Chap 6. Surface Analysis with Electron Spectroscopy

- Electron spectroscopy for chemical analysis (ESCA)
  - **X-ray photoelectron spectroscopy (XPS)**
  - Ultraviolet photoelectron spectroscopy (UPS)

- **Auger electron spectroscopy (AES):**

Surface Analysis

- Surface & interface controls many aspects of chemistry
  - Catalysts
  - Corrosion
  - Thin films
- Surfaces
  - Boundary between solid and other phase (Gas, vacuum, liquid)
  - Surface differs from solid bulk

Decarburised surface layer on the seal rim. Preferential grain boundary oxidation evident

Surface Analysis Techniques for Materials

- **Electron Spectroscopy for Chemical Analysis (ESCA / XPS / UPS)**
- **Auger Electron Spectroscopy (AES)**
- **Secondary Ion Mass Spectroscopy (SIMS)**
- **Rutherford Backscattering Spectroscopy (RBS)**
- **Scanning Probe Microscopy (AFM)**
- **Scanning Electron Microscopy (SEM)**
- Surface Plasmon Resonance (SPR)
- Optical Imaging and Spectroscopy (microscopy, TIRF)
- Ellipsometry
- Near Edge X-ray Absorption Fine Structure (NEXAFS)
- Infrared Spectroscopy (FTIR)
- Many more…

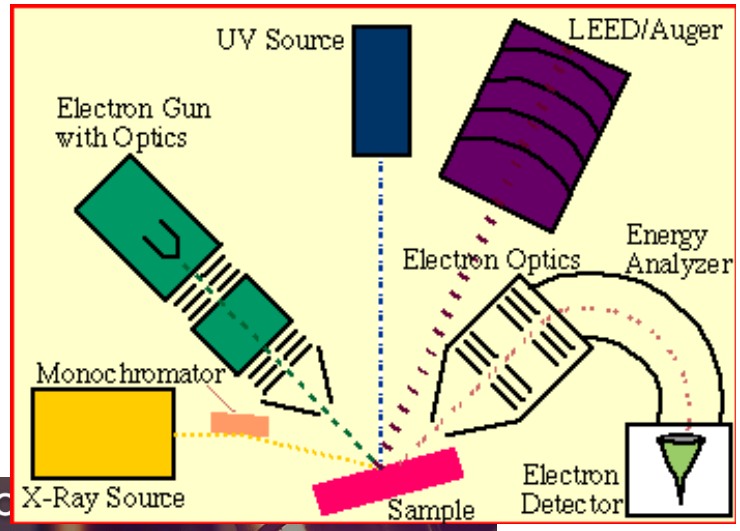
Photoelectric Techniques

- Modes
  - XPS (x-ray photoelectron spectroscopy)
  - UPS (UV photoelectron spectroscopy)
  - Auger Spectroscopy
- Probe: Photons (x-rays, UV)/ sometime electrons
- Signal: Electrons
- Information: Elemental Composition and molecular environment
- Sample: Any that can withstand ultra-high vacuum
- Depth: 100 Å (1000+ Å in destructive mode)
- Spatial Resolution: μm^2
- Sensitivity: 1% error not unreasonable
- Relative Cost: Very Expensive
- Other
  - Semi-quantitative to quantitative
  - Imaging modes

Electron spectroscopy can be used for the identification of all of the elements in the periodic table except for H and He.

Photoelectron Spectroscopy

- Electron spectroscopy for chemical analysis (ESCA)
  - X-ray photoelectron spectroscopy (XPS): The most common type is based upon the irradiation of the sample surface with monochromatic X-radiation.
  - Ultraviolet photoelectron spectroscopy (UPS): A monochromatic beam of ultraviolet radiation causes the ejection of electrons form the analyte.
- Auger electron spectroscopy (AES): Auger spectra are most commonly excited by a beam of electrons, although X-rays are also used.



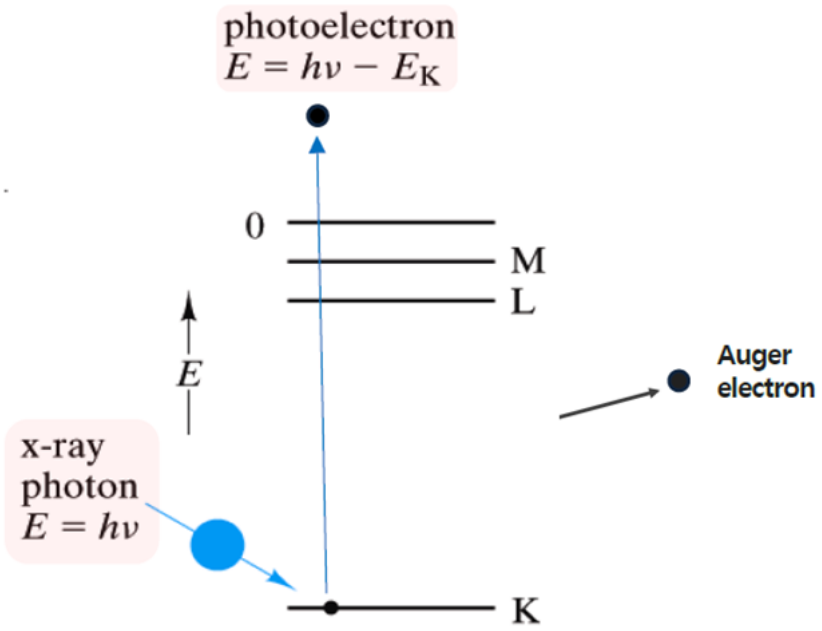
Incident beams: photons (UV, x-ray), electrons

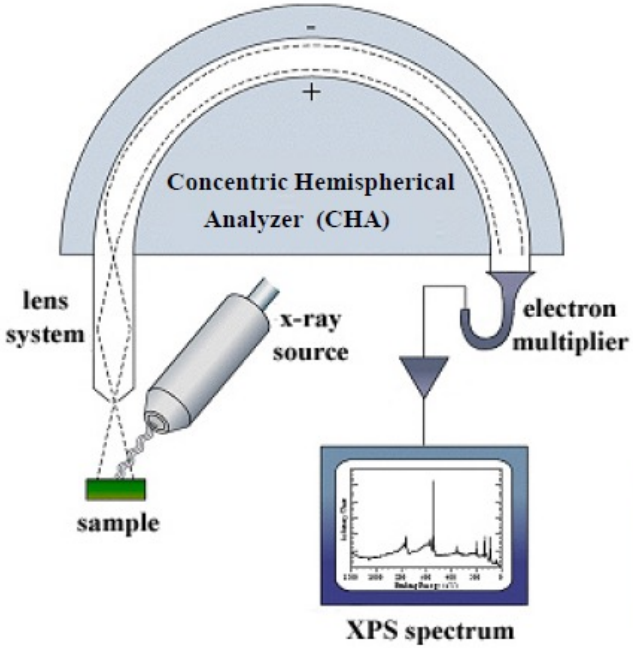
→ Secondary beam: electrons

Photoemission as an analytical tool

Kai Siegbahn, Nobel Prize 1981

6.1. X-Ray Photoelectron Spectroscopy (XPS)



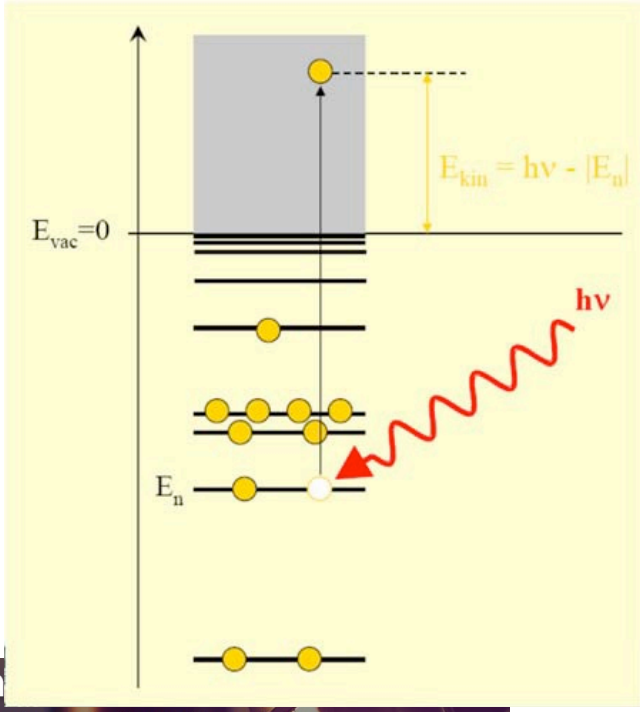


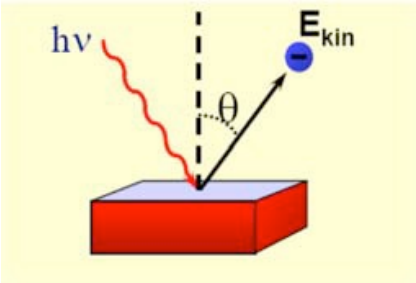
Depth resolution	Lateral resolution
0.5 ~ 5 nm	~ 1 mm (microXPS ~3 μm)

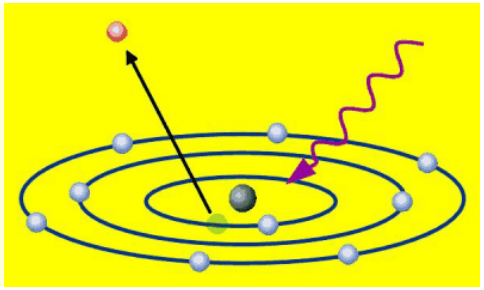
X-ray source: Al Kα (1486.6 eV), Mg Kα (1253.6 eV)

6.1. X-Ray Photoelectron Spectroscopy (XPS)

- The energy of the incident photon is so great that electrons are ejected from inner cores of the atoms.
- Core ionization energies are generally insensitive to the bonds between atoms so XPS gives lines characteristic of the elements present in a compound.





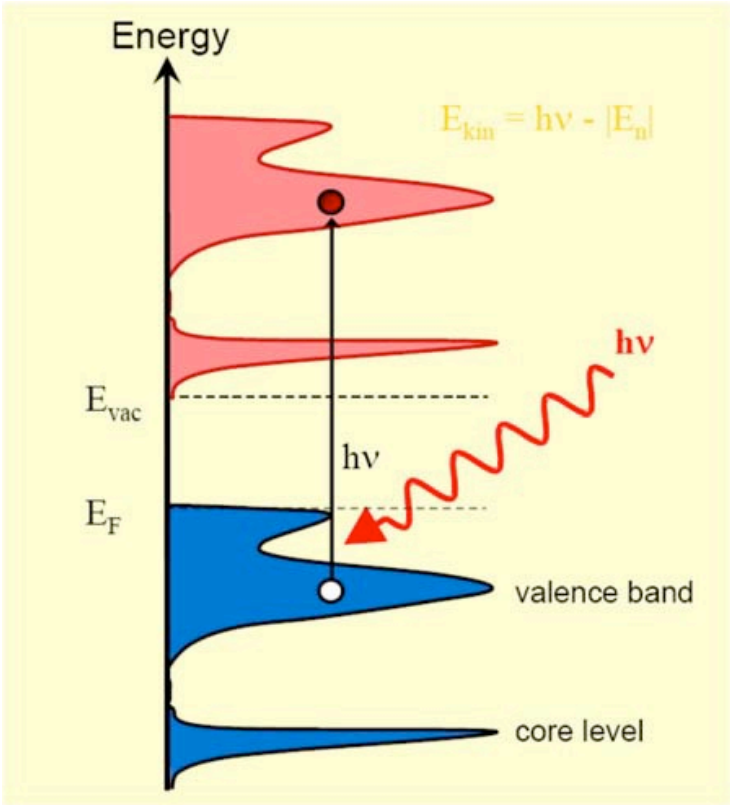


- **Photoelectric Effect**: induced by x-ray irradiation
- Electronic binding energy can be determined from kinetic energy of photoelectron:

$$|E_n| = h\nu - E_{kin}$$

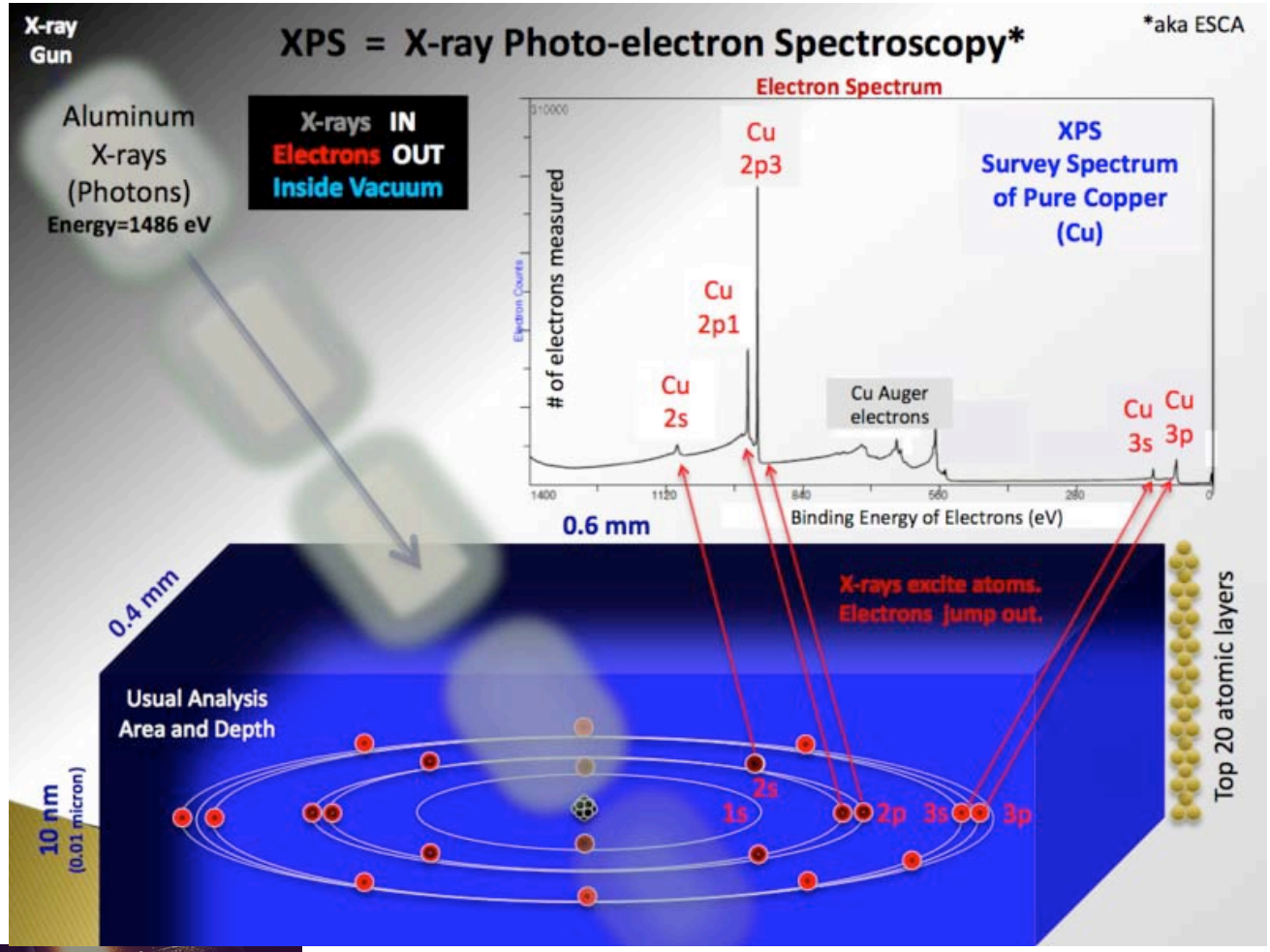
element specific !!

X-Ray Photoelectron Spectroscopy (XPS)



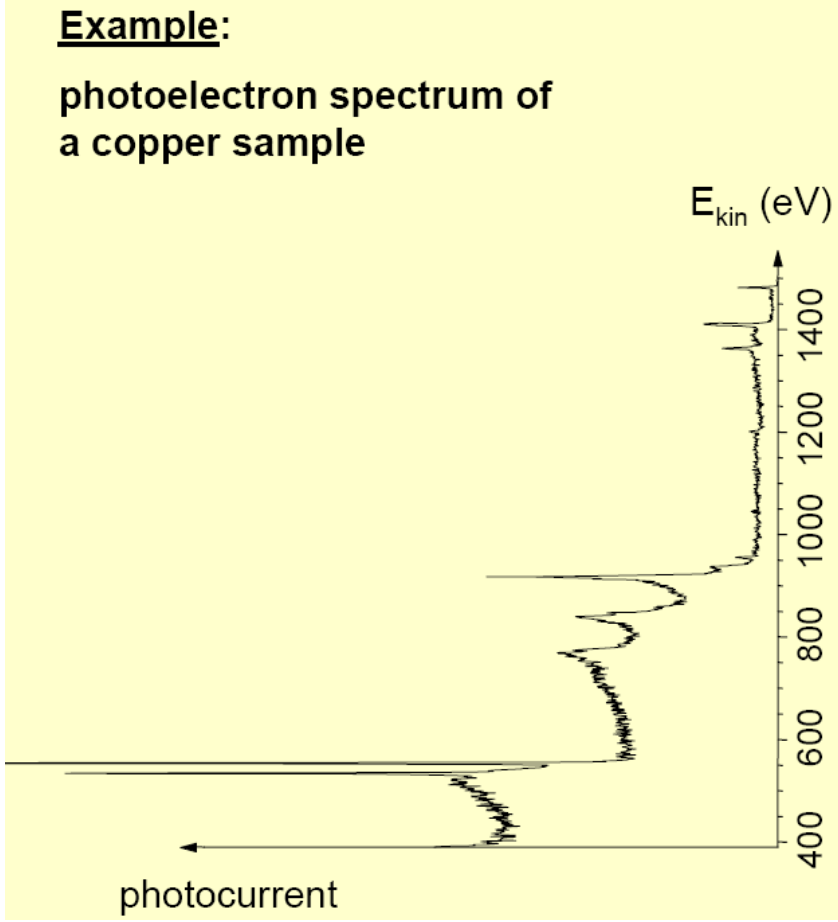
→ energy distribution of photoelectrons is image of energy level distribution in the atom, shifted by photon energy !

