EE 527 MICROFABRICATION

Lecture 5

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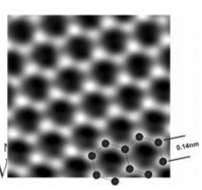
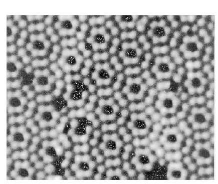
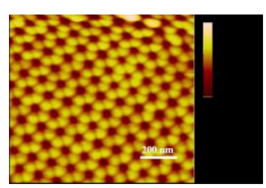
MICROSCOPY AND VISUALIZATION

- Electron microscope, transmission electron microscope
  - Resolution: atomic imaging
  - Use: lattice spacing.
- Scanning probe microscope (SPM) or (STM)
  - Resolution: atomic range
  - Use: surface characterization
- Atomic force microscope (AFM)
  - Resolution: nanometer
  - Use: surface characterization and measuring vertical dimensions.







LATERAL AND VERTICAL DIMENSIONS

- For device lateral dimensions, 10% deviation is usually accepted as a fabrication tolerance. Measurement precision should be 10% of that variation.
- Linewidth is often known as a critical dimension (CD). The measurement depends on edge detection in all methods.
- Film thicknesses ranges from one atomic layer to hundreds of micrometers.
  - Conductive and dielectric films are measured by different techniques.
  - Optical thickness measuring methods: ellipsometry and reflectometry.
  - X-ray reflection (XRR): very thin films.

ELECTRICAL MEASUREMENTS

- Some electrical parameters:

$$\text{resistivity } \rho = \frac{1}{nq\mu} \text{ cm} - \Omega$$

$$\text{resistance } R = \frac{\rho L}{WT} \; \Omega$$

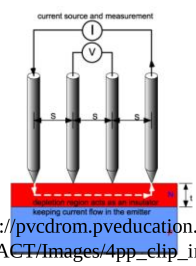
$$\text{sheet resistance } R_s = \frac{\rho}{T} \; \Omega/\square$$

- The four-point probe (4PP):

$$\rho = 2\pi s \frac{V}{I}$$

For thin films

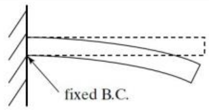
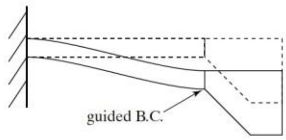
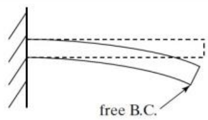
$$\rho = 4.53 \frac{V}{I} T$$



http://pvcdrom.pveducation.org/CHARACT/Images/4pp_clip_image001.jpg

MECHANICAL PROPERTIES/TYPES OF BEAMS

TABLE 3.2 Possible boundary conditions.

Boundary Conditions	Number of Linear DOF	Number of Angular DOF	Example
Fixed (clamped)	0	0	
Guided	**2**	0	
Free	2	**1**	

MECHANICAL PROPERTIES/SPRING CONSTANTS

Example 3.8 Cantilevers with Parallel Arms

Find the force constant associated with the case *g* depicted in Figure 3.20.

Solution. Case (g) consists of two fixed-free cantilever connected in parallel. The pertinent moment of inertia of each arm is

$$I = \frac{w_2 t^3}{12}$$

The overall force constant is

$$k = 2\left(\frac{F}{x}\right) = 2\frac{3EI}{l_2^3} = \frac{Ew_2t^3}{2l_2^3}$$

PHYSICAL AND CHEMICAL ANALYSES

Analysis area

- Optical methods:
  - Large areas from lamp illumination, or micrometer laser spot.
- X-ray:
  - Large areas in the millimeter range
- Focused ion beam:
  - Submicron spots or broader beams
- Electron beam:
  - Most accurate and the smallest possible analysis volume.

PHYSICAL AND CHEMICAL ANALYSES

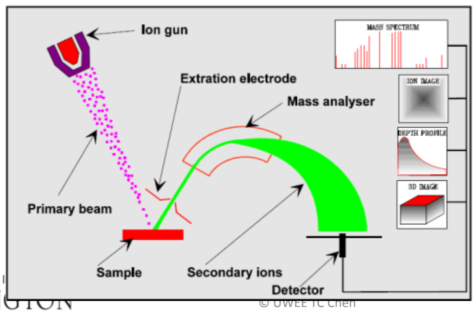
Analysis depth

- Electron:
  - Electrons have very small mean free paths in solids
  - Electron spectroscopies are very surface sensitive – only top few nanometers.
- X-ray:
  - X-rays penetrate deep into matter.
- Ion:
  - Ion penetration depth is easily varied by changing energy.

