2009 spring

Microstructural Characterization of Materials

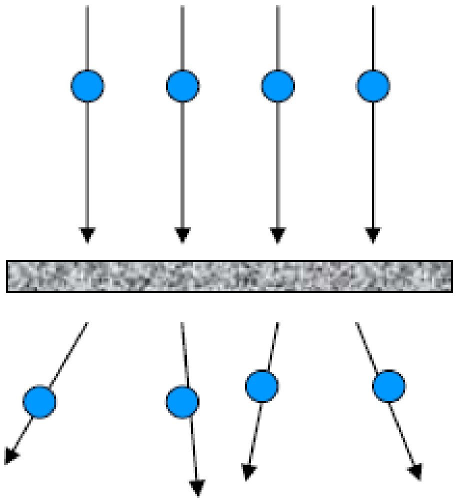
05. 20. 2009

Eun Soo Park

Office: 33-316
Telephone: 880-7221
Email: espark@snu.ac.kr
Office hours: by an appointment

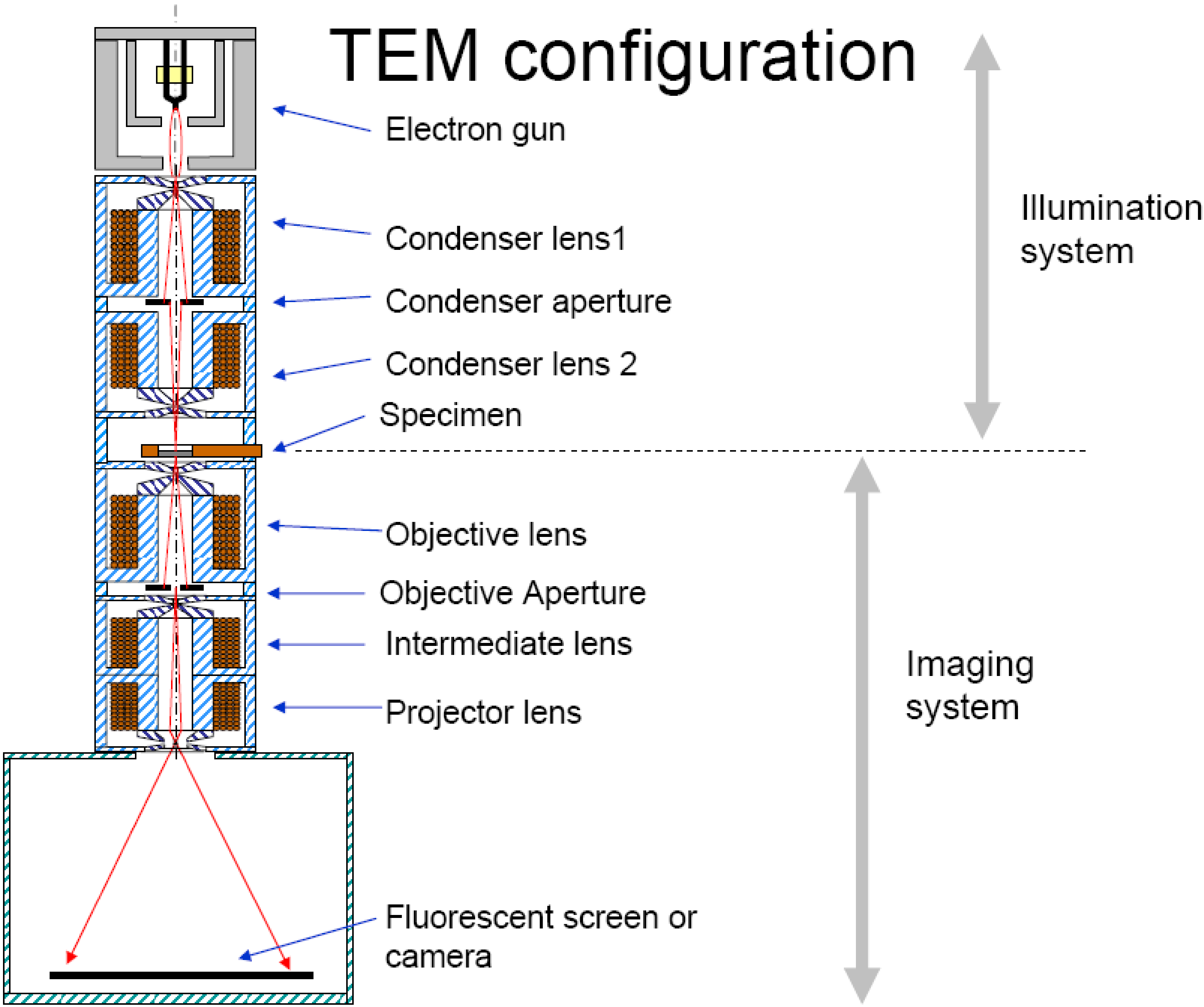
The transmission electron microscope

- Analogous to optical microscope in transmission light mode
- Relies on samples so thin that electrons of ~100 keV can be transmitted through them
- Difficulty in making samples thin enough for electrons to pass through
- Up to 1 MeV energy used to handle thicker specimens, but…. Radiation damage

