SECONDARY ELECTRON DETECTION

CAMTEC Workshop Presentation

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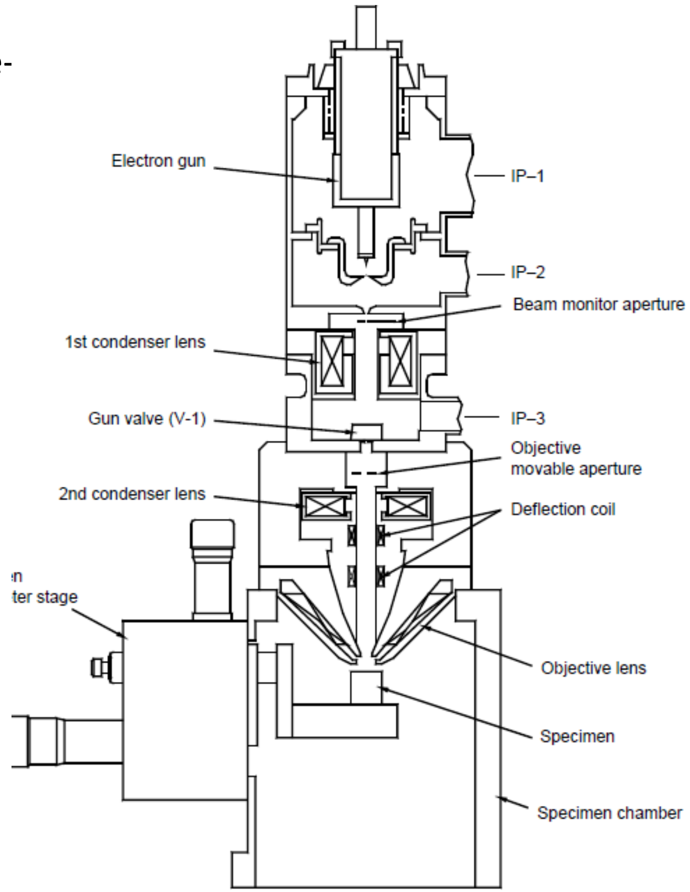
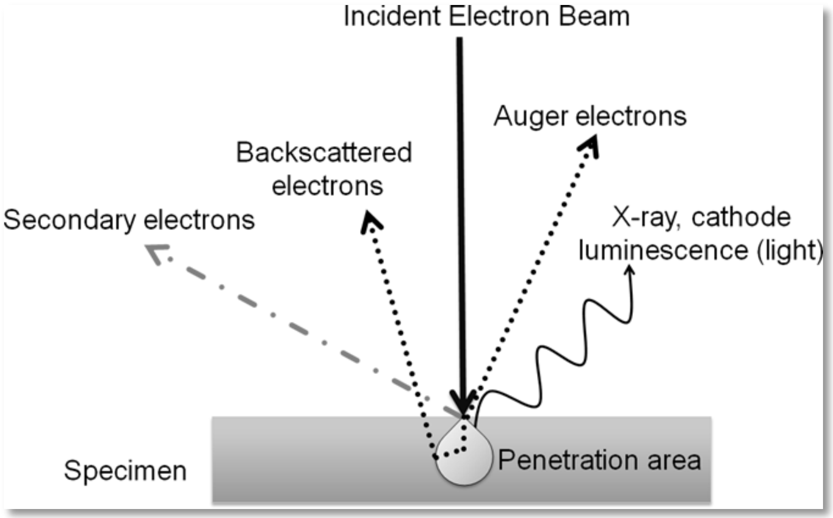
Introduction

- SEM
  - Raster scan specimen surface with focused high energy e-beam
  - Signal produced by beam interaction with near-surface specimen atoms
  - Information on surface topography and chemical composition
  - Stereoscopic image and spectrum of specimen surface



