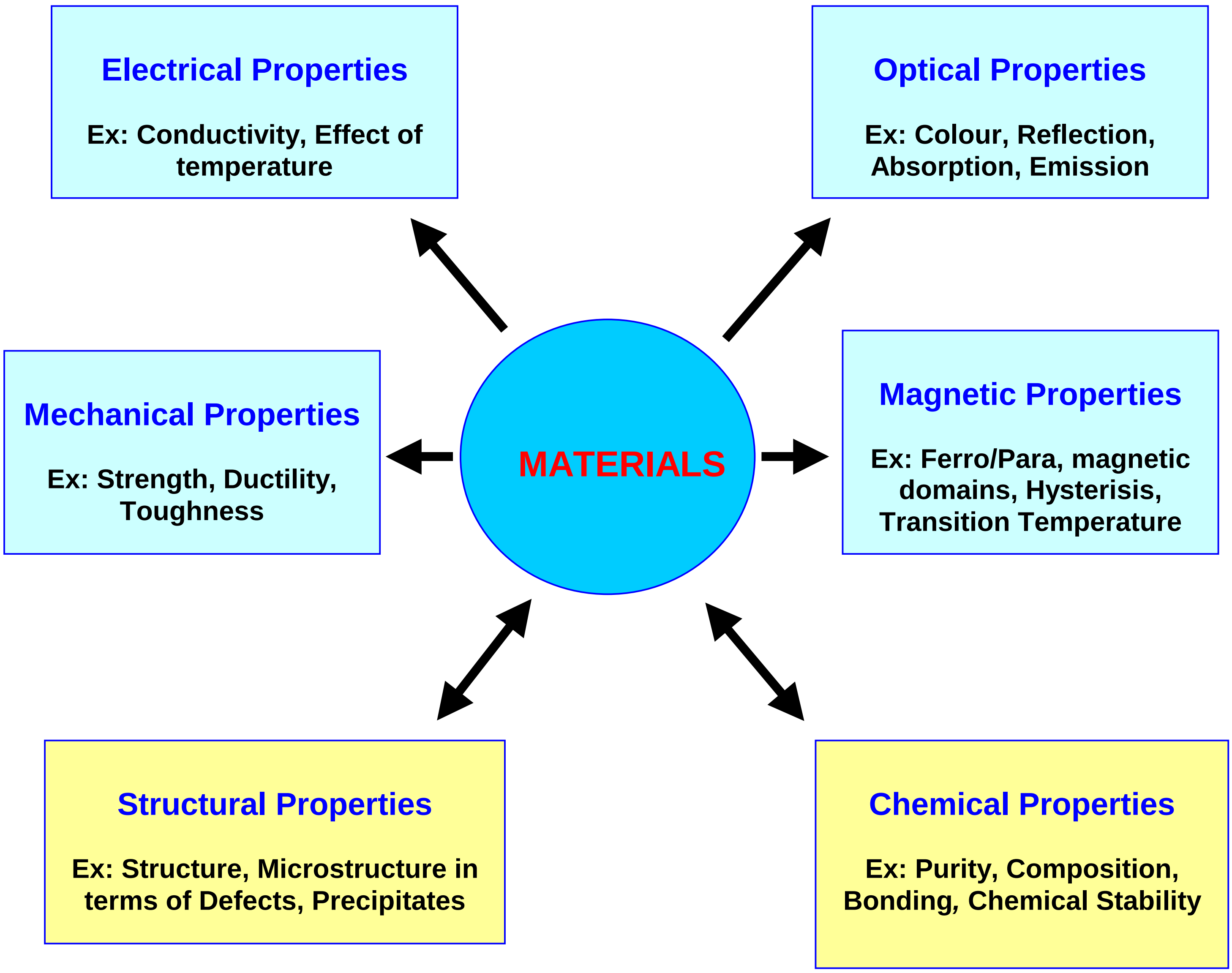
Trends and Techniques in

Materials Synthesis
&
Characterisation

Figure 1. Physical and Chemical properties of materials.

The chemical and structural properties are the basic and fundamental properties of materials. By modifying these, the designed performance with respect to electrical, optical, mechanical and magnetic properties can be achieved.