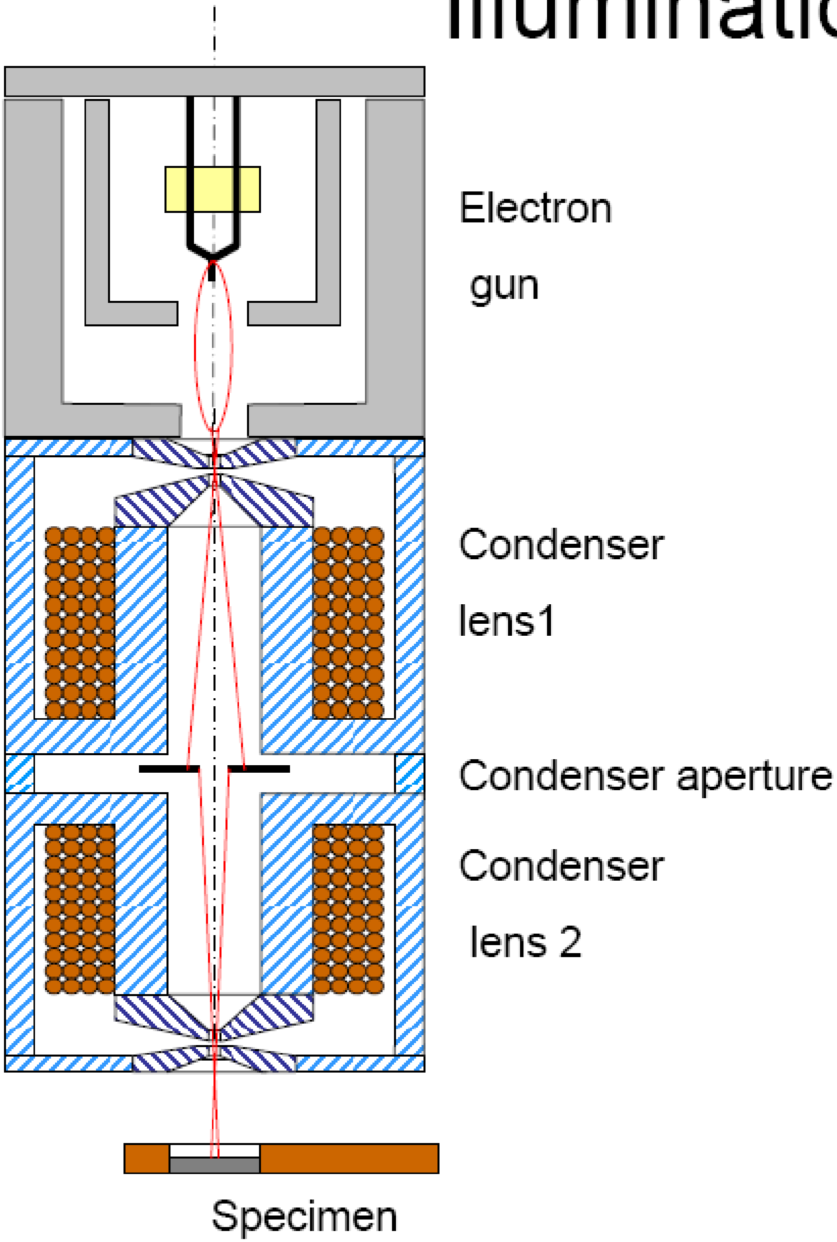


Structure of the specimen locally perturbs the electron trajectories. This gives rise to contrast in the image