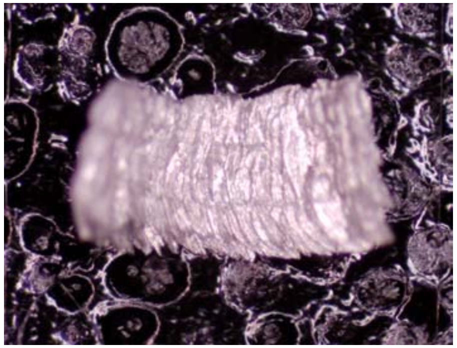
Introduction

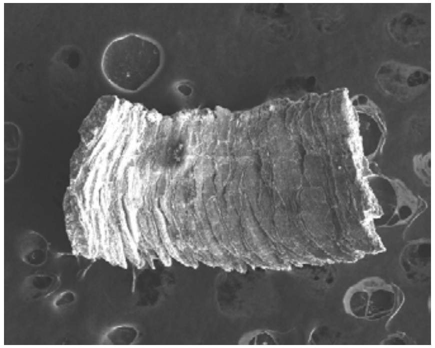
- Primary signals
  - **Secondary electron (SE)**
    - SEM micrograph, surface topography
  - Backscattered electron (BSE)
    - SEM micrograph
    - Atomic number → contrast
  - Characteristic x-ray
    - Energy dispersive spectrometry

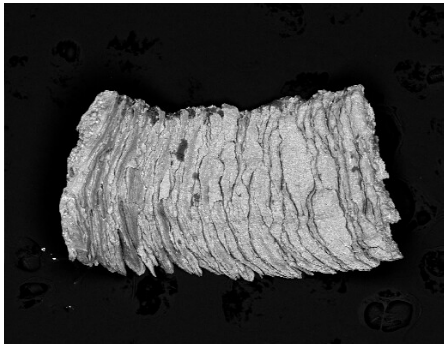


Introduction

- Features
  - Stereoscopic image of surface topography at nm resolution
  - Orders-of-magnitude greater depth of field than optical microscopy due to much smaller limiting aperture
  - Left to right: optical, SE, BSE of slightly warped metal chip
    - Blurring of optical image
    - SE: most visually interesting, rich surface details and shadow
    - BSE: flat contrast, ideal for accurate image analysis

