

Auger Electron Spectroscopy at IME

Background

Auger Electron Spectroscopy (AES or just Auger) is one of several surface analysis techniques capable of analysing the top few nanometres of a sample surface. Auger is usually used where we need to determine the elemental composition of a surface with good spatial resolution, better than 1 micrometre. Combined with an ion gun to sputter the surface Auger can also provide depth profiles. Surfaces are important since this is where materials meet and interact with the outside world; interfaces are where they meet and interact with each other. Typically surfaces dominate materials properties such as:

- Chemical reaction, particularly kinetics
- Barrier performance
- Adhesion/stiction
- Etching
- Surface electrical states
- Solderability

Auger provides similar compositional information to SEM/EDX but with much higher surface sensitivity, ie Auger analyses the top few nanometres whereas SEM/EDX typically analyses to top micrometre or so.

The effect which forms the basis of Auger analysis was discovered independently by Lise Meitner and Pierre Auger in the 1920's. Although the discovery was made and reported by Meitner in 1923, two years before Auger discovered the effect, it is Auger's name that is associated with it, possibly because of the political climate of Europe at the time, or possibly because of sexism. "Auger" is pronounced as the letters "OJ", but with the softer G associated with French pronunciation.

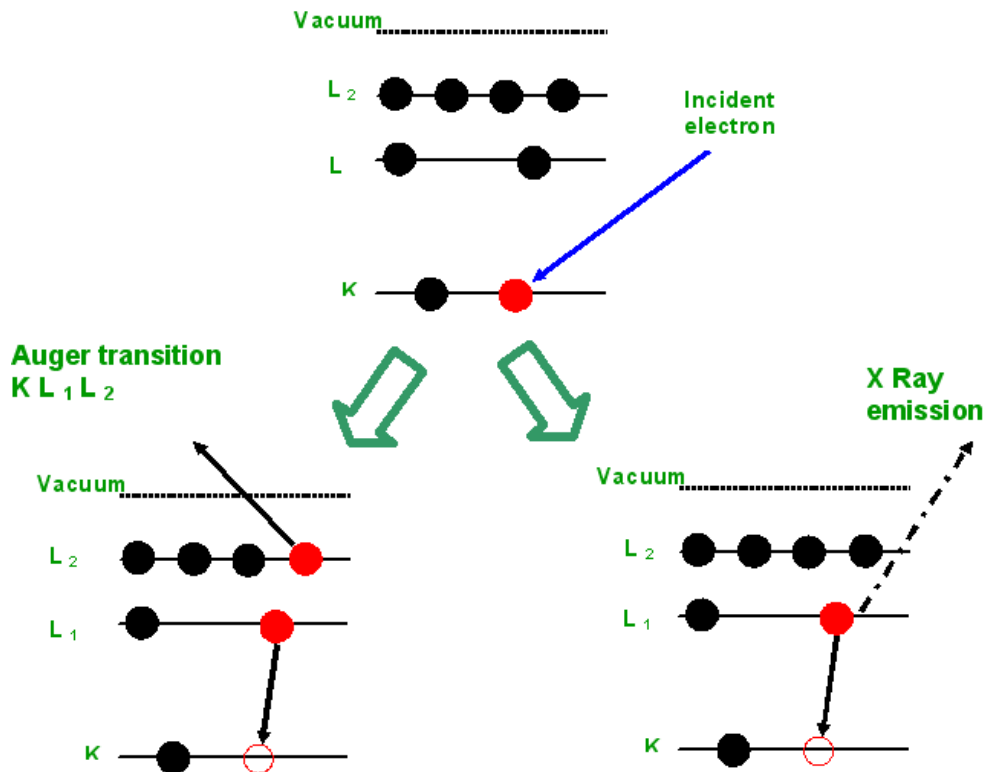
Principle – How does it work.

Auger spectroscopy can be considered as involving three basic steps :

- Atomic ionization (by removal of a core electron)
- Electron emission (the Auger process)
- Analysis of the emitted Auger electrons

Atomic ionisation is carried out in exactly the same way as in SEM/EDX using an electron beam with an energy typically between 3 & 25 keV.

The Auger process, and the competing X-ray emission process which forms the basis for EDX, are shown schematically below.