TEM configuration

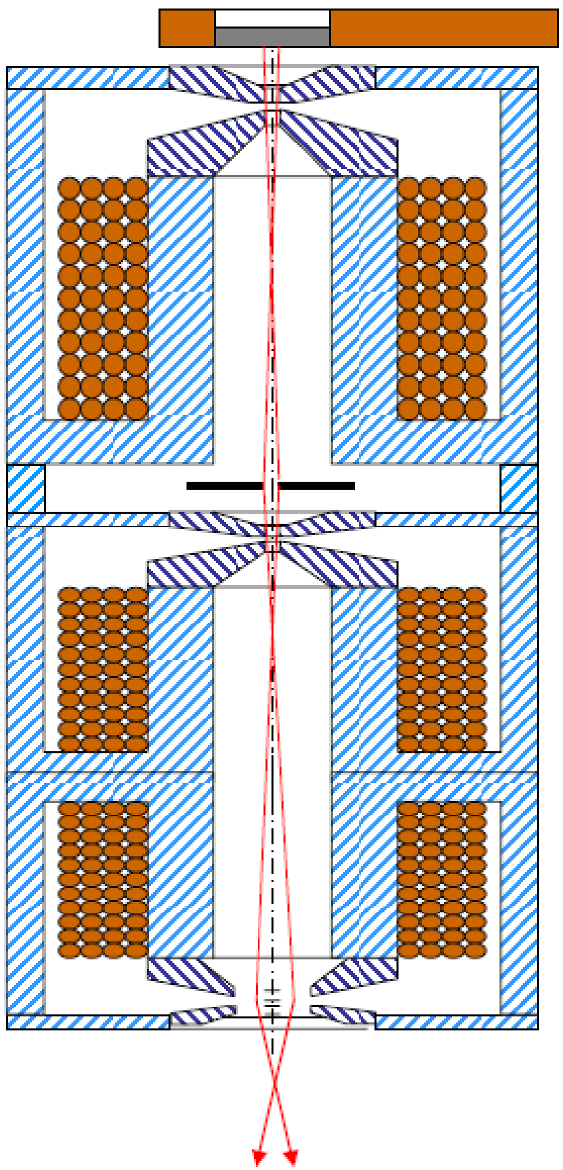


Illumination system



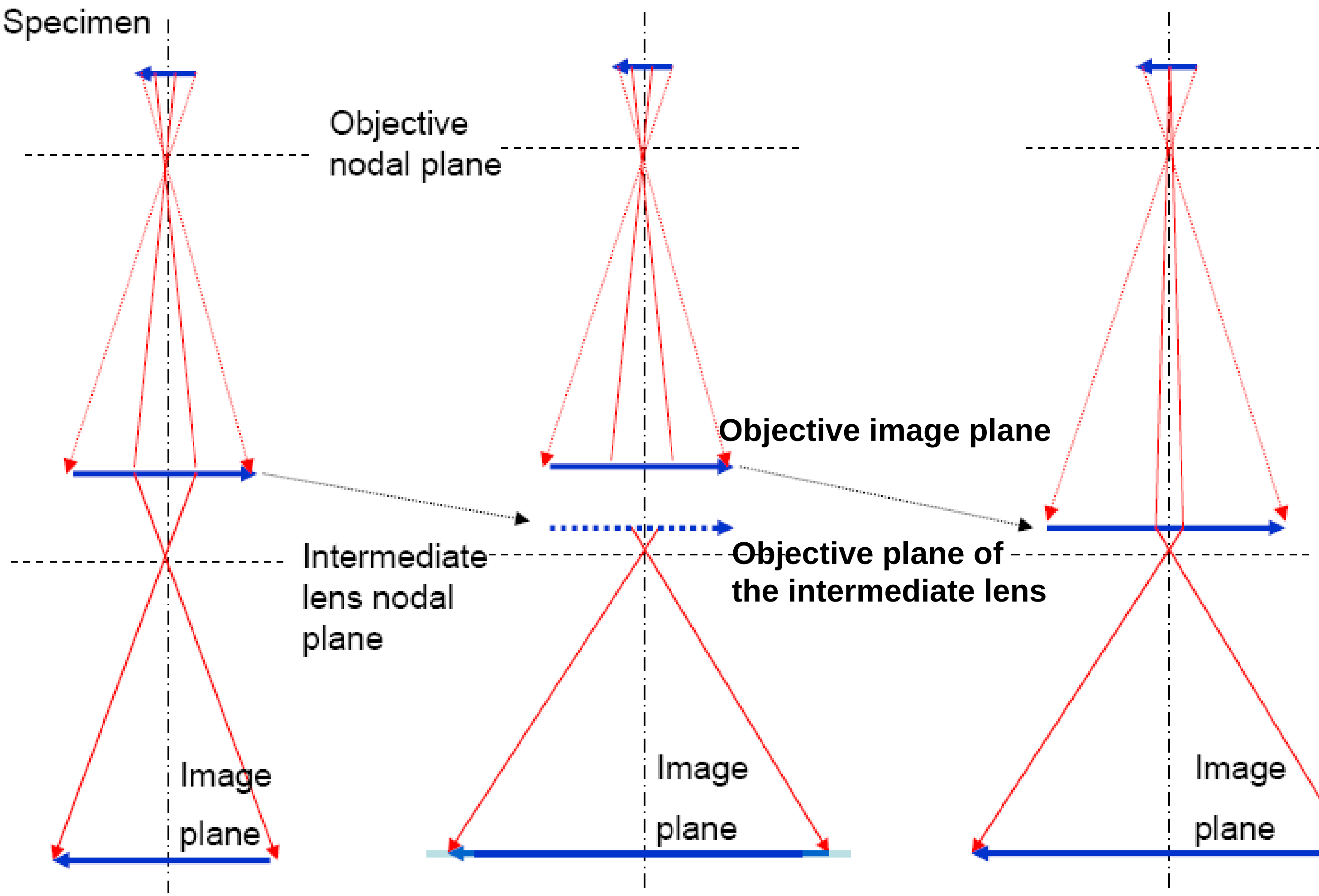
- Illuminates only region of interest ~1 μm
  - Lower contamination
  - Minimises beam heating
- Demagnification factor 50 -100
- 2nd condenser lens has long focal length
  - Astigmatism
  - Need to introduce correction coils
- Large divergence at condenser aperture
  - Need to improve brightness to improve image intensity

Imaging System



- Three lenses used:
  - Objective
    - Short focal length
    - Fixed specimen-1st nodal point distance
    - Current adjusted to obtain focus
  - Intermediate
    - Current adjusted to obtain magnification 1000 – 100 000 X
  - Projector
    - Operated at constant current

