SCANNING ELECTRON MICROSCOPY (SEM)

SCANNING ELECTRON MICROSCOPY

What is SEM?

Working principle of SEM

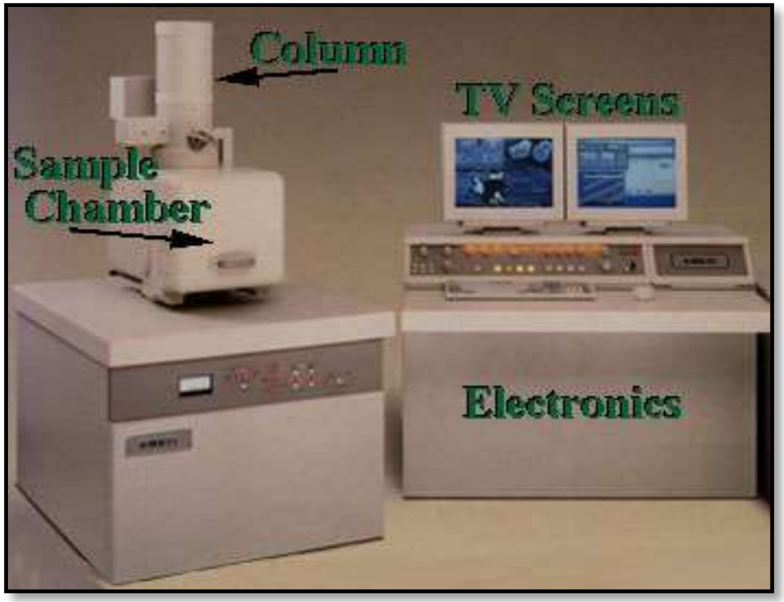
Major components and their functions

Magnification, resolution, depth of field and image contrast

Energy Dispersive X-ray Spectroscopy (EDS)

WHAT IS SEM?

Scanning electron microscope (SEM) is a microscope that uses *electrons* rather than *light* to form an image. There are many advantages to using the SEM instead of a OM.



The SEM is designed for direct *studying of the surfaces of solid objects*

ADVANTAGES OF SEM

	Magnification	Depth of Field	Resolution
OM	4x – 1000x	1.5mm – 0.19mm	~ 0.2mm
SEM	10x – 3000000x	4mm – 0.4mm	1-10nm

The SEM has a *large depth of field*, which allows a large amount of the sample to be in focus at one time and produces an image that is a good representation of the three-dimensional sample. The SEM also produces images of *high resolution*, which means that closely features can be examined at a *high magnification*.

The combination of *higher magnification, larger depth of field*, *greater resolution* and *compositional* and *crystallographic information* makes the SEM one of the most heavily used instruments in research areas and industries, especially in **semiconductor industry**.

IMAGING CONCEPT OF SEM

Instead of using the full-field image, a point-to-point measurement strategy is used.

High energy *electron beam* is used to *excite* the *specimen* and the signals are collected and analyzed so that an *image* can be *constructed*.

The signals carry *topological, chemical* and *crystallographic informations* of the samples surface.

APPLICATIONS OF SEM

- Topography

  The surface features of an object and its texture (hardness, reflectivity… etc.)

- Morphology

  The shape and size of the particles making up the object (strength, defects , etc.)

- Composition

  The elements and compounds that the object is composed of and the relative amounts of them (melting point, reactivity, hardness...etc.)

- Crystallographic Information

  How the grains are arranged in the object (conductivity, electrical properties, strength...etc.)

PRINCIPLE OF SEM

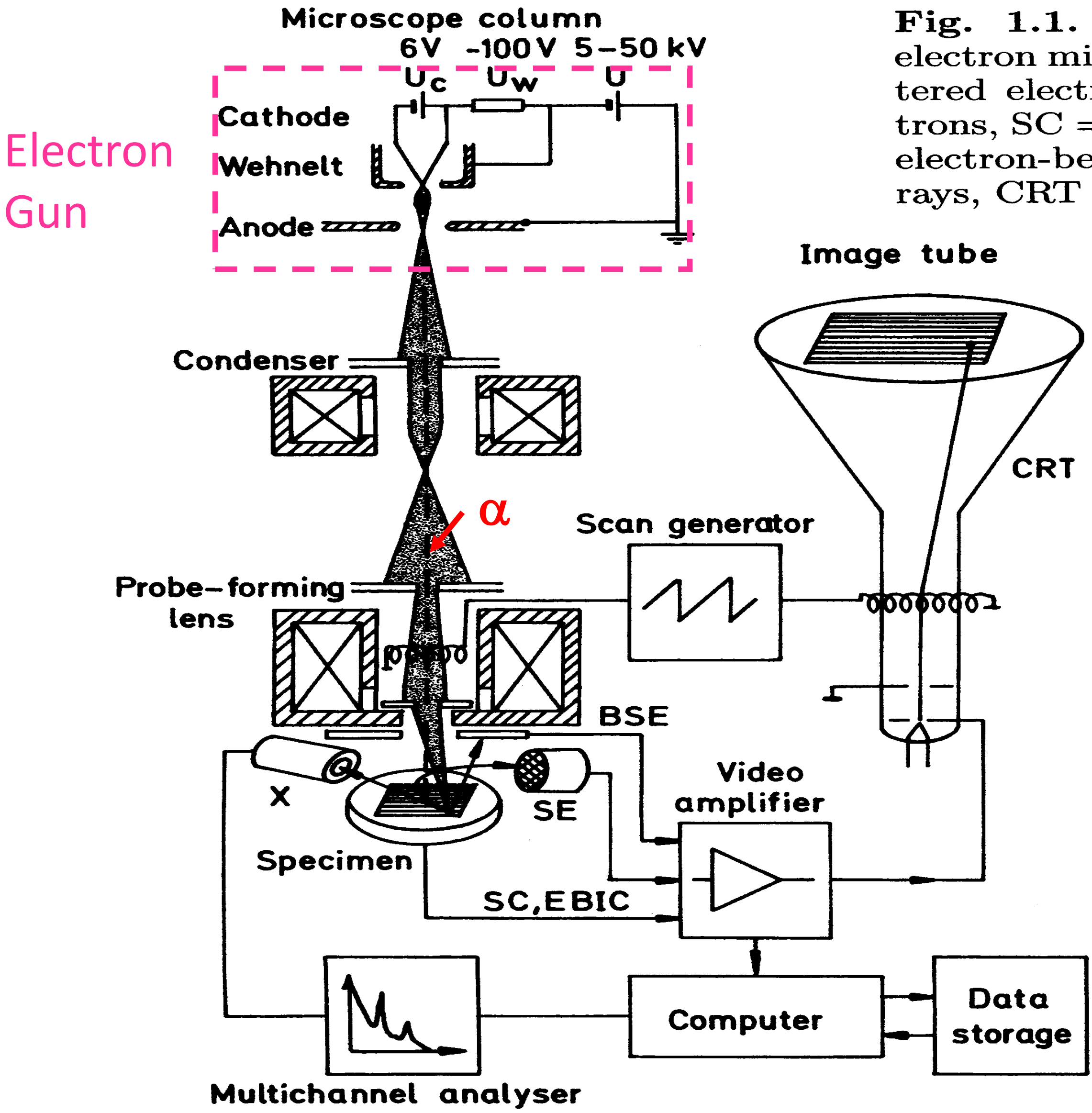


Fig. 1.1. Principle of the scanning electron microscopoe (BSE = backscattered electrons, SE = secondary electrons, SC = specimen current, EBIC = electron-beam-induced current, X = x-rays, CRT = cathode-ray tube)

PRINCIPLE OF SEM

The basic steps involved in all SEMs are

A stream of electrons is formed (by the Electron Source) and *accelerated* toward the specimen using a *positive electrical potential*

