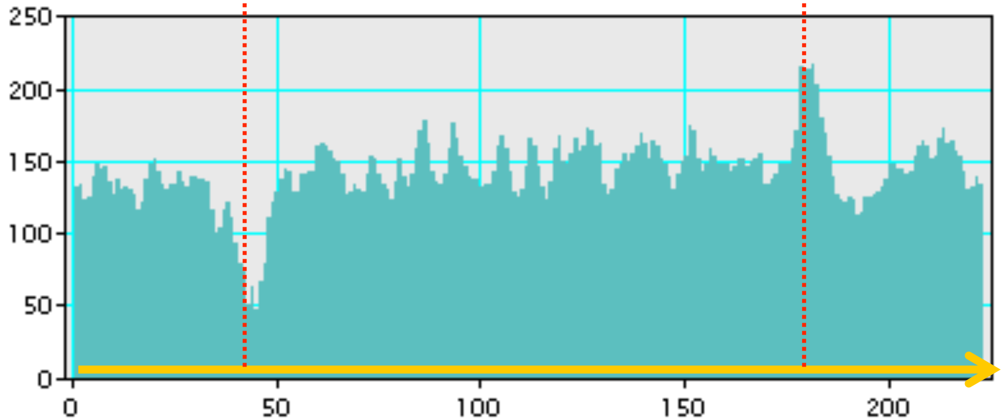
under−focused



Line profile



differential image

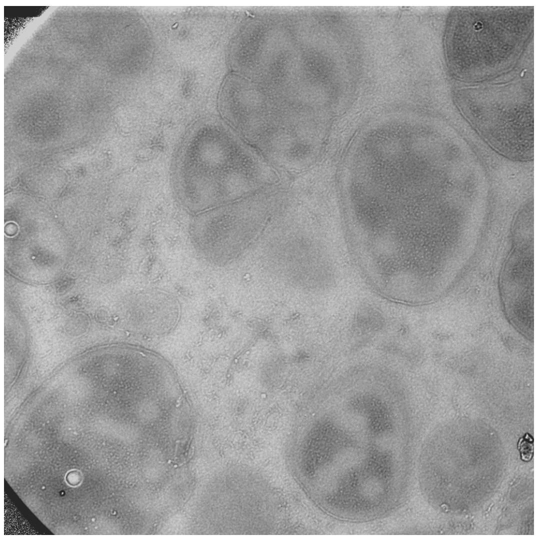


Line profile

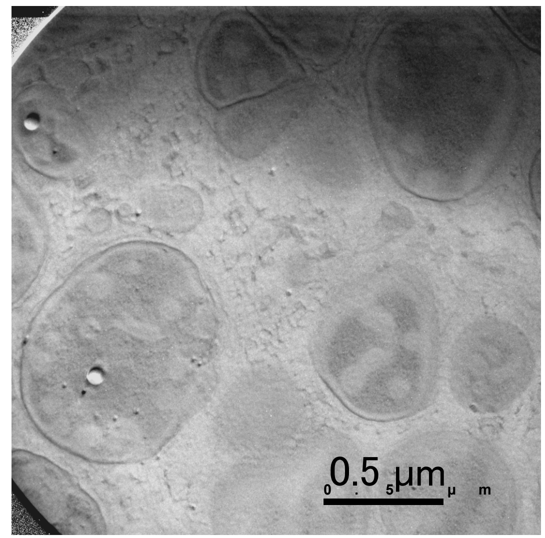
Observation of Bio-specimen

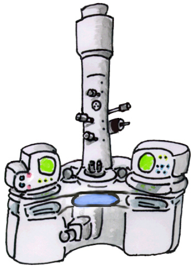
Colon bacillus（Pb stained）

Under-focused image



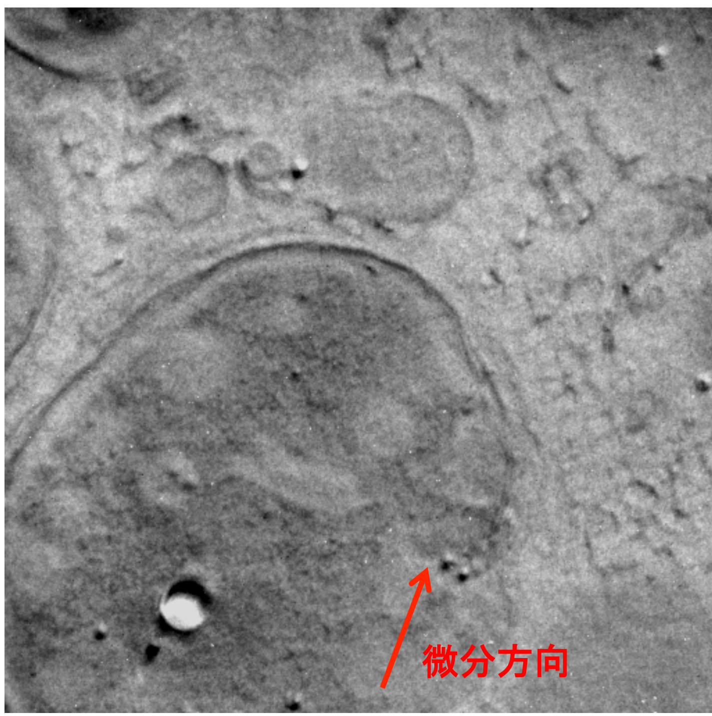
Differential image in focus



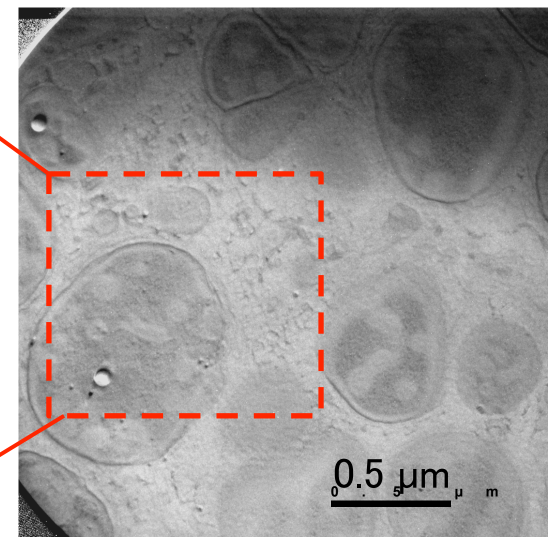


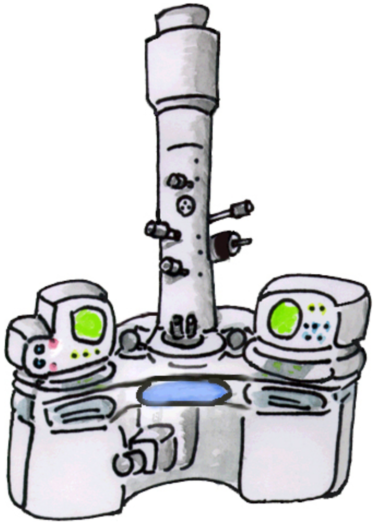
Observation of Bio-specimen

Colon bacillus（Pb stained）



微分像





Thank you for your attention !!