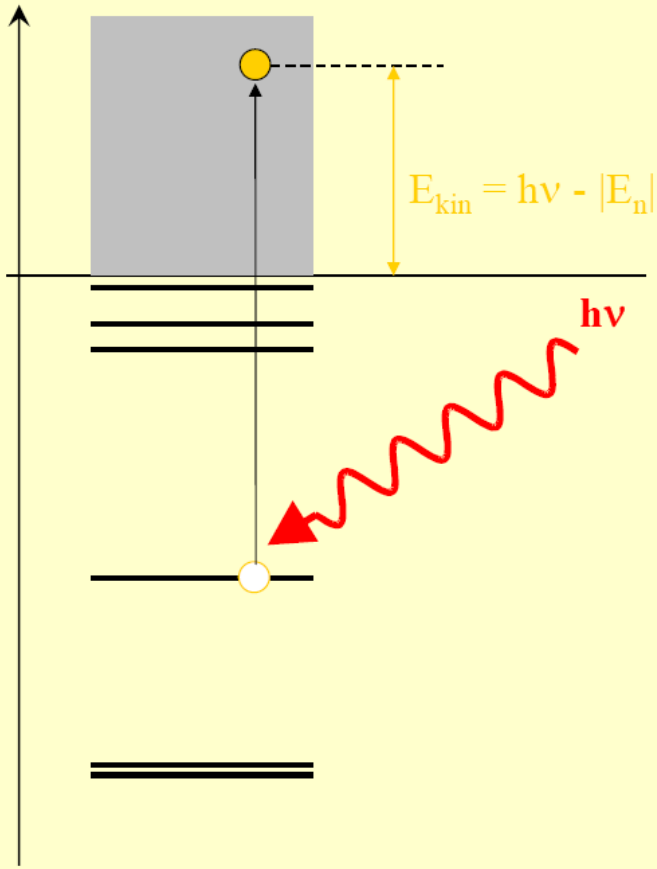
- Detection limits
  - parts per million (ppm) at special conditions
  - parts per thousand range for most of the elements
- It cannot detect hydrogen (Z = 1) or helium (Z = 2) because the diameter of these orbitals is so small, reducing the catch probability to almost zero.

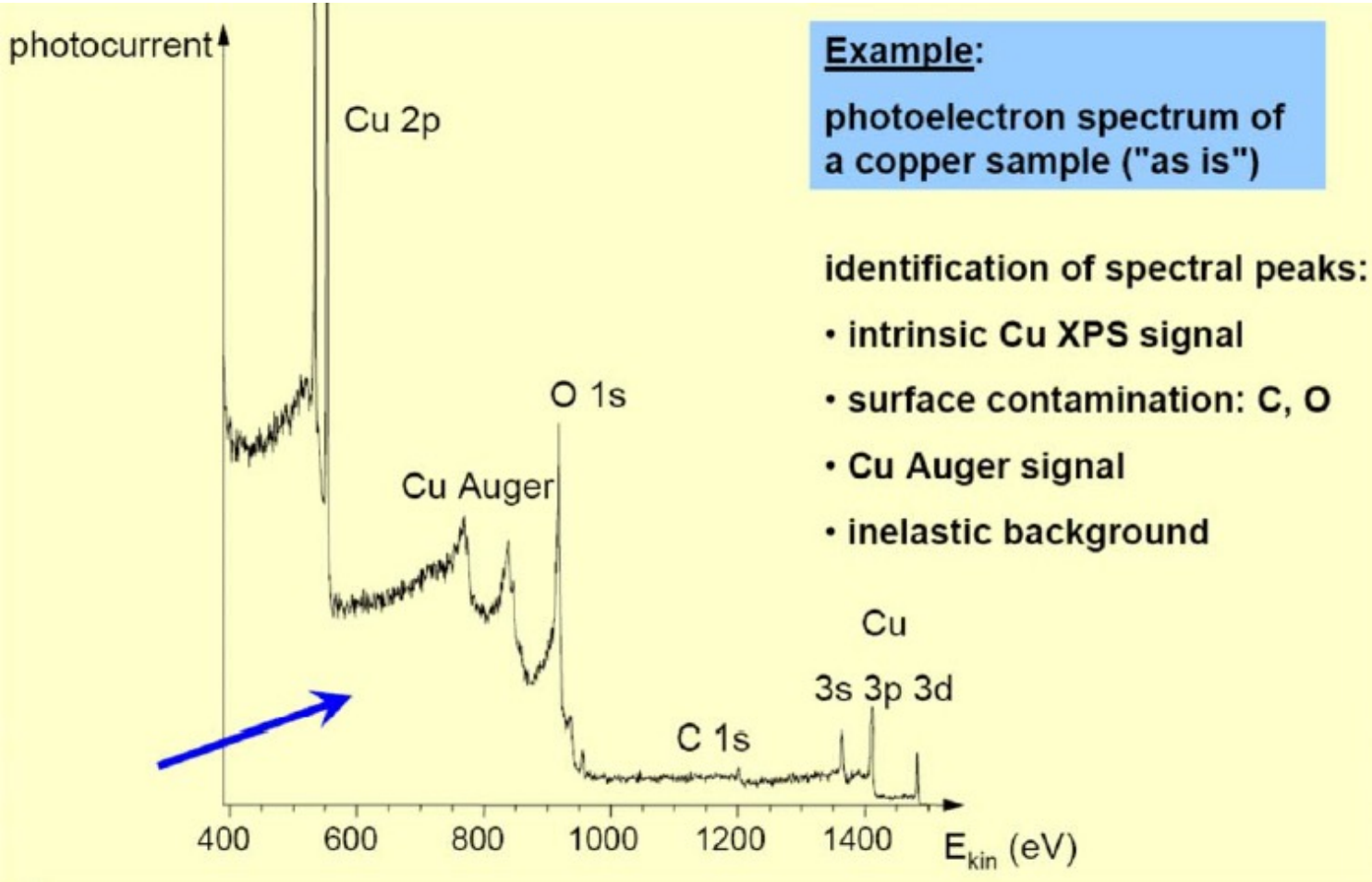

X-ray Gun
XPS = X-ray Photo-electron Spectroscopy*
*aka ESCA
Aluminum X-rays (Photons)
Energy=1486 eV
X-rays IN
Electrons OUT
Inside Vacuum
Electron Spectrum
# of electrons measured
Cu 2p3
Cu 2p1
Cu 2s
Cu Auger electrons
Cu 3s
Cu 3p
XPS Survey Spectrum of Pure Copper (Cu)
Binding Energy of Electrons (eV)
0.6 mm
0.4 mm
X-rays excite atoms. Electrons jump out.
Usual Analysis Area and Depth
10 nm (0.01 micron)
2s
1s
2p
3s
3p
Top 20 atomic layers

Example:

photoelectron spectrum of a copper sample







Example:

photoelectron spectrum of a copper sample ("as is")

identification of spectral peaks:

- **intrinsic Cu XPS signal**
- **surface contamination: C, O**
- **Cu Auger signal**
- **inelastic background**

Binding Energies of Some Elements

Z	El	$1s_{1/2}$ K	$2s_{1/2}$ L_1	$2p_{1/2}$ L_2	$2p_{3/2}$ L_3	$3s_{1/2}$ M_1	$3p_{1/2}$ M_2	$3p_{1/2}$ M_3	$3d_{3/2}$ M_4	$3d_{5/2}$ M_5
1	H	14								
2	He	25								
3	Li	55								
4	Be	111								
5	B	188			5					
6	C	284			6					
7	N	399			9					
8	O	532	24		7					
9	F	686	31		9					
10	Ne	867	45		18					
11	Na	1072	63		31	1				
12	Mg	1305	89		52	2				
13	Ml	1560	118	74	73	1				
14	Si	1839	149	100	99	8				
15	P	2149	189	136	135	16	10			
16	S	2472	229	165	164	16	8			
17	Cl	2823	270	202	200	18	7			
18	Ar	3202	320	247	245	25	12			
19	K	3608	377	297	294	34	18			
20	Ca	4038	438	350	347	44	26			5
21	Sc	4493	500	407	402	54	32			7
22	Ti	4965	564	461	455	59	34			3

http://jpkc.whut.edu.cn/web18/main/wangluo/webelements/default.htm

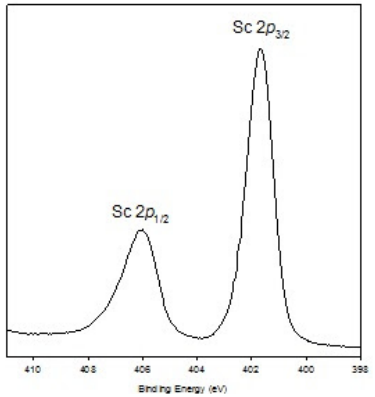
Table 1-1. *Electron binding energies, in electron volts, for the elements in their natural forms.*

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$	N_3 $4p_{3/2}$
1 H	13.6											
2 He	24.6*											
3 Li	54.7*											
4 Be	111.5*											
5 B	188*											
6 C	284.2*											
7 N	409.9*	37.3*										
8 O	543.1*	41.6*										
9 F	696.7*											
10 Ne	870.2*	48.5*	21.7*	21.6*								
11 Na	1070.8†	63.5†	30.65	30.81								
12 Mg	1303.0†	88.7	49.78	49.50								
13 Al	1559.6	117.8	72.95	72.55								
14 Si	1839	149.7*b	99.82	99.42								
15 P	2145.5	189*	136*	135*								
16 S	2472	230.9	163.6*	162.5*								
17 Cl	2822.4	270*	202*	200*								
18 Ar	3205.9*	326.3*	250.6†	248.4*	29.3*	15.9*	15.7*					
19 K	3608.4*	378.6*	297.3*	294.6*	34.8*	18.3*	18.3*					
20 Ca	4038.5*	438.4†	349.7†	346.2†	44.3 †	25.4†	25.4†					
21 Sc	4492	498.0*	403.6*	398.7*	51.1*	28.3*	28.3*					
22 Ti	4966	560.9†	460.2†	453.8†	58.7†	32.6†	32.6†					
23 V	5465	626.7†	519.8†	512.1†	66.3†	37.2†	37.2†					
24 Cr	5989	696.0†	583.8†	574.1†	74.1†	42.2†	42.2†					
25 Mn	6539	769.1†	649.9†	638.7†	82.3†	47.2†	47.2†					
26 Fe	7112	844.6†	719.9†	706.8†	91.3†	52.7†	52.7†					
27 Co	7709	925.1†	793.2†	778.1†	101.0†	58.9†	59.9†					
28 Ni	8333	1008.6†	870.0†	852.7†	110.8†	68.0†	66.2†					
29 Cu	8979	1096.7†	952.3†	932.7	122.5†	77.3†	75.1†					
30 Zn	9659	1196.2*	1044.9*	1021.8*	139.8*	91.4*	88.6*	10.2*	10.1*			
31 Ga	10367	1299.0*b	1143.2†	1116.4†	159.5†	103.5†	100.0†	18.7†	18.7†			
32 Ge	11103	1414.6*b	1248.1*b	1217.0*b	180.1*	124.9*	120.8*	29.8	29.2			
33 As	11867	1527.0*b	1359.1*b	1323.6*b	204.7*	146.2*	141.2*	41.7*	41.7*			
34 Se	12658	1652.0*b	1474.3*b	1433.9*b	229.6*	166.5*	160.7*	55.5*	54.6*			
35 Br	13474	1782*	1596*	1550*	257*	189*	182*	70*	69*			
36 Kr	14326	1921	1730.9*	1678.4*	292.8*	222.2*	214.4	95.0*	93.8*	27.5*	14.1*	14.1*
37 Rb	15200	2065	1864	1804	326.7*	248.7*	239.1*	113.0*	112*	30.5*	16.3*	15.3 *
38 Sr	16105	2216	2007	1940	358.7†	280.3†	270.0†	136.0†	134.2†	38.9†	21.3	20.1†
39 Y	17038	2373	2156	2080	392.0*b	310.6*	298.8*	157.7†	155.8†	43.8*	24.4*	23.1*
40 Zr	17998	2532	2307	2223	430.3†	343.5†	329.8†	181.1†	178.8†	50.6†	28.5†	27.1†
41 Nb	18986	2698	2465	2371	466.6†	376.1†	360.6†	205.0†	202.3†	56.4†	32.6†	30.8†
42 Mo	20000	2866	2625	2520	506.3†	411.6†	394.0†	231.1†	227.9†	63.2†	37.6†	35.5†
43 Tc	21044	3043	2793	2677	544*	447.6	417.7	257.6	253.9*	69.5*	42.3*	39.9*
44 Ru	22117	3224	2967	2838	586.1*	483.5†	461.4†	284.2†	280.0†	75.0†	46.3†	43.2†
45 Rh	23220	3412	3146	3004	628.1†	521.3†	496.5†	311.9†	307.2†	81.4*b	50.5†	47.3†
46 Pd	24350	3604	3330	3173	671.6†	559.9†	532.3†	340.5†	335.2†	87.1*b	55.7†a	50.9†
47 Ag	25514	3806	3524	3351	719.0†	603.8†	573.0†	374.0†	368.3	97.0†	63.7†	58.3†

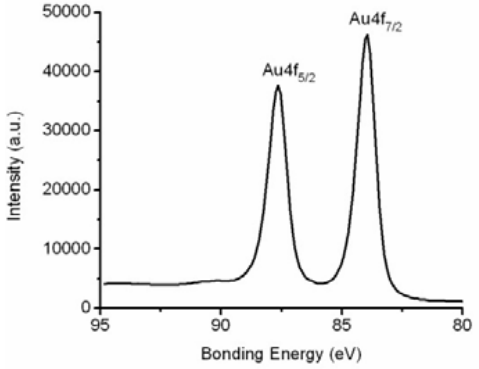
Spin Orbit Splitting

- For p, d and f peaks, two peaks are observed: a doublet with the two possible states having different binding energies. The values of spin orbital splitting of a core level of an element in different compounds are nearly the same.
- The peaks will also have specific area ratios based on the degeneracy of each spin state.
- **Spin orbital splitting and peak area ratios assist in element identifications.**

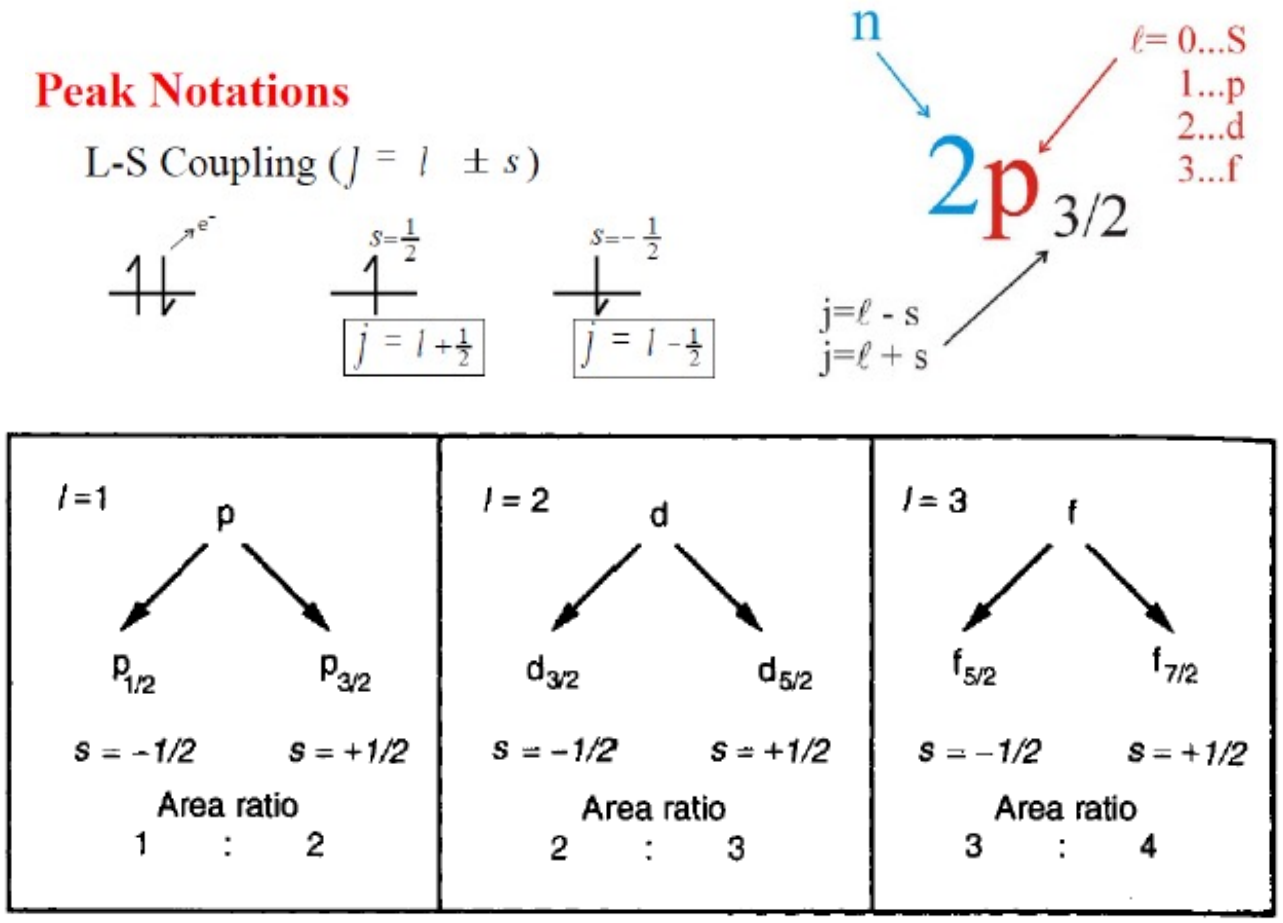
Spin-orbit splitting in the Sc 2*p* spectrum of Sc_2O_3