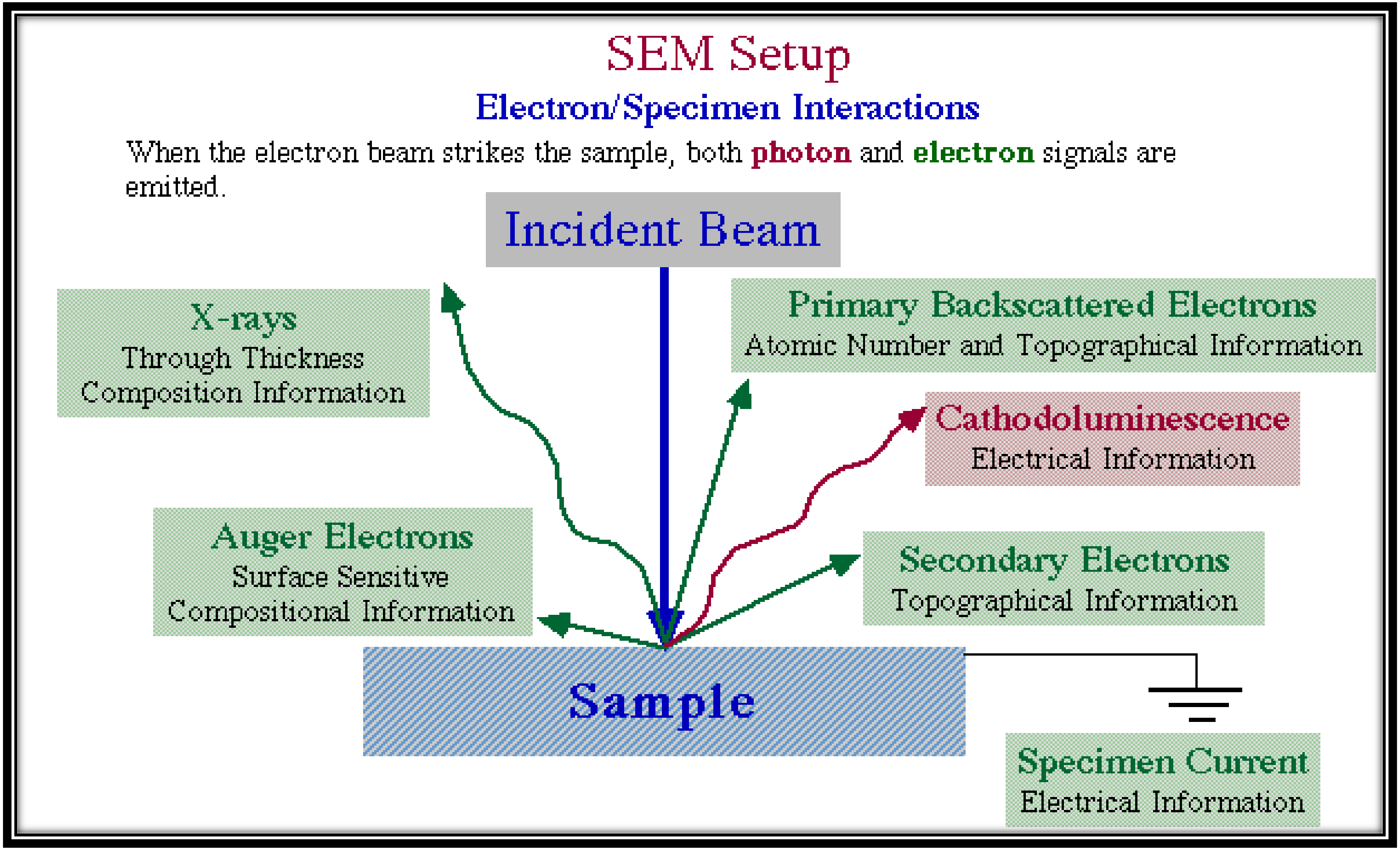
This stream is confined and focused using metal *apertures* and magnetic *lenses* into a thin, focused, *monochromatic beam*.

This beam is focused onto the sample using a *magnetic lens*

Interactions occur inside the irradiated sample, affecting the electron beam. *These interactions and effects are detected and transformed into an image*.

The various phenomenon taking place *due to interaction of the accelerated electrons with the specimen* are shown in Fig.

PRINCIPLE OF SEM



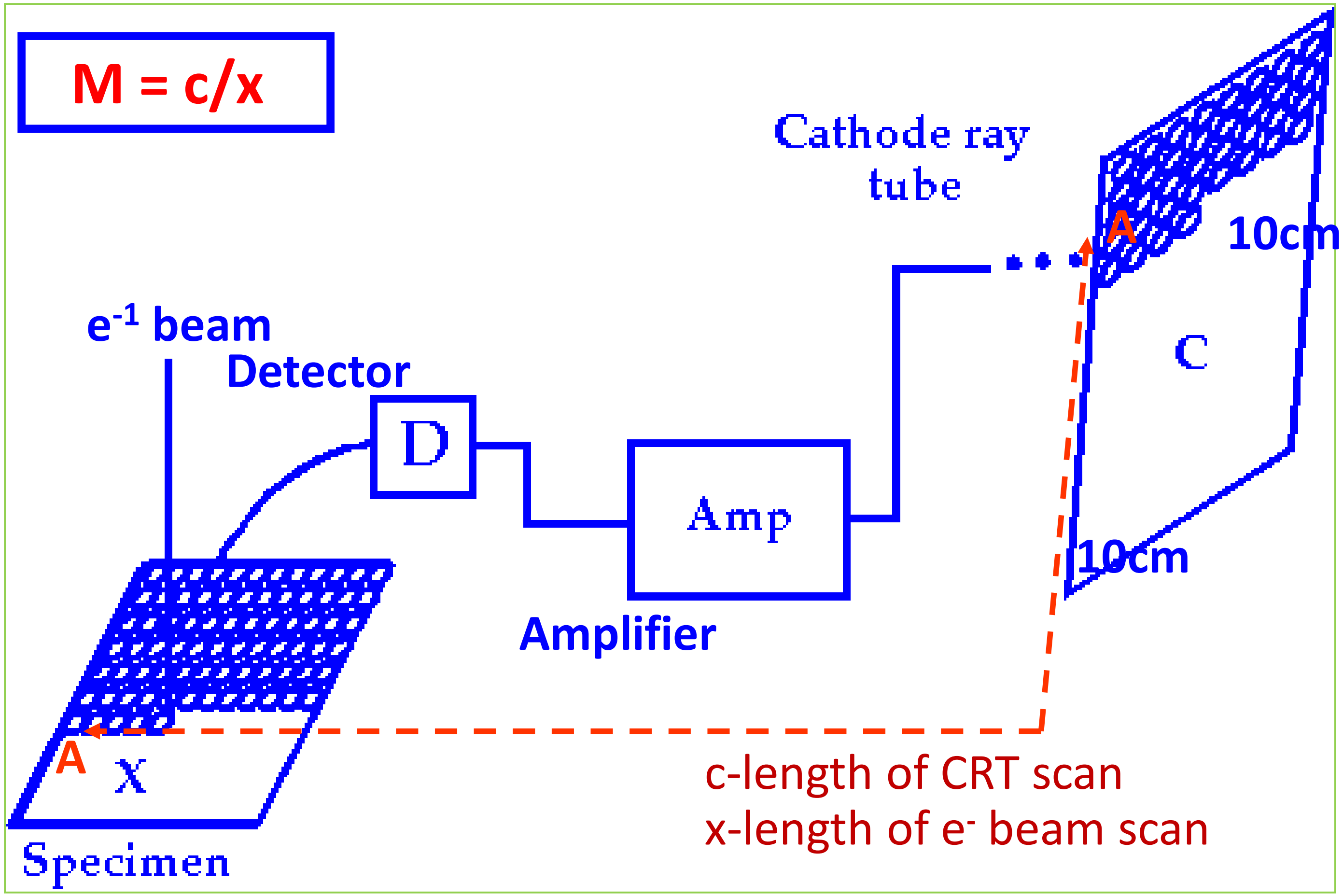
SEM Setup

Electron/Specimen Interactions

When the electron beam strikes the sample, both **photon** and **electron** signals are emitted.

IMAGE FORMATION IN SEM

$M = c/x$

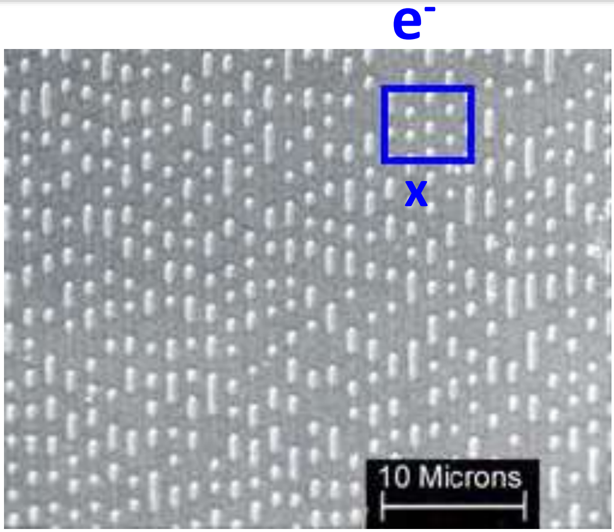


c-length of CRT scan

x-length of e^- beam scan

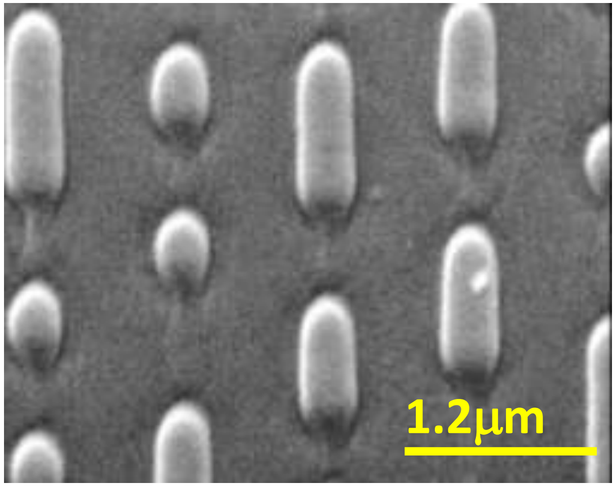
Beam is scanned over specimen in a raster pattern in *synchronization* with beam in CRT. Intensity at *A* on CRT is proportional to *signal* detected from *A* on specimen and signal is modulated by amplifier.