PHYSICAL AND CHEMICAL ANALYSES

Secondary Ion Mass Spectrometry (SIMS)

- The surface to be analyzed is bombarded by ions which knock atoms from the surface.
- Some of the atoms have been ionized, and subsequently mass analyzed.
- SIMS measurement is slow and expensive.



http://www.geos.ed.ac.uk/facilities/ionprobe/SIMS4.pdf

PHYSICAL AND CHEMICAL ANALYSES

Rutherford Backscattering (RBS)

- Energy spectrometry using MeV He^+ ions. The incident He^+ ions are elastically scattered by nuclei of the analytical sample, providing a quantitative elemental depth profile. Multi-component, multi-layered samples can be analyzed to a depth of 1mm or more.

RBS has the following characteristics:

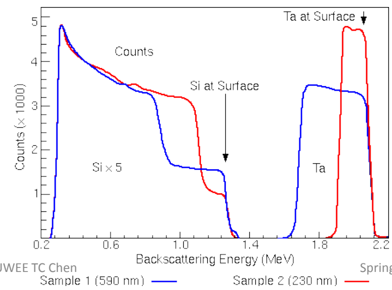
- Multi-element depth concentration profiles
- Fast, non-destructive analysis (no sample preparation or sputtering required)
- Quantitative without standards

PHYSICAL AND CHEMICAL ANALYSES

Rutherford Backscattering (RBS)

RBS has the following characteristics:

- High precision (typically ±3%)
- High sensitivity (e.g. 10^{11} Au/cm^2 on Si, depends on Z and sample composition)
- Depth range typ. 0 - 1mm
- Depth resolution ~20 Å typ. near surface

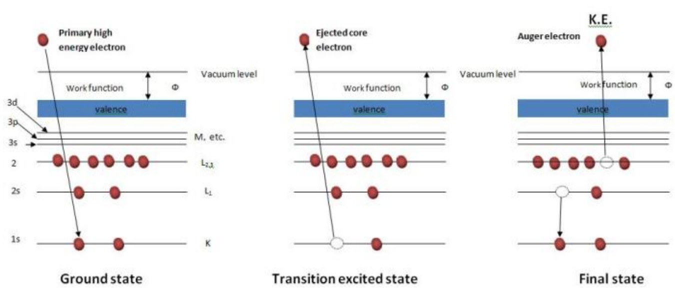


http://www.eaglabs.com/mc/rbs-metal-silicide-example.html

PHYSICAL AND CHEMICAL ANALYSES

Auger Electron Spectroscopy (AES)

- An E-beam hits the surface and an inner core electron is rejected.
- The vacancy is filled by an electron from an outer shell.
- The third (auger) electron receives the energy and escapes.

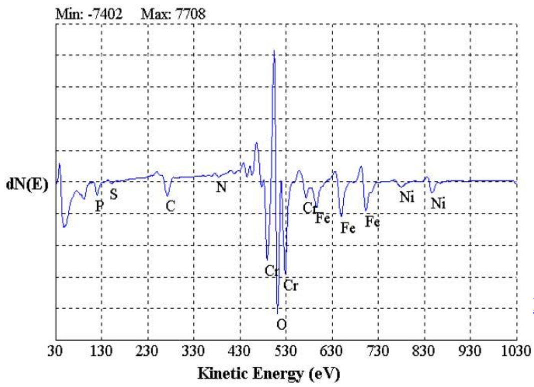


http://wiki.utep.edu/display/~ckroy/Auger+Electron+Spectroscopy+%28AES%29

PHYSICAL AND CHEMICAL ANALYSES

Auger Electron Spectroscopy (AES)

- The energy of the escaping electron is determined by the atomic energy levels and can be uniquely identified.



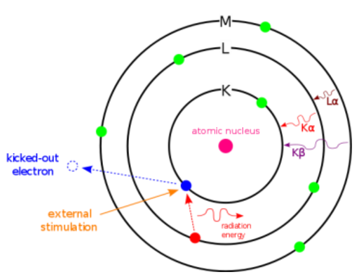
http://mee-inc.com/sam.html

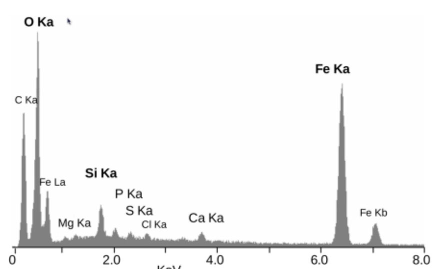
AES Spectrum for Passivated Stainless Steel

PHYSICAL AND CHEMICAL ANALYSES

Energy Dispersive X-ray spectroscopy (DEX)

- Detect x-ray emitted by incident electron.



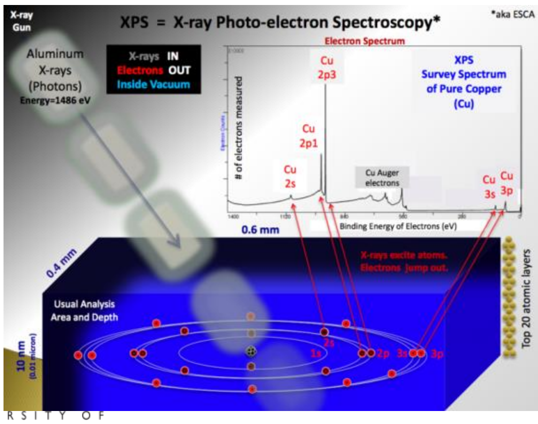


http://en.wikipedia.org/wiki/Energy-dispersive_X-ray_spectroscopy

PHYSICAL AND CHEMICAL ANALYSES

X-ray Photoelectron Spectroscopy (XPS)

- Detect electron energy emitted by incident x-ray.

