

2009 spring

***Microstructural Characterization
of
Materials***

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Contents for previous class

General Sample Preparation

- 1. Sectioning – typically abrasive cutting
- 2. Mounting (optional)
- 3. Coarse grinding
- 4. Fine grinding
 - 3. and 4. Grinding sequence – 120, 240, 320, 400, 600 grit SiC rotating 45 or 90 degrees between steps (center to edge)
- 5. Coarse polishing – 6 micron diamond paste or 6 micron and 1 micron diamond. Rotate sample counter to the wheel rotation. Wash after each step under running water and rinse with alcohol
- 6. Fine polishing – 0.3 and 0.05 micron alumina slurry

Contents for today's class

Microscope

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graph TD; A[Microscope] --> B[Optical microscope]; A --> C[Electron Microscope]; C --> D[1. Scanning Electron Microscope]; C --> E[2. Transmission Electron Microscope];
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Optical microscope

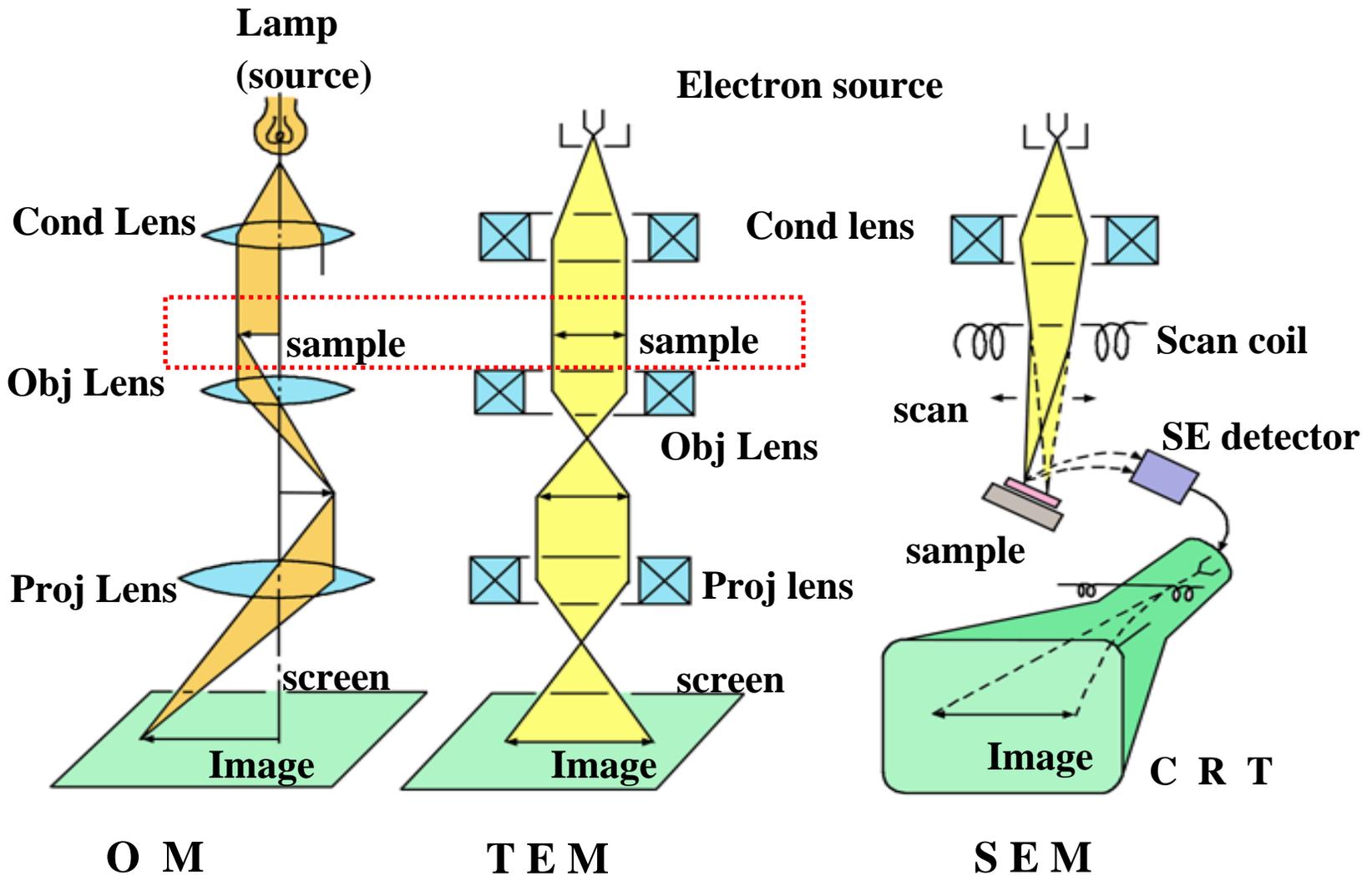
Electron Microscope

1. Scanning Electron Microscope

2. Transmission Electron Microscope

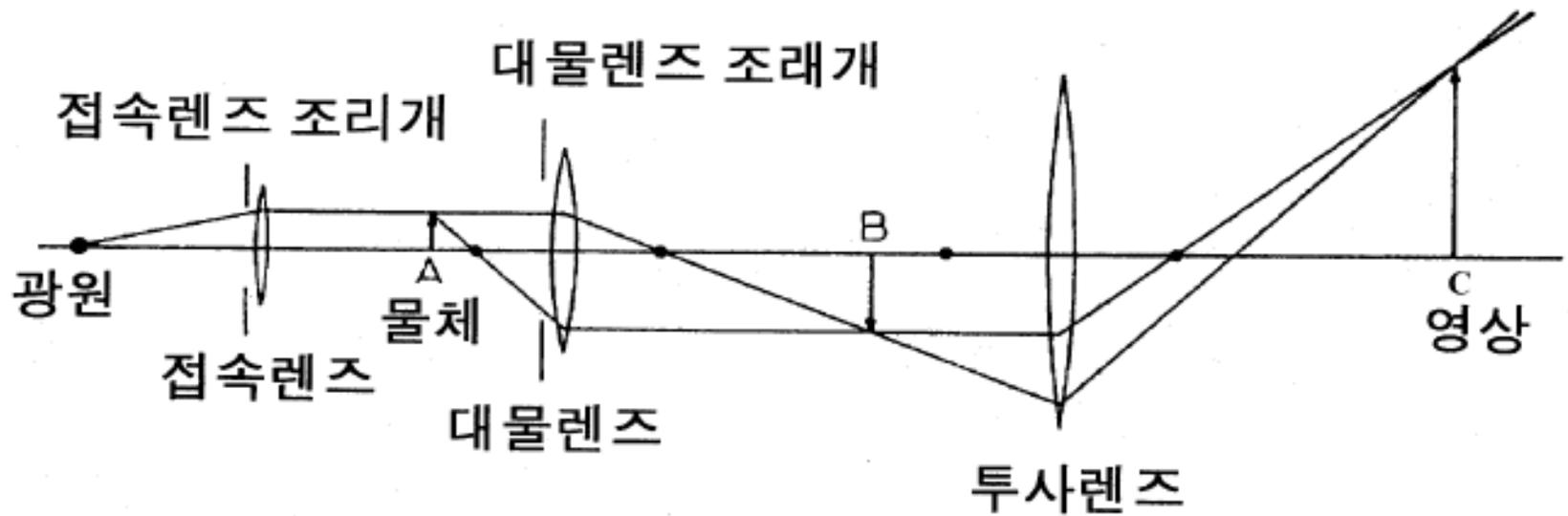
광학현미경과 전자현미경의 비교

항 목	전자현미경	광학현미경
광 원	전자빔	가시광선
파 장	0.0859 Å (20KV) ~ 0.0251 Å (200KV)	7,500 Å(가시광선)~ 2,000 Å(자외선)
전파매질	진 공	공 기
렌즈(방법)	전자기렌즈	유리렌즈
분해능	점분해능 : 3.5 Å 격자분해능 : 1.4 Å	가시광선 : 2000 Å 자외선 : 1000 Å
사용배율	100X ~ 450,000X	10X ~ 2,000X
초점조절	전기적	기계적

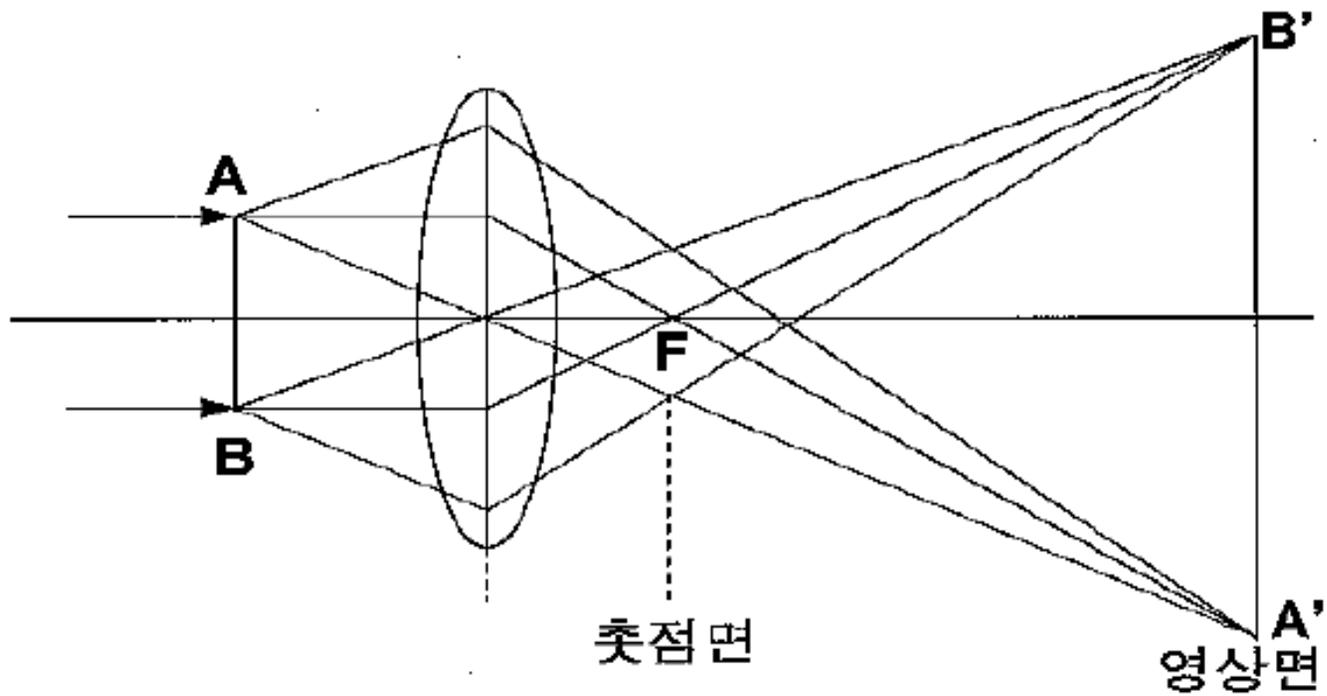


Difference among OM, TEM and SEM

광학현미경의 빛과 경로

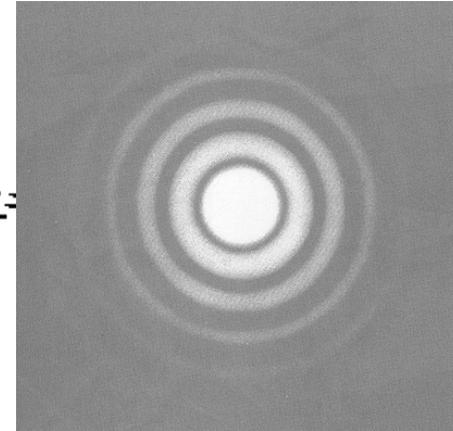
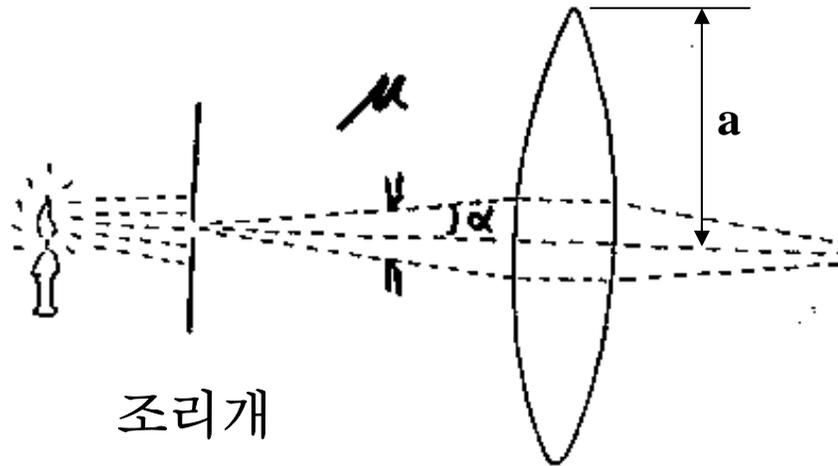


렌즈에 의한 영상의 형성



Airy 원반

일정크기의 조리개하에서 피사체 점은 회절현상에 의하여 원반상으로 나타난다.