Magnification



Low M
Large x
40μm

2500x



High M
small x
7μm

15000x

The magnification is simply the ratio of the length of the scan C on the Cathode Ray Tube (CRT) to the length of the scan x on the specimen. For a CRT screen that is 10 cm square:

$$M = C/x = 10cm/x$$

Increasing M is achieved by decreasing x.

M	x	M	x
100	1 mm	10000	10 mm
1000	100 mm	100000	1 mm

IMAGE MAGNIFICATION IN SEM

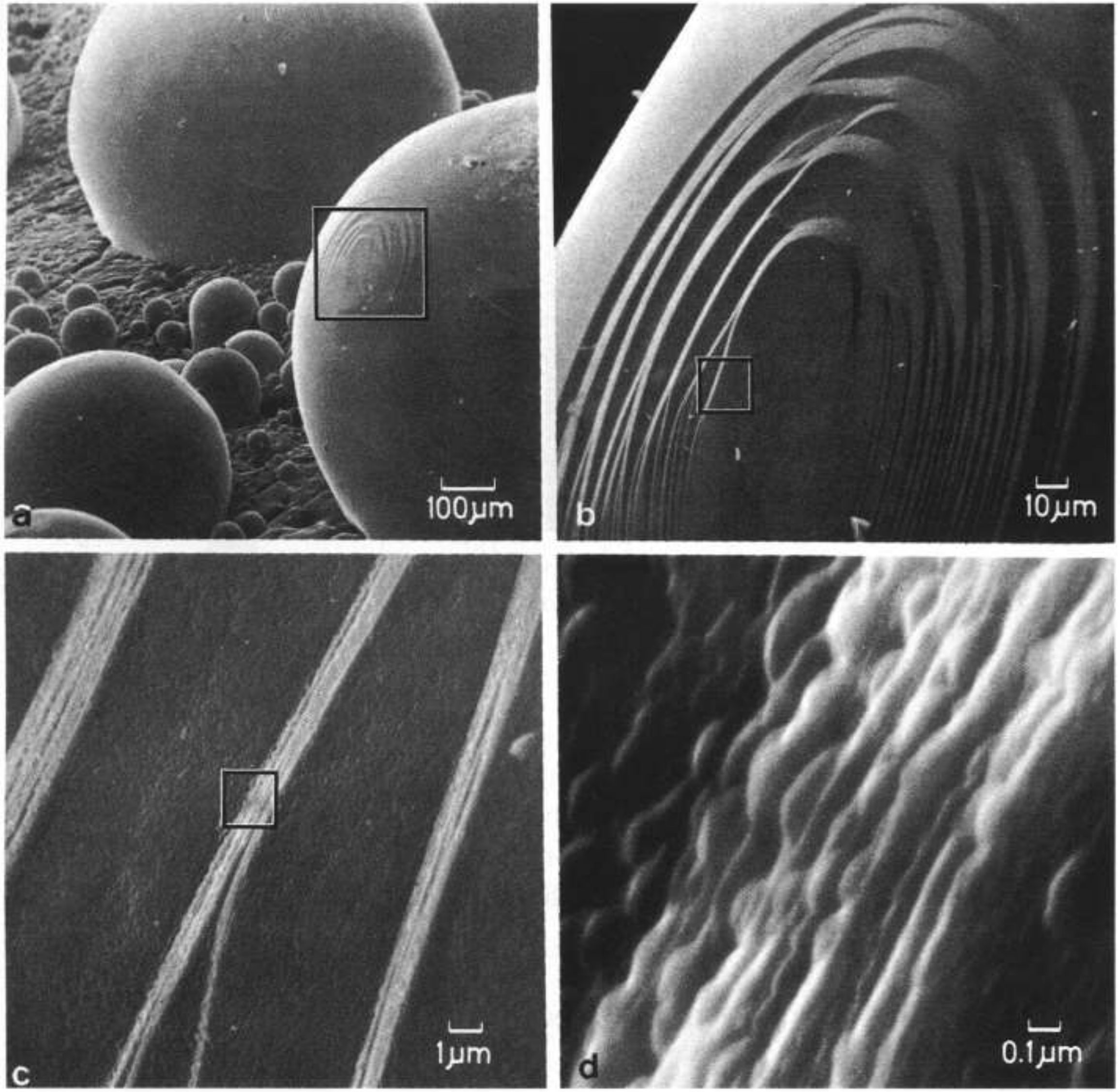
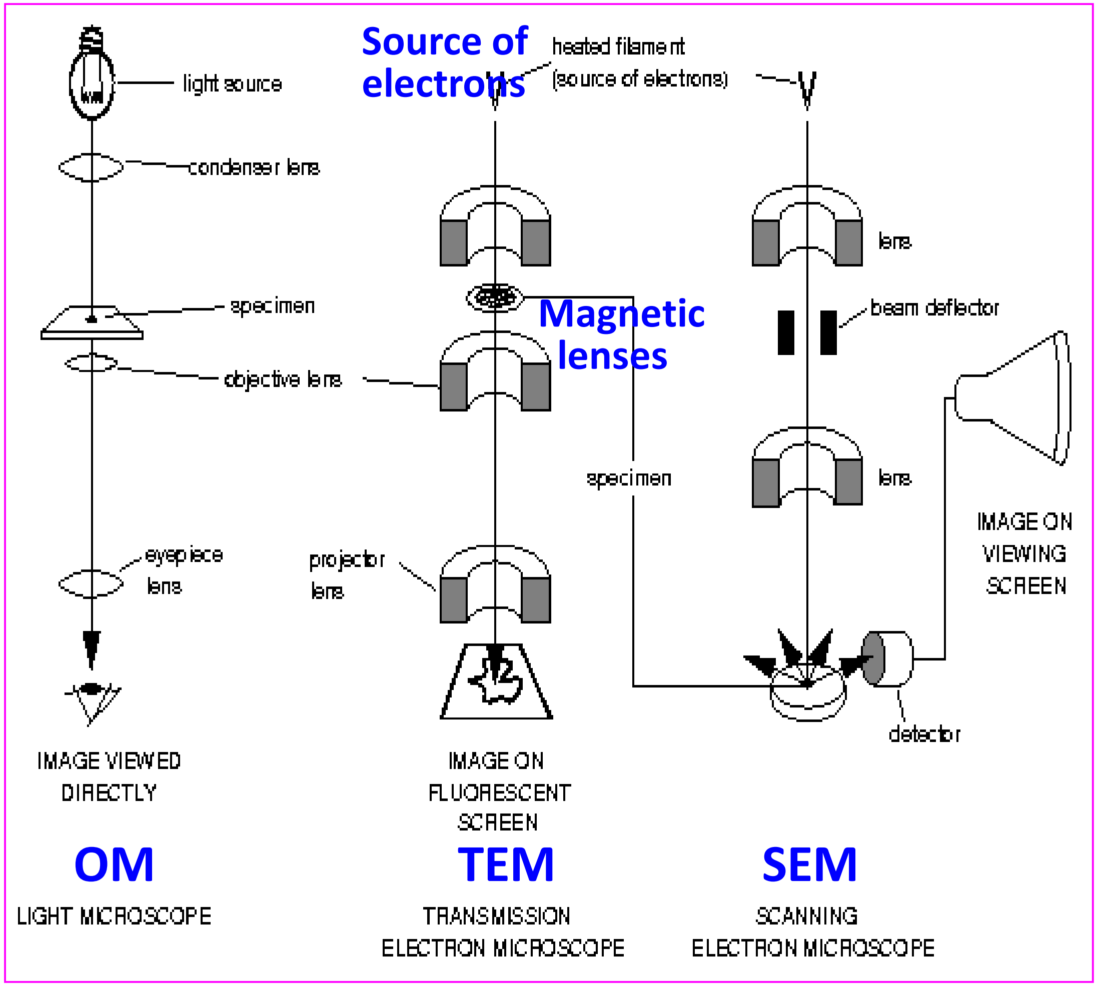


Fig. 1.3. Example of a series of increasing magnification (spherical lead particles imaged in the SE mode)