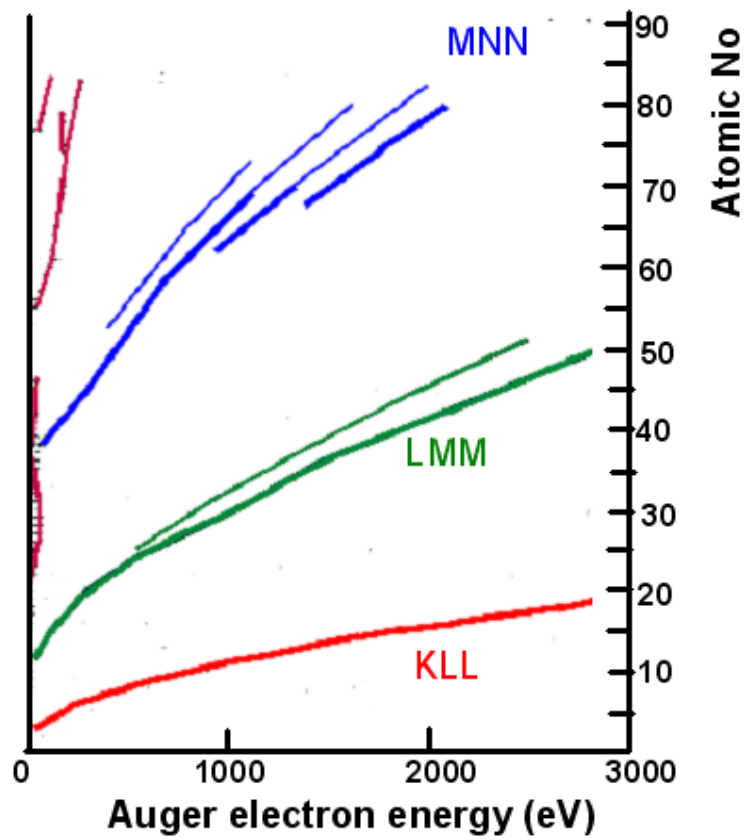
The energy of the Auger electron is given by:

$$E = E_K - E_{L1} - E_{L2} - \Phi$$

where Φ is the Work function

Note that L1 & L2 are in a charged ion

The energies of the major Auger transitions are given in the figure below. Note that they fall in the range 0- 2400 eV. In general at low energies auger emission has a high probability relative to X-ray emission. The converse is true at higher energies.



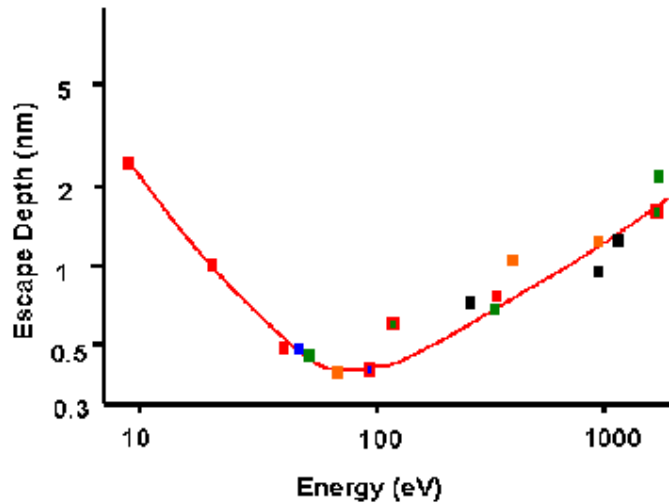
Auger Electron energies

The high surface sensitivity of Auger is due to the short mean free path of electrons.

Escape depth, Mean Free Path of electrons (λ)