Magnification and focussing

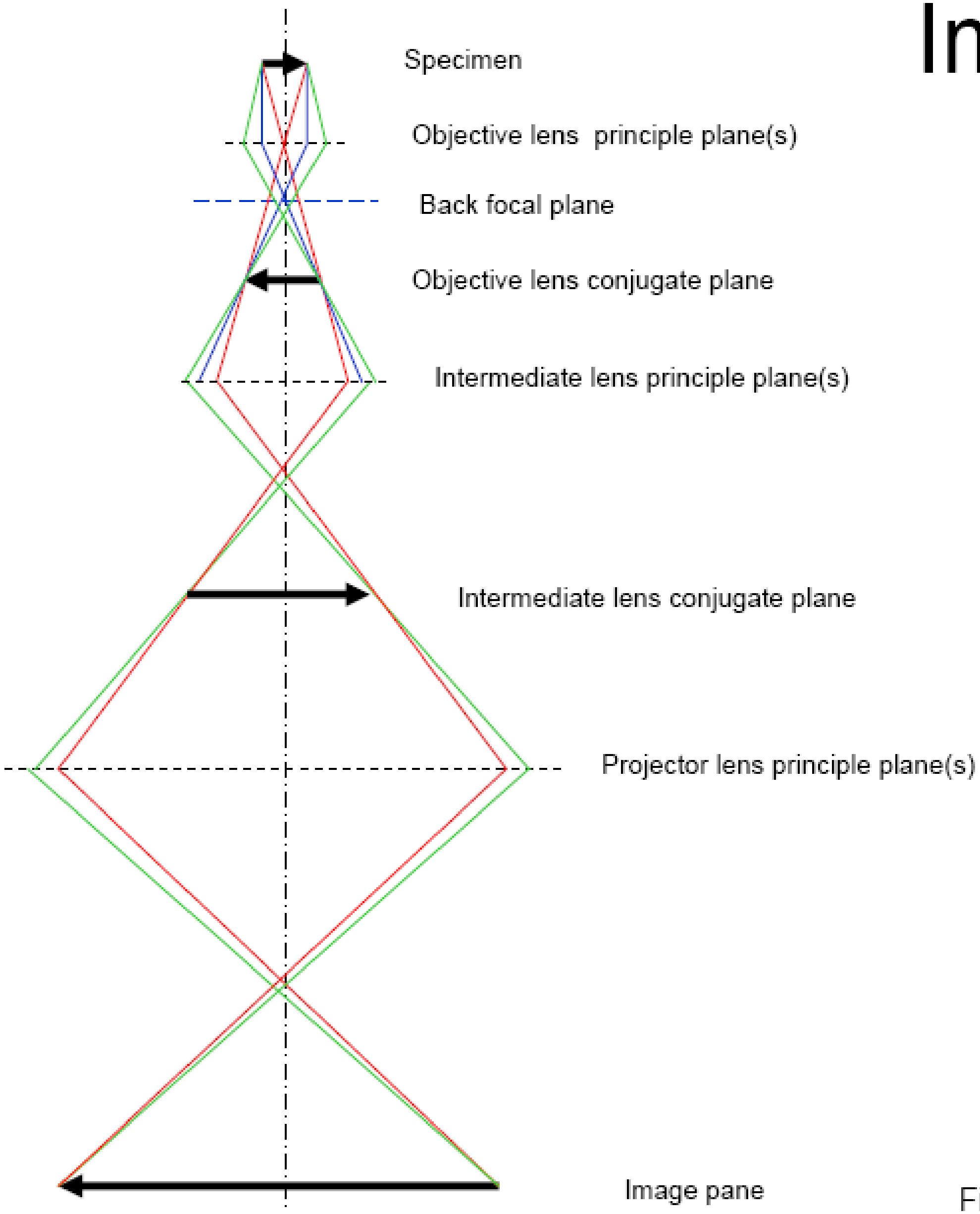


Low Magnification: Ojbect image plane and intermediate lens object plane coincide. Low current in intermediate implies long focal length and low magnification

High Magnification: Intermediate lens current increased to give high magnification which moves intermediate object plane closer to lens

Focussing: Object lens current reduced to move objectve image plane into coincidence with object plane of the intermediate lens.

Imaging ray paths



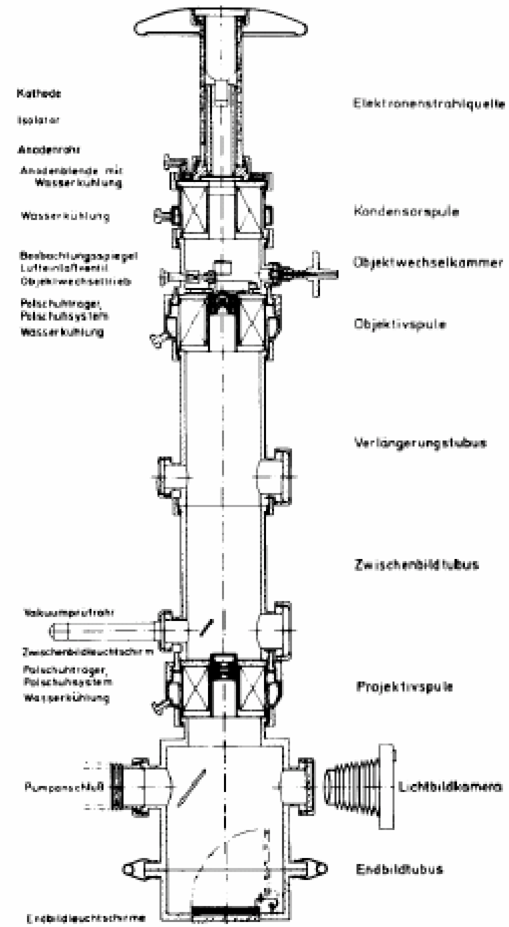


Fig. 5: First (two-stage) electron microscope magnifying higher than the light microscope. Cross-section of the microscope column (Re-drawn 1976) [15].