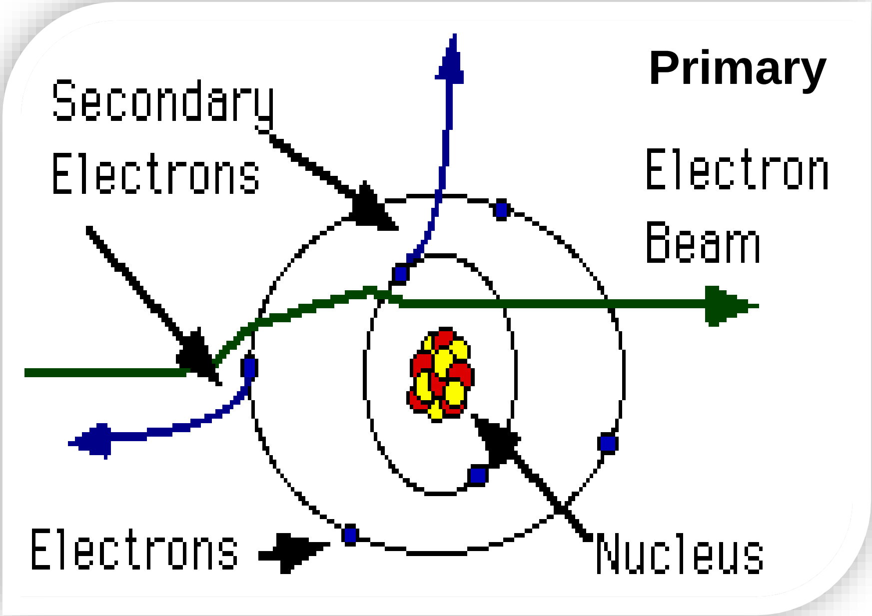
Example of a series of increasing magnification (spherical lead particles imaged in SE mode)

COMPARISON OF OM,TEM AND SEM



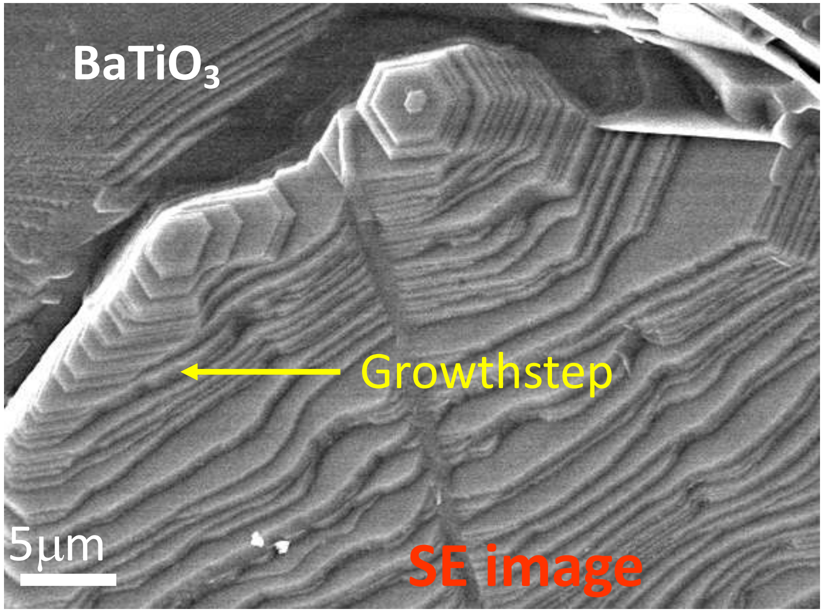
Principal features of an optical microscope, a transmission electron microscope and a scanning electron microscope, drawn to emphasize the similarities of overall design.

Secondary Electrons (SE)

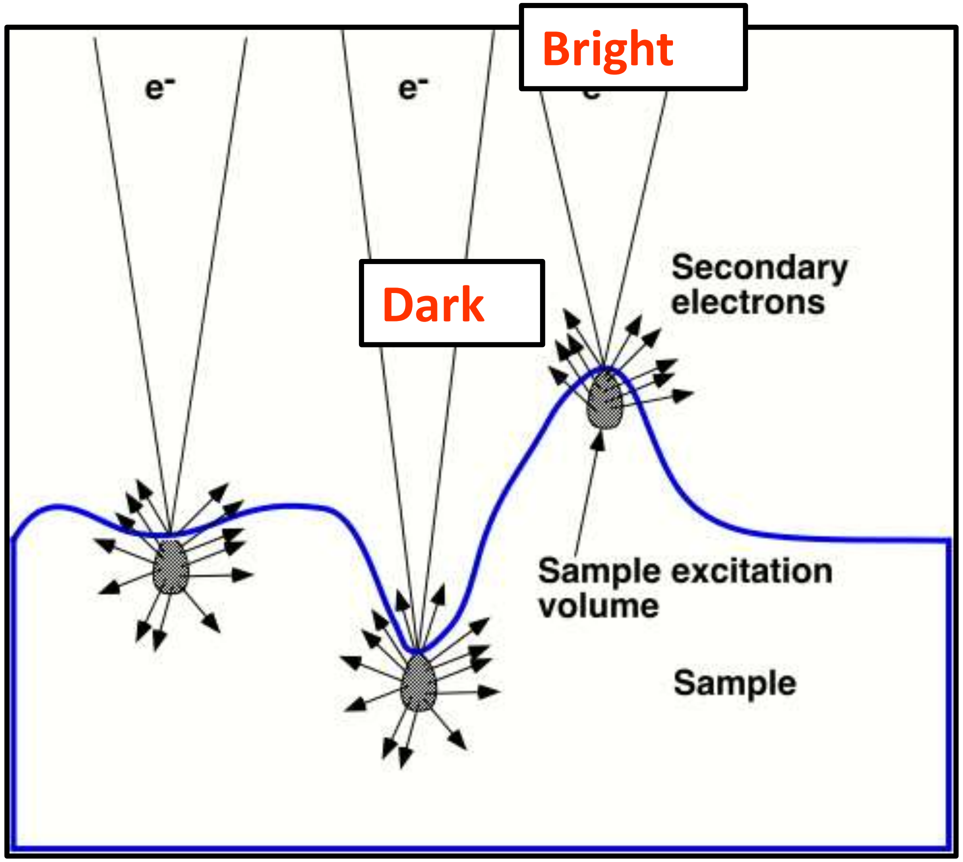


Produced by inelastic interactions of high energy electrons with valence (or conduction) electrons of atoms in the specimen, causing the ejection of the electrons from the atoms. These ejected electrons with energy less than 50eV are termed "secondary electrons". Each incident electron can produce several secondary electrons.

Production of SE is topography related. Due to their low energy, only SE that are very near the surface (<10nm) can exit the sample and be examined (small escape depth).

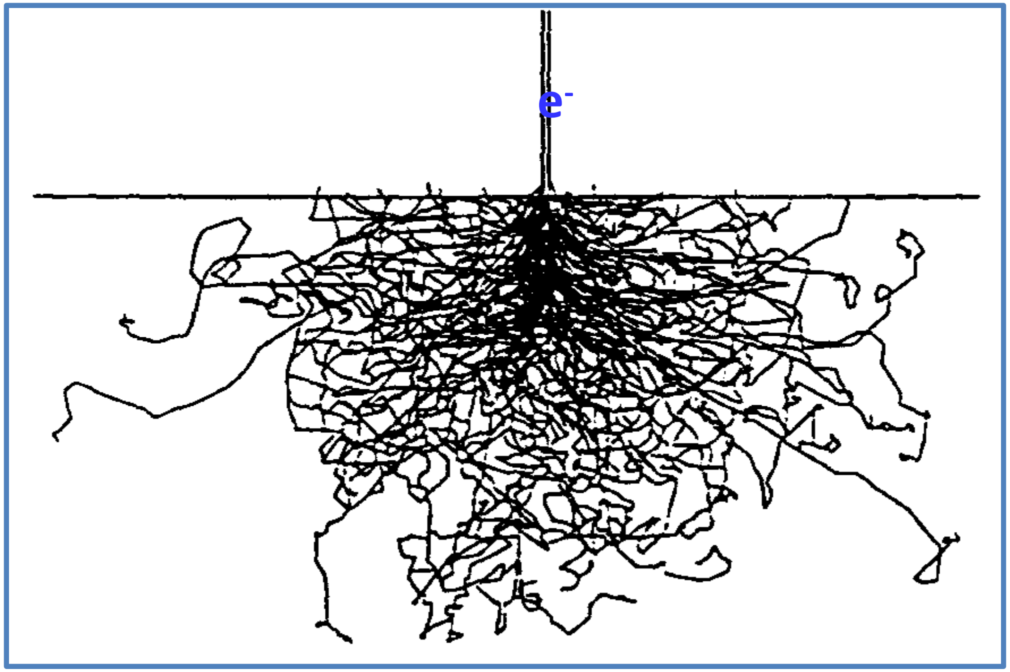


Topographical Contrast



Topographic contrast arises because SE generation depend on the angle of incidence between the beam and sample.