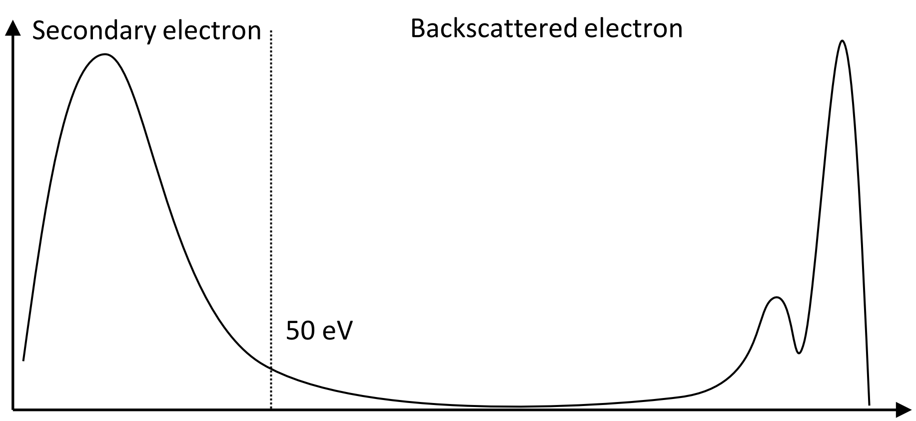


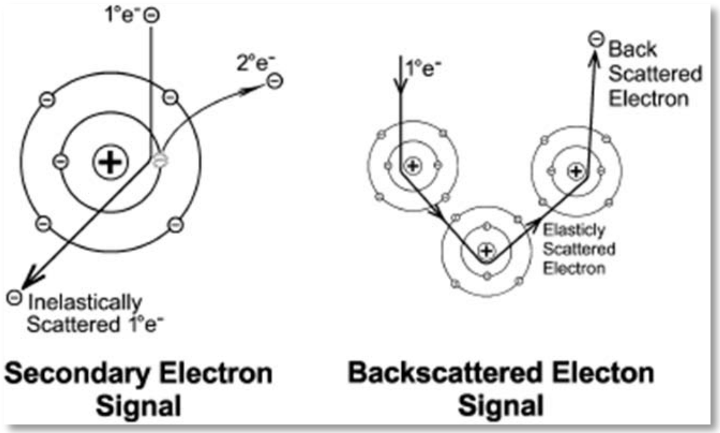




Secondary Electron

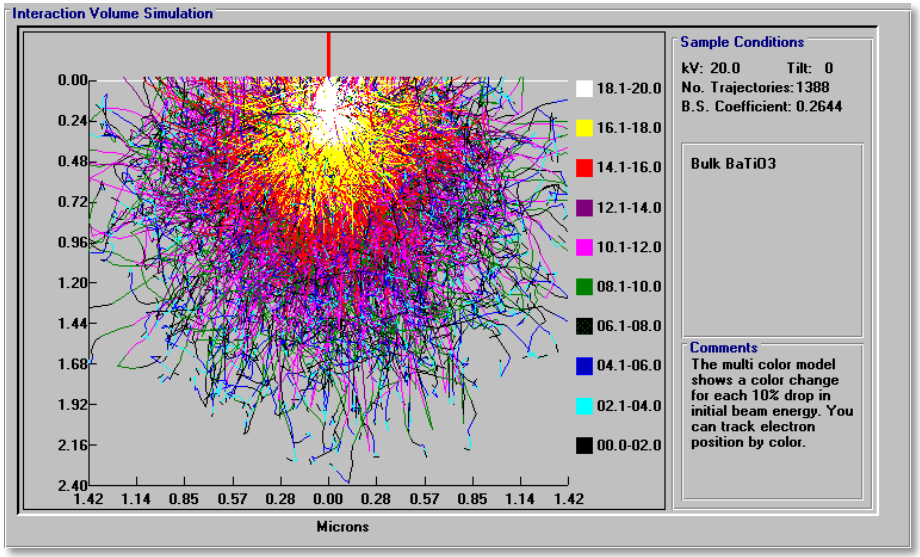
- Electrons scatter via interactions with specimen atoms
- Nature of resulting electronic signal depends on nature of interaction and energy
- **SE**
  - **Inelastic scattering of primary electrons eject free electron from K-orbital of specimen atom with small fraction of energy < 50 eV**
  - **Shallow escape depth (~2nm), information of specimen surface only**
- BSE
  - Elastically and inelastically scattered primary electrons
  - > 50% primary electron energy





Secondary Electron

- Electron penetration studied using simulation
- Resolution depends on size of signal-producing region
- Secondary electron emitted from shallow escape depth → highest resolution



Secondary Electron

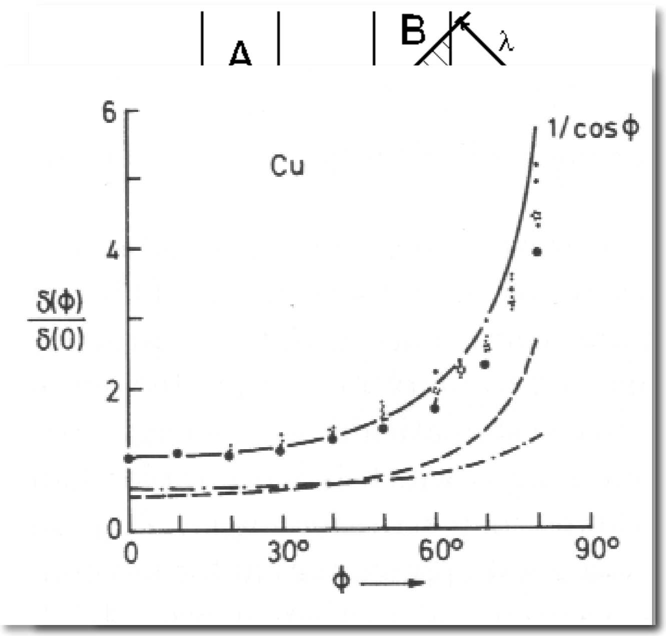
- Yield
  - Average number of secondary electrons produced per incident electron, 0.1-10

$$\delta = \frac{\bar{N}_{secondary}}{N_{primary}}$$

  - Strongly dependent on material, surface structure, angle of incidence, energy of incident electron (V_{acc})