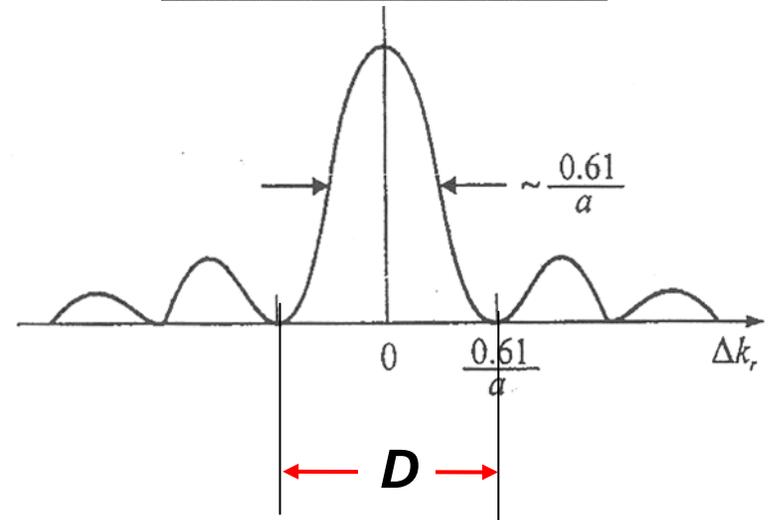


원반의 지름 $D = \frac{1.22\lambda}{n \sin \alpha} M$

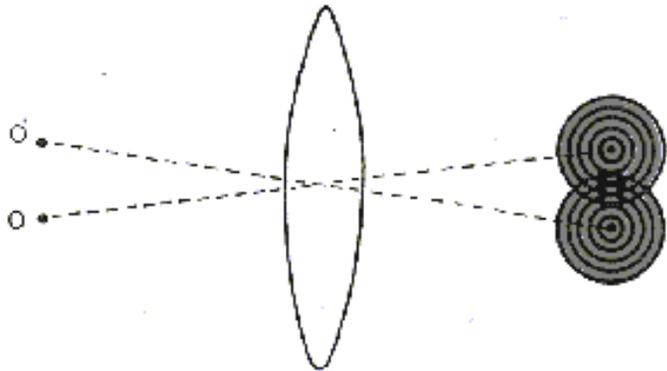
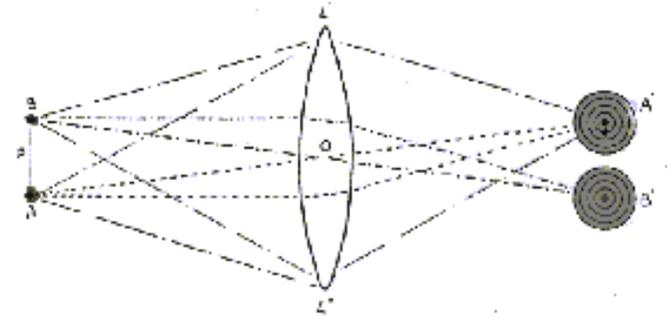
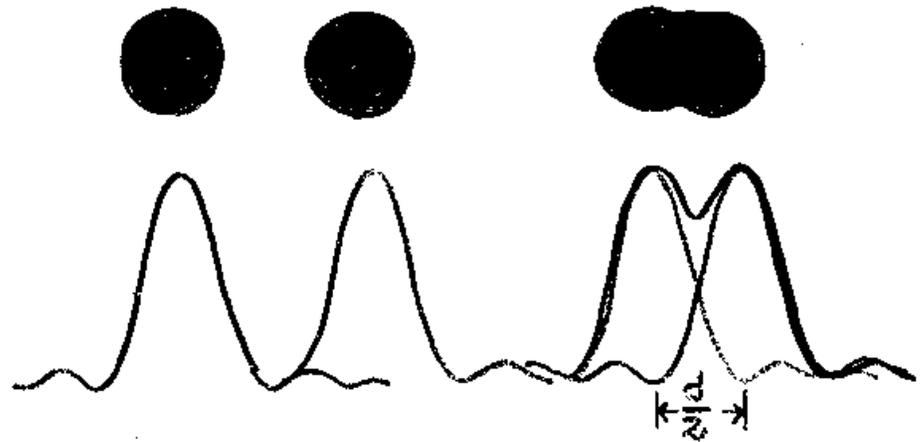
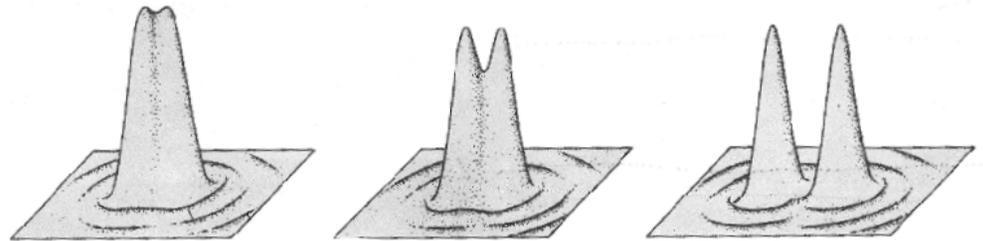
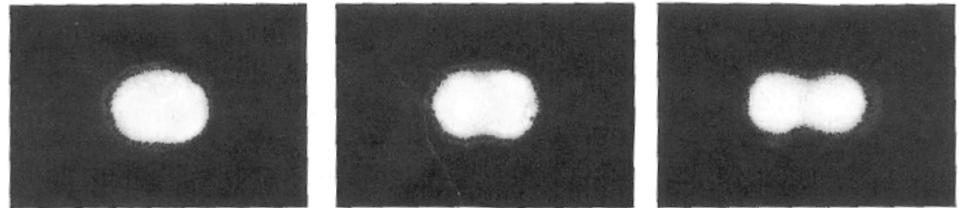
λ : 빛의 파장, n : 굴절률, α : 입사각, M : 배율
 $n \sin \alpha$: numerical aperture

원반에 해당하는 물체의 지름 d

$$d = \frac{1.22\lambda}{n \sin \alpha}$$



Rayleigh Resolution



원반사이의 거리가 반지름 보다 작아지면 둘 사이를 구분할 수 없음
 구분 가능한 최소거리 : $d/2 = 0.61 \lambda / n \sin \alpha \Rightarrow$ **Rayleigh Resolution**

Resolution

$$r = \frac{0.61\lambda}{n \sin \alpha}$$

좋은 분해능을 얻기 위해선

$n \sin \alpha$ (numerical aperture) 값을 크게 한다.