Interaction Volume: I

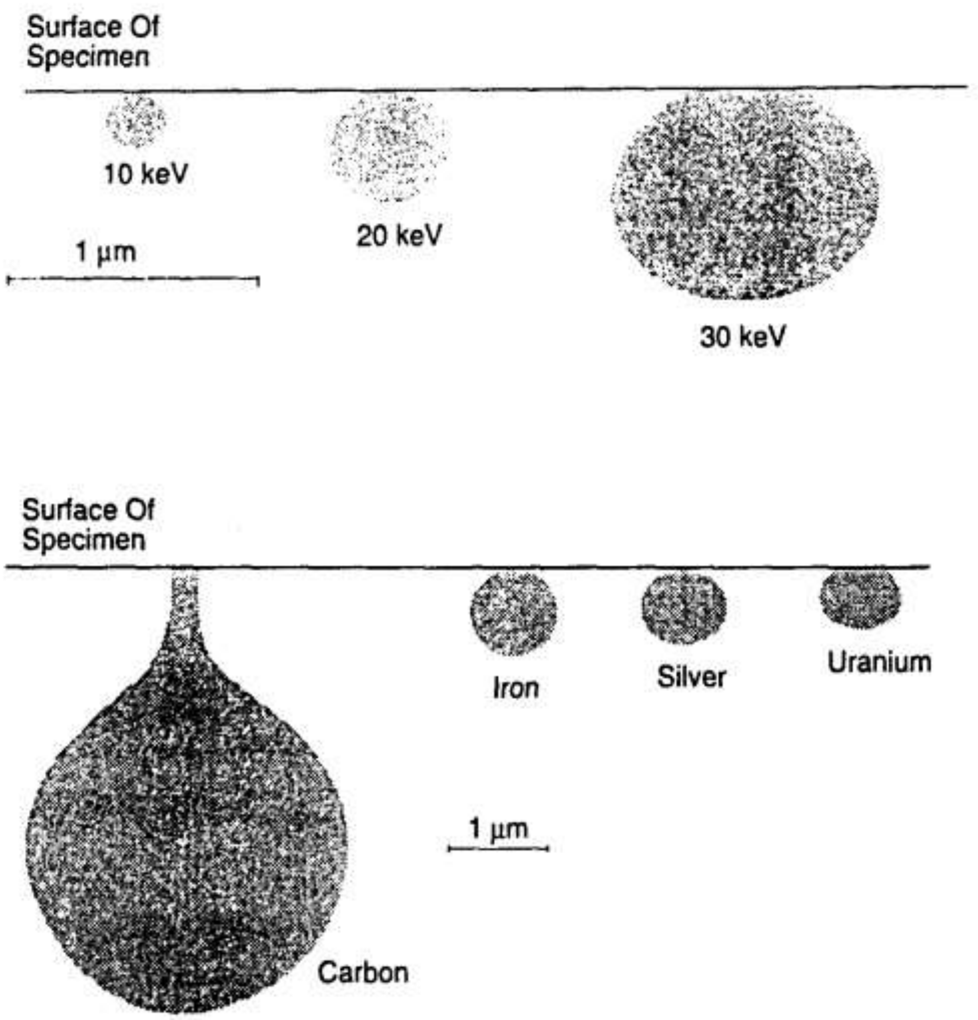


Monte Carlo simulations of 100 electron trajectories

The incident electrons do not go along a straight line in the specimen, but a zig-zag path instead.

Interaction Volume: II

The penetration or, more precisely, the **interaction volume** depends on the **Acceleration voltage** (energy of electron) and the **atomic number** of the specimen.



Escape Volume of Various Signals

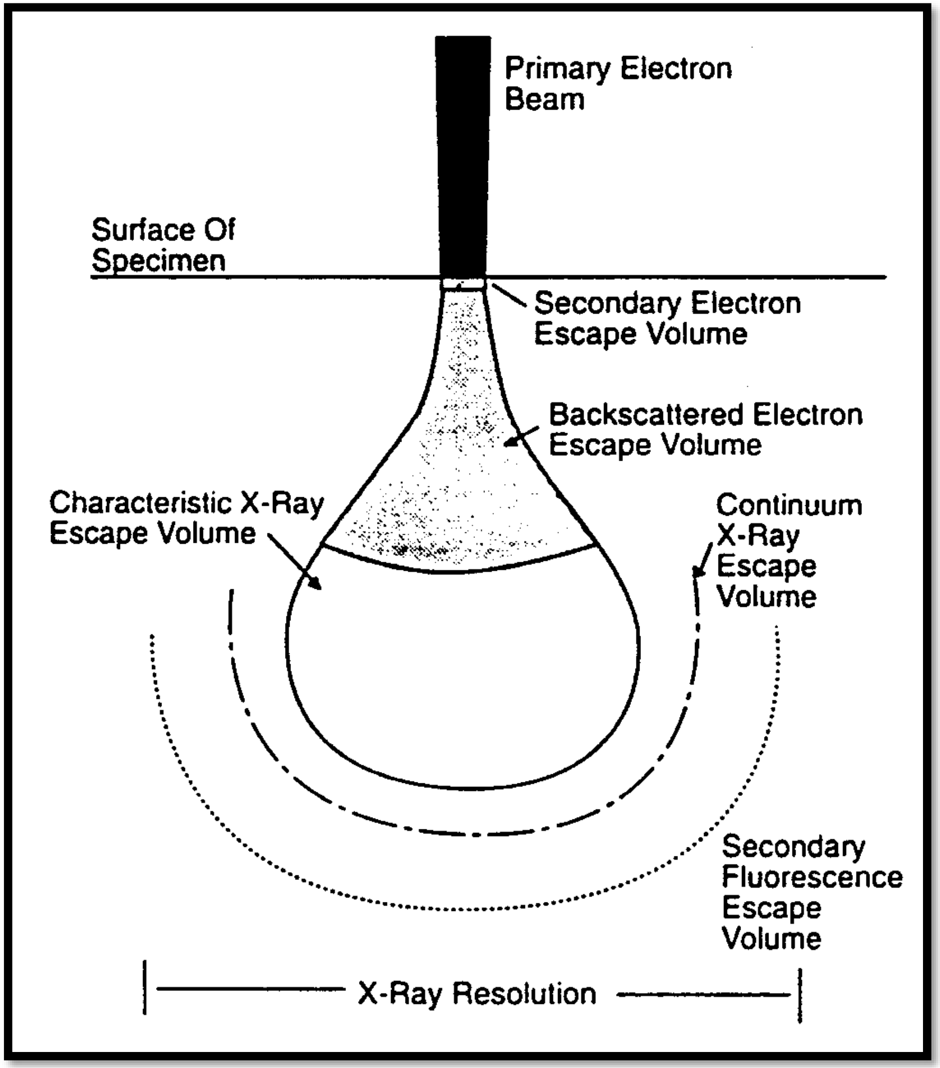
- The incident electrons interact with specimen atoms along their path in the specimen and generate various signals.
- Owing to the difference in energy of these signals, their ‘penetration depths’ are different
- Therefore different signal observable on the specimen surface comes from different parts of the interaction volume
- The volume responsible for the respective signal is called the escape volume of that signal.

Escape Volume of Various Signals

If the diameter of primary electron beam is ~5nm

- Dimensions of escape zone of

- Secondary electron: diameter~10nm; depth~10nm
- Backscattered electron: diameter~1μm; depth~1μm
- X-ray: from the whole interaction volume, i.e., ~5μm in diameter and depth



Resolution of Images: V

In extremely good SEM, resolution can be a few nm. The limit is set by the electron probe size, which in turn depends on the quality of the objective lens and electron gun.

	Pixel diameter on Specimen	
Magnification	**µm**	**nm**
10	10	10000
100	1	1000
1000	0.1	100
10000	0.01	10
100000	0.001	1

Other Imaging Modes

- Cathodoluminescence (CL)
- Nondestructive analysis of impurities and defects, and their distributions in semiconductors and luminescence materials
- Lateral resolution (~0.5mm)
- Phase identification and rough assessment of defect concentration
- Electron Beam Induced Current (EBIC)
- Electron-hole pairs generated in the sample
- Image defects and dislocations

Elemental Dispersive X-ray Analysis

The electron beam produced by electron source hits the sample and produce secondary electrons from the sample. These electrons are collected by a *secondary detector or a backscatter detector,* converted to a voltage, and amplified.

The amplified voltage is applied to the grid of the CRT and causes the intensity of the spot of light to change. The image consists of thousands of spots of varying intensity on the face of a CRT that correspond to the topography of the sample.

Further the detectors sense the energy of the secondary electrons, X-rays and the intensity. From these *data the composition of various elements* and their level in percentage will be estimated. These studies are essential to gain knowledge of various elements present in the synthesized sample which in turn helps one to improve the quality of the prepared sample.

Elemental Dispersive X-ray Analysis

To stimulate the emission of characteristic X-rays from a specimen, a high-energy beam of charged particles such as electrons, is focused into the sample being studied.

At rest, an atom within the sample contains ground state(or unexcited) electrons in discrete energy levels or electron shells bound to the nucleus.