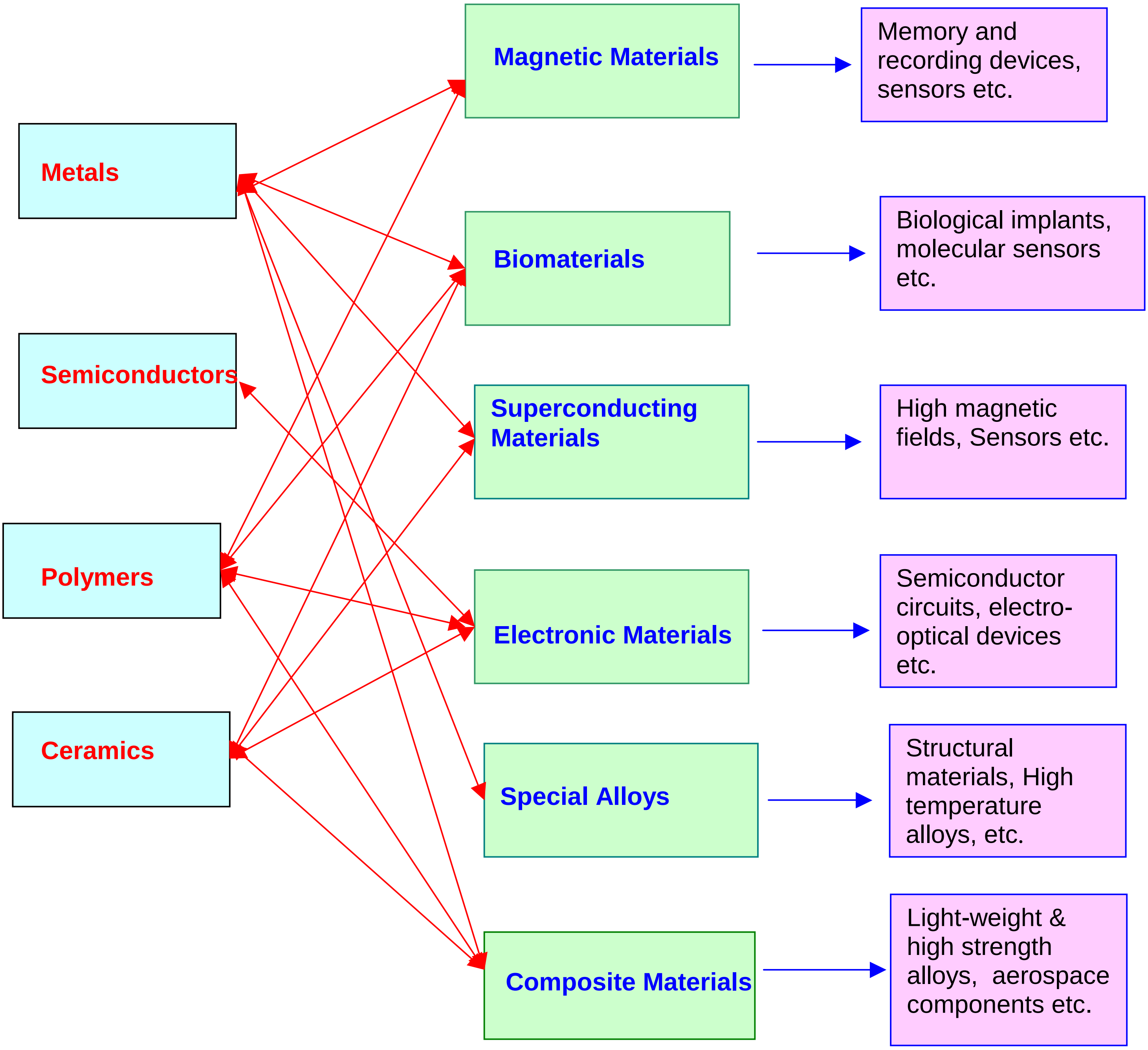
Evolution of newer materials

The following table shows the evolution of materials so as to have improved or better performance meant for special applications.