→ 렌즈의 수차를 증가시킴, 한계가 있음

파장을 작게

→ 전자현미경의 도입이유

By light

OM Image

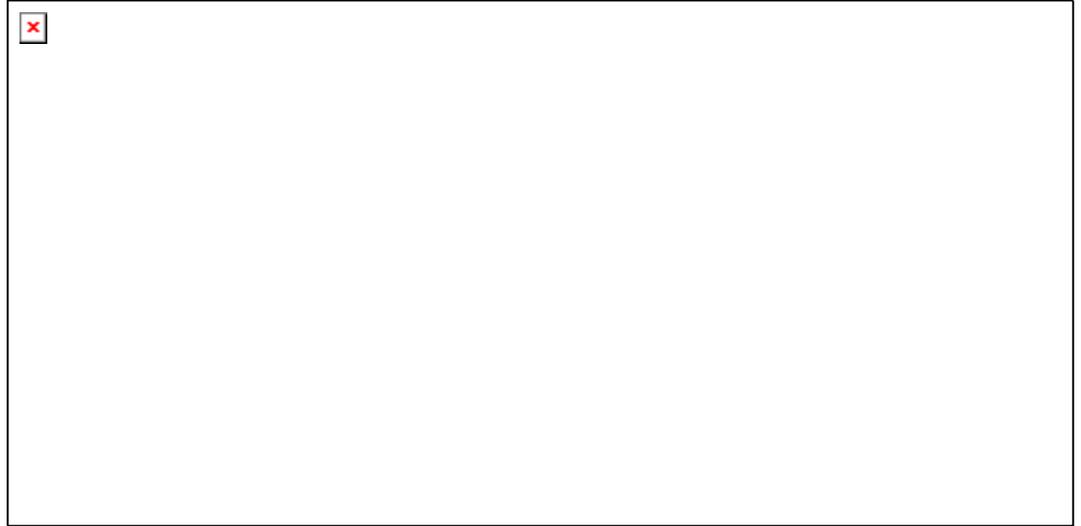
By electron

SEM Image

x400 0014 5.0kV 100µm

가속전압과 분해능

입사빔의 파장



전자현미경의 분해능

진공 $\Rightarrow n=1$

α 값이 작음 $\Rightarrow \sin \alpha = \alpha$

$$R = \frac{0.61\lambda}{\alpha}$$

가속전압 200kV

$\lambda = 0.00251\text{nm}$

$\alpha = 5 \times 10^{-3}\text{rad}$

$R = 0.3\text{nm}$

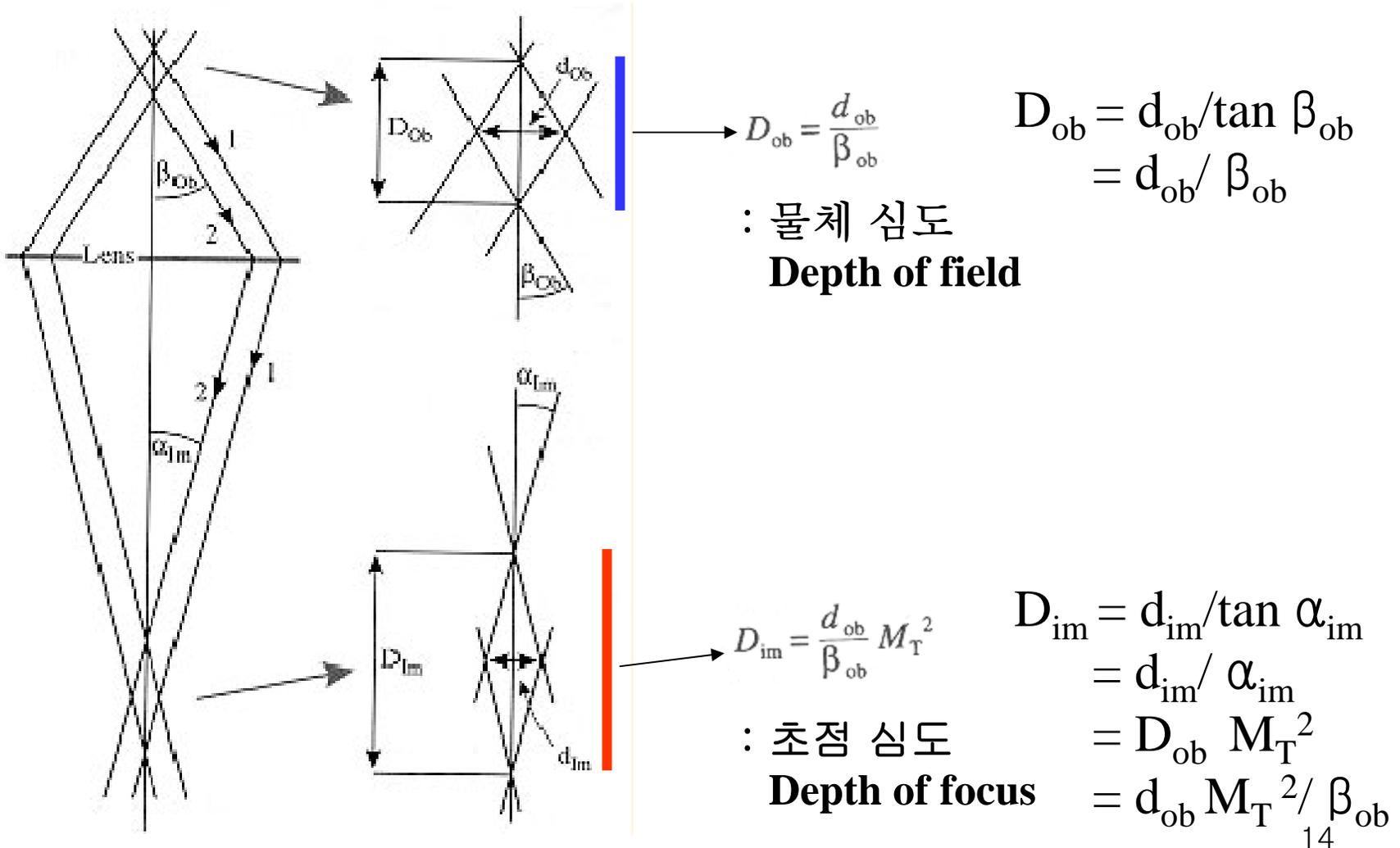
Philips CM200

JEOL 2010

Hitachi H8000

0.25~0.27nm

Depth of focus



$$D_{im} = \frac{d_{ob}}{\beta_{ob}} M_T^2$$

Depth of Focus (Field) in μm			
Magnification	α (rad)		
	5×10^{-3}	1×10^{-2}	3×10^{-2}
10X	4,000	2,000	670
50X	800	400	133
100X	400	200	67
500X	80	40	13
1,000X	40	20	6.7
10,000X	4	2	0.67
100,000X	0.4	0.2	0.067