Au 4f spectrum



Spin Orbit Splitting



Three-Step Model of Photoemission

1. photoexcitation in the solid

- takes place within penetration depth of x-ray radiation (> μm)
- energy conservation: $E_{kin} = h\nu - E_B$

2. transport of photoelectron to the surface

- photoelectrons from deep within the solid experience inelastic scattering with other electrons and loose kinetic energy

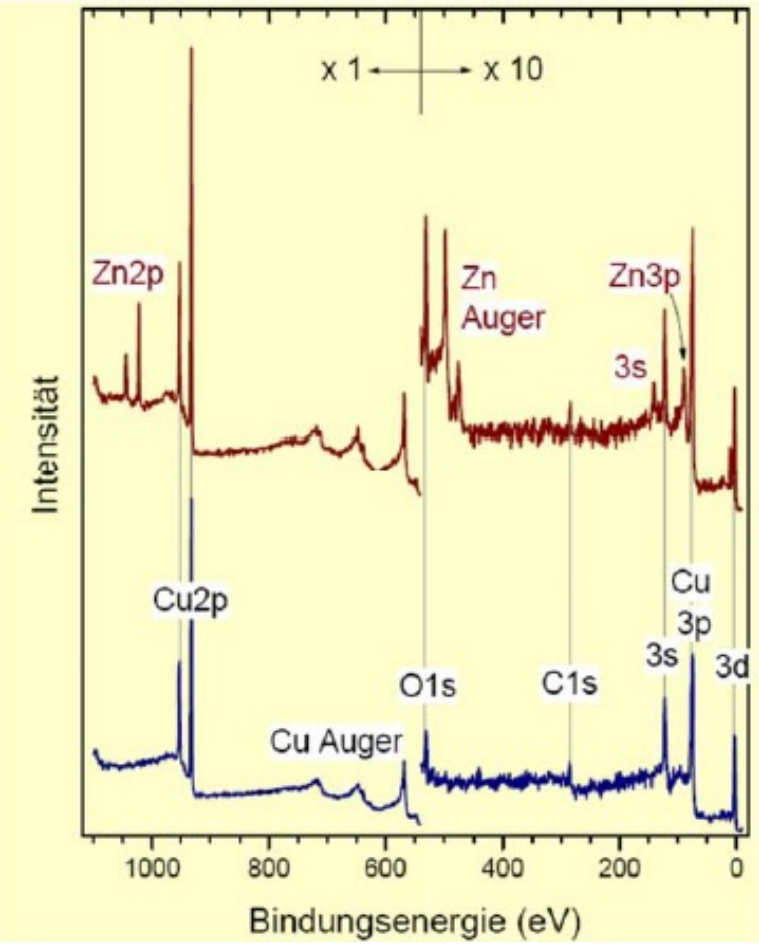
  →**inelastic background**

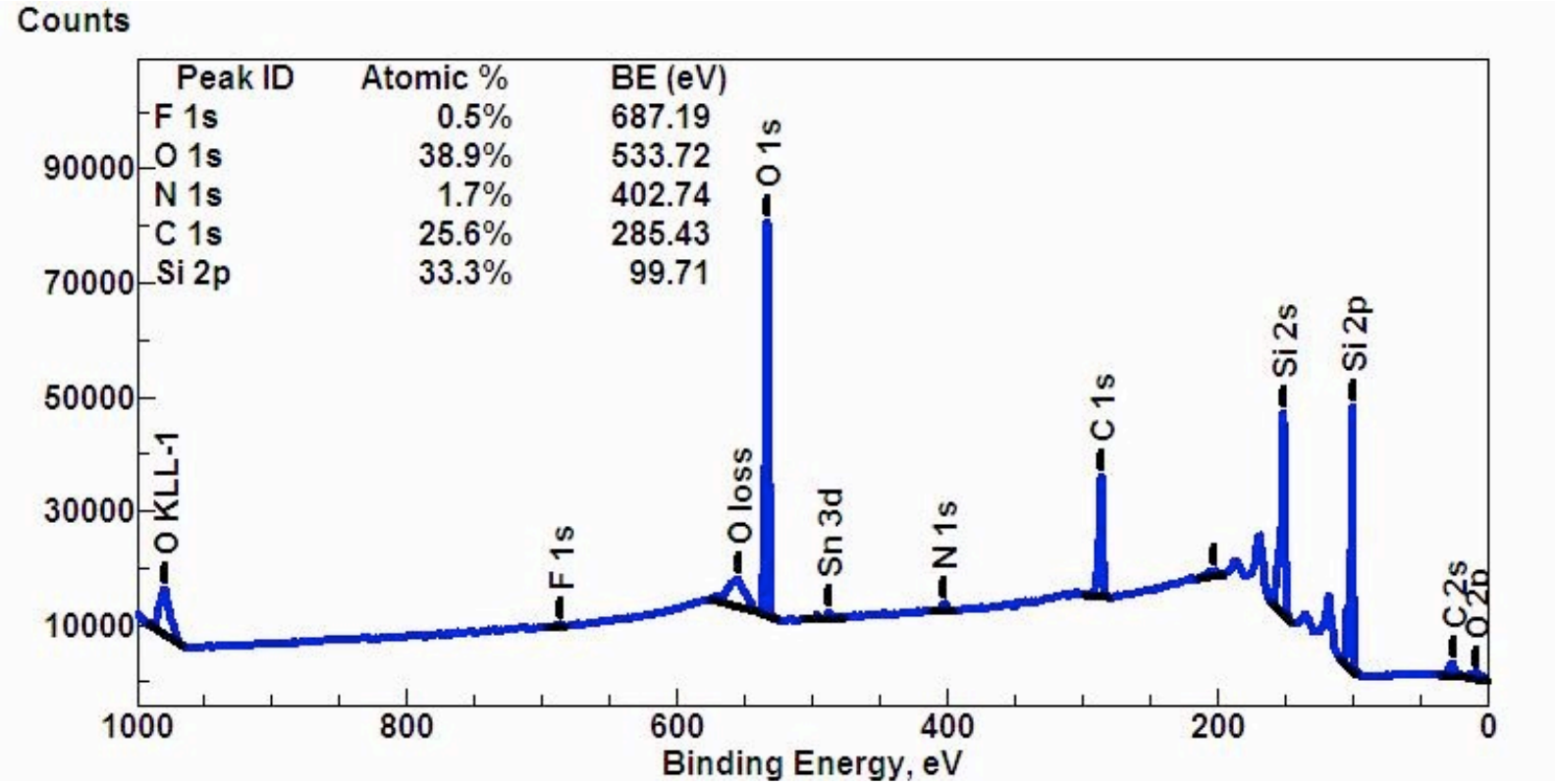
- only photoelectrons generated within a mean free path from the surface reach the surface without loss of energy

  →**surface sensitivity of XPS ~ 1 nm**

3. transition into vacuum

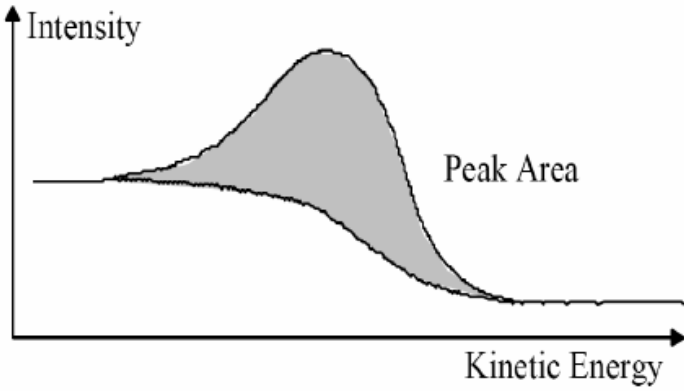
Qualitative Element Analysis: Example




Counts
Peak ID Atomic % BE (eV)
F 1s 0.5% 687.19
O 1s 38.9% 533.72
N 1s 1.7% 402.74
C 1s 25.6% 285.43
Si 2p 33.3% 99.71
90000
70000
50000
30000
10000
O KLL-1
F 1s
O loss
O 1s
Sn 3d
N 1s
C 1s
Si 2s
Si 2p
C 2s
O 2s
1000
800
600
400
200
0
Binding Energy, eV

Quantitative Element Analysis

- Intensity of XPS peaks (=peak area) contains information on chemical stoichiometry



- Let A_i denote core level *i* element A and E_{kin}^{i} the kinetic energy, at which A_i appears in the XPS spectrum. Then the intensity (=peak area) is given by:

$$I_{XPS}(i) = N_A \times J \times T(E_{kin}^{i}) \times \sigma_{A_i}(h\nu)$$

atomic density of element A

photon flux = const

transmission of analyzer ~ $(E_{kin})^{-1/2}$

photoexcitation "cross-section" of core level A_i at photon energy $h\nu$; calculated & tabulated; relative accuracy ±20%

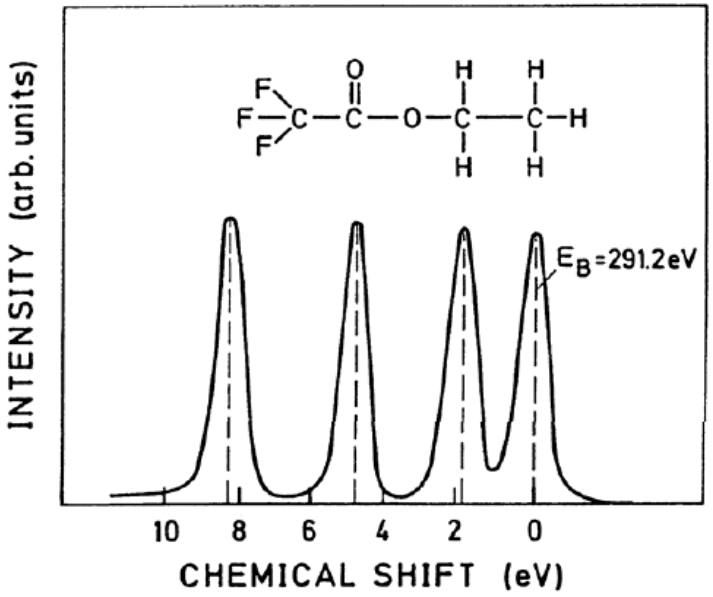
Chemical Shifts: Sensitivity to Local Bonding

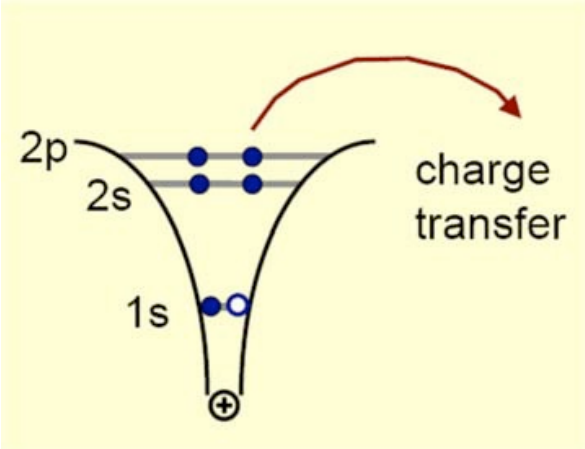
- **Chemical Shifts: Sensitivity to Local Bonding:**

  binding energy of a given core level not only identifies element, but can also give *information on local bonding* of atom

- **Example:**

  C 1s XPS signal in ethyl-trifluoro-acetate



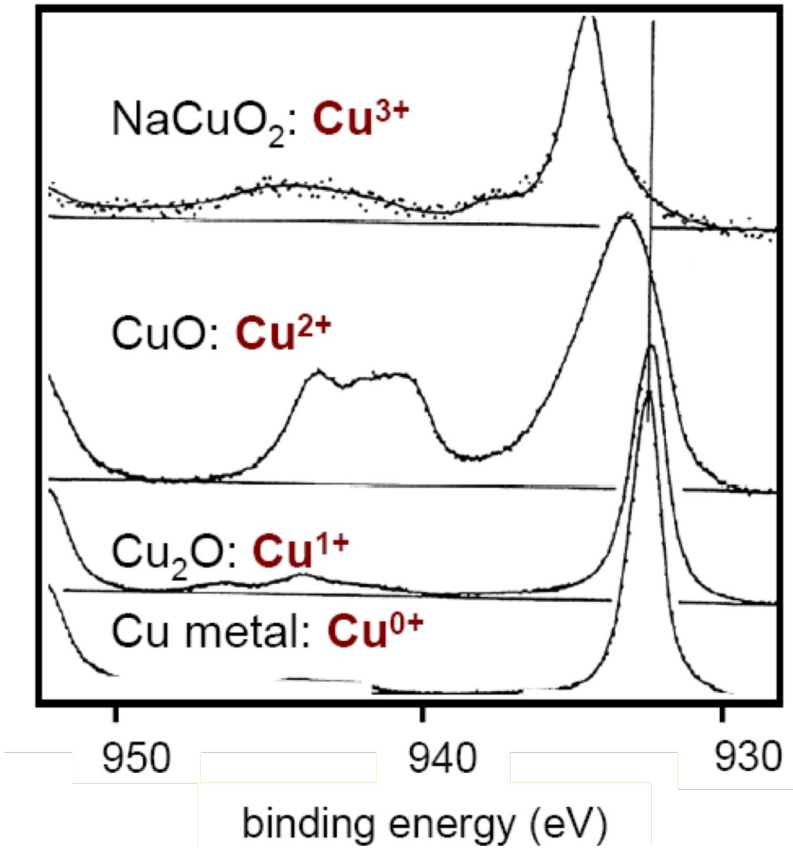


Chemical Shifts: Sensitivity to Local Bonding

- **Chemical Shifts: Sensitivity to Atomic Valence:**

  in metals the spectrum of a given core level is often affected by the metals´ valency

- **Example: Valence effects in Cu compounds**
  - for higher valency XPS main peak shifts to higher binding energy
  - occurrence of additional "satellite" peaks on high binding energy side ("shakeup satellites")



Examples of XPS Spectra

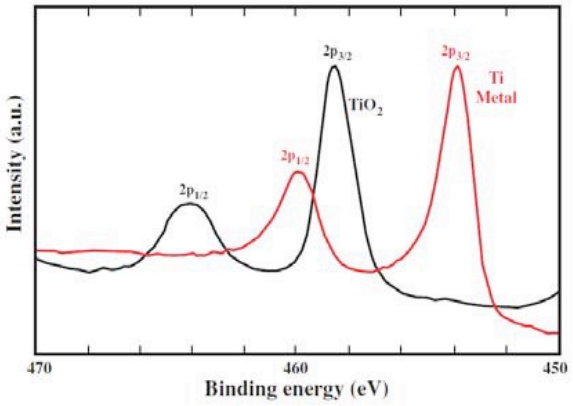
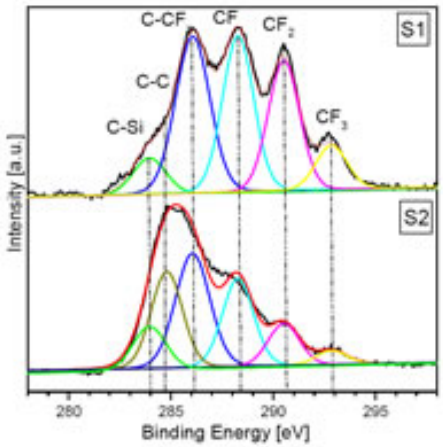
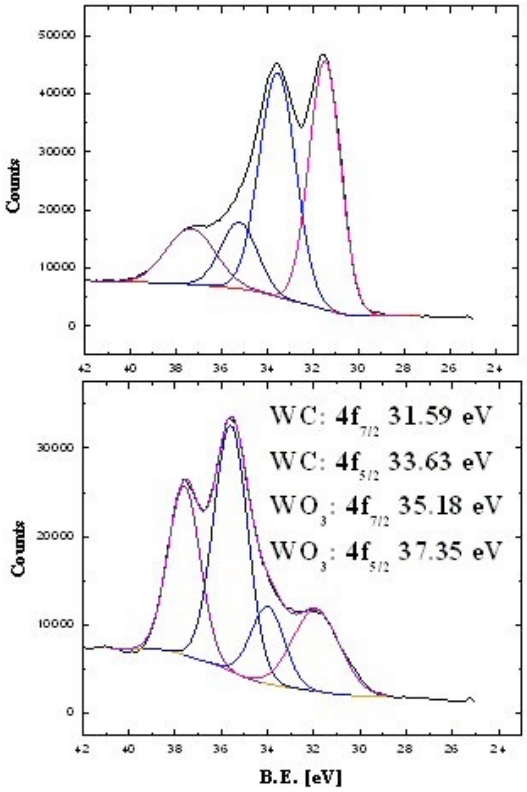