Metals	Semiconductors	Insulators	Polymers
http://www.matweb.com/search/SearchSubcat.asp	http://matse1.mse.uiuc.edu/~tw/sc/time.html	http://www.ceramic.org/resources.asp	http://abalone.cwru.edu/tutorial/enhanced/files/polymers/Intro.htm
Fe, Cu, Al (simple metals) ↓	**Elemental Ex. Si, Ge** http://www.americanmicrosemi.com/tutorials.htm ↓	**Ceramics Ex. Al_2O_3** http://www.ceramic.org/cic/propertiesdb.asp ↓	**Plastics Ex. Nylon, Teflon** ↓
Alloys ↓	**Compound Ex. GaAs, InP (Group III-V) CdTe, CdS (Group II-VI)** http://jas.eng.buffalo.edu/ ↓	**Reinforced fiber materials, MMC, Surface reinforcement** ↓	**Improved: Kevlar, conducting polymers etc.** ↓
Lighter, Stronger & tougher materials	**Band gap engineering (Composition or thickness modulated), Semiconductor multilayers, Quantum dots**	**Harder ceramics**	**Bio-degradable/ compatible polymers**

Figure 2: Materials, their connectivity and advanced applications.

Newer materials are obtained by intelligent and judicious intermixing of existing materials. This is illustrated by the following schematic showing the basic materials and their interconnectivity so as to have tailor-made materials for a specific application.



Materials of recent interest

Photonic materials

Manipulation of band gaps of semiconductors to make materials suitable for opto-electronic applications Ex. Quantum heterostructures for laser diodes.

http://people.deas.harvard.edu/~jones/ap216/images/bandgap_engineering/bandgap_engineering.html

http://www.ioffe.rssi.ru/SVA/NSM/Hetero/index.html

Smart materials

Materials changing their properties based on the external stimulus such as changes in temperature or stress etc. Ex. Shape memory alloys of Ni and Ti are being used for making thermo-electrical switches, which act as smart sensors.

http://robby.caltech.edu/~chen/res-piezo.html

Information storage materials

Magnetic, optical and hybrid materials used for memory storage systems. Ex. Giant magneto-resistance (GMR) materials.