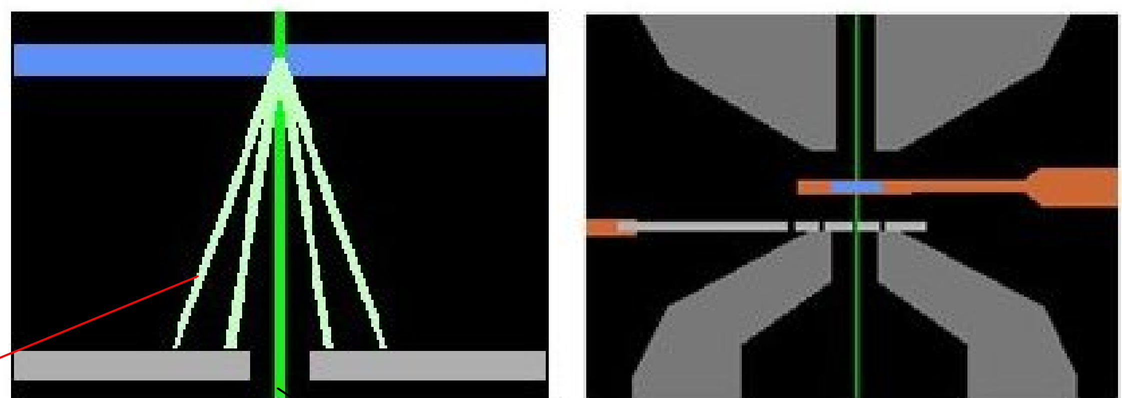
First true transmission electron microscope. E. Ruska, Nobel Lecture
http://nobelprize.org/physics/laureates/1986/ruska-lecture.html

Bright-Field Image

✓TEM 관찰시 주로 많이 이용하는 방법으로서 대개 이미지가 밝기 때문에 명시야상으로 불리움

✓전자빔이 시편에 충돌하면 시편과의 상호간섭에 의해 광축으로 부터 벗어남

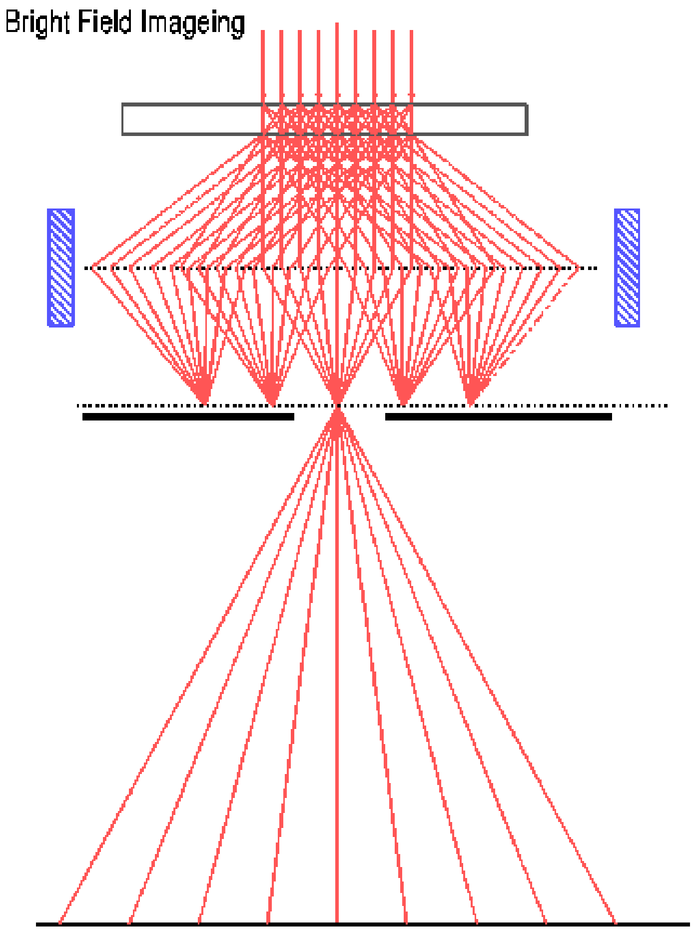
✓산란된 전자들은 조리개에 의해 차단되고, 광축에 가까운 투과된 전자빔만으로 image형성