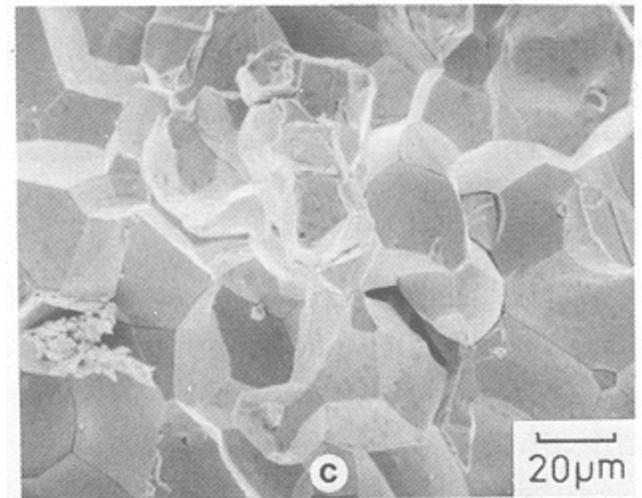
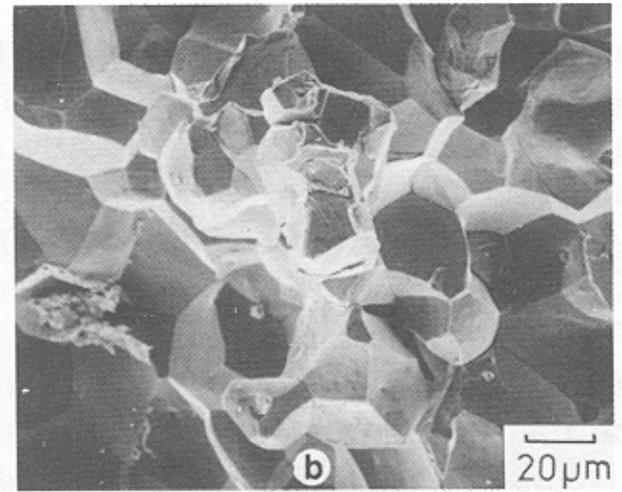
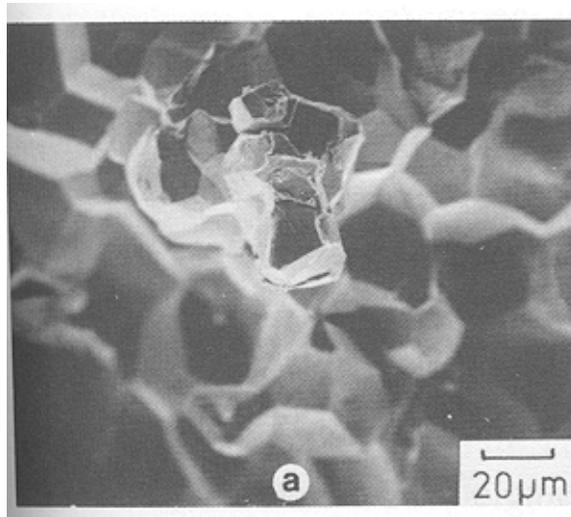
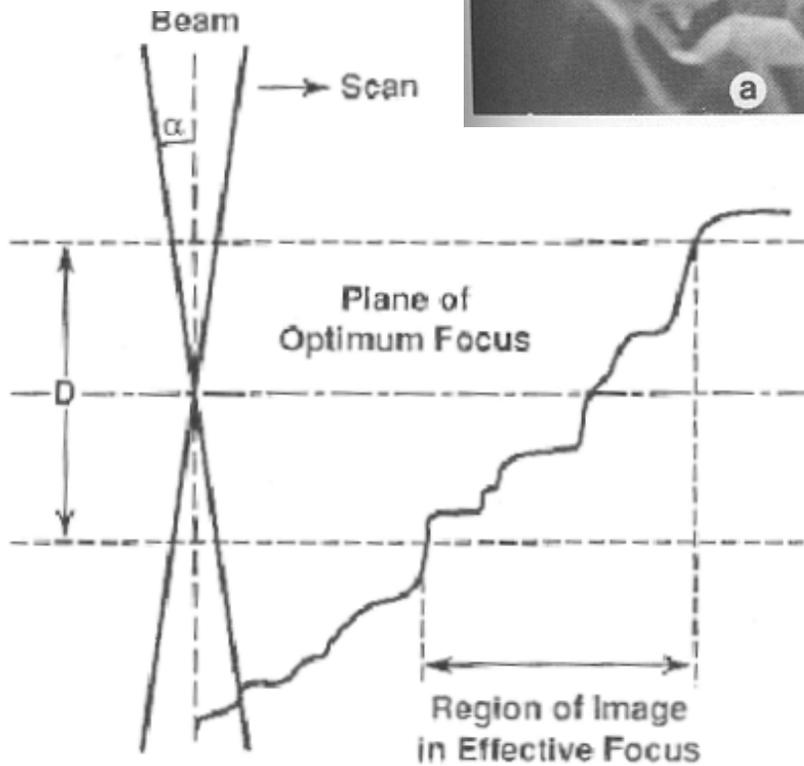
$$d_{ob}/2 = r = \frac{0.61\lambda}{n \sin \alpha}$$

Resolution

$$D_{im} = \frac{2r}{\alpha} M_T^2$$

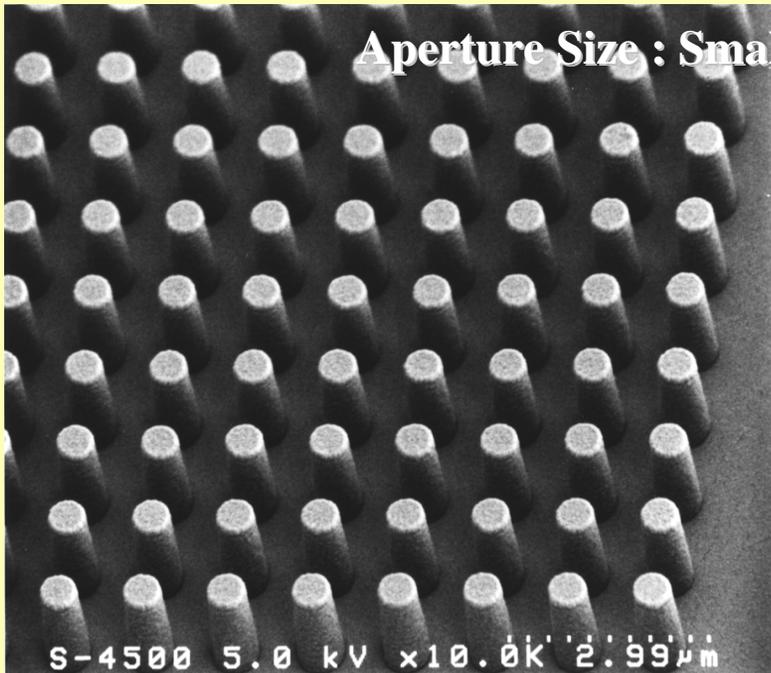
Depth of focus

분해능을 좋게 하기 위해 NA값을 증가시키면 초점심도는 작아짐.
전자현미경- α 값이 작아 초점 심도가 크다.