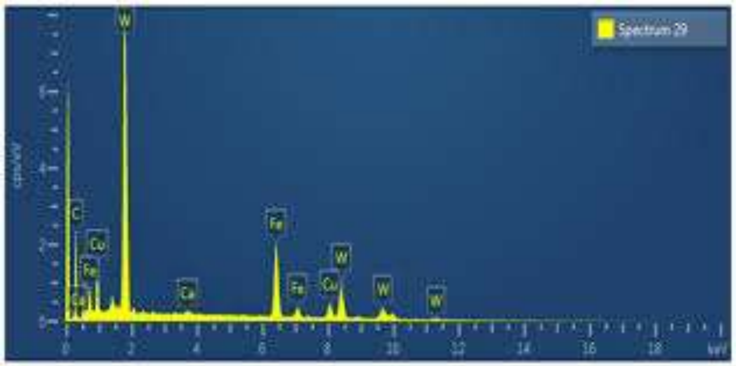
The incident beam may excite an electron in an inner shell, ejecting it from the shell while creating an electron hole where the electron was.

An electron from an outer, higher-energy shell then fills the hole, and the difference in energy between the higher-energy shell and the lower energy shell may be released in the form of an X-ray.

The number and energy of the X-rays emitted from a specimen can be measured by an energy-dispersive spectrometer.

As the energies of the X-rays are characteristic of the difference in energy between the two shells and of the atomic structure of the emitting element, EDS allows the elemental composition of the specimen to be measured.

EDX IMAGES


W
Spectrum 29
cps/eV
C
Cu
Fe
Ca
Fe
Fe
Cu
W
W
W
0
2
4
6
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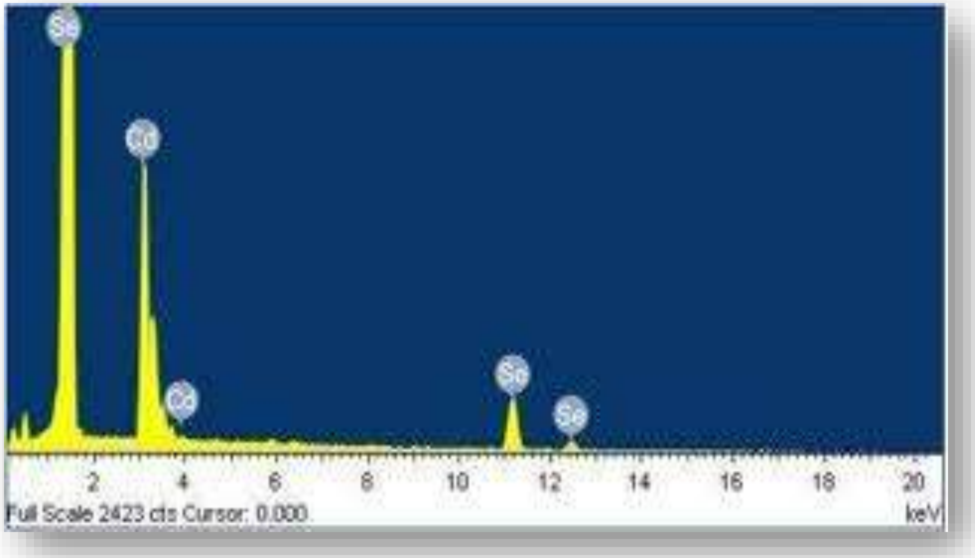
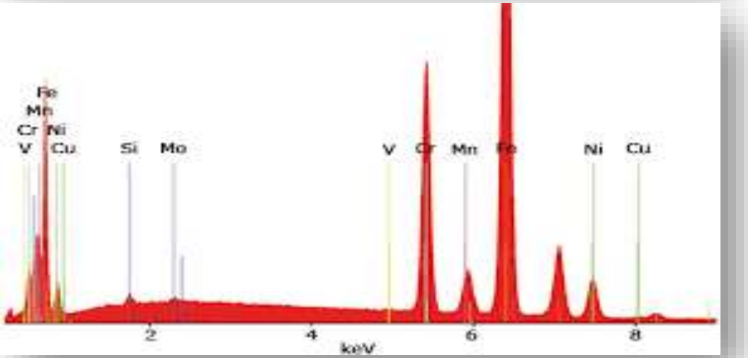
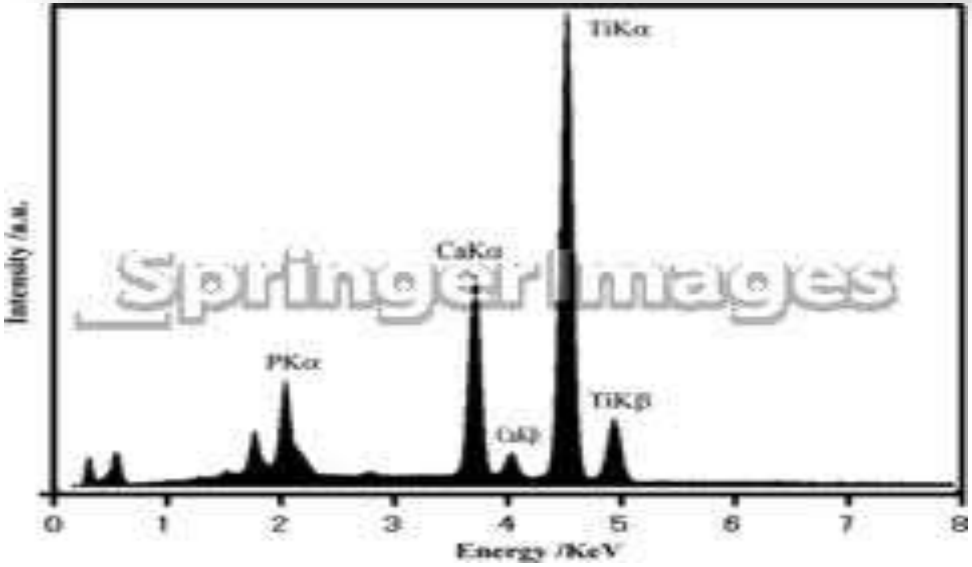
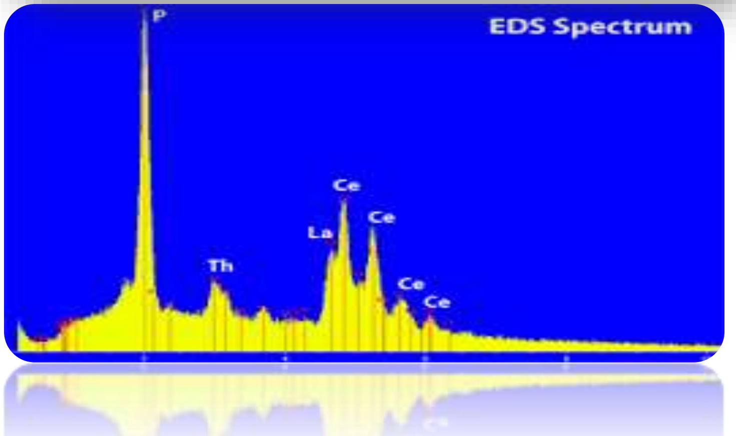
10
12
14
16
18
keV


Se
Cd
Cd
Se
Se
2
4
6
8
10
12
14
16
18
20
Full Scale 2423 cts Cursor: 0.000
keV


Fe
Mn
Cr
Ni
V
Cu
Si
Mo
V
Cr
Mn
Fe
Ni
Cu
2
4
6
8
keV


TiKα
CaKα
PKα
CaKβ
TiKβ
Intensity /a.u.
0
1
2
3
4
5
6
7
8
Energy /KeV
SpringerImages