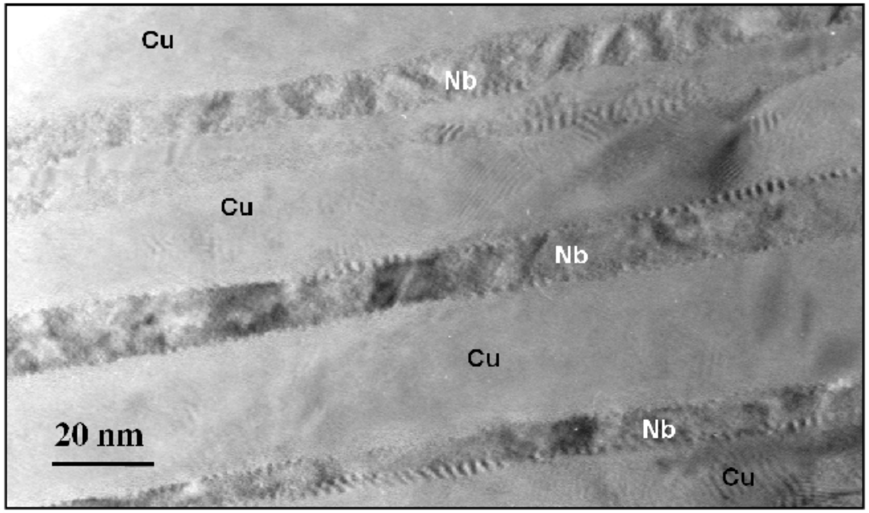


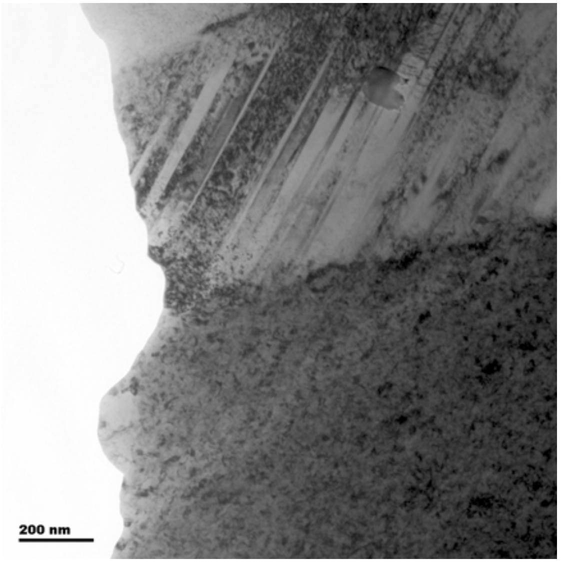
Refraction beam

Transmission beam

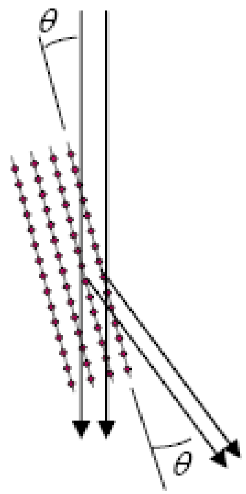
Bright-Field Image



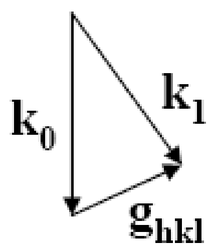




Electron diffraction



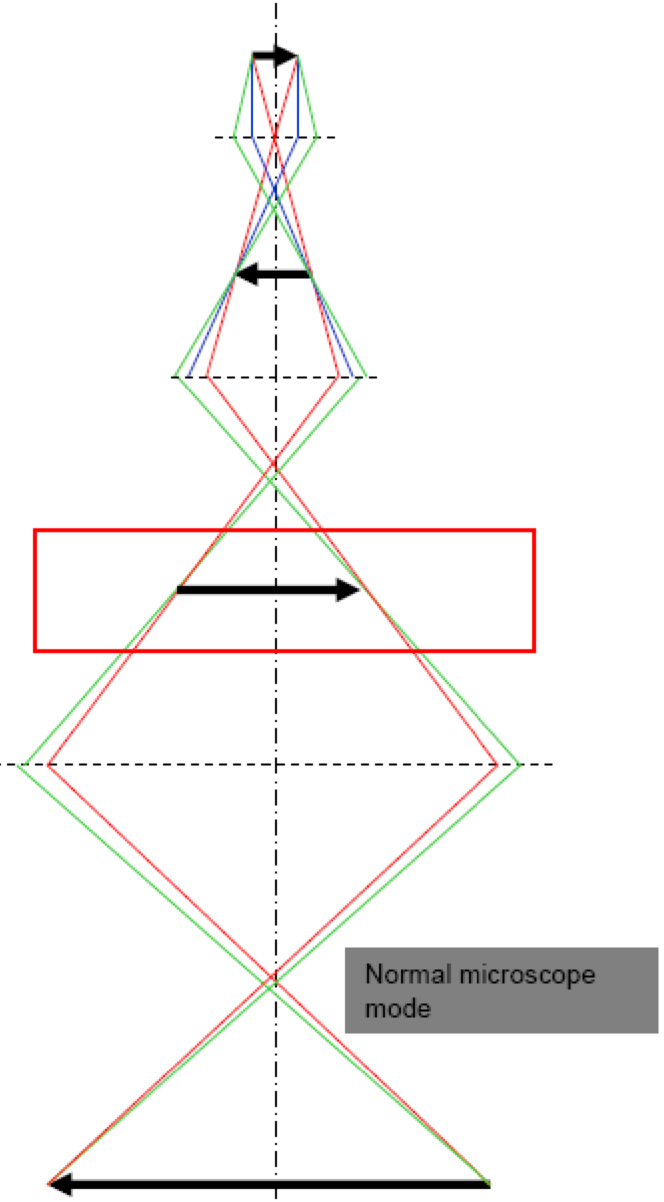
$$2d_{hkl}\sin\theta = \lambda$$



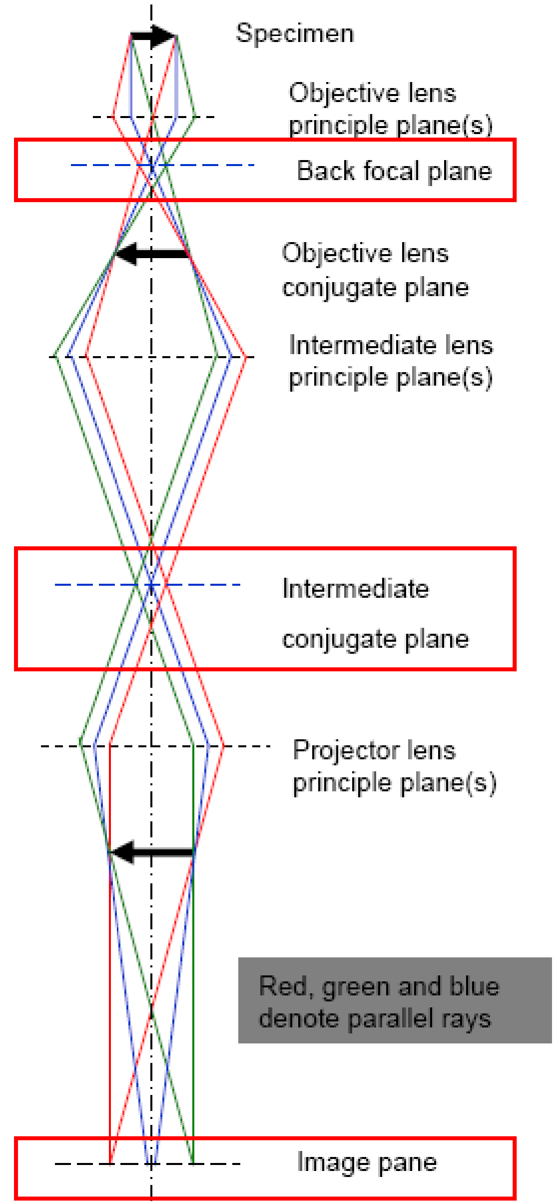
$$\mathbf{k}_1 - \mathbf{k}_0 = \mathbf{g}$$

- For crystal specimens the electrons may scattered into diffracted beams if the diffraction condition is met.
- Scattering amplitude generally quite large which permits multiple diffraction
- **Diffracted beams are always parallel** (This is a necessary condition of the vector formulation of diffraction.)