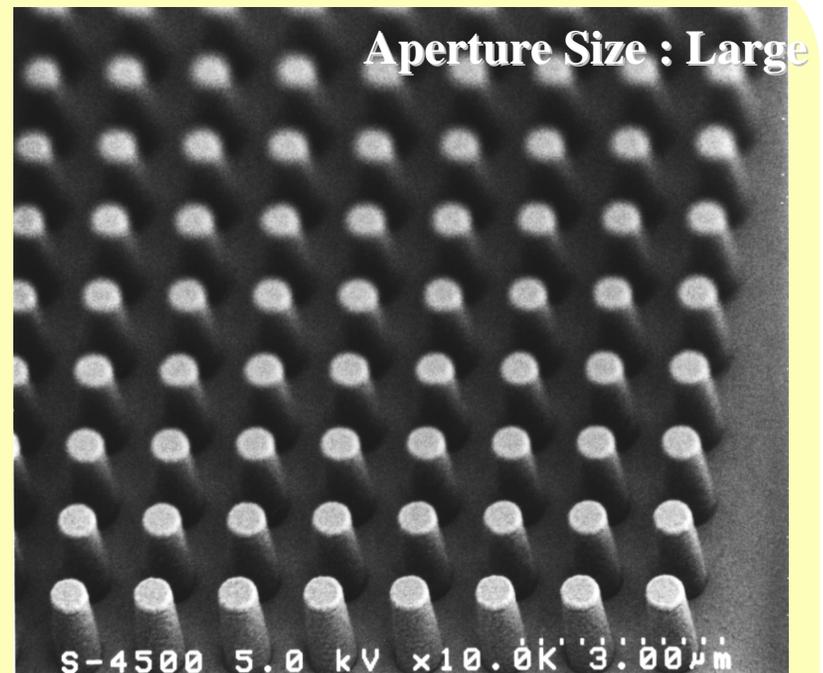


저배율, **topology** 차이(높이 차이) 심한 영상 관찰시
: Working Distance 크고, Spot size 큰 것이 관찰이 더 유리 16

Theory of Scanning Electron Microscope



Focus Depth → Deep



Focus Depth → Shallow

Specimen : Si on Photo Resist Pattern

Comparison of objective movable aperture hole size

전자기 렌즈의 결함

- 1. Chromatic aberration**
 - 2. Spherical aberration**
 - 3. Diffraction aberration**
 - 4. Astigmatism**
 - 5. Distortion**
- and so on...**