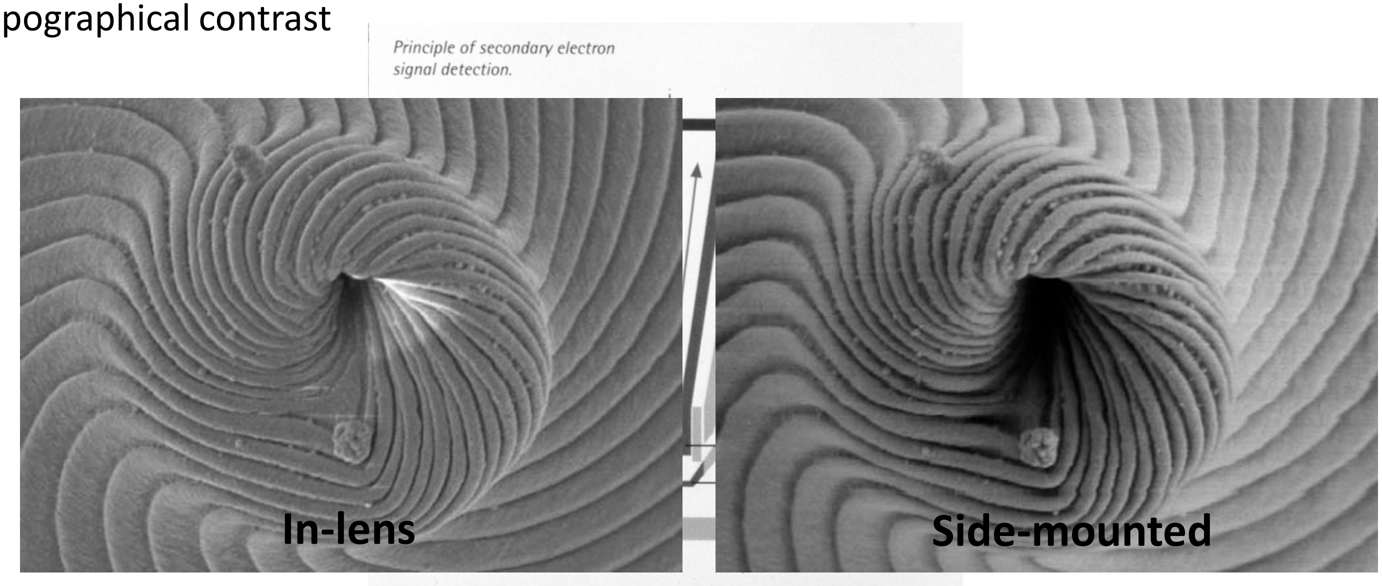
Secondary Electron

- Yield
  - Large at specimen edge due to edge effect → contrast at edge
  - Yield larger for inclined incidence as volume from which SE can escape is proportional to 1/cosθ
  - SE yield sensitive to surface detail
  - Plot of yield against specimen angle relative to primary beam follows 1/cos curve