Energy storage/generation materials

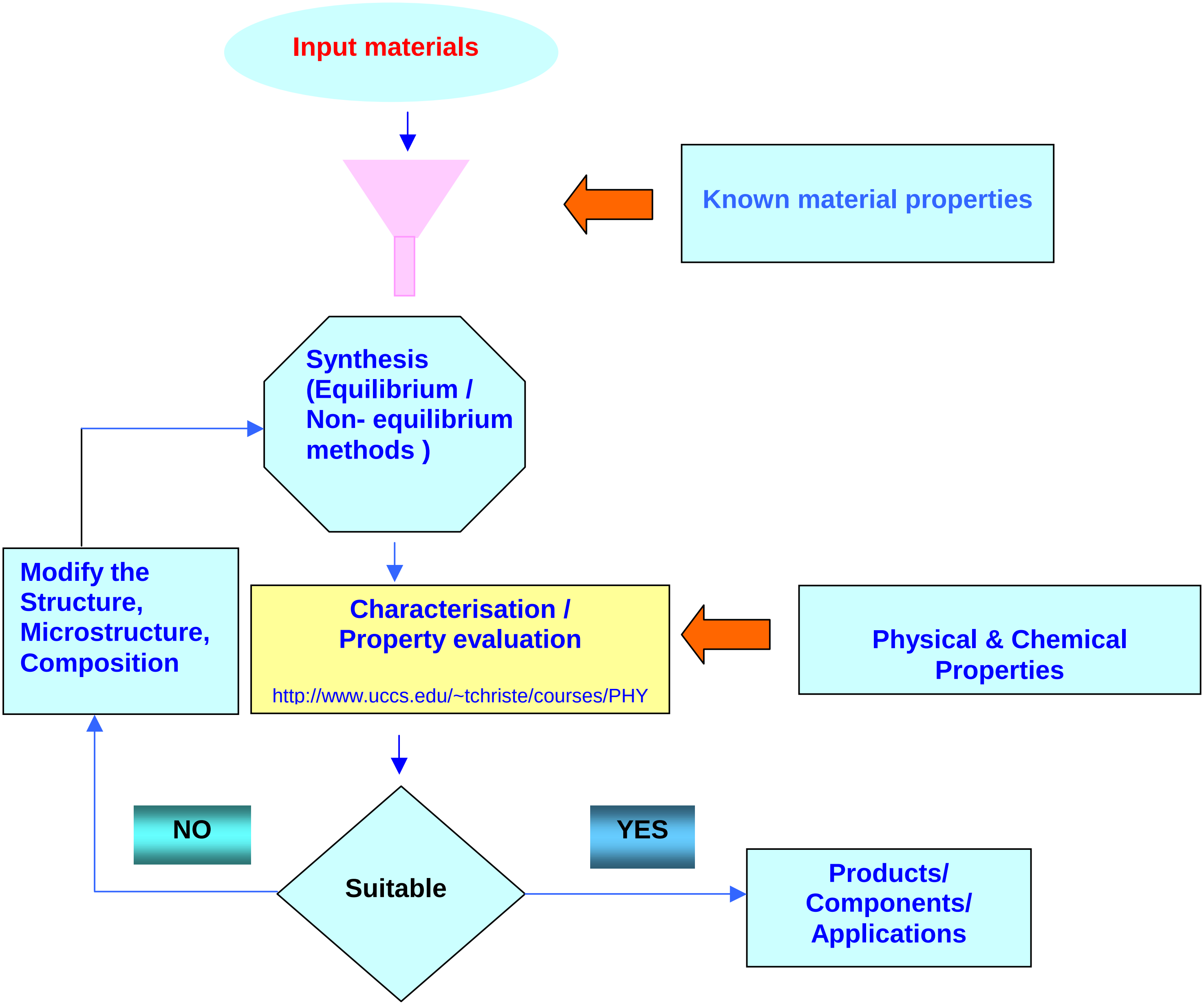
Improved hydrogen storage materials, fuel cells for clean power generation etc. Ex. Metal hydrides, porous electrode materials.

MEANS OF MATERIALS SYNTHESIS

The following table shows various methods for synthesizing materials.

Equilibrium Methods	Non-equilibrium Methods
Bulk synthesis **Alloying, Solid state synthesis, Co-precipitation etc.**	**Splat quenching** **(Very short time scales- Microstructure frozen)** **Ex. Metallic glasses** http://www.binghamton.edu/physics/splat2.html
Thin film synthesis **Physical vapor deposition (PVD),** http://www.icmm.csic.es/fis/english/evaporacion_resistencia.html **chemical vapor deposition (CVD),** http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/cvd.html **Molecular beam epitaxy (MBE)** http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/mbe.html	**Ion beam synthesis** **(High concentration of non-equilibrium species viz., defects or chemical dopants)** **Surface Modification** **Plasma or laser treated surfaces.**
	High Pressure & High temperature Synthesis **(~ Mbar pressure, ~ 10^4 K temperature)**

Figure 3. Development of tailor-made materials: Steps in synthesis and characterisation of materials.



Trends in Materials Synthesis-I

Modifying the bulk state of materials in terms of composition or microstructure has been the established route for synthesizing new materials. With increasing developments in thin film sensors or semiconductor devices, the emphasis is shifting to modifying the surface and interfaces of materials. Finally, advances in new techniques enable us to manipulate atoms to synthesize quantum dots.

Modifying the bulk

(alloying, precipitate hardening etc.)