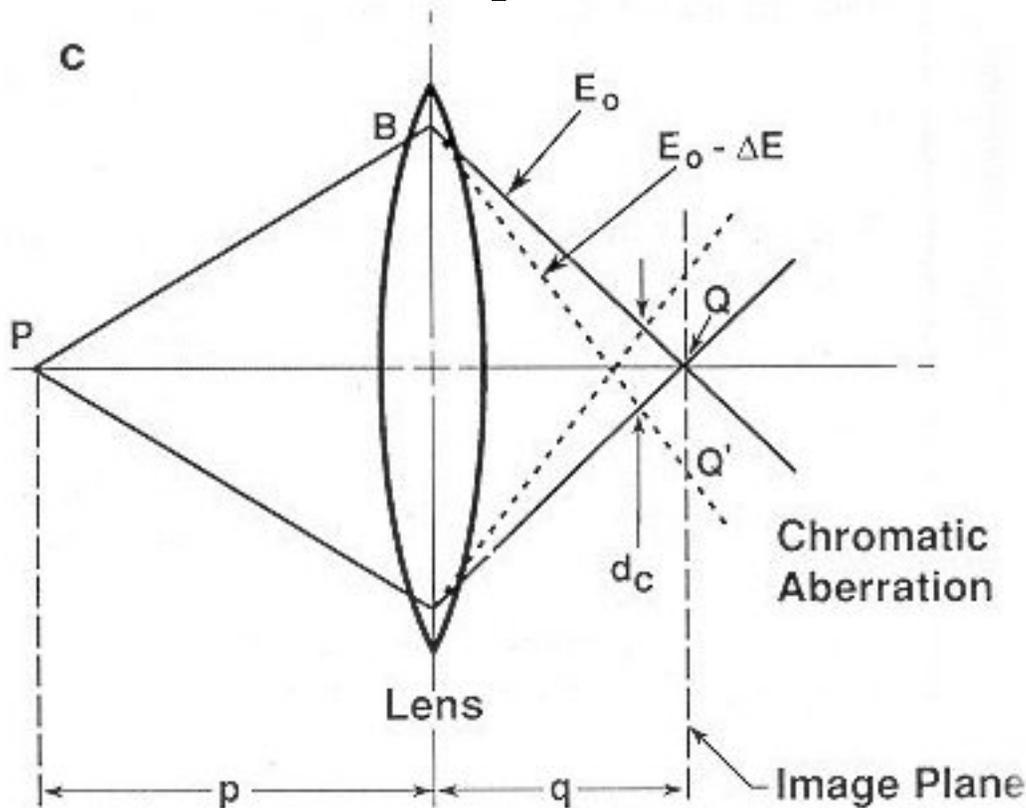
Chromatic aberration

굴절률 차이에 의해 생김

전자현미경의 경우 -전자의 에너지 (파장)차이에 의한 굴절률의 차이

1. 전자의 비탄성산란, 2. 가속 전압의 안정성

ΔE : 1-3eV for W hairpin, 1-2eV for LaB₆, and 0.2-0.3eV for cold FE



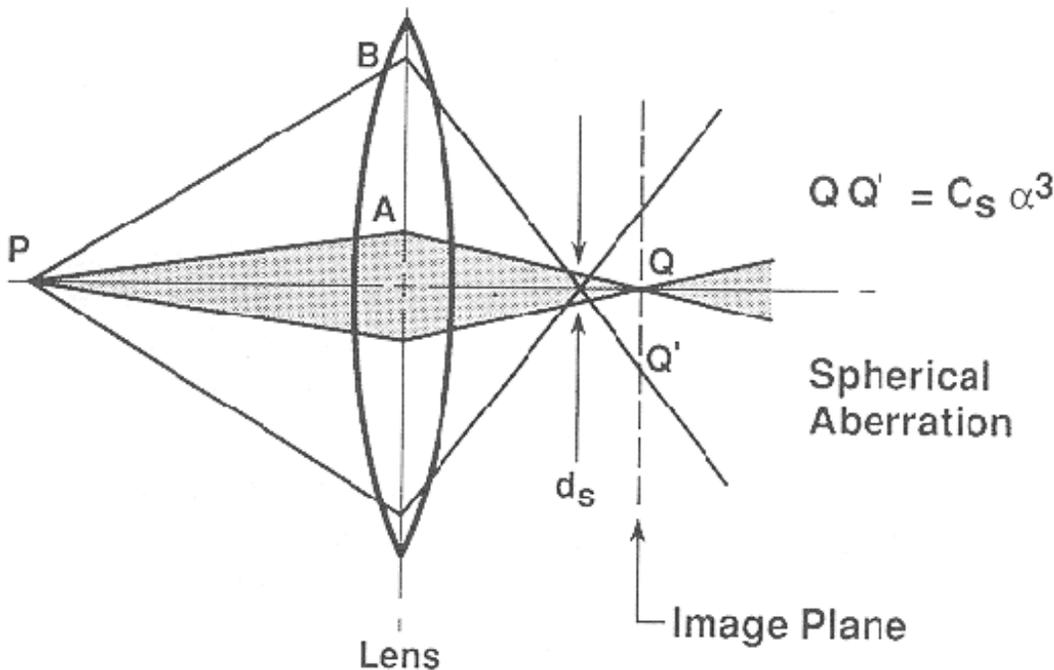
$$d_c = C_c \alpha \frac{\Delta E}{E}$$

C_c : 색수차 계수

Spherical aberration

광학 렌즈 : 렌즈 형상에 따른 자체 결함

전자기 렌즈 : 자기장의 밀도가 렌즈내에서 균일하지 않아 생김



$$d_s = C_s \alpha^3 M$$

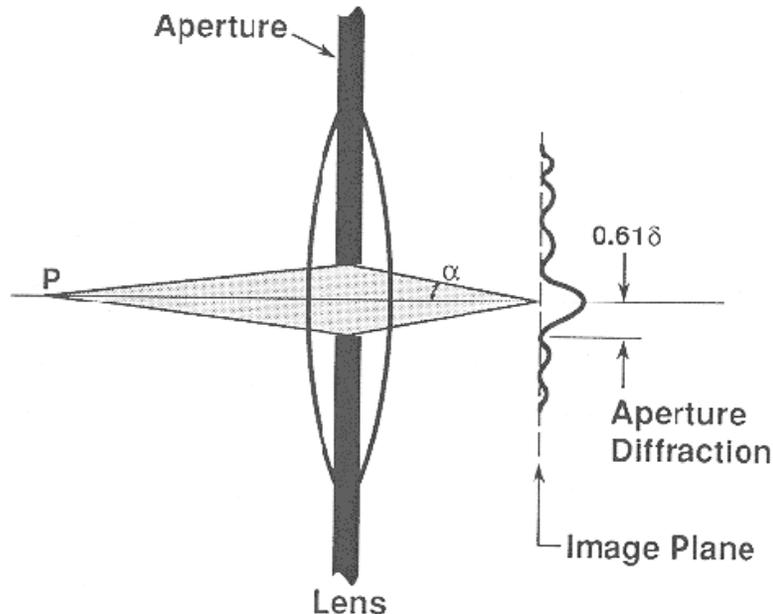
C_s : 구면수차 계수

But, small aperture (small α) reduces the current in the probe & introduces aperture diffraction 20

Diffraction aberration- Rayleigh Resolution

작은 aperture를 쓸 경우, 점이 아닌 원모양의 상이 생김

→전자의 파동성으로 인해 생김, 구면수차를 줄이고자 작은 aperture를 쓸 경우

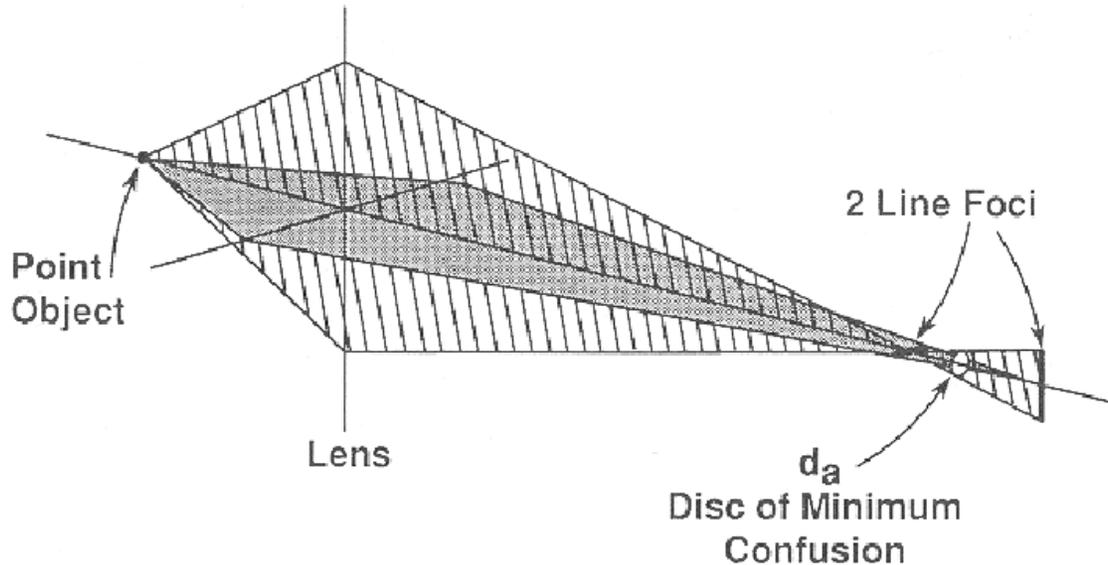


$$d_d = \frac{0.61\lambda}{\alpha}$$

Spherical aberration and aperture diffraction vary in opposite directions with α . This leads to the need to find an optimum aperture angle α_{opt} .

Astigmatism

자기장의 원 방향의 분포가 원 대칭을 이루지 못하는 경우
→ Stigmator 에 의해 완전히 교정할 수 있다.