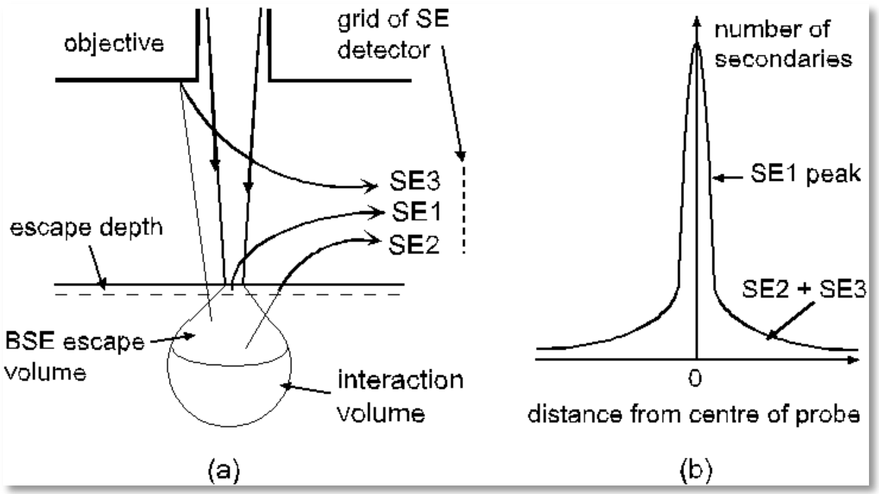
Secondary Electron

- Yield
  - SE detector usually located to one side of the beam column
  - Surface features tilted towards detector appear particularly bright
  - This fact can be used to distinguish between raised features and depressions
  - Characteristic three-dimensional appearance of the SE image with easy-to-interpret topographical contrast



Secondary Electron

- SE by BSE
  - Primary incident beam → SE1, independent of V_{acc}
  - BSE as they leave the specimen → SE2
  - BSE colliding with chamber or lens system → SE3
  - SE2 and SE3 yield depends on V_{acc}