↓

Tinkering the surfaces & Interfaces

(surface modification → coatings,

Grain refinement → Nanophase materials

Semiconductor multilayers → Band gap engineering)

↓

Manipulation of individual atoms

(atomic clusters, Quantum dots)

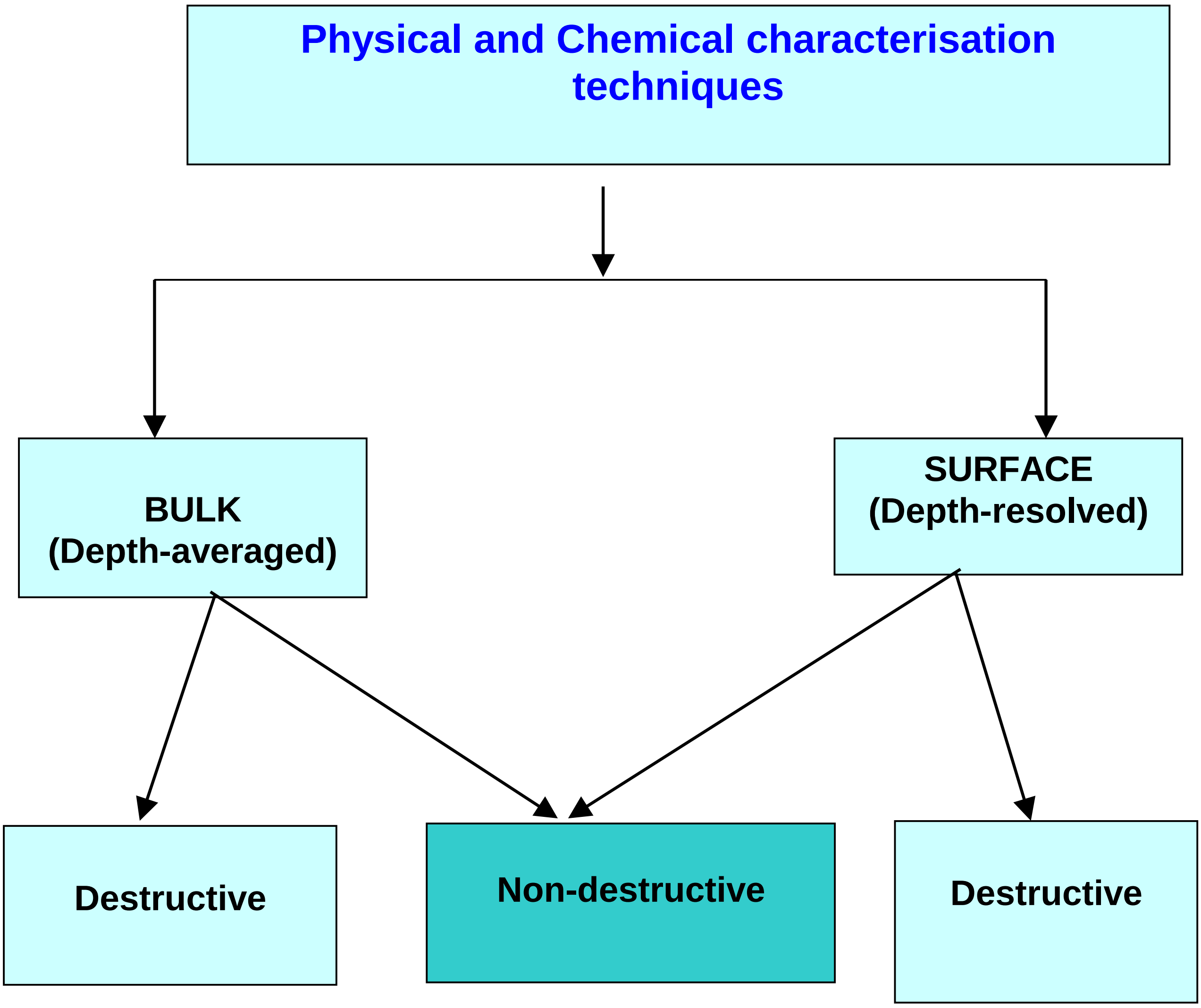
Trends in Materials Synthesis - II

Basic Materials :
Metals, Semiconductors, Ceramics, Polymers

Evolution of sensors or devices as a multilayer combination of basic materials

Metal-Metal bilayers,
Semiconductor-Semiconductor,
Metal-Semiconductor,
Metal-Ceramic,
Metal-Polymer,
Semiconductor-Polymer

Classification of experimental techniques



CHARACTERISATION OF MATERIALS

A selected list of experimental techniques for structural and compositional characterisation of materials.