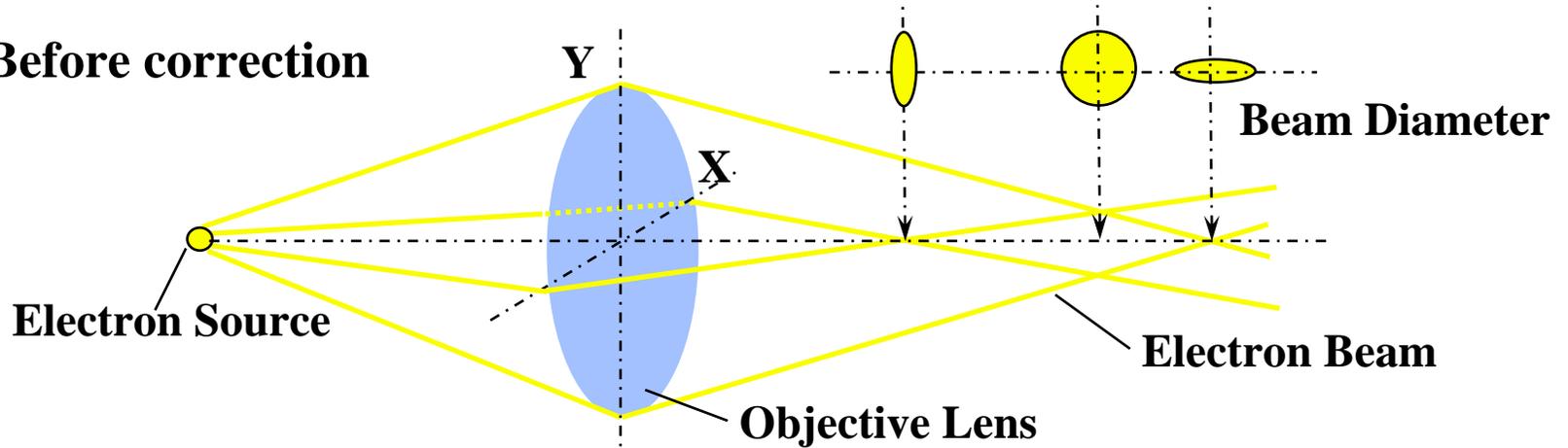


$$d_a = \alpha^3 \Delta f$$

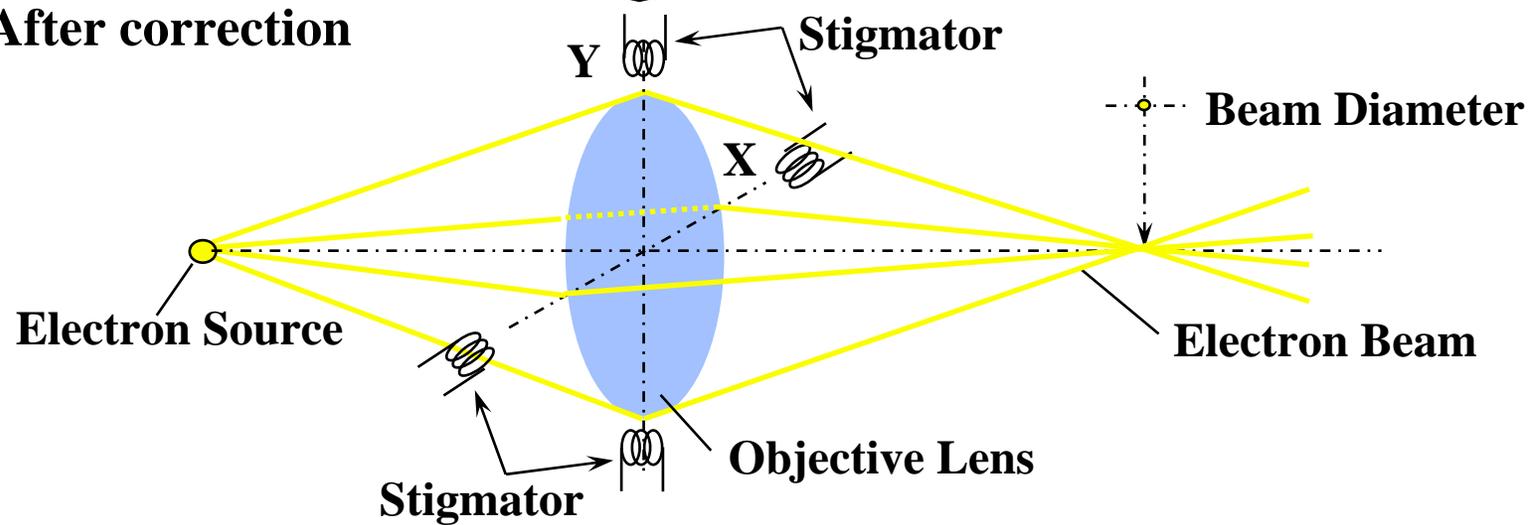
Astigmatism can be corrected with the stigmator.
(x-stig. → focus → y-stig. → focus →...)

Theory of Scanning Electron Microscope

Before correction

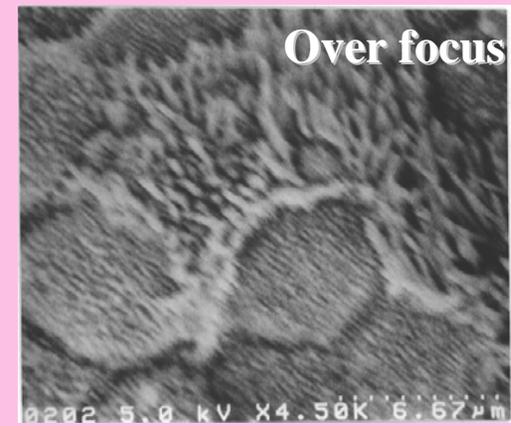
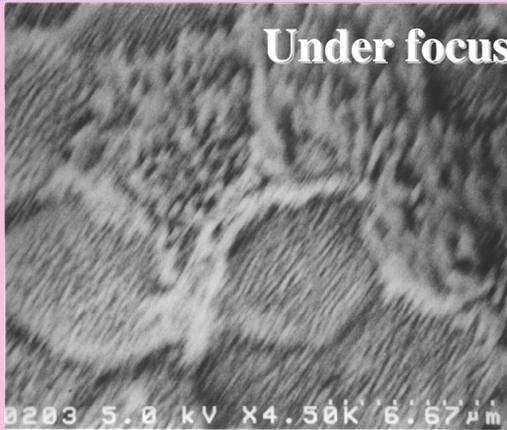


After correction



Astigmatism correction method

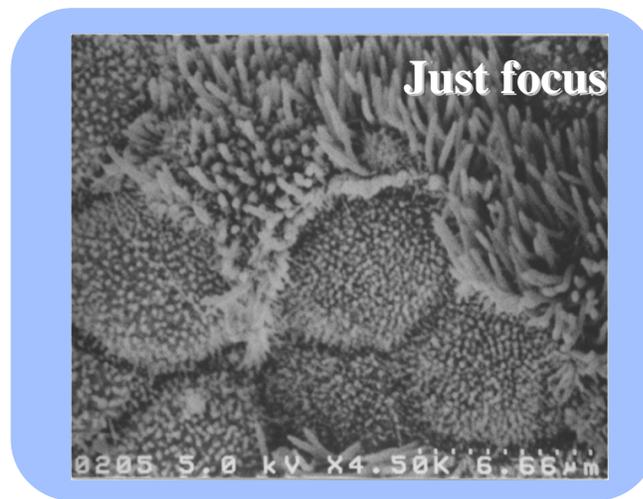
Theory of Scanning Electron Microscope



Before correction



After correction



Specimen: Trachea of rat

Astigmatism correction method

전자기렌즈에 의한 분해능의 한계

Ideal Res. Limit : **Rayleigh limit**

Practical Res. is determined by **various Lens aberrations**

$$d = \sqrt{d_d^2 + d_s^2 + d_c^2 + d_a^2} \quad \text{Negligible } d_c, d_a \quad d = \sqrt{d_d^2 + d_s^2}$$

$$d_d = \frac{0.61\lambda}{\alpha}$$

$$d_s = C_s \alpha^3 M$$

C_s : 구면수차 계수

$$d_a = \alpha^3 \Delta f$$

$$d_c = C_c \alpha \frac{\Delta E}{E}$$

C_c : 색수차 계수