Diffraction pattern observation

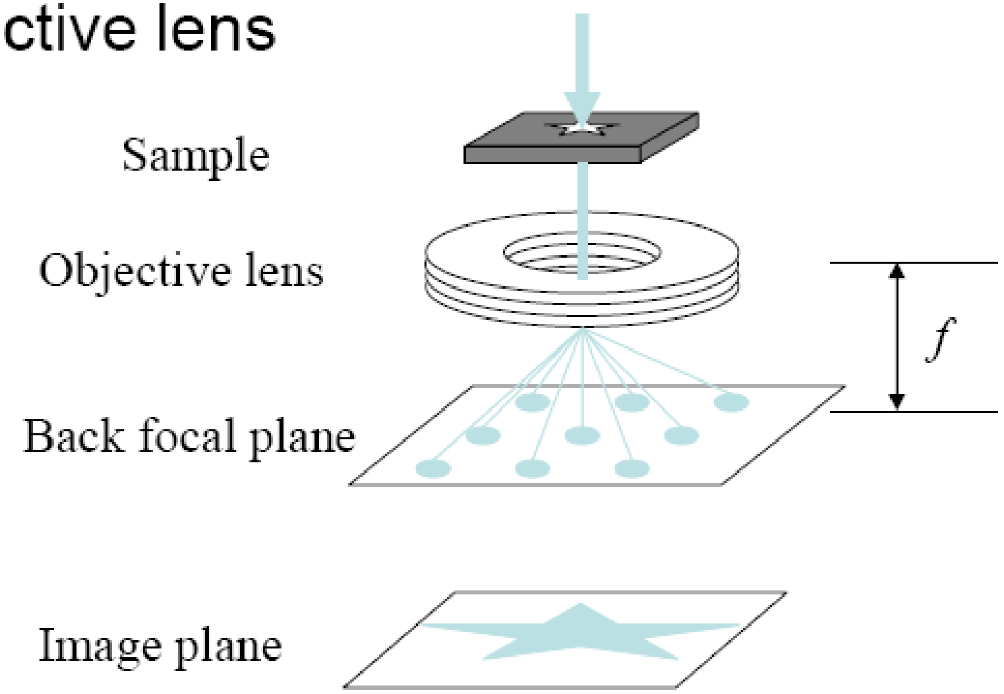


- Electrons in diffracted beams have parallel trajectories
- Parallel rays conjugate at a plane a $f_{objective}$ below the principle planes of the objective lens to form a diffraction pattern
- To obtain a diffraction pattern the current in the intermediate lens is reduced to make the objective back focal plane conjugate to the intermediate plane (the plane there objective normally forms a image of the specimen
- The projector lens then forms a magnified image of the diffraction pattern in the conjugate plane of the intermediate lens