Figure 8.5 *Oxidation states on metal surfaces are resolvable by XPS. The growth of TiO_2 on titanium metal is accompanied by 2p peak shifts of 4–5 eV. (Courtesy of G.C. Smith,* Materials Characterization, *Elsevier Science Publishing Co.).*



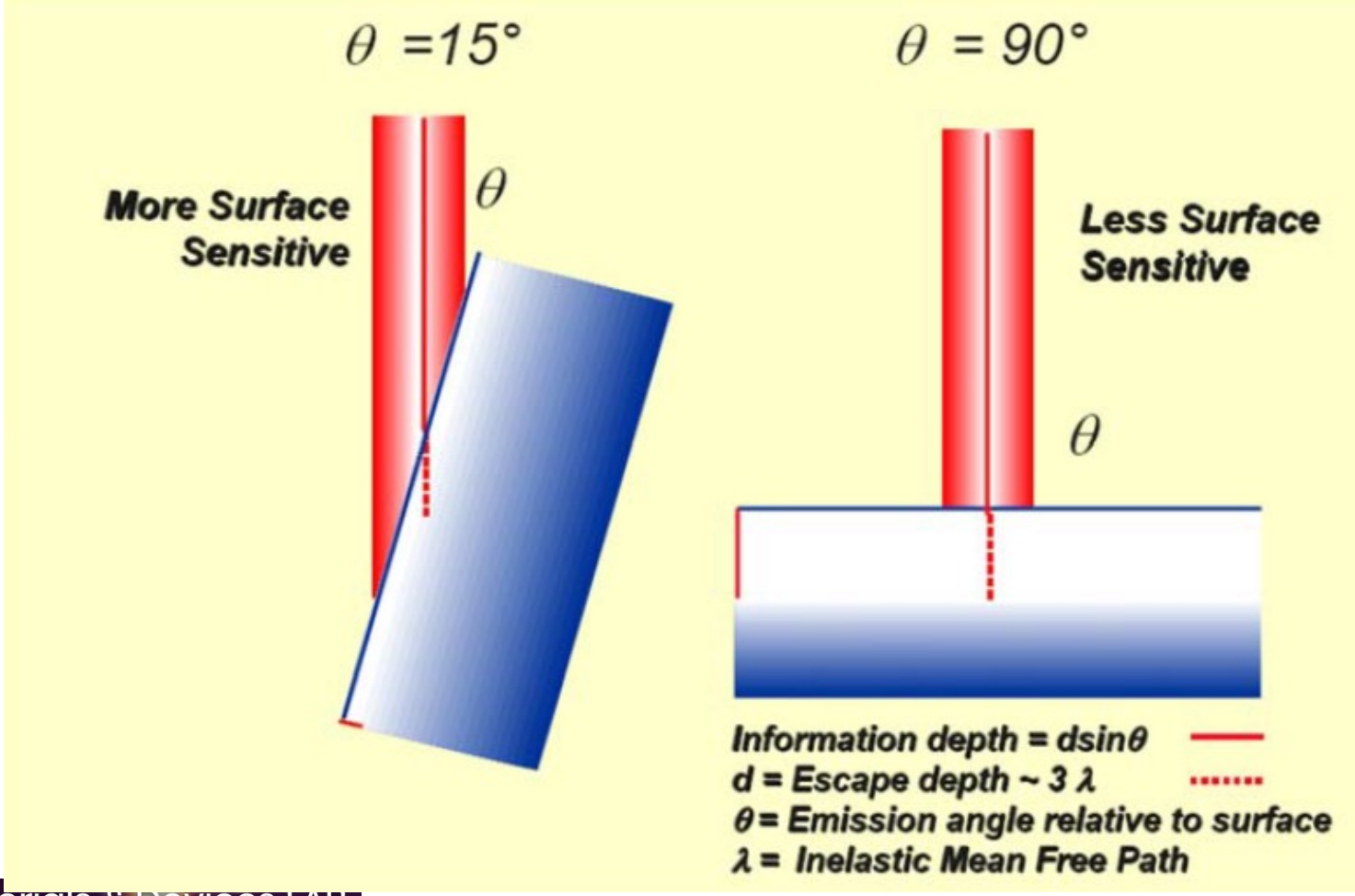


High Resolution XPS spectra of W4*f* region of pure WC samples before (top) and after 5 cycles of $DeNO_x$ (bottom)

Depth Profiling

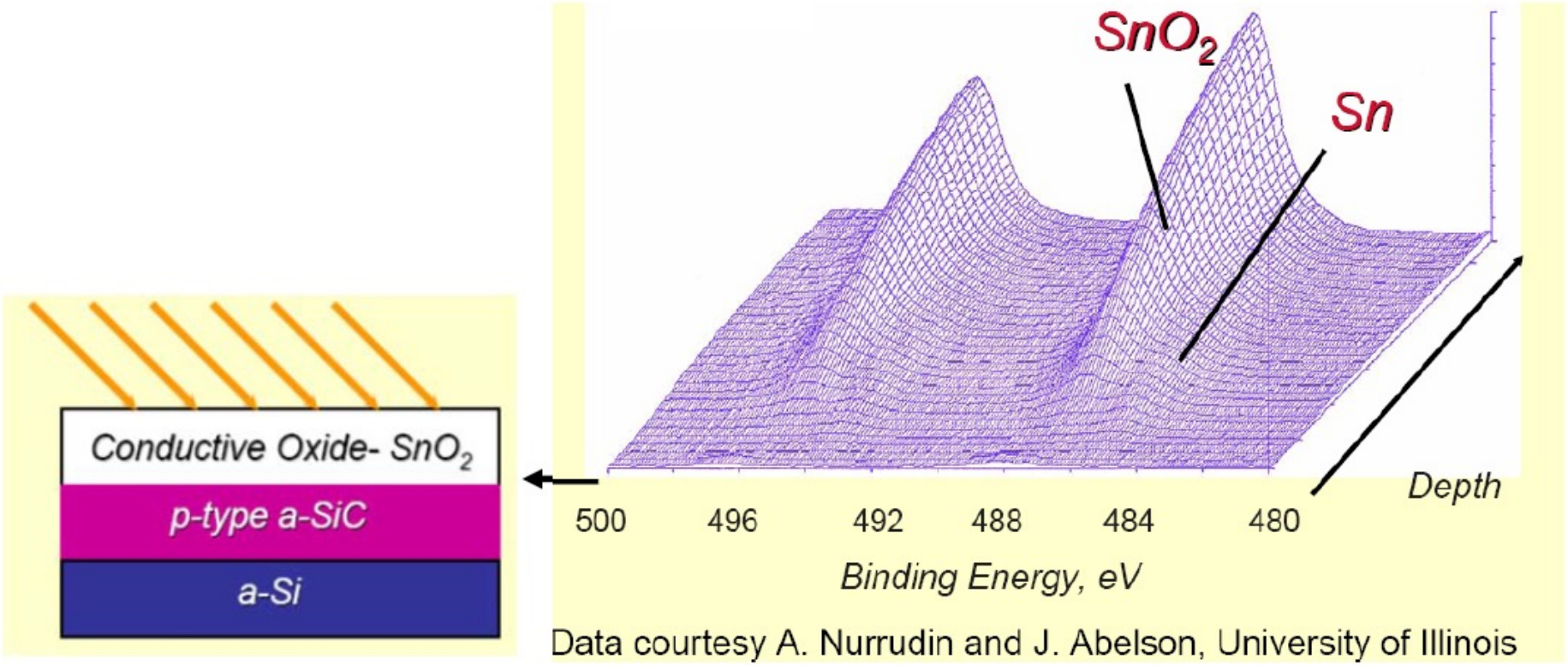
- **Generally, the XPS probing depth is determined (and thus limited) by the electron mean free path of order 1 nm.**
- **In order to obtain vertical information on chemical composition two separate techniques have been developed:**
  - **Angle-Resolved XPS (ARXPS): tunes probing depth from surface-sensitive to very surface-sensitive**
  - **Depth Profiling by Ion Sputtering: a chemical depth profile can be obtained by continuous removal of surface material using Ar ion bombardment**

Angle-Resolved XPS (ARXPS): Varying the Information Depth



XPS Depth Profiling

Example: analysis of photovoltaic device by XPS depth profiling

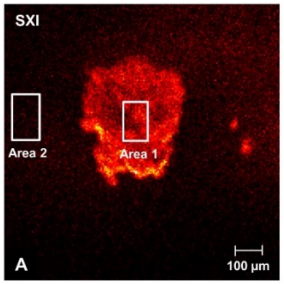


- The profile indicates a reduction of the SnO_2 occurred at the interface during deposition. Such a reduction would affect the collector's efficiency.

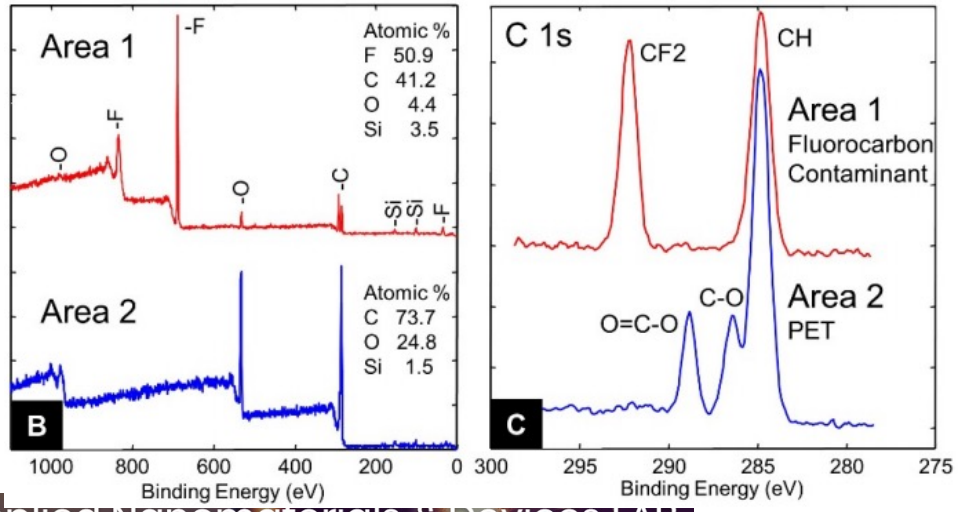
Micro-XPS and Mapping

- **Selected area micro-XPS**

- Micro analysis: X-ray beam down to 3 μm size
- Very long analysis time (~hours) due to small signal.

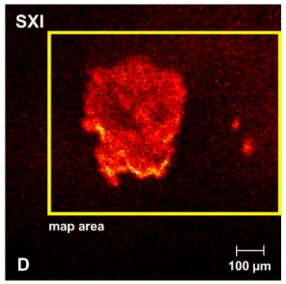


- Contamination on the polymer (PET) surface

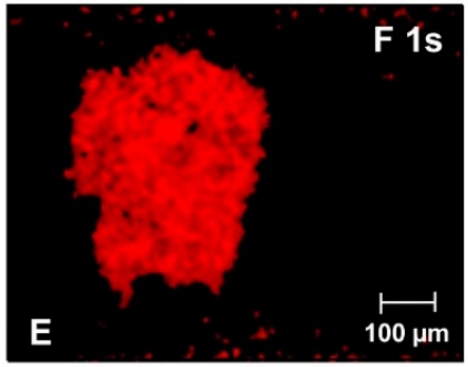


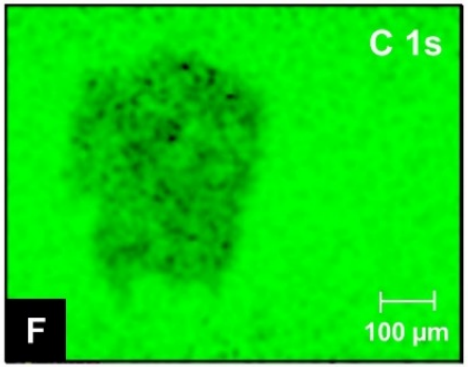
- **XPS mapping**

- 2D XPS mapping, very long analysis time (~hours)



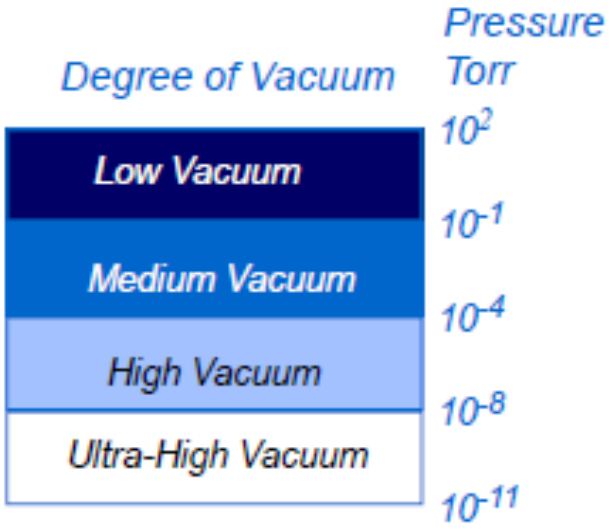
- Contamination on the polymer (PET) surface





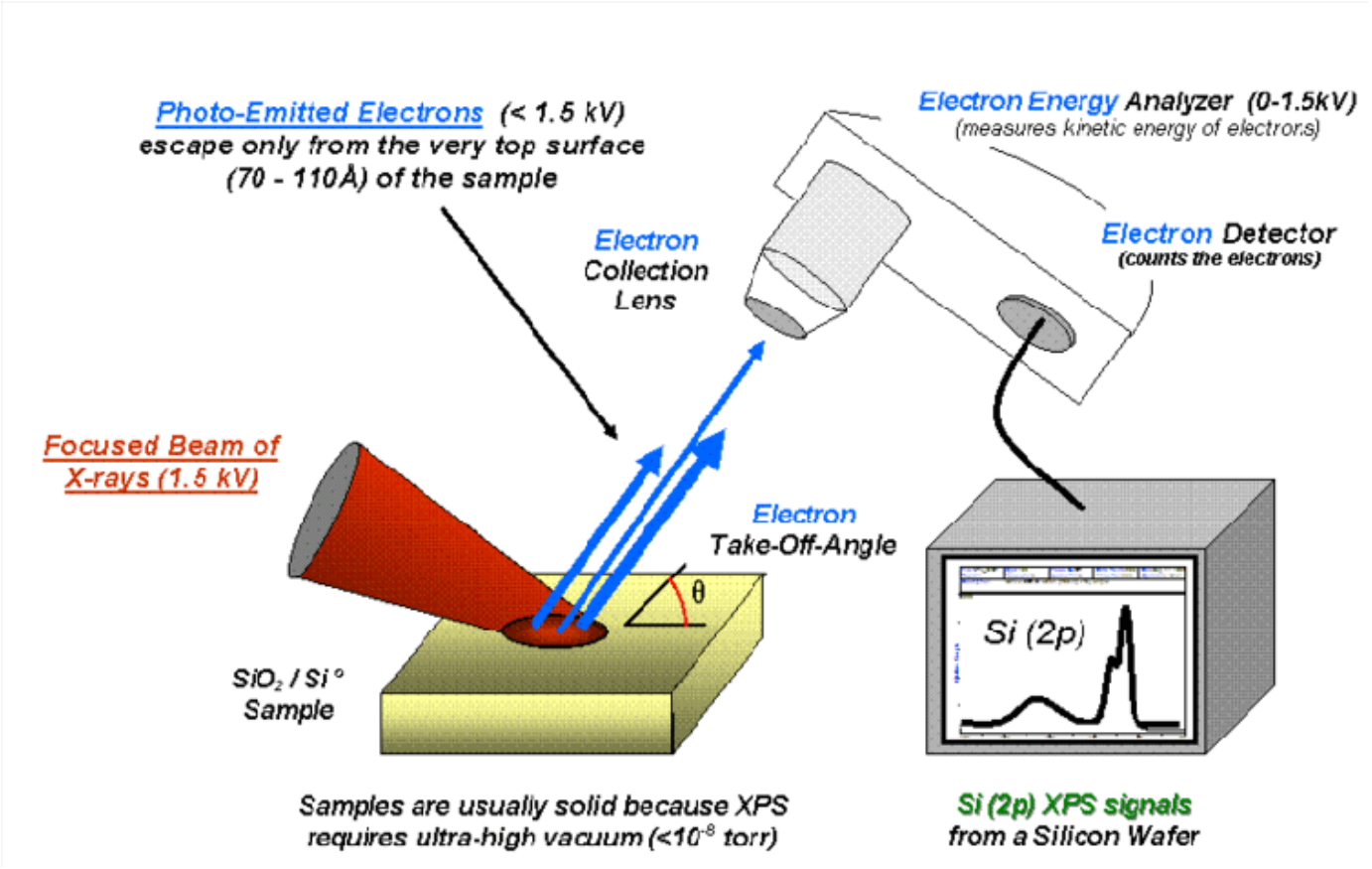
Instrumentation for XPS

- **Surface analysis by XPS requires irradiating a solid in an Ultrahigh Vacuum (UHV) chamber with monoenergetic soft X-rays and analyzing the energies of the emitted electrons.**
- **Why UHV for Surface Analysis?**