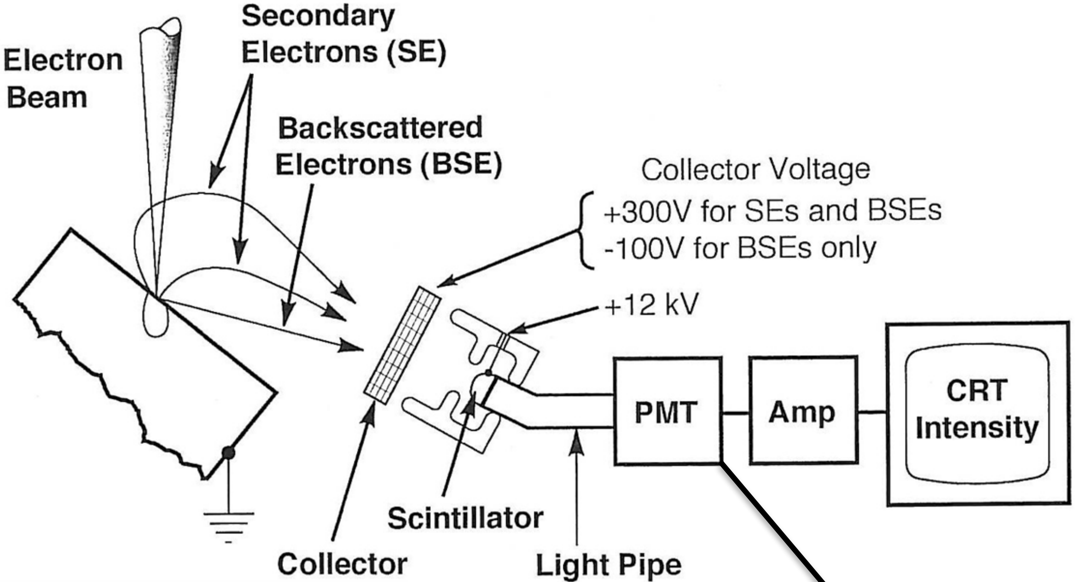


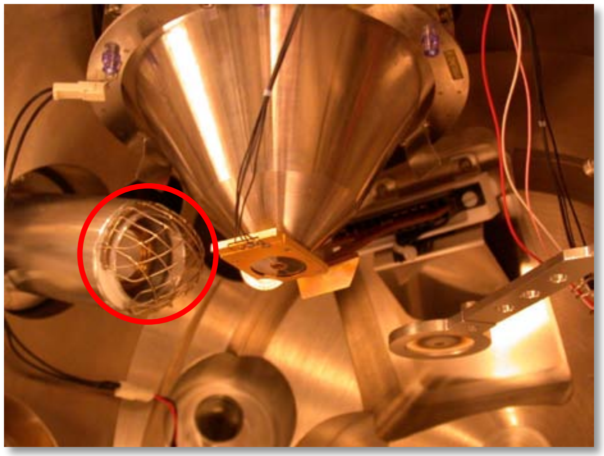
Everhart-Thornley Detector

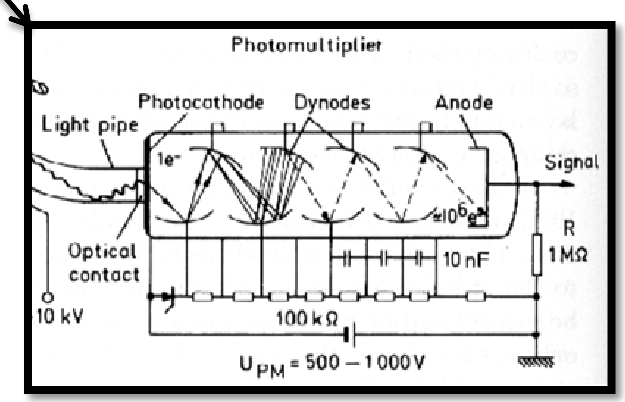
- Simplest scheme
  - Collect SE using positively-biased electrode
  - Amplify resulting current gives SE signal
  - Weak, low SNR
- Everhart-Thornley Detector
  - 1960[1], scintillator-photomultiplier system
  - Amplifies SE signal and improves SNR through electron → photon → photoelectron → SE conversion process

1. Everhart, T.E. and R.F.M. Thornley, Journal of Scientific Instruments, **37** (7): 246–248 (1960)

Everhart-Thornley Detector





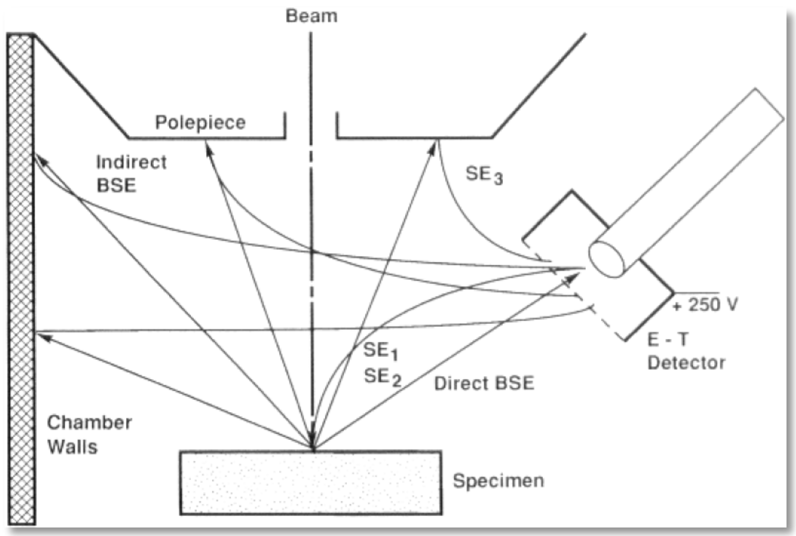


Everhart-Thornley Detector

- Photomultiplier tube
  - Entrance coated with material of low work function, absorbs photons from scintillator and emits low-E photoelectrons (photocathode)
  - Photoelectrons accelerate towards dynodes at positive bias (~+100 V) with high yield coating
  - Accelerated photoelectrons generate SE at dynode, giving off excess electrons
  - SE repeatedly accelerated towards N successive dynodes biased at ~+100 V positive with respect to the last, producing more excess SE.
  - Scintillator signal amplified by $(\delta)^N$, typically 10^6
  - Total effective amplification of PM/scintillator combination typically 10^8

Everhart-Thornley Detector

- Functions as inefficient BSE detector
  - LoS only, wire-mesh cannot attract high-E BSE electrons moving in other directions
  - Bias Faraday cage at negative V and/or switch off scintillator bias to exclude SE detection
- Detects SE2 and SE3 which contain information on BSE



Summary

- SE are low energy surface electrons emitted as a result of inelastic scattering of primary incident electrons by specimen atoms
- SE yield is sensitive to surface detail, gives high-resolution stereoscopic image of specimen surface
- Detection of SE achieved in most commercial SEM by side-mounted Everhart-Thornley detector, a scintillator/photomultiplier construct which amplifies the SE signal through a series of photon-electron conversions/amplification to achieve high SNR