Basic Principles

Auger electron spectroscopy (AES) is a surface analysis technique.

AES uses an electron beam to eject an electron.

AES analyzes the kinetic energy, E_k, of an electron to determine its binding energy, E_b.

E_b is found from the following equation:

$$E_b = h\nu - E_k + \Delta\phi$$

where hν is the energy of the incident photon and $\Delta\varphi$ is the difference in work function between the sample and the detector material (Young).

Spectrum of data collected with AES.

The E_b is dependent on the electronic environment and the nucleus of that element (Fe^{3+} versus Fe^0). The E_k is different and can therefore distinguish the oxidation states.

Analysis spot size is roughly 10 nm while the collection depth is limited to 1-5 nm.

Auger Process

An Auger electron comes from a cascade of events. First, an electron beam comes in with sufficient energy to eject a core electron creating a vacancy. A secondary electron (imaging electron) of higher energy drops down to fill the vacancy and emits sufficient energy to eject a tertiary electron (Auger electron) from a higher shell.

Schematic of the Auger process.

The shells from which the electrons move from lowest to highest energy are described as the K shell, L shell, and M shell.

The K shell represents the 1s orbital, the L shell represents the 2s and 2p orbitals, and the M shell represents the 3s, 3p, and 3d orbitals.

The peak seen in the spectrum is labeled according to the shells involved in the movement of the electrons. For example, an electron ejected from a gold atom could be labeled as Au KLL or Au KLM.

The peaks are characteristic of the element and of the chemical environment.

Instrumentation

AES must be performed under pressures of 10^{-3} pascal (Pa). This can be achieved using ultra-high-vacuum systems with typical pressures of 10^{-8} to 10^{-9} Pa.

Electron sources including tungsten filament (electron beam diameter of a few micrometers), LaB_6 electron sources (beam diameter less than 40 nm), and Schottky barrier filaments (beam diameter 20 nm and high beam current density) (Turner).

Cylindrical mirror analyzers (CMA)

An electron gun is directed at the sample. An ejected electron enters the space between the inner and outer cylinders (IC and OC). The inner cylinder is at ground potential,

while the outer cylinder's potential is proportional to the kinetic energy of the electron. Due to its negative potential, the outer cylinder deflects the electron towards the electron detector. Only electrons within the solid angle cone are detected.

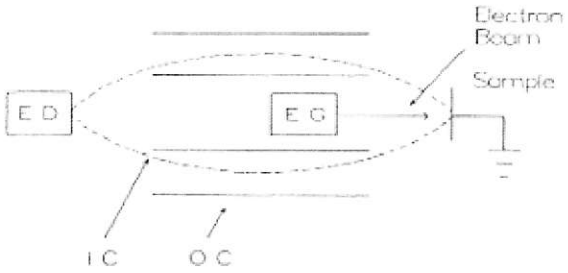

Figure 8.
A schematic cross-section of a CMA analyzer with a coaxial electron gun. Note that some CMSs have the electron gun independent of the analyzer. IC is the inner cylinder, OC is the outer cylinder, EG is the electron gun, and ED is the radiation detector.

Schematic of a CMA from Turner

Concentric hemispherical analyzer (CHA)

Three parts: (1) retarding and focusing input lens assembly (L), (2) inner and outer hemispheres (IH and OH), and (3) electron detector (ED).

Electrons ejected from the surface enter the input lens, which focuses the electrons and retards their energy for better resolution. Electrons then enter the hemispheres through an entrance slit. A potential difference is applied on the hemispheres so that only electrons with a small range of energy differences reach the exit. Finally, the electrons are analyzed by an electron detector.

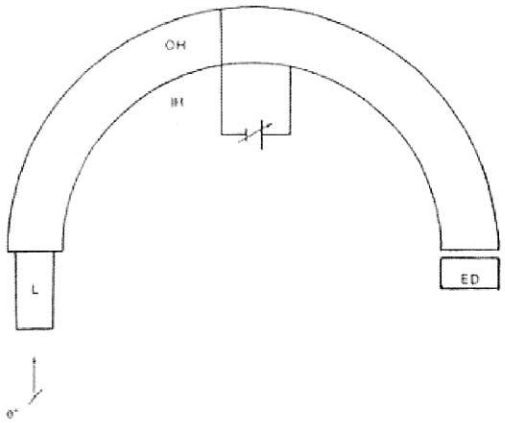

Figure 7.
A schematic cross-section of a CHA analyzer: L is the electron focusing and retardation lens, IH and OH are the inner and outer hemispherical sections, and ED is the electron detector.

Schematic of a CHA from Turner

Applications

AES has widespread use.

Used to study film growth and surface-chemical composition.

Depth profiling (Lüth). Depth is governed by the incident an collection angles, and the primary beam energy (Young).

Used for areas that require high spatial resolution which XPS cannot achieve.

Due to fast collection times, AES is used for quality control surface analyses in integrated circuit production lines.

Often used to analyze grain boundaries in metals and ceramics (Bubert).

Advantages

Simultaneously sputtering and collecting Auger data.

The depth profile does not have the problem of diffusion of hydrocarbons into the trenches. Thus, AES is better for depth profiles of reactive metals (ex: gold or any metal or semiconductor).

Limitations

AES destroys the sample with high-energy electrons.

During sputtering, it's possible to mix up different elements, changing the composition.

Detection limits

Charging of the electron beam on insulating samples can be a problem.

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