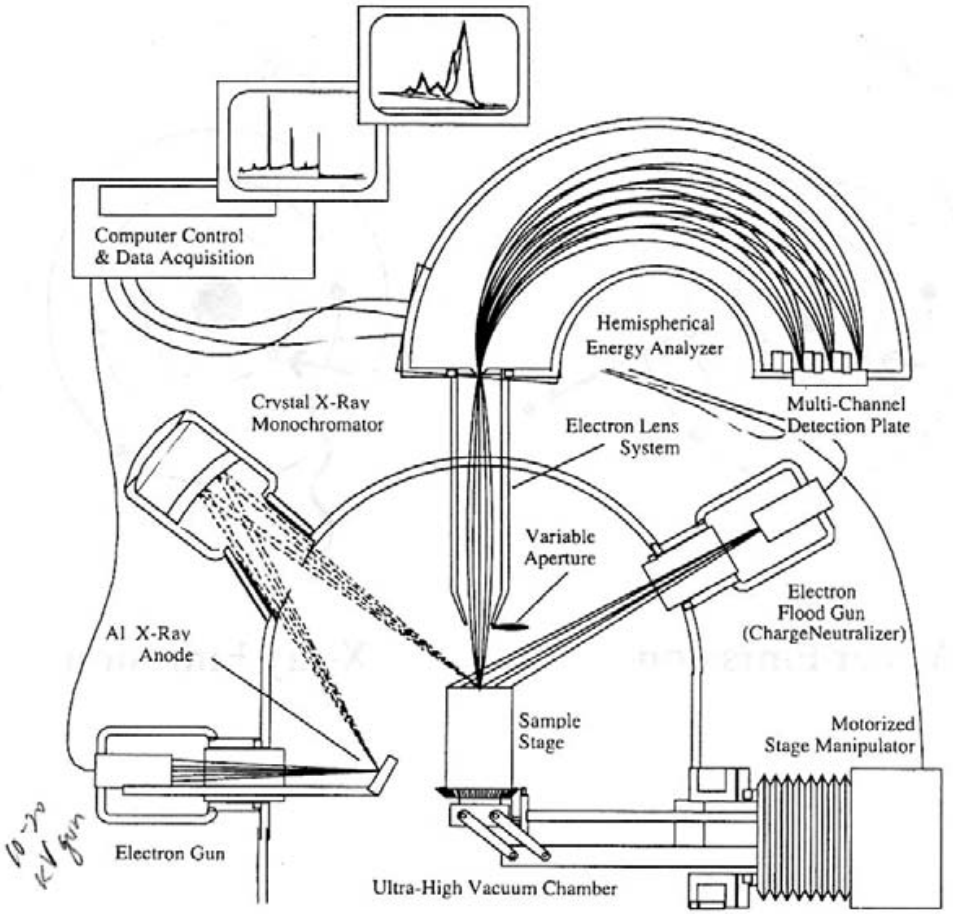


- *Remove adsorbed gases from then sample.*
- *Eliminate adsorption of contaminants on the sample.*
- *Prevent arcing and high voltage breakdown.*
- *Increase the mean free path for electrons, ions and photons.*

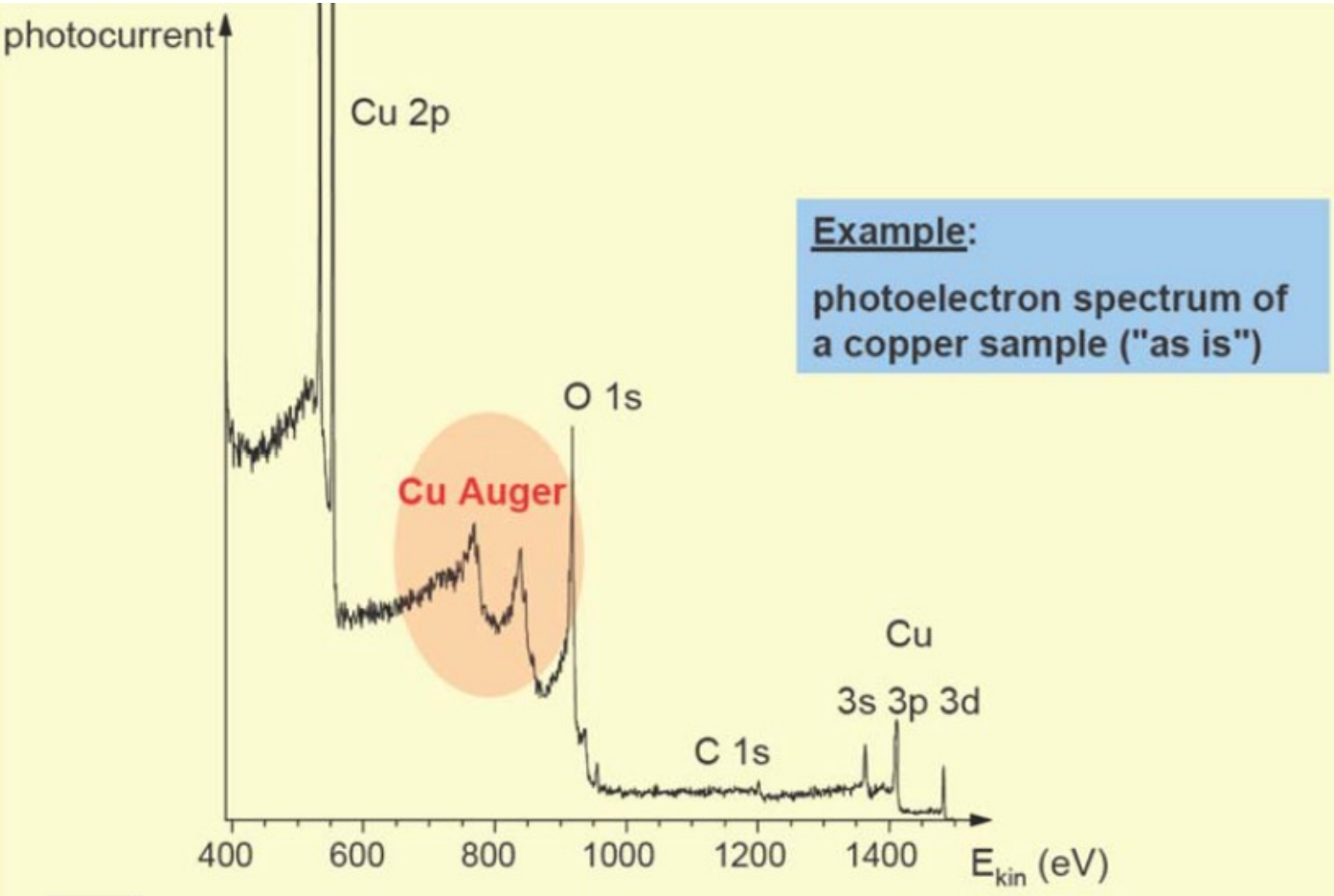
Basic Components of a Monochromatic XPS System



X-Ray Photoelectron Spectrometer



6.2. Auger Electron Spectroscopy (AES)



6.2. Auger Electron Spectroscopy (AES)

- Auger Electron Spectroscopy (AES) is a surface-sensitive spectroscopic technique used for elemental analysis of surfaces
- It offers high sensitivity (typically ca. 1% monolayer) for all elements except H and He.
- A means of monitoring surface cleanliness of samples
- quantitative compositional analysis of the surface region of specimens, by comparison with standard samples of known composition.
- In addition, the basic technique has also been adapted for use in :
  - Auger Depth Profiling : providing quantitative compositional information as a function of depth below the surface
  - Scanning Auger Microscopy (SAM) : providing spatially-resolved compositional information on heterogeneous samples

AES and XPS.

Is AES a technique often described as more sensitive than XPS?

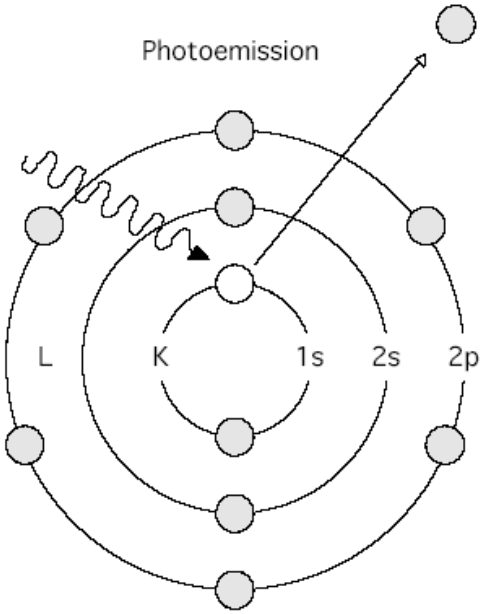
Answer: It is partially true. In fact, the difference in sensitivity is primarily due to the differences in electron kinetic energies.

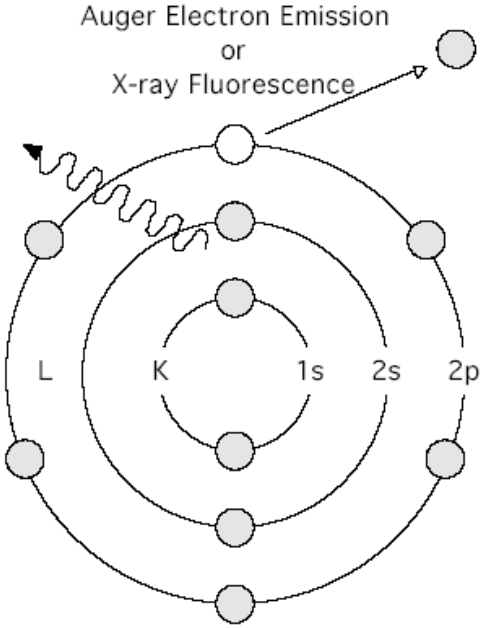
For example, in the case of carbon, in XPS the kinetic energy is close to 1000 eV as opposed to 250 eV in AES. Because the mean free path changes with the electron kinetic energy, the depth of analysis will be smaller in AES than in XPS in the case of a carbon containing specimen.

As a matter-of-fact, the surface contamination (primarily carbon and oxygen) is a much more sensitive factor in AES. An ion etching is sometimes necessary to study surfaces with this spectroscopy.

Auger... Pierre Auger

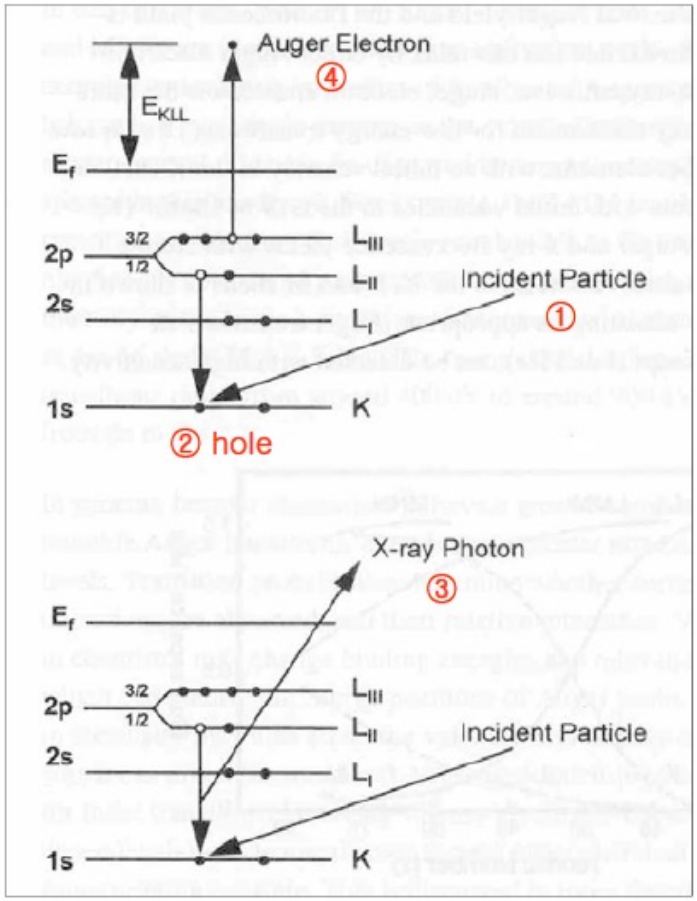
What is fate of core hole?





- Auger electron emission - basis of Auger electron spectroscopy (AES)
- X-ray fluorescence

Principles: Auger Process

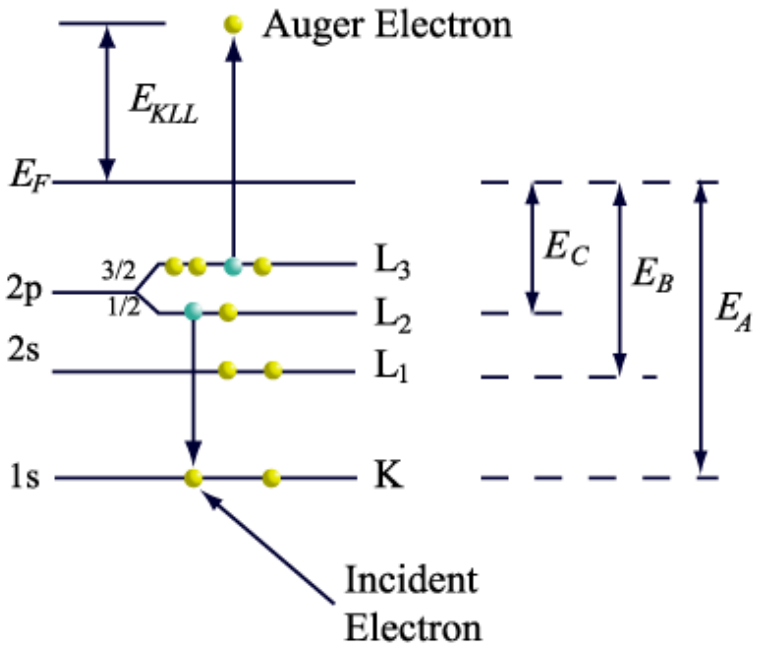


Incident particle

- Electron, X-ray

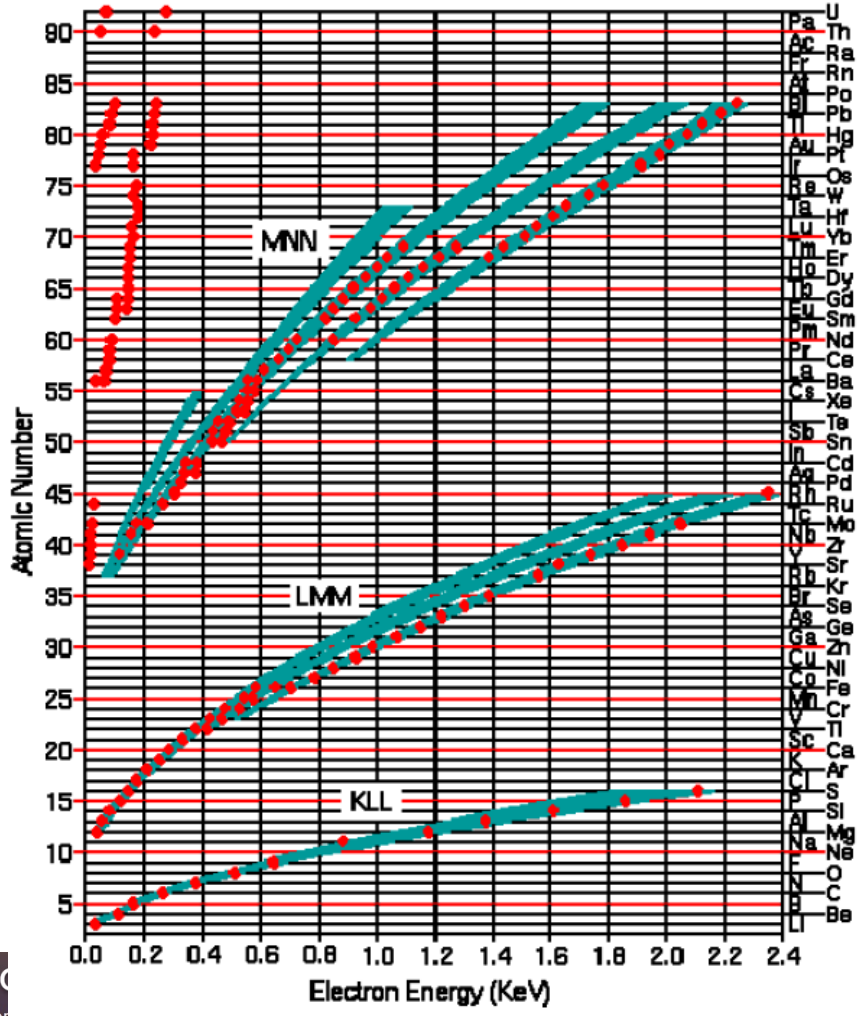
Emission (Stabilized)

- Auger electron, X-ray fluorescence



$$E_{Aug}(E_{KLL}) = E_A - E_B - E_C$$

Principles: Calculate Auger Electron Energy



$E_{Aug} = E_A - E_B - E_C$

- E_A: the core level electron energies
- E_B : first outer shell electron energies
- E_C : second outer shell electron energies
- *All of the energies are measured from the vacuum level.*