P
EDS Spectrum
Th
La
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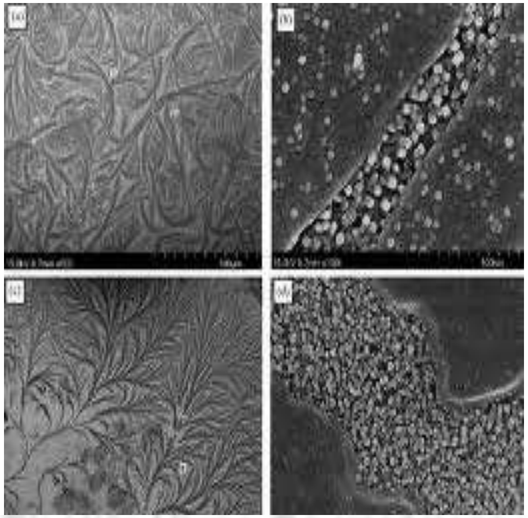
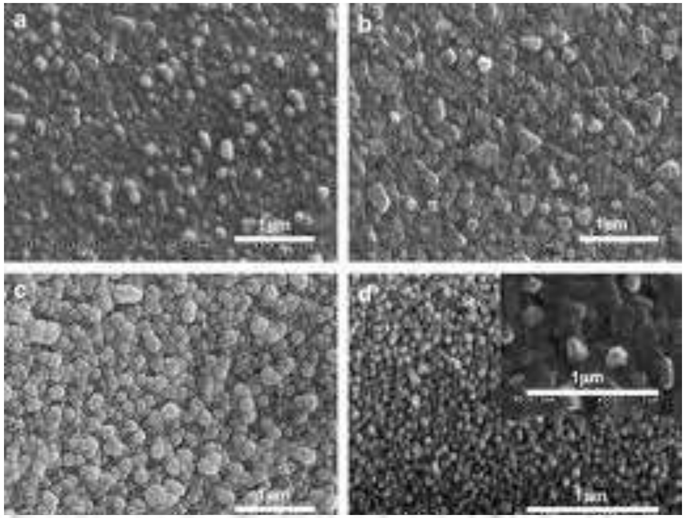
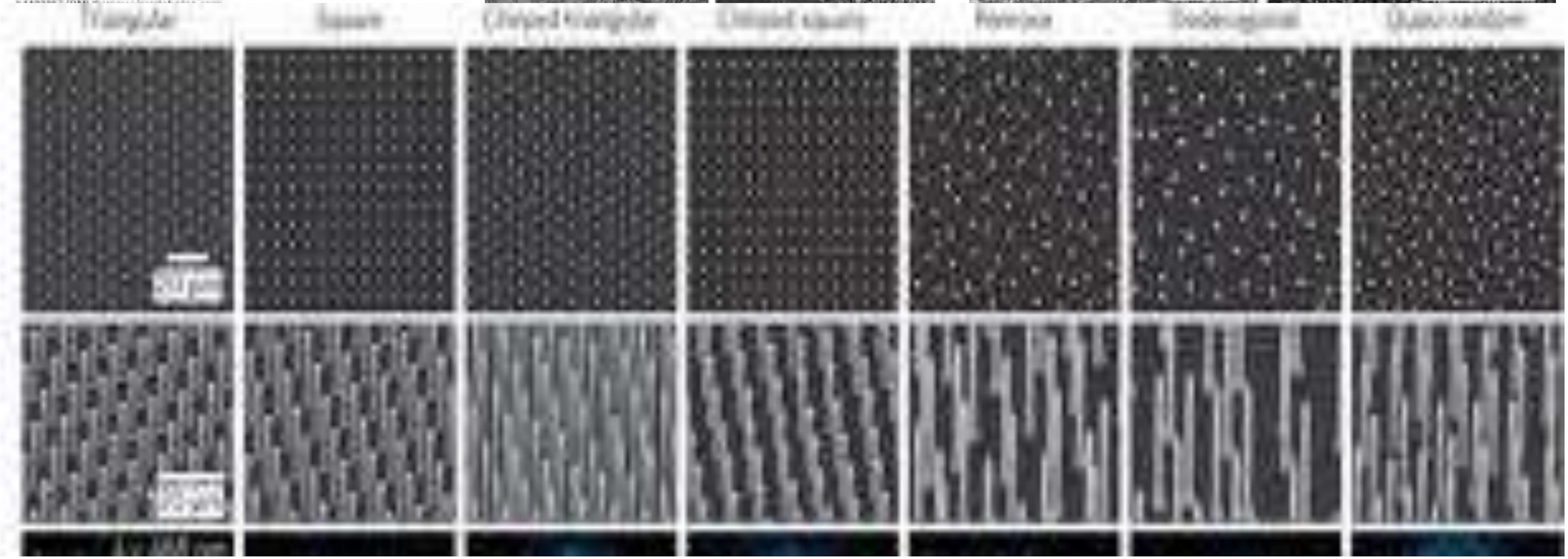
Ce
Ce
Ce

SEM IMAGES

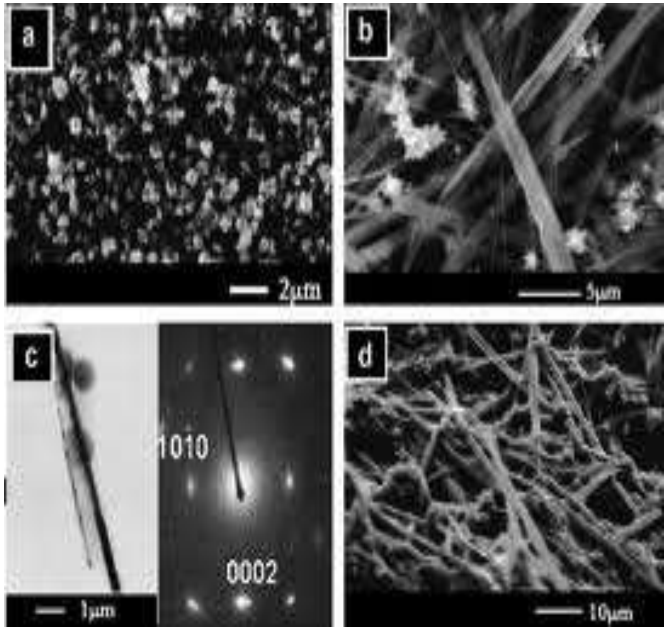

visualphotos.com

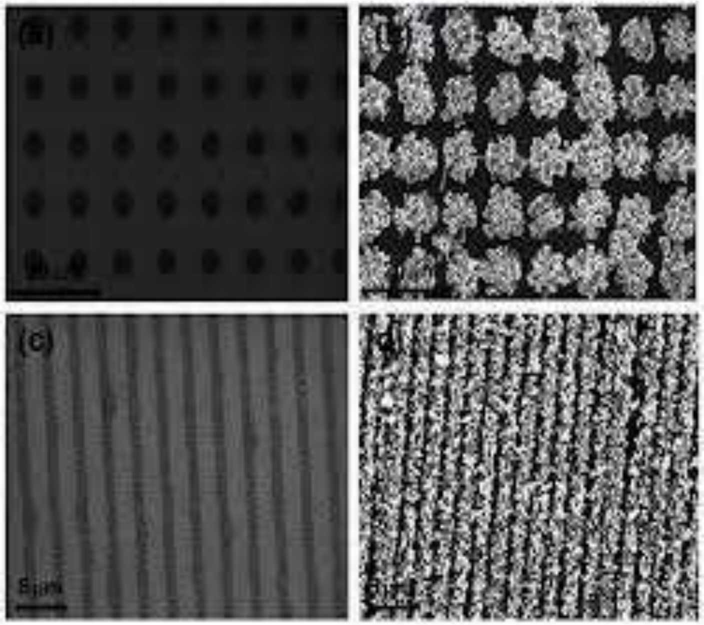

(a)
(b)
(c)
(d)

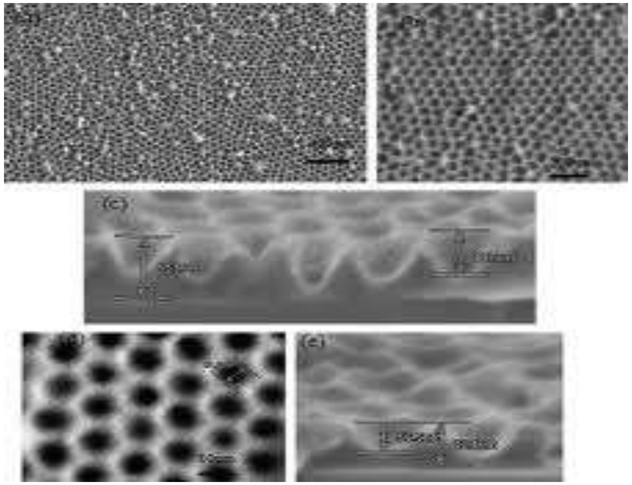

a
1μm
b
1μm
c
1μm
d
1μm
1μm

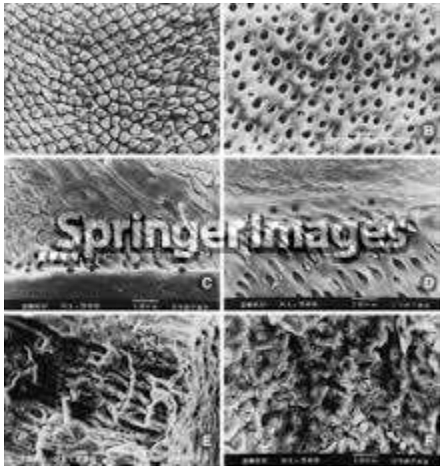

Triangular
Square
Chirped triangular
Chirped square
Penrose
Dodecagonal
Quasi-random