$$N = N_0 \exp(-z/\lambda)$$

From Seah & Dench

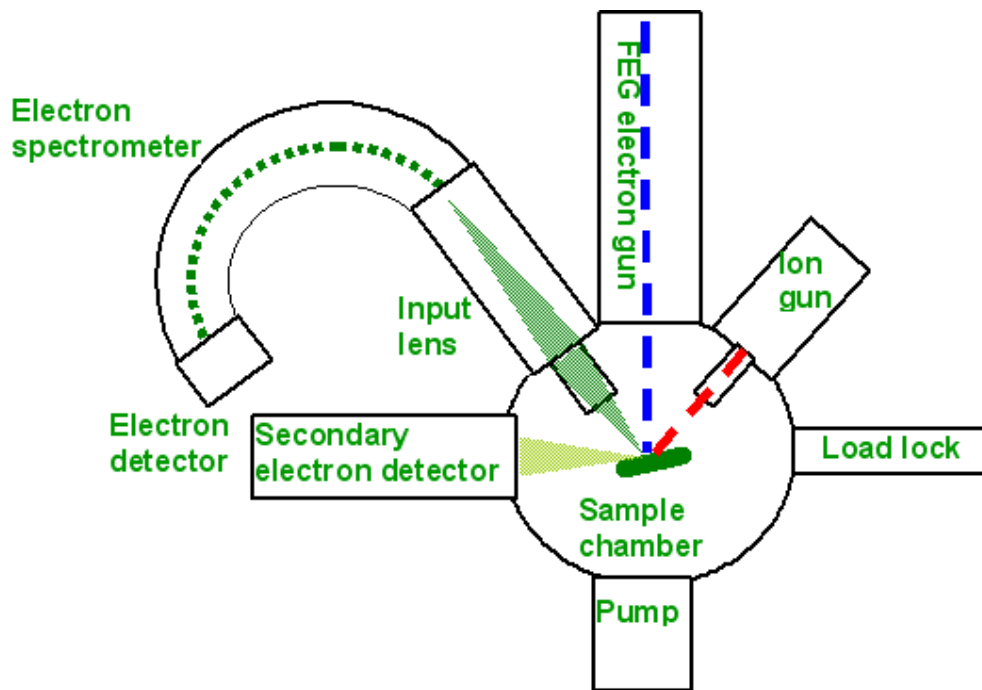


So, depending on the energy of the Auger transition the information depth ranges from less than 1 nanometre to a few nanometres.

The Auger electrons emitted from the surface are analysed using an electron spectrometer, usually fitted with an input lens to improve sensitivity, and are detected by a channeltron electron multiplier.

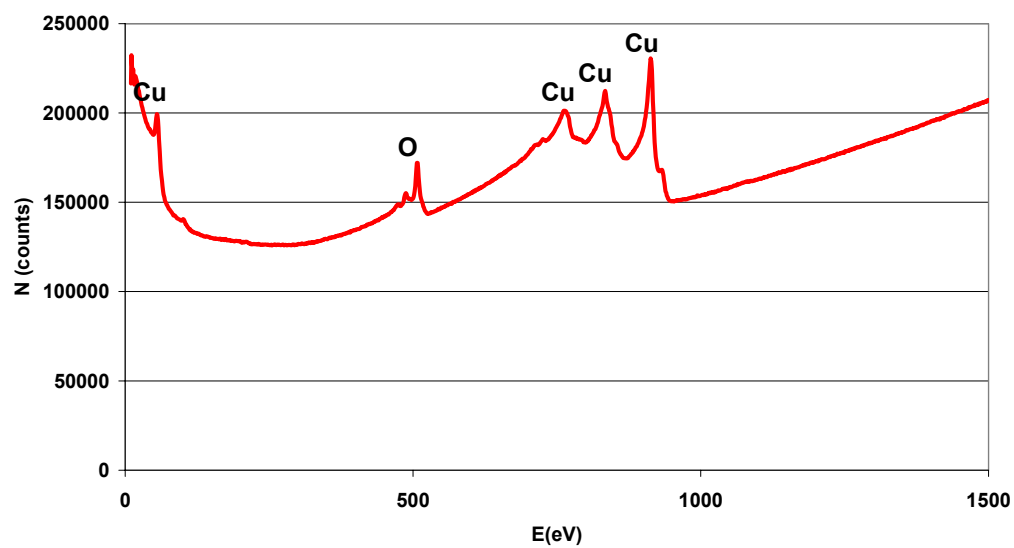
A schematic of a typical Auger system such as that used at IME is shown below:

Schematic of Auger analysis system

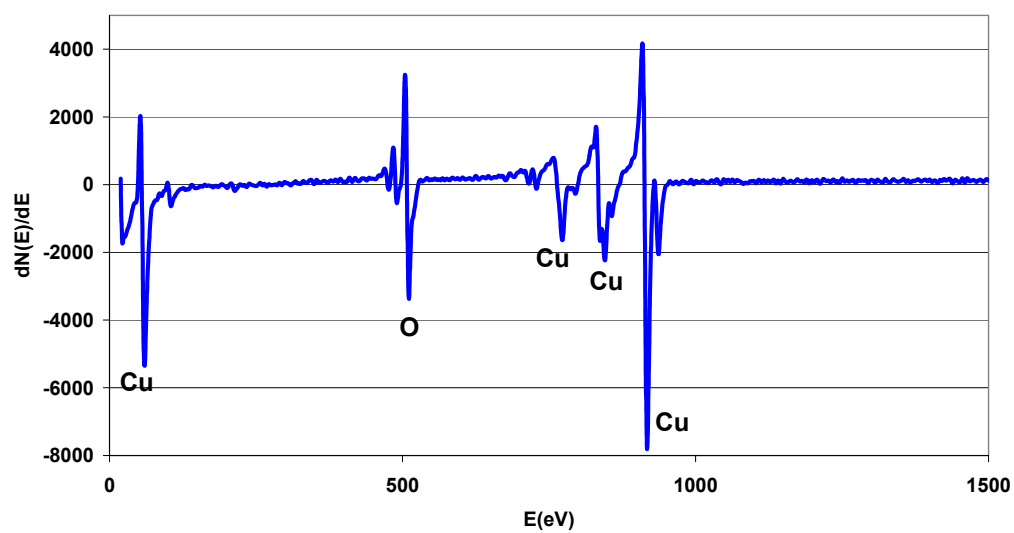


A typical Auger spectrum has a large background due to inelastically scattered secondary electrons on which are superimposed the characteristic Auger peaks of the elements present. Because of this large background and also for historical reasons, because of the lock-in amplification techniques that were used to detect the signal in the earlier instruments, it is very common to present Auger spectra in differentiated form.

Copper Spectrum $N(E)$



Copper Spectrum $dN(E)/dE$



It is more difficult to quantify Auger spectra compared with EDX spectra so usually the relative sensitivity factor approach is used to obtain semi-quantitative results.

This is based on the equation

$$X_i = \frac{I_i / S_i}{\sum_{j=1..n} I_j / S_j}$$

Where X_i is at% element i
 I_i intensity of peak i
 I_j intensity of peak j
 S_i RSF for i
 S_j RSF for j
 n no. of elements

Specifications and operation modes

The general capabilities of the Auger technique are:

- **Surface sensitive - 1 to 5 nm**
- **Spatial resolution < 1 μm**
- **Can detect all elements except H & He**
- **Detection limit typically approx 1% of a monolayer**
- **Depth profiles to approx 1 μm deep**
- **Chemical information (limited)**
- **Semiquantitative (usually)**

Auger data are typically presented as spectra, depth profiles or element maps.

IME has a JEOL 7800F instrument with the following specification:

Electron optics

- Schottky field emitter
- Accelerating voltage: 0.5 to 25 kV
- Probe current : 10^{-11} to 10^{-7} A
- 2-stage magnetic field condenser lens, single-stage objective lens
- 4 apertures, motor driven
- Spatial resolution in analysis mode approx 0.2 μm

Analysis system

- Hemispherical analyzer / input lens
- 7 parallel channel electron multipliers

Vacuum: 5×10^{-8} Pa

Specimen stage: all motor-driven

X & Y: $\pm 10\text{mm}$, Z: $\pm 6\text{mm}$, Tilt: 0 to 90° , Rotation: 360°

Ion Gun

Argon gas - Automatic pressure control

0.1 to 4 kV

Max. $3,000\ \mu\text{Acm}^{-2}$

Etch rate typically 30 nm/ minute

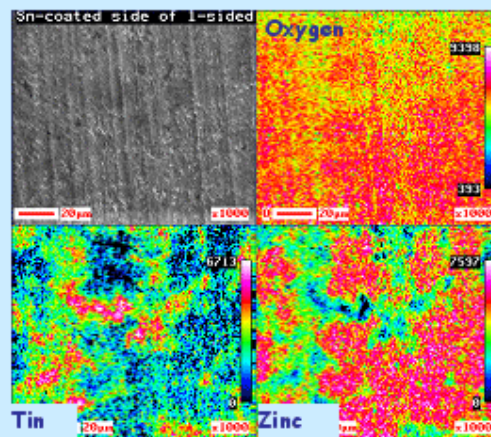
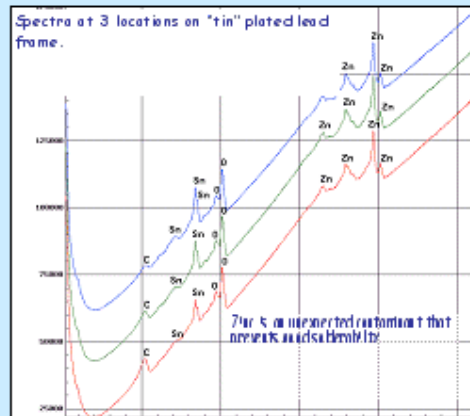
Sample requirements

Maximum sample size is approx 50 mm across and 5 mm thick but more commonly samples are less than 10 mm square and 1 mm thick. It is important that the samples are compatible with an Ultra High Vacuum (UHV) environment which may preclude some organic materials. Because Auger uses an electron beam to excite the samples, conducting samples are generally much easier to analyse although insulating materials may be suitable under certain conditions. Because of the sensitivity of the Auger technique to surface contamination, it is very important that samples are prepared and stored in clean conditions if analysis of the surface is to be meaningful.