EX: Calculate Auger Electron Energy

Table 4.2. Binding energies of some elements

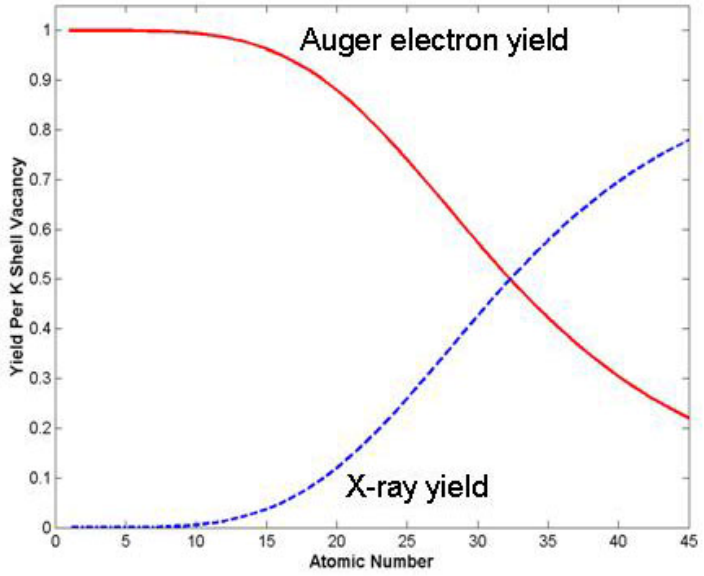
Z	El	$1s_{1/2}$ K	$2s_{1/2}$ L_1	$2p_{1/2}$ L_2	$2p_{3/2}$ L_3	$3s_{1/2}$ M_1	$3p_{1/2}$ M_2	$3p_{1/2}$ M_3	$3d_{3/2}$ M_4	$3d_{5/2}$ M_5
1	H	14								
2	He	25								
3	Li	55								
4	Be	111								
5	B	188			5					
6	C	284			6					
7	N	399			9					
8	O	532	24		7					
9	F	686	31		9					
10	Ne	867	45		18					
11	Na	1072	63		31		1			
12	Mg	1305	89		52		2			
13	Ml	1560	118	74		73	1			
14	Si	1839	149	100		99	8			
15	P	2149	189	136		135	16		10	
16	S	2472	229	165		164	16		8	
17	Cl	2823	270	202		200	18		7	
18	Ar	3202	320	247		245	25		12	
19	K	3608	377	297		294	34		18	
20	Ca	4038	438	350		347	44		26	5
21	Sc	4493	500	407		402	54		32	7
22	Ti	4965	564	461		455	59		34	3

$$E_{Aug} = E_A - E_B - E_C$$

- Kinetic energy of each Auger electron (E_{Aug}):
  - Core hole ionization of K electron BE in O =532eV(E_A)
  - BE of L_1 electron in O = 24eV(E_B)
  - BE of $L_{2,3}$ electron in O = 7eV(E_C)

- Auger electron Kinetic energy (E_{KLL}) in O:
  - KL_1L_1: 532–24–24 = 484eV
  - $KL_1L_{2,3}$: 532–24–7 = 501eV
  - **$KL_{2,3}L_{2,3}$: 532–7–7 = 518eV**

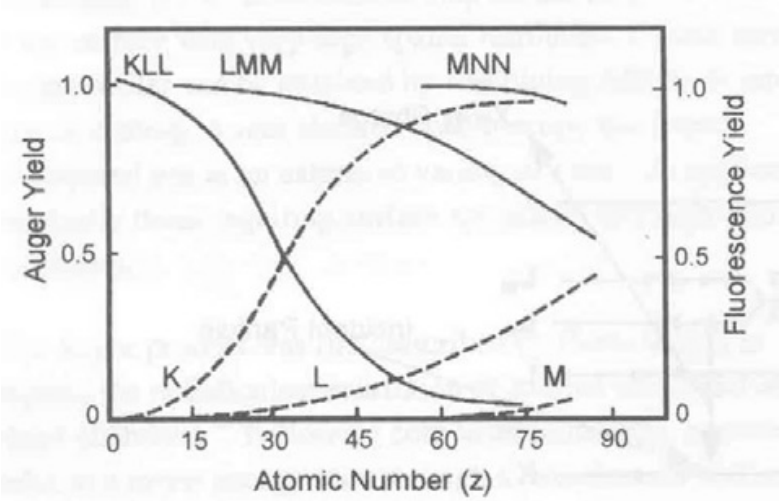
Principles: Fluorescence and Auger Electron Yields



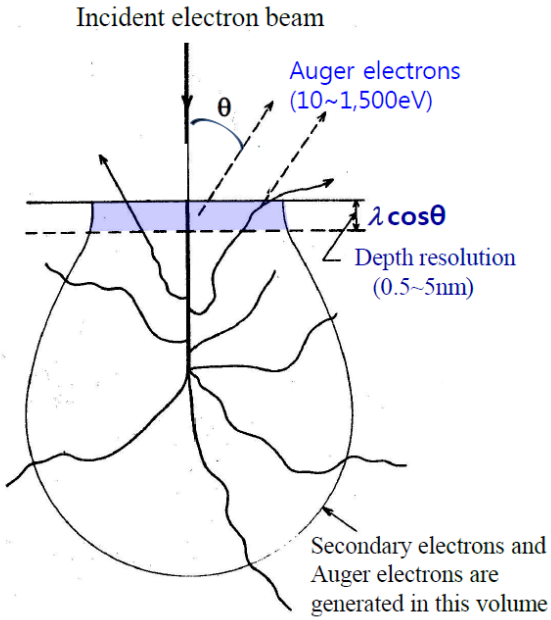
For K shell vacancies.

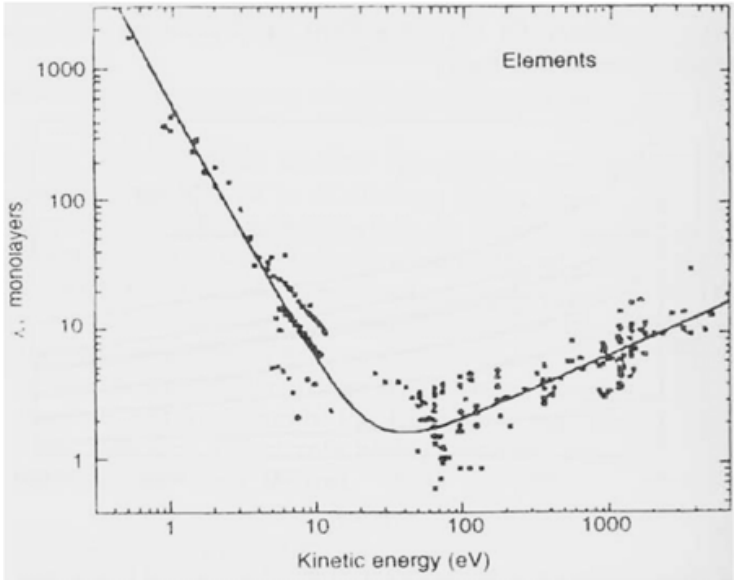
- For lighter elements: Auger transitions are more probable
- For higher elements: X-ray yield becomes dominant
- Similar plots can be obtained for L and M shell transitions. Coster-Kronig (i.e. intra-shell) transitions are ignored in this analysis.

For L and M shell transitions.



Surface Sensitivity

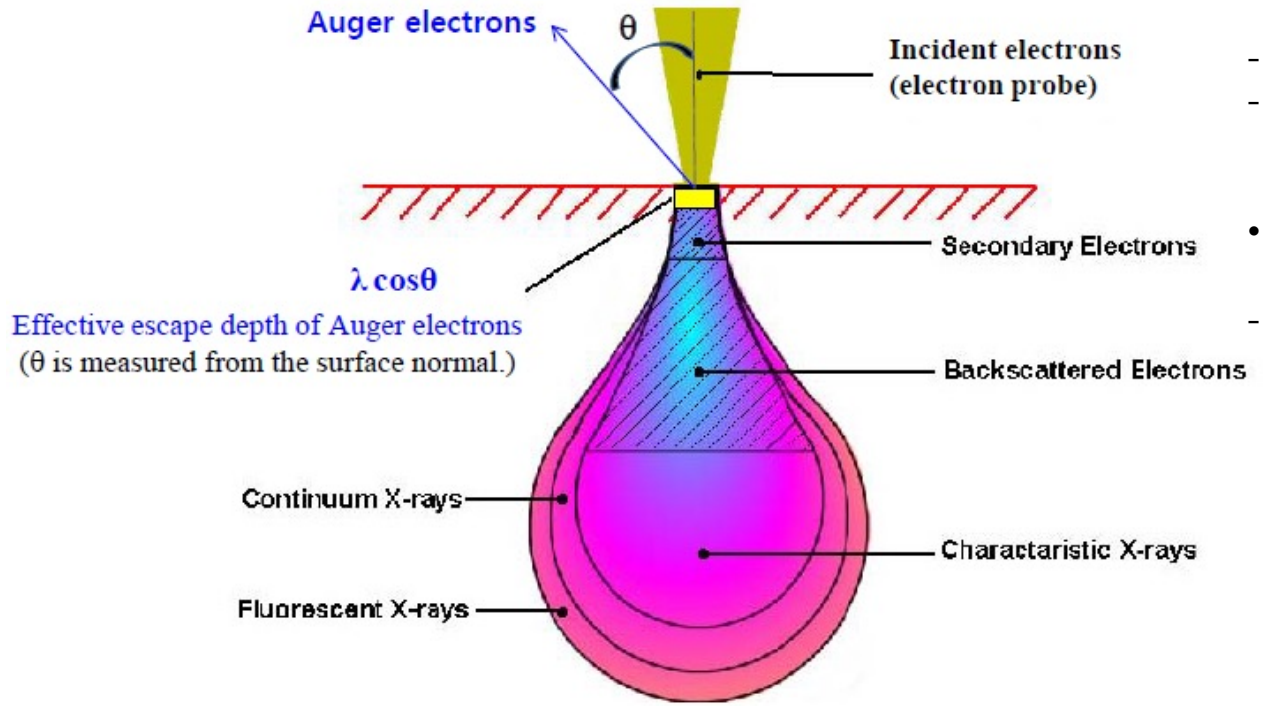




- **Surface Sensitivity**

Surface sensitivity in AES arises from the fact that emitted electrons usually have energies ranging from 50 eV to 3 keV and at these values, electrons have a short mean free path in a solid. The escape depth of electrons is therefore localized to within a few nanometers of the target surface, giving AES an extreme sensitivity to surface species.

Lateral and Depth Resolution of AES



- **Lateral resolution : down to 5nm** (lateral resolution = area of the specimen surface from which Auger electrons originate.)
- Electron probe diameter: down to 5nm
- - Lateral resolution ≥ Electron probe beam diameter

- **Depth resolution (surface sensitivity) : λ = 0.5~5nm (typically 1.0~2.5nm)**
- Probability that an Auger electron escapes from depth **t** to the surface without energy loss

$$q = \exp(-\frac{t}{\lambda cos\theta})$$

λ = inelastic Mean Free Path of Auger electron
θ = emission (or detection) angle
t = depth from surface

AES 분석

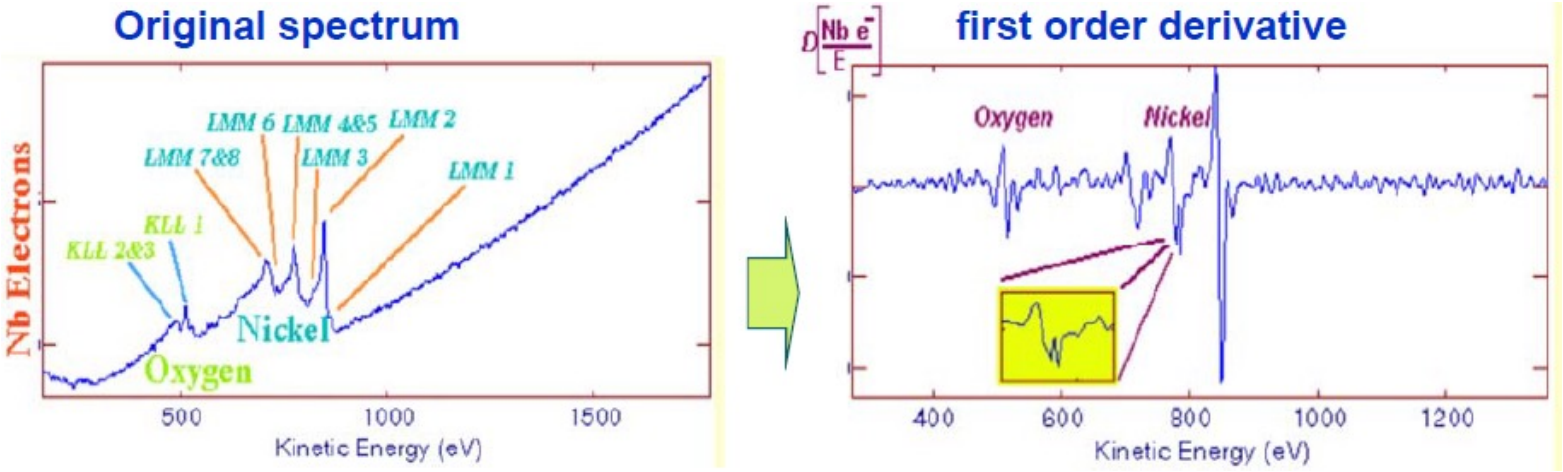
➤ 주요적용범위

- **Chemical analysis** (정성 및 정량분석: **Auger peak**)
- **Depth profiling (Ion beam)**
- **point analysis**
- **line scan**
- **Image mapping**

➤ 장점 및 단점

- 표면선택성 우수 **(~25Å)**
- 평면 분해능이 우수 (전자빔의 집속 ~수백**Å**)
- 깊이에 따른 조성 및 결합상태 분석
- 검출한계**(0.1at%)**이하 농도 분석이 어려움
- **Bulk** 절연체의 분석이 어려움**(Charging effect)**

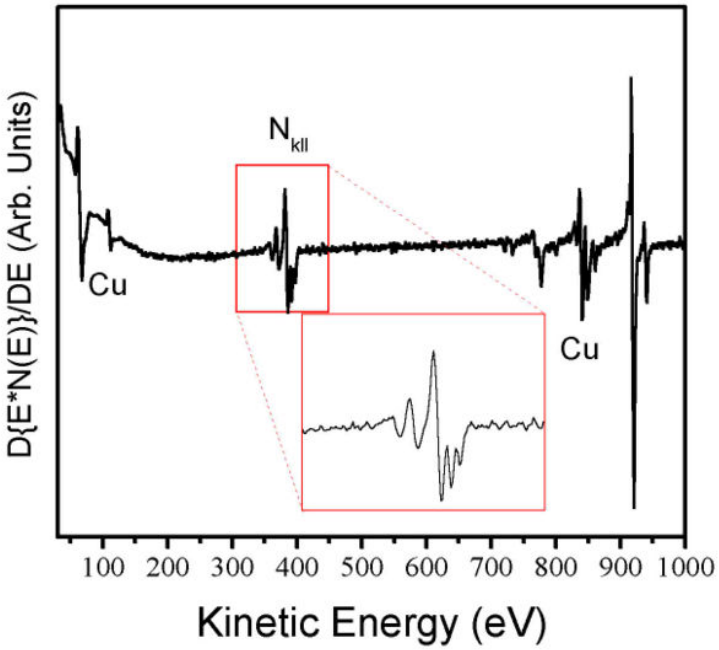
Auger Spectra: Qualitative Element Analysis



- For a given element, several lines and Auger emissions can be observed.
- This spectrum is generally obtained with a 1 eV acquisition step and it shows the main lines for this element.

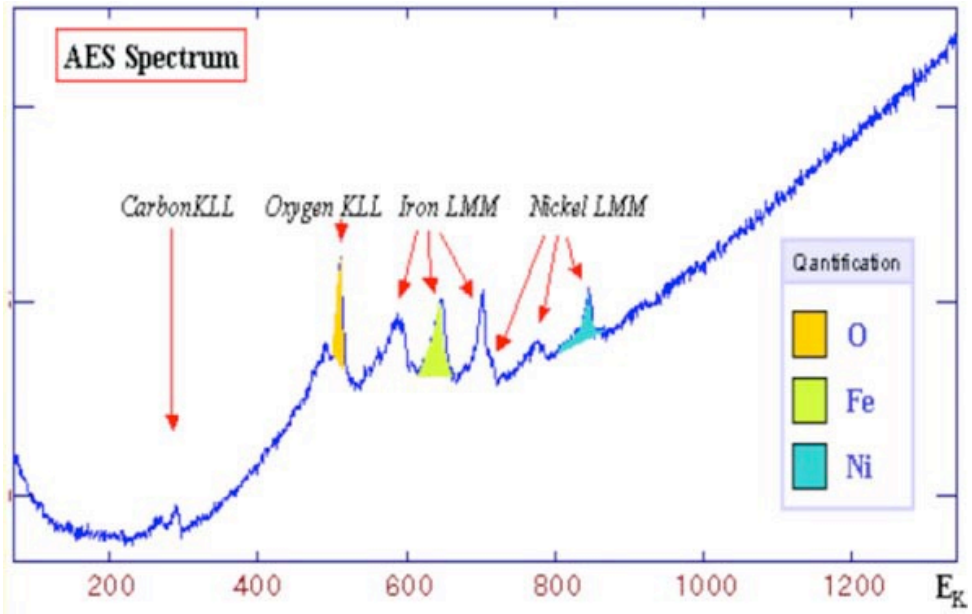
- By using the first order derivative of the signal it is possible to get a better line assignment.
- It becomes then easier to distinguish between LMM4 and LMM5 transitions.