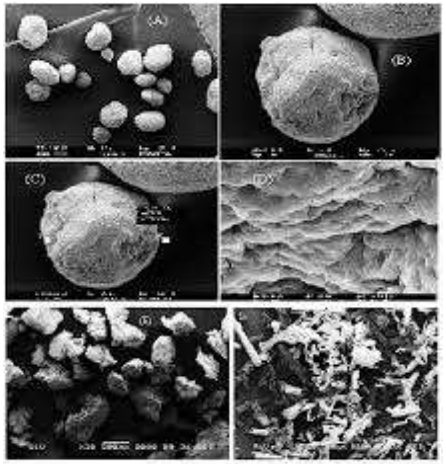
SEM IMAGES

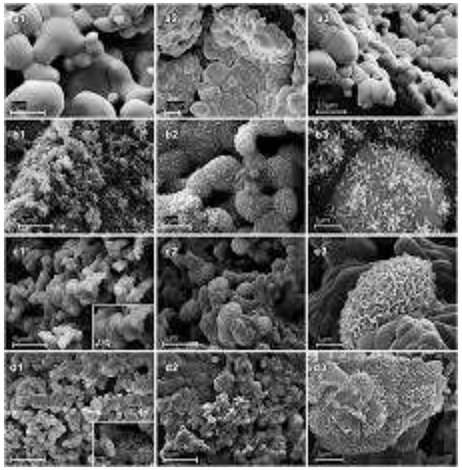


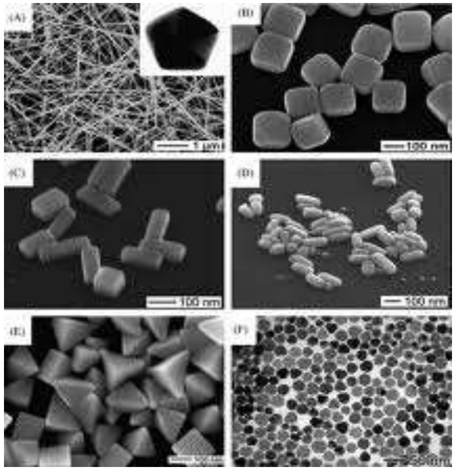


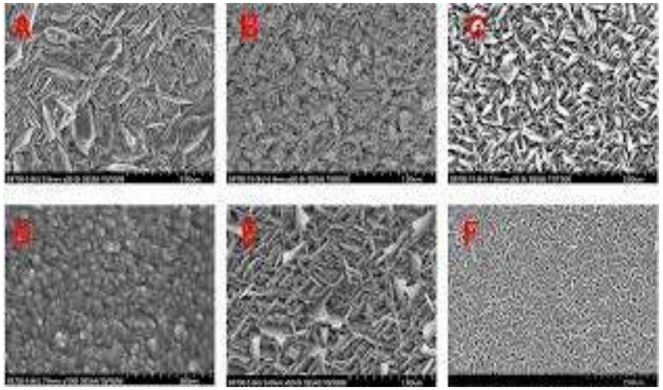


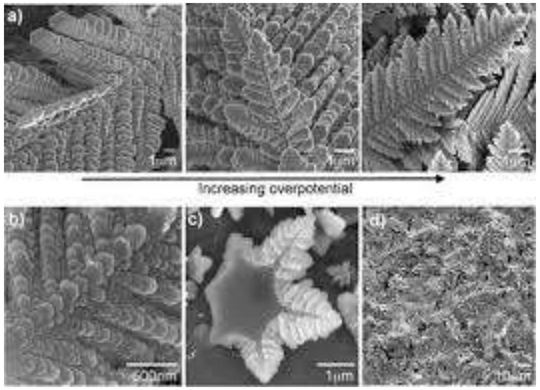


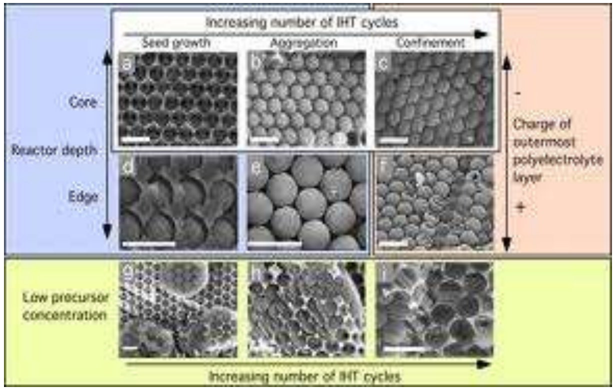


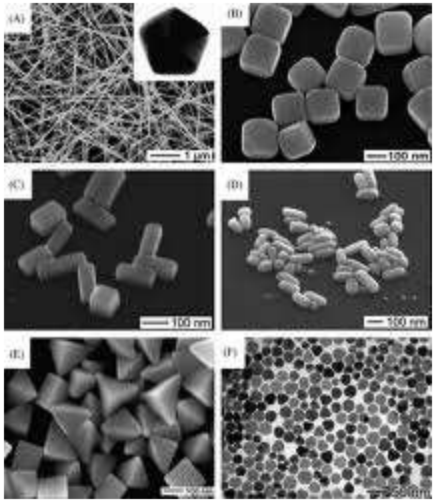


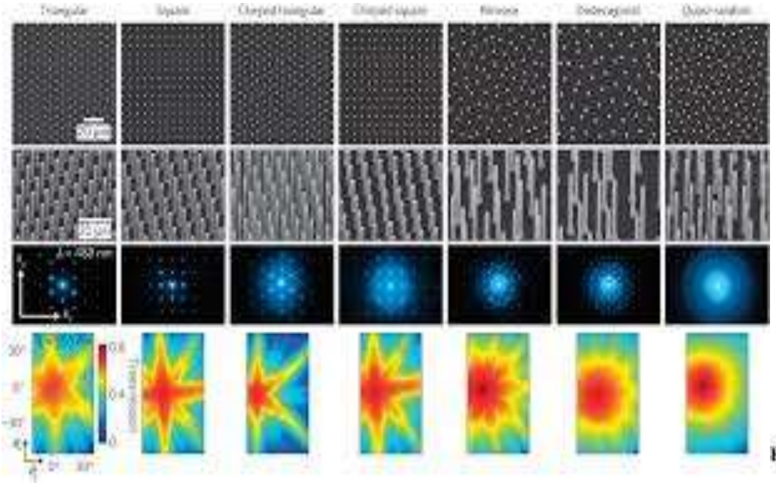












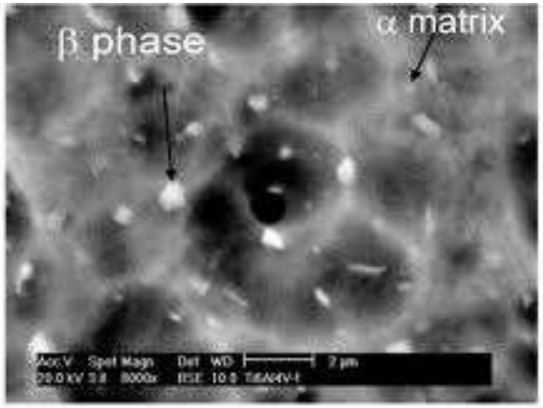
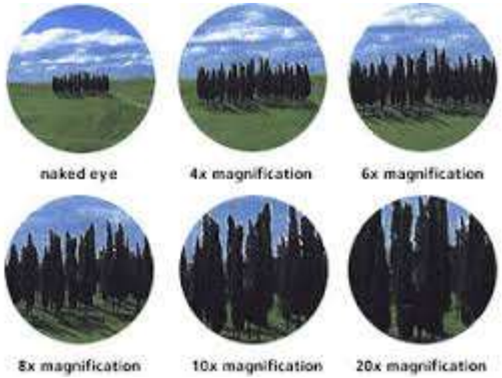
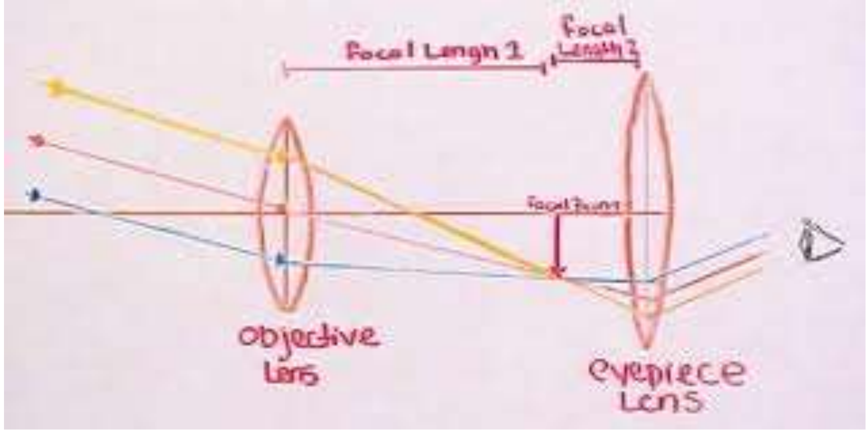


Figure 5: SEM image of microstructure of the sample Ti-6Al-4V annealed at 800°C for two hours


DEUTSCHE
1
RM
POST


naked eye
4x magnification
6x magnification
8x magnification
10x magnification
20x magnification


Focal Length 1
Focal Length 2
Focal Point
Objective Lens
eyepiece Lens


Total Magnification:
X
= 40 X
4X Scanning Objective
10X Eyepiece
X
= 100 X
10X Objective
10X Eyepiece
X
= 400X
40X Objective
10X Eyepiece