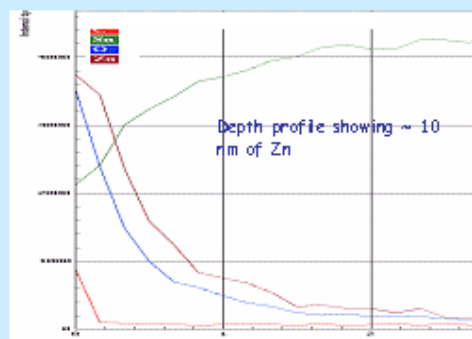
Applications

Case studies

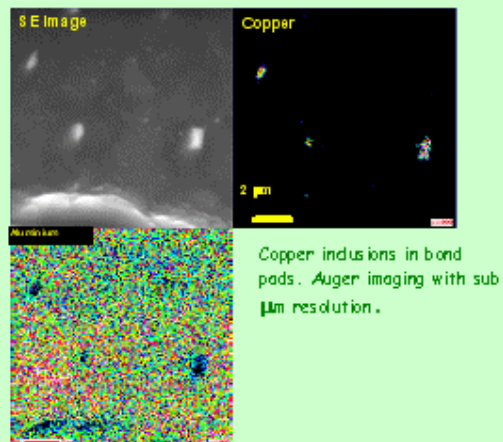
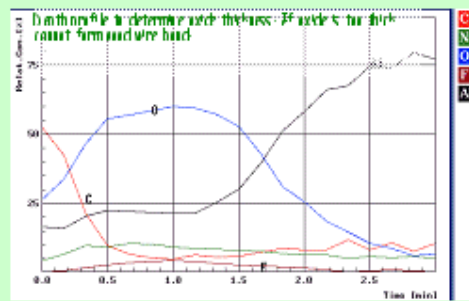
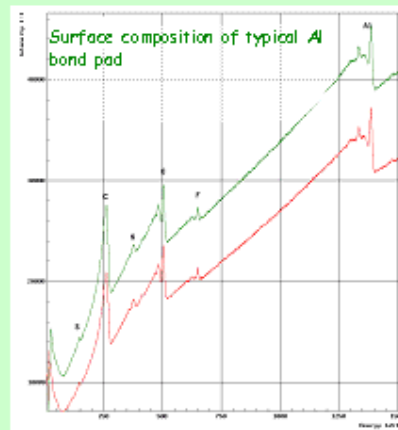
Soldering



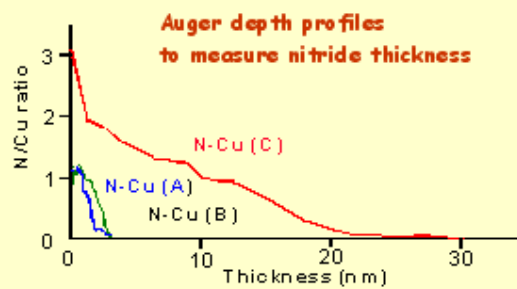
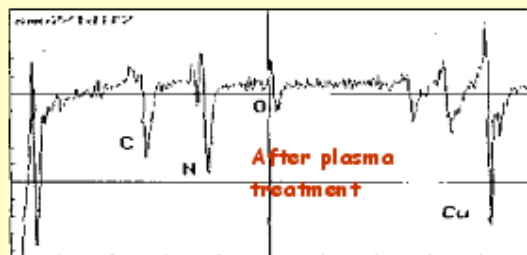
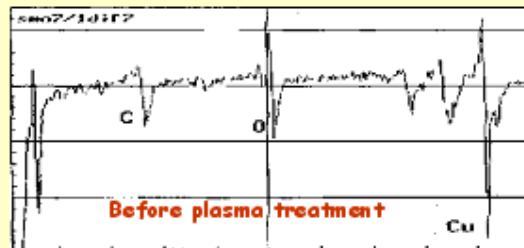
Auger maps shows Zn distribution



Bond pad Analysis



Plasma nitridation of Cu leadframe



Nitrided copper resists oxidation