Auger Spectra: Qualitative Element Analysis



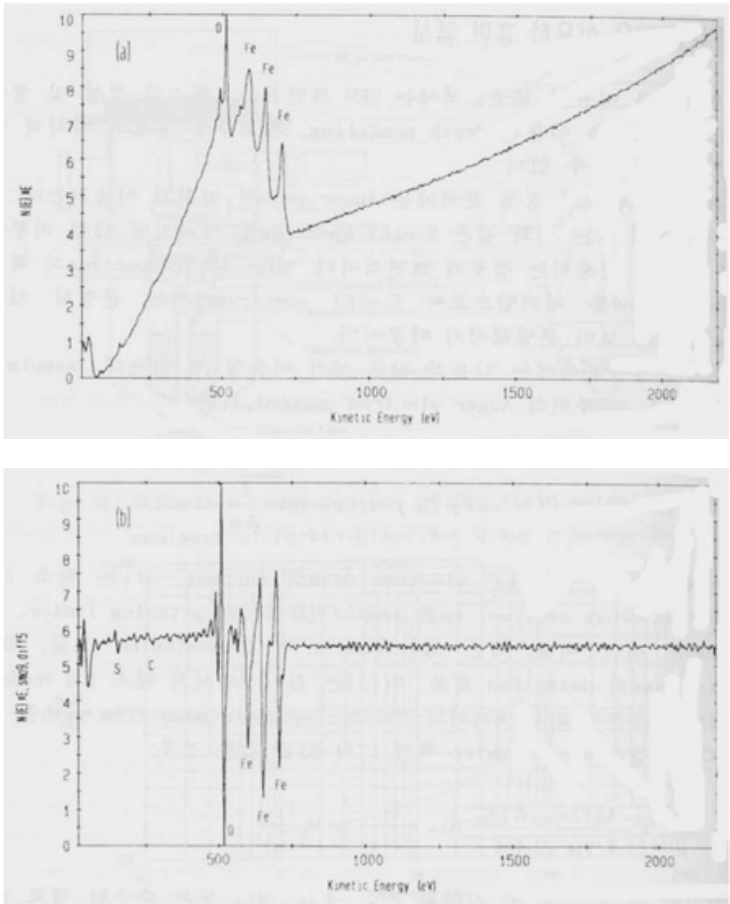
- Auger spectrum of a copper nitride film in derivative mode plotted as a function of energy.
- Different peaks for Cu and N are apparent with the N_{KLL} transition highlighted.

Quantitative Element Analysis I



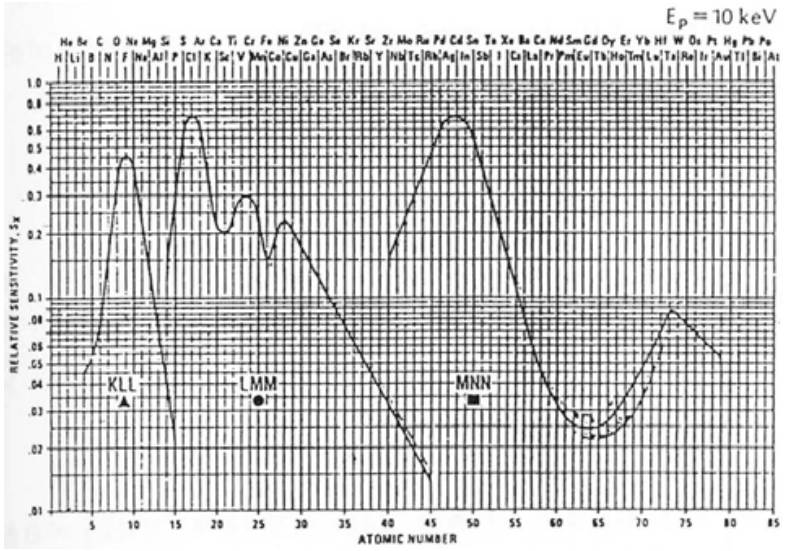
- Considering the identified peaks, we choose among the most intense lines which are well separated from each other.
- The spectrum below contains four elements: Carbon, oxygen, iron and nickel.
- Each one of these elements shows several transitions. The colored areas represent our choice.

Quantitative Element Analysis II



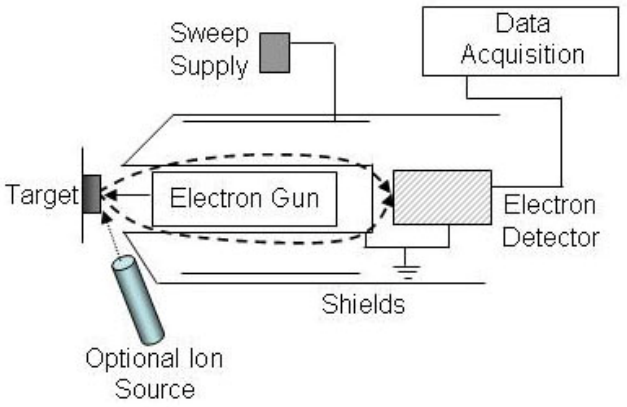
$$X_A = \frac{P_A / S_A}{\sum i(P_i / S_i)} \times 100$$

X_A: A의 atomic%, P: Peak to peak, S:sensitivity factor



AES Experimental Setup

Cylindrical Mirror Analyzer (CMA)



Auger analysis

In UHV: < 10^{-8}torr

Electron gun : Primary electron beam

Electron energy analyzer and detector: measurement and collection of emitted electrons.

Sample manipulator : to locate the area of interest at the analyzer focal point.

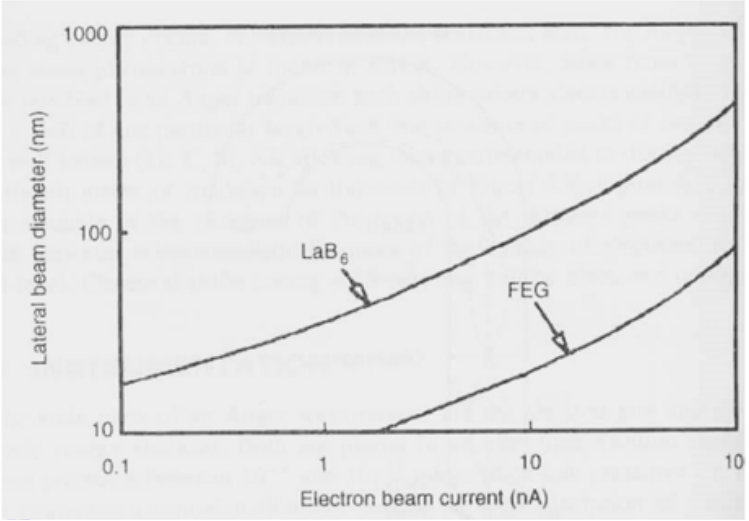
Ion gun : cleaning of the sample and for depth profiling

- An electron beam is focused onto a specimen and emitted electrons are deflected around the electron gun and pass through an aperture towards the back of the CMA.
- These electrons are then directed into an electron multiplier for analysis. Varying voltage at the sweep supply allows derivative mode plotting of the Auger data.
- An optional ion gun can be integrated for depth profiling experiments.

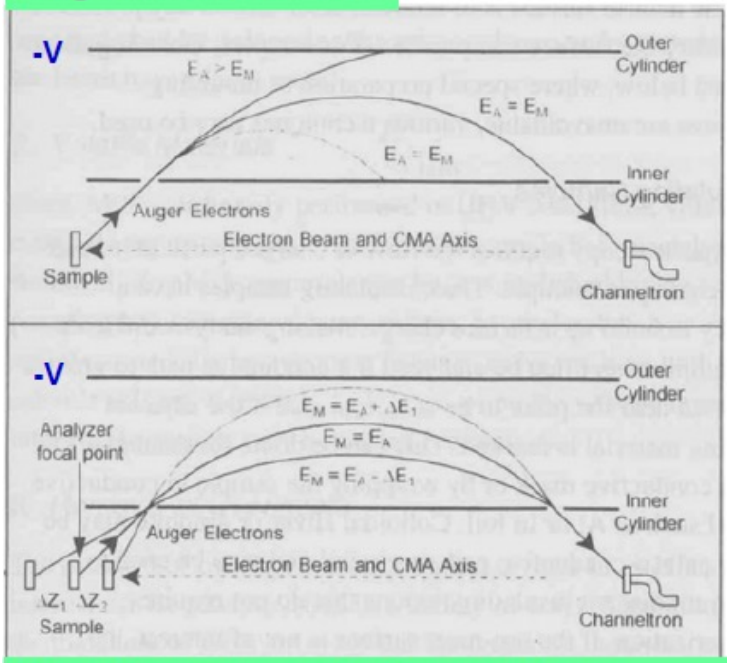
Electron Source & Analyzer

Electron sources
- Tungsten filament (~100 ㎛)
- LaB_6 (lanthanum boride) crystal (~ 5 ㎛)
- Field emission gun (< 10nm)

High resolution
- Beam voltage (higher)
- Beam Current (lower)



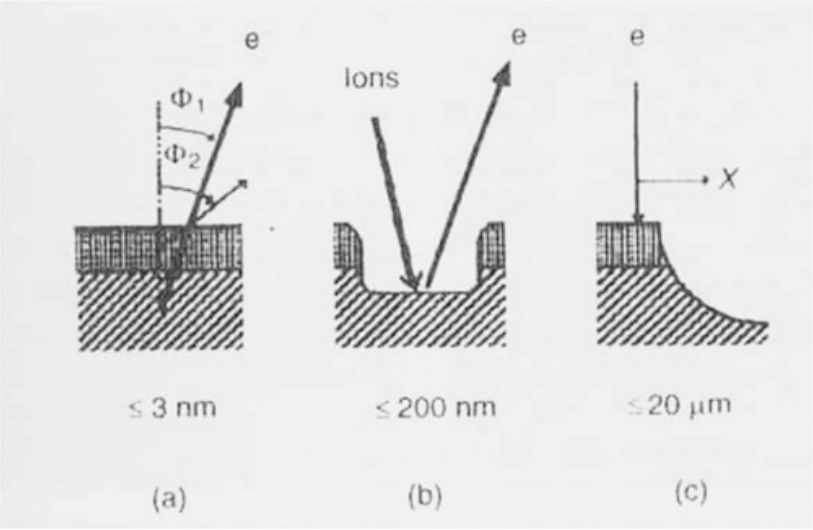
Auger electron scan



Error (sample position) : roughness

Cylindrical Mirror Analyzer (CMA)
- Auger electron $E_A \propto V$

line Scan & Image Mapping



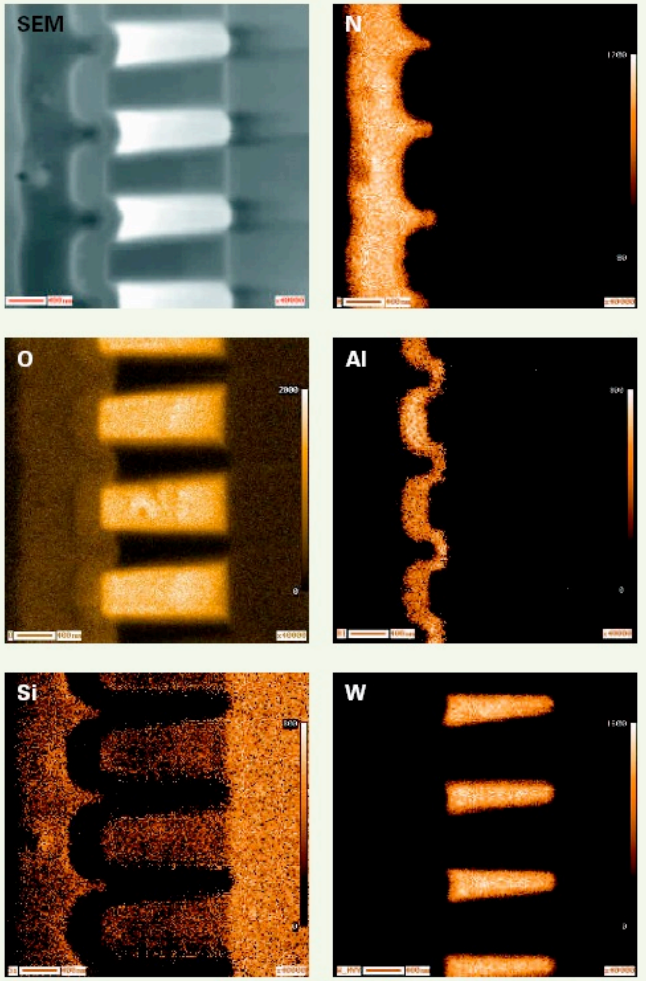
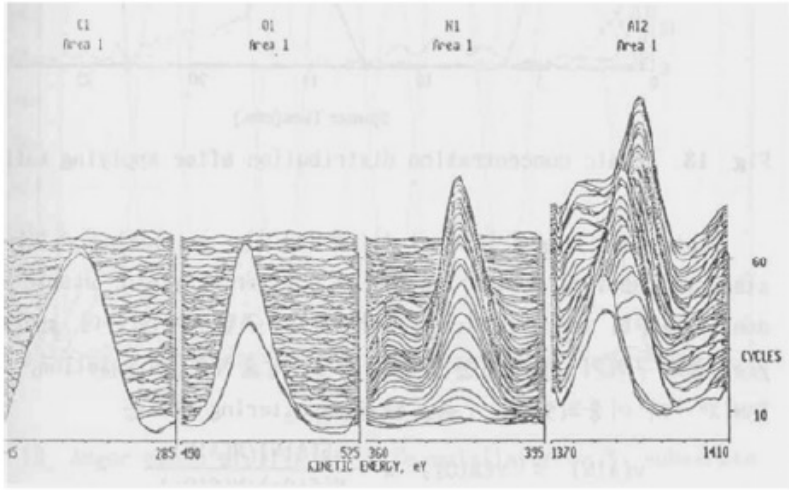
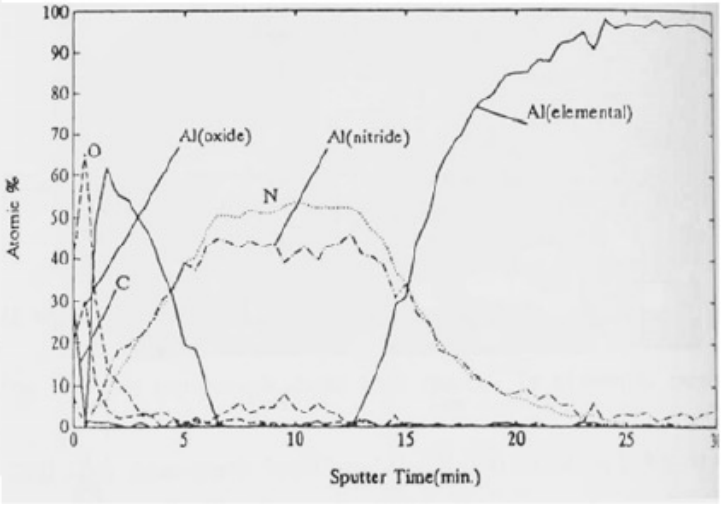


Fig. 17. Auger images of the semiconductor specimen made by the thin-film method

AES Spectrum: Depth Profile





AES spectrum

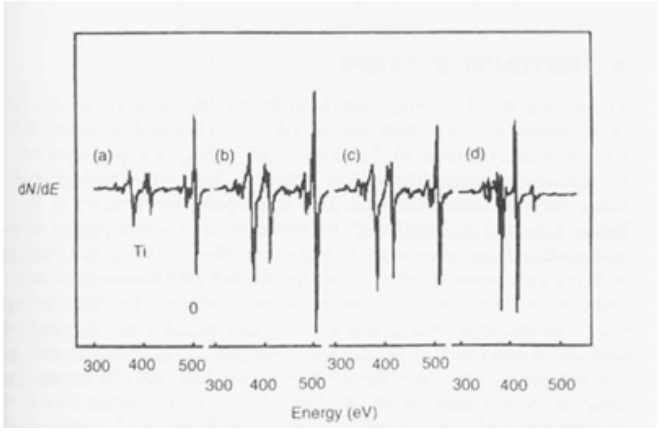
-Noise 혹은 다른 원소로 부터의 peak중첩을 고려 해야함

-Spectrum 해석(S/W)→ Depth profile data 획득

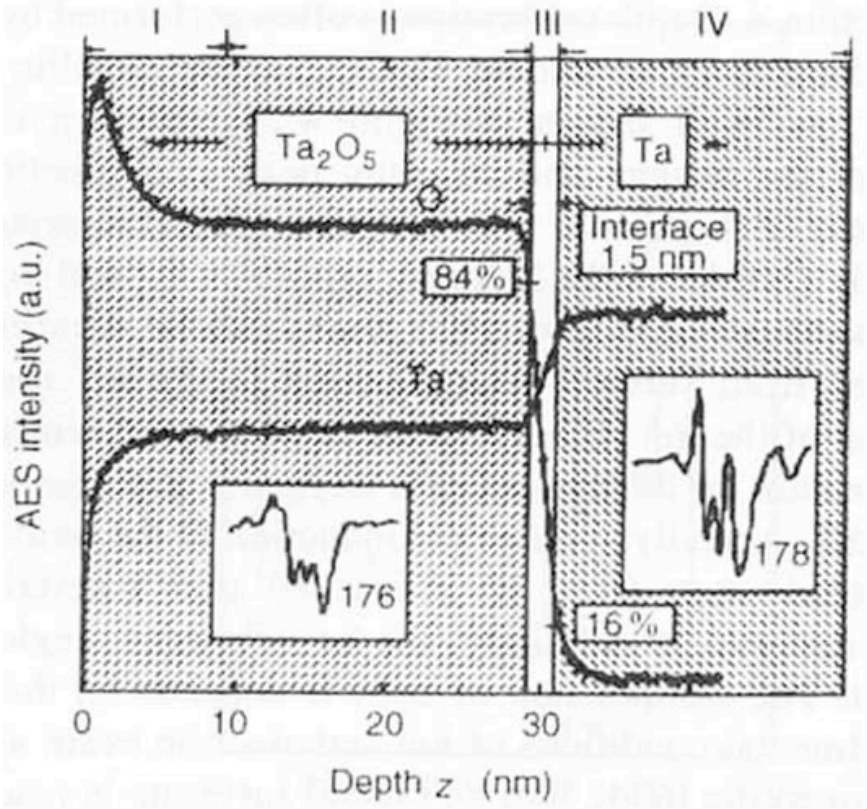
Chemical shifts in AES profiles

-분석가능하지만 일반적으로 ESCA사용

(Auger process중 3개의 전자준위에 의한 간섭때문)