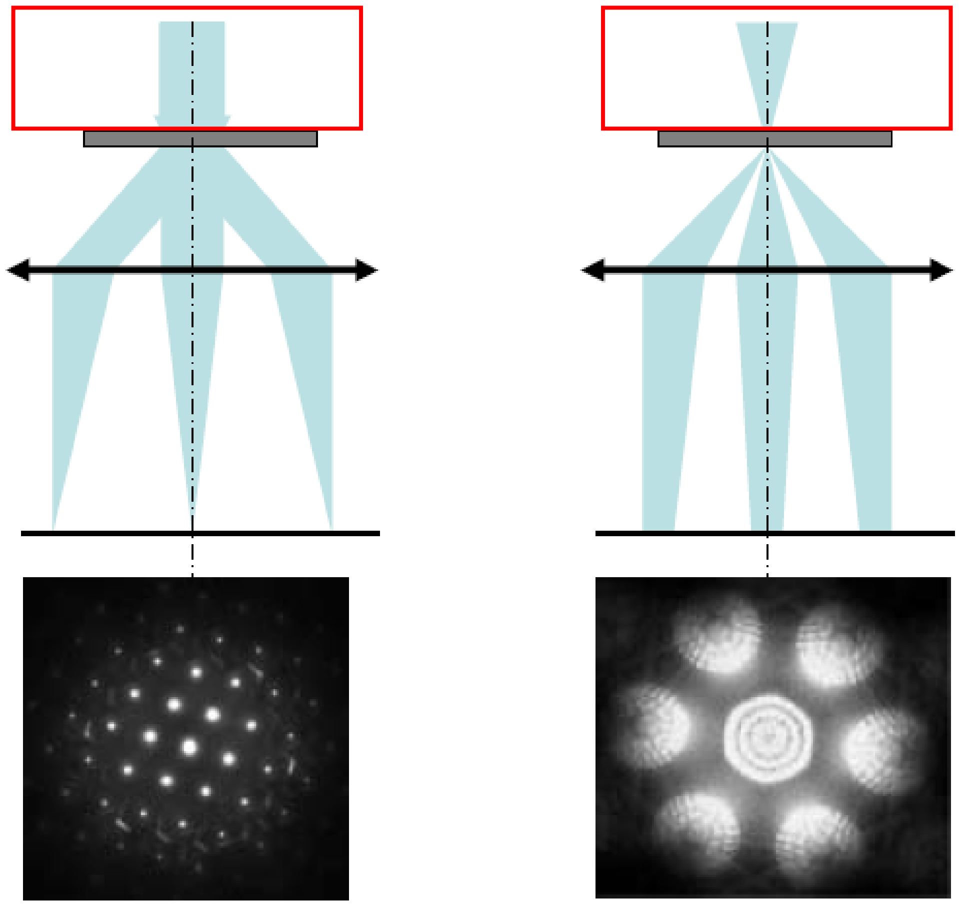
Electron diffraction

- Diffraction pattern locates at the back focal plane of the objective lens



Diffraction with parallel illumination and conical illumination

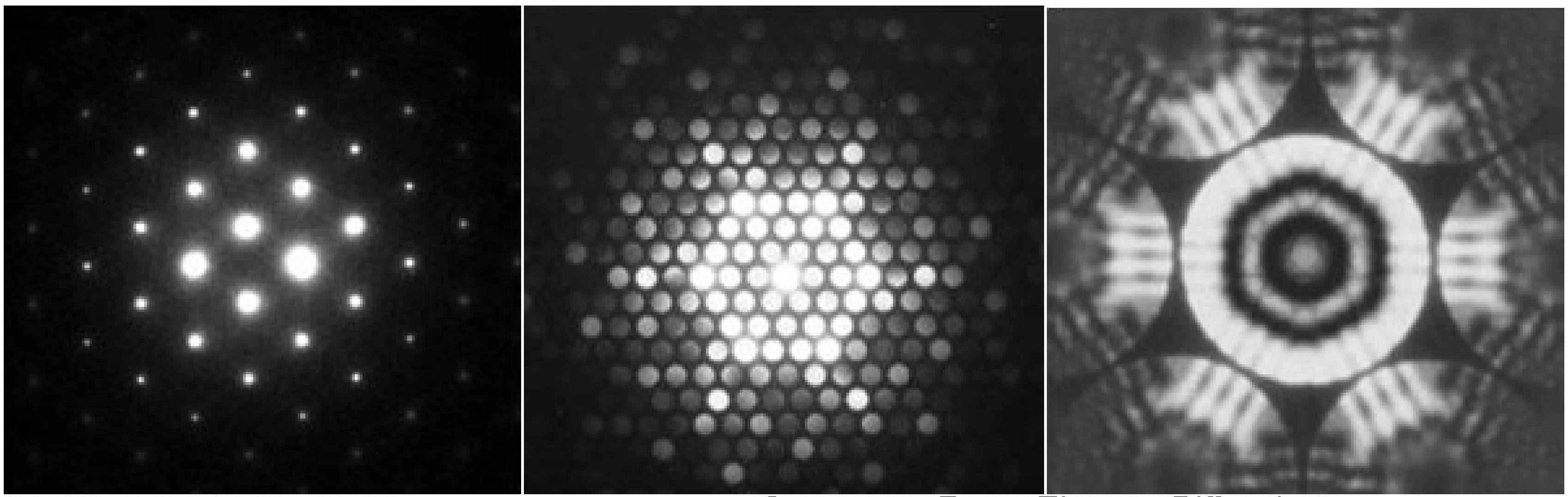
- Parallel beams are focused at the back focal plane
- Parallel illumination results sharp spots at the plane
- Conical illumination results discs at the plane



SADP CBED

Diffraction pattern

회절패턴은 시편에 입사된 전자빔이 **시편의 결정면에 의하여 회절된 3차원적 역격자 배열이 전자현미경의 back-focal plane높이의 평면에 의하여 잘린 면에 해당**



Selected Area Diffraction Convergent Beam Electron Diffraction

screen상에 보이는 grain이 어떠한 물질의 결정이고 격자상수가 얼마인지, 그리고 grain의 결정학적 방향(Miller 지수)이 어떠한지를 알기 위해서는 **적어도 3개 이상의 zone-axis에서 회절패턴을 얻은 다음 회절 spot들 사이의 거리와 각도를 측정하여 물질의 종류와 격자상수**를 분석한다