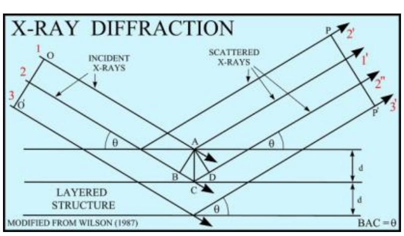


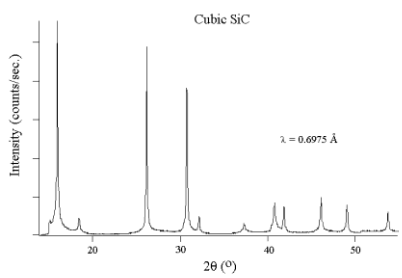
http://en.wikipedia.org/wiki/X-ray_photoelectron_spectroscopy

PHYSICAL AND CHEMICAL ANALYSES

X-ray Diffraction (XRD)

- XRD is used to measure crystallinity.





http://www.spec2000.net/09-xrd.htm

SILICON

SILICON PROPERTIES

- The experimental values of silicon properties are relatively scattered.
  - Material properties are affected by a variety of subtle factors, such as material growth conditions, surface finish, and thermal treatment history.
- Macroscopic samples display less obvious because of the average effect from a large specimen.
  - For example, the fracture behavior of silicon is governed by the presence of flaws and preexsiting cracks.
  - Small single crystal silicon may exhibit large elastic strength and strain than bulk silicon.

SILICON PROPERTIES

Crystal properties

PROPERTY	VALUE	UNITS
Structure	Cubic	
Atomic weight	28.0855	
Lattice spacing (a_0) at 300K	0.54311	nm
Density at 300K	2.3290	g/cm^3
Nearest Neighbour Distance at 300K	0.235	nm
Number of atoms in 1 cm^3	4.995×10^{22}	
Isotopes	28 (92.23%) 29 (4.67%) 30 (3.10%)	
Electron Shells	$1s^2 2s^2 2p^6 3s^2 3p^2$	
Common Ions	Si^{4+}, Si^{4-}	

http://www.phy.duke.edu/~hx3/physics/silicon/silicon.htm

SILICON PROPERTIES

Band structure properties

PROPERTY	VALUE	UNITS
Dielectric Constant at 300 K	11.9	
Effective density of states (conduction, N_c T=300 K)	2.8×10^{19}	cm^{-3}
Effective density of states (valence, N_v T=300 K)	1.04×10^{19}	cm^{-3}
Energy Gap E_g at 300 K (Minimum Indirect Energy Gap at 300 K)	1.12	eV
Energy Gap E_g at ca. 0 K (Minimum Indirect Energy Gap at 0K)	1.17 (at 0 K)	eV
Intrinsic carrier concentration	1.5×10^{10}	cm^{-3}
Intrinsic resistivity	3.2×10^5	Ω-cm

http://www.phy.duke.edu/~hx3/physics/silicon/silicon.htm

SILICON PROPERTIES

Electrical properties

PROPERTY	VALUE	UNITS
Breakdown field	$\approx 3 \times 10^5$	V/cm
Mobility electrons	≈ 1400	cm^2 / (V x s)
Mobility holes	≈ 450	cm^2 / (V x s)
Diffusion coefficient electrons	≈ 36	cm^2/s
Diffusion coefficient holes	≈ 12	cm^2/s
Electron thermal velocity	2.3×10^5	m/s
Hole thermal velocity	1.65×10^5	m/s
Optical phonon energy	0.063	eV
Work function (intrinsic)	4.15	eV

http://www.phy.duke.edu/~hx3/physics/silicon/silicon.htm

SILICON PROPERTIES

Mechanical properties

PROPERTY		VALUE	UNITS
Bulk modulus of elasticity		9.8×10^{11}	dyn/cm^2
Density		2.329	g/cm^3
Hardness		7	on the Mohs scale
Surface microhardness (using Knoop's pyramid test)		1150	kg/mm^2
Elastic constants		$C_{11} = 16.60 \times 10^{11}$ $C_{12} = 6.40 \times 10^{11}$ $C_{44} = 7.96 \times 10^{11}$	dyn/cm^2 dyn/cm^2 dyn/cm^2
Young's Modulus (E)	[100]	129.5	GPa
	[110]	168.0	GPa
	[111]	186.5	GPa
Shear Modulus		64.1	GPa
Poisson's Ratio		0.22 to 0.28	-

http://www.phy.duke.edu/~hx3/physics/silicon/silicon.htm