Depth Resolution

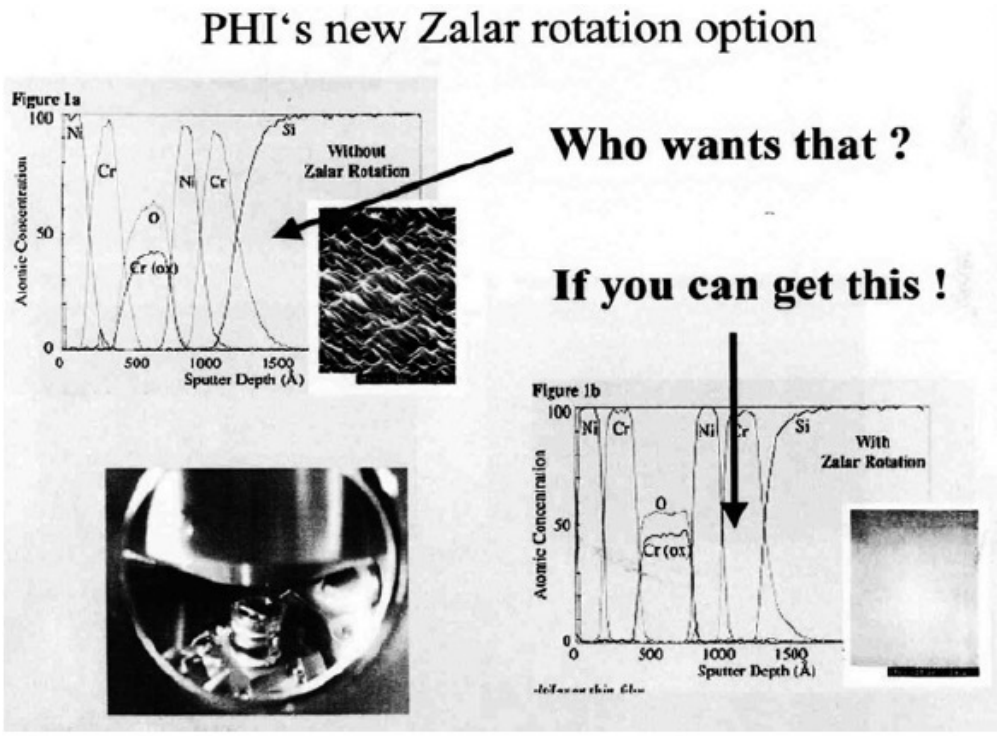


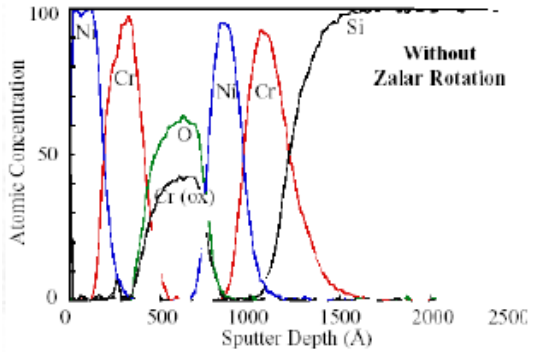
- **Instrumental**
  - 내부잔류 gas로 부터의 흡착
  - 식각된 물질의 재침전
  - 이온빔의 impurities
  - 이온빔으로부터의 neutrals
  - 이온빔 intensity의 불균일성
  - 시간에 따른 이온빔 intensity의 변화
- **Sample**
  - 시료표면의 roughness
  - 시료 결정의 방향 및 결함
  - 성분마다 다른 sputtering yield
  - Atomic mixing
  - 시료 원자들의 확산이나 분리, 결합

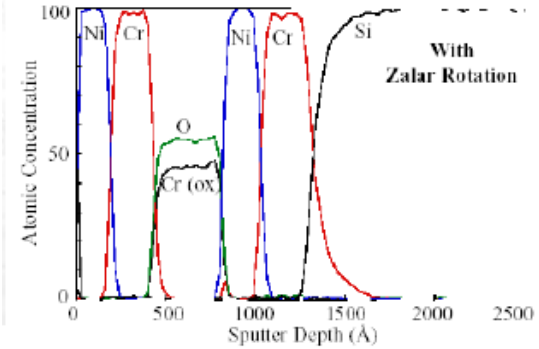
- Unidirectional Sputtering

→ Surface roughness increases (∝depth Z)

Zalar Rotation



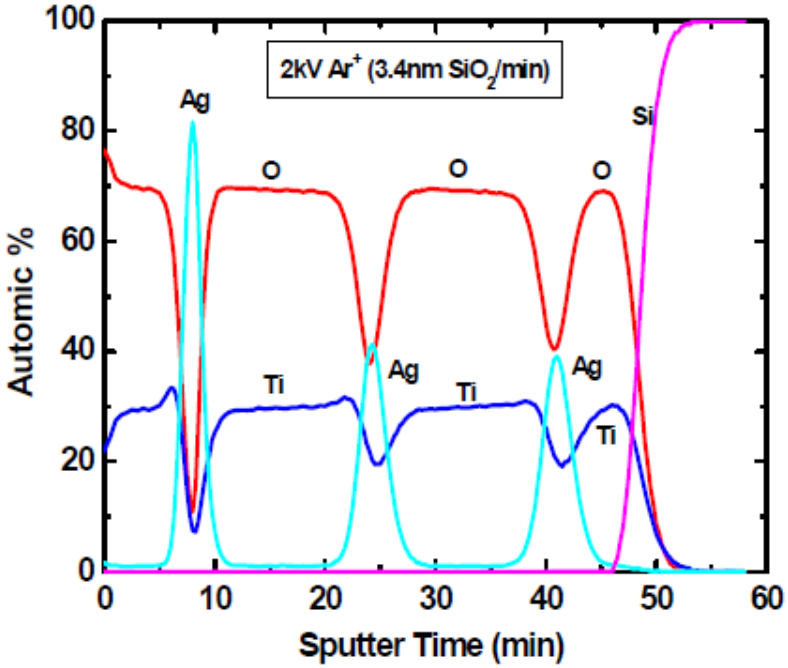




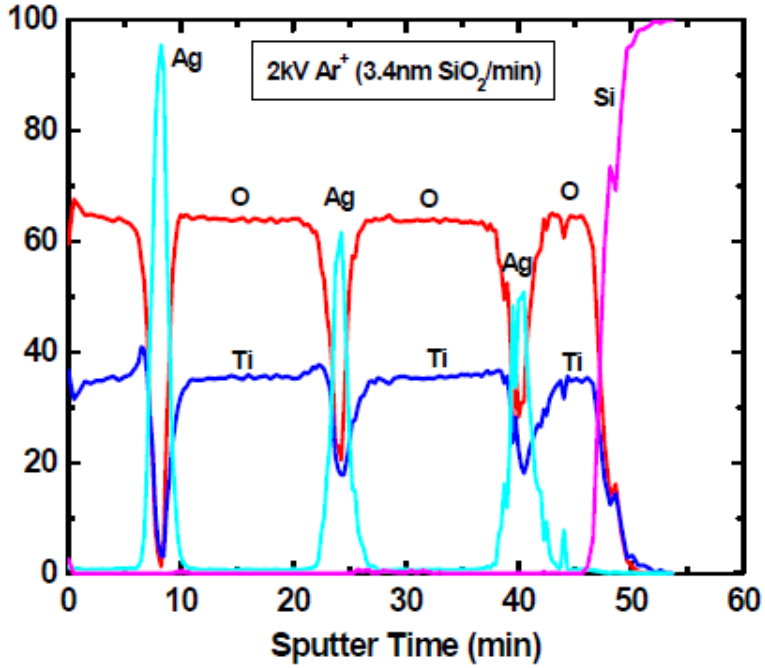
Increase of Depth resolution (decrease of Surface roughness)
- Rotate the sample during sputtering (Zalar rotation)
- Use the multiple ion guns at different angles.

Zalar Rotation

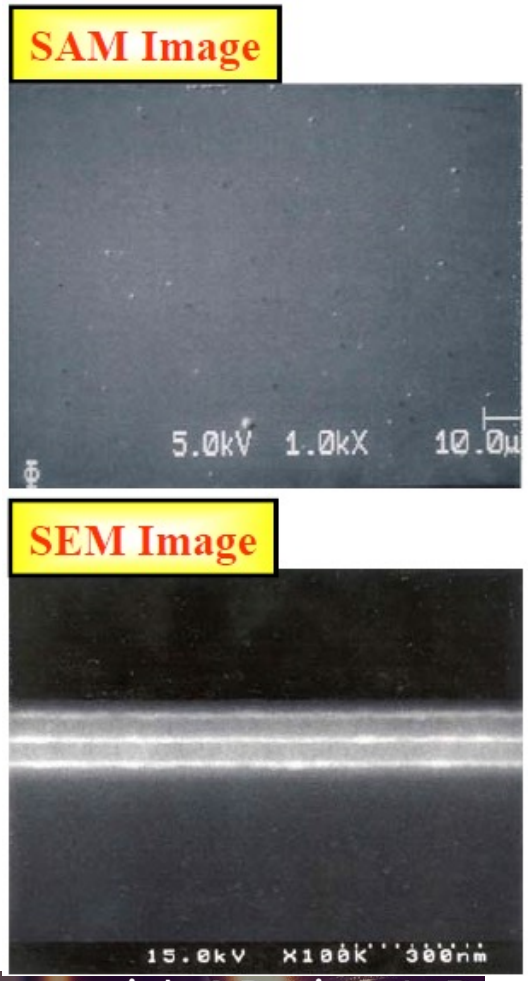
Without Zalar rotation



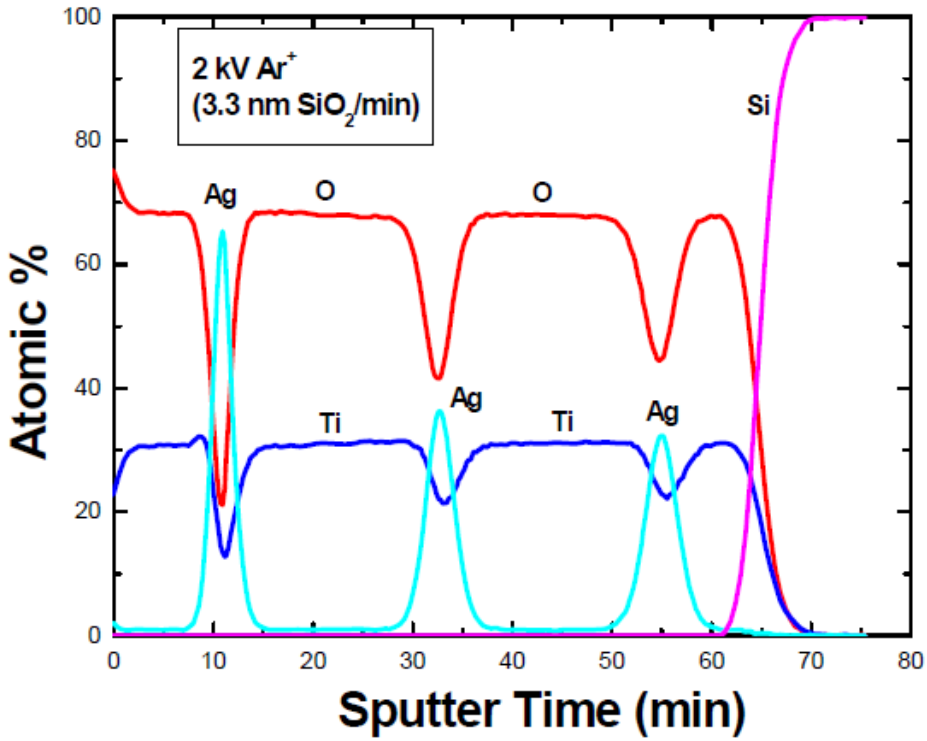
With Zalar rotation



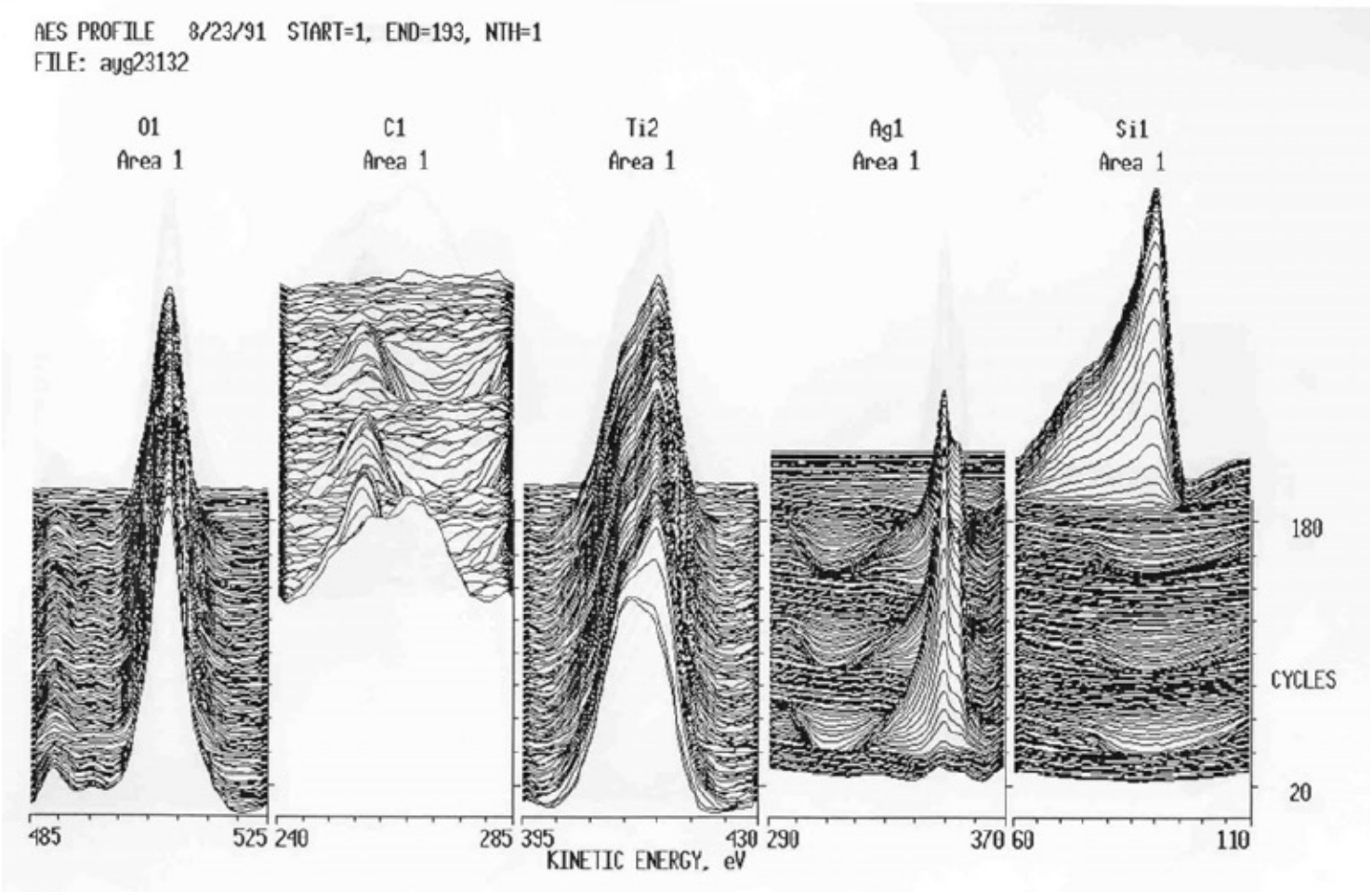
Example I



[air | TiO_2 (24 nm)|Ti (1 nm)|Ag (17 nm)|TiO_2 (24 nm)
{TiO_2 (24 nm)|Ti (1 nm)|Ag (13 nm)|TiO_2 (24 nm) }^{2} |glass]



Example II


AES PROFILE 8/23/91 START=1, END=193, NTH=1
FILE: ayg23132
O1
Area 1
C1
Area 1
Ti2
Area 1
Ag1
Area 1
Si1
Area 1
180
CYCLES
20
485
525
240
285
395
430
290
370
60
110
KINETIC ENERGY, eV