Techniques for Structural and Microstructural information	Techniques for chemical information about composition, purity etc.
1) Optical Microscopy http://micro.magnet.fsu.edu/primer/index.html http://www.thebritishmuseum.ac.uk/science/text/techniques/sr-tech-optmic-t.html **2) Non-destructive techniques based on Ultrasound and micro-magnetic methods** www.asnt.org www.bindt.org **3) X-ray diffraction (XRD)** http://epswww.unm.edu/xrd/resources.htm http://www.journey.sunysb.edu/projectjava/bragg/home.html http://www.uni-wuerzburg.de/mineralogie/crystal/teaching/teaching.html **4) Electron microscopy (SEM,TEM,HRTEM,LEED, EELS)** http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/image.html http://cryoem.berkeley.edu/~nieder/em_for_dummies/ http://www.unl.edu/CMRAcfem/em.htm http://www.soton.ac.uk/~micro/links.html http://www.ou.edu/research/electron/www-vl/long.shtml **5) Field Ion microscopy (FIM)** http://www.uksaf.org/tech/fim.html http://www.physics.purdue.edu/nanophys/lovall/fimpics.html http://physics.unipune.ernet.in/~fem/intro-fim.htm	**1) Spectrophotometry** http://www.chm.davidson.edu/ChemistryApplets/spectrophotometry/index.html **2) Optical emission spectroscopy** http://icp-oes.com/ **3) Atomic absorption spectroscopy** http://www.thebritishmuseum.ac.uk/science/text/techniques/sr-tech-aas-t.html **4) Mass spectrometric methods (ICP-MS, EG-MS)** http://www.chem.vt.edu/chem-ed/crossref/ac-mass-spec.html **5) Energy dispersive X-ray analysis (EDXA)** http://www.nlectc.org/assistance/edx.html **6) Electron probe microanalysis (EPMA)** http://www.cameca.fr/html/epma_technique.html http://www.nhm.ac.uk/mineralogy/facilities/probe.htm **7) X-ray photoelectron spectroscopy (XPS)** http://www.xpsdata.com/ **8) Auger electron spectroscopy (AES)** http://www.eaglabs.com/cai/auginst/caiainst.htm http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/element.html

6) Neutron diffraction

http://www.ansto.gov.au/ansto/neut/b_jamehunt.pdf

http://www.gkss.de/Themen/W/p5e.html

7) Optical techniques

a) Ellipsometry

http://www.beaglehole.com/elli_intro/elli_intro.html

http://www.grc.nasa.gov/WWW/OptInstr/tuma/ellipse.html

b) Raman spectroscopy

www.elen.utah.edu/~devans/raman/report1.htm

http://www.thebritishmuseum.ac.uk/science/text/techniques/sr-tech-ramen-t.html

c) FTIR

http://userwww.port.ac.uk/eatonp/tutorial/sld002.htm

http://www.spectroscopynow.com/Spy/basehtml/SpyH/1,2466,3-4-9806-0-9806-directories--0,00.html

8) Positron Annihilation Spectroscopy (PAS)

http://www.ep3.uni-halle.de/positrons/talks/Intro.pdf

9) Scanning tunnelling microscopy (STM)

http://www.chembio.uoguelph.ca/educmat/chm729/STMpage/stmconc.htm

http://www.mobot.org/jwcross/spm/

9) Secondary ion mass spectroscopy (SIMS)

http://www.eaglabs.com/cai/simstheo/caistheo.htm

10) Rutherford back scattering (RBS)

http://www.eaglabs.com/cai/rbsinst/cairinst.htm

11) Particle induced X-ray emission (PIXE)

http://www.supernet.net/~pixe/pixeinfo.html#Whatis

http://www.mrsec.harvard.edu/cams/PIXE.html

For more details on materials science, please visit the following sites

- http://www.mrs.org/related/materials.html
- http://dns.mrs.org/
- http://directory.google.com/Top/Science/Technology/Materials/

Disclaimer: The web links included here are by no means exhaustive and are provided to have a feel for the vast literature available on Internet