Physics of Nanotechnology

Muhammad Amer Mustafa

Lecturer UOS Sub Campus Bhakkar

Scanning Electron Microscope(SEM)

What is SEM?

- SEM stands for scanning electron microscope.
- Electron microscopes use electrons for imaging, in a similar way that light microscopes use visible light.
- SEMs use a specific set of coils to scan the beam in a raster-like pattern and use the electrons that are reflected or knocked off the near-surface region of a sample to form an image.
- Since the wavelength of electrons is much smaller than the wavelength of light, the resolution of SEMs is superior to that of a light microscope.

Types of Electron Microscopes

There are two main types of electron microscopes:

- The transmission electron microscope (TEM), which detects electrons that pass through a very thin specimen;

- The scanning electron microscope (SEM), which uses the electrons that are reflected or knocked off the near-surface region of a sample to create an image.

How does SEM technology work?

- Let's focus on a SEM. A schematic representation of the technology of a SEM is shown in Figure 1 below.
- In this type of electron microscope, the electron beam scans the sample in a raster pattern. But first, electrons are generated at the top of the column by the **electron source**.
- These are emitted when their thermal energy overcomes the work function of the source material. They are then accelerated and attracted by the positively-charged anode. You can find a more detailed description of the different types of electron sources and their characteristics in **this guide**.

SEM Schematic

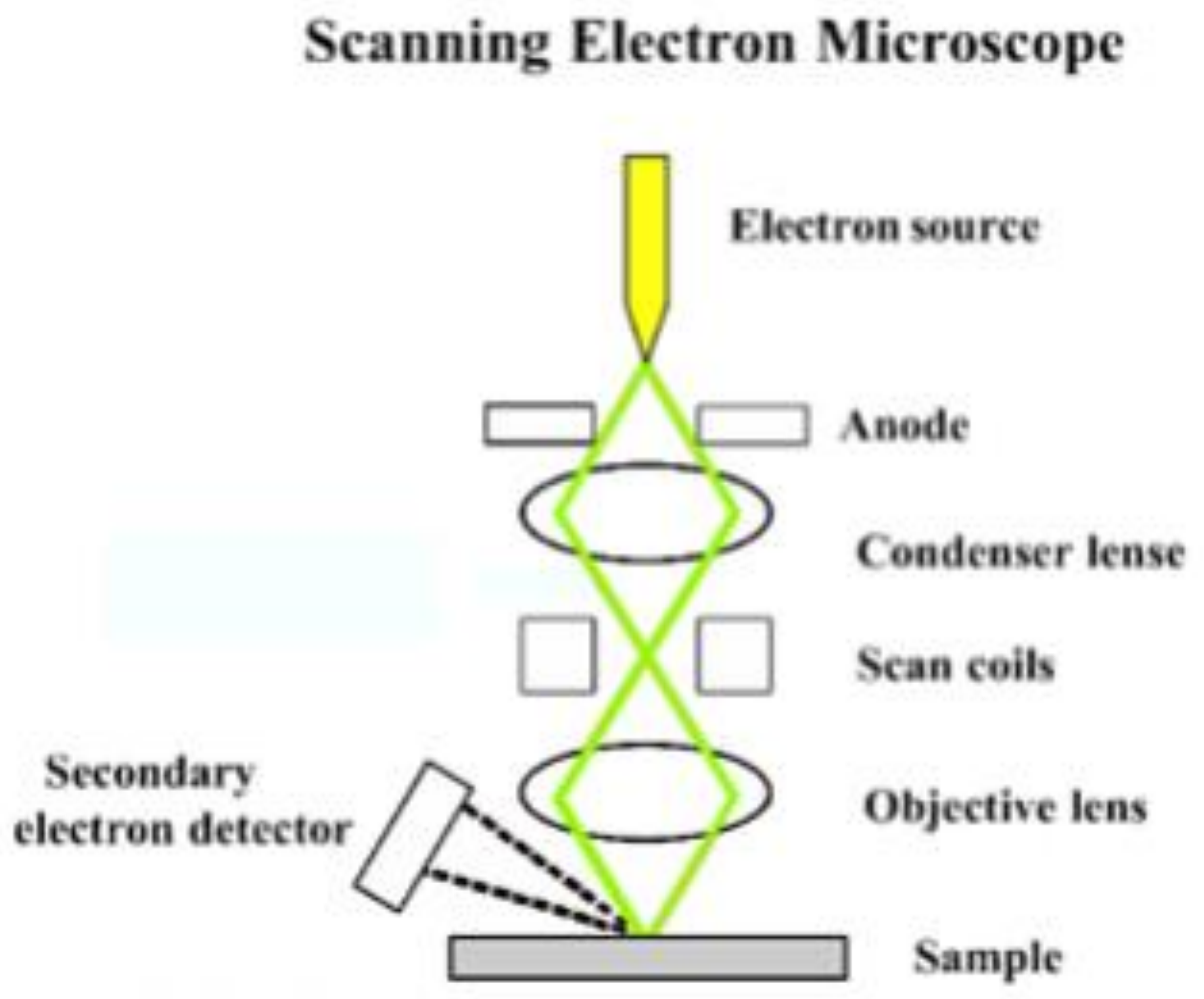

Figure 1: schematic representation of the basic SEM components

How does SEM technology work?

- The entire electron column needs to be under vacuum. Like all the components of an electron microscope, the electron source is sealed inside a special chamber in order to preserve vacuum and protect it against contamination, vibrations or noise. Although the vacuum protects the electron source from being contaminated, it also allows the user to acquire a high-resolution image.
- In the absence of vacuum, other atoms and molecules can be present in the column. Their interaction with electrons causes the electron beam to deflect and reduces the image quality. Furthermore, high vacuum increases the collection efficiency of electrons by the detectors that are in the column.

How is the path of electrons controlled?

- In a similar way to optical microscopes, lenses are used to control the path of the electrons. Because electrons cannot pass through glass, the lenses that are used here are electromagnetic. They simply consist of coils of wires inside metal pole pieces. When current passes through the coils, a magnetic field is generated. As electrons are very sensitive to magnetic fields, their path inside the microscope column can be controlled by these electromagnetic lenses - simply by adjusting the current that is applied to them. Generally, two types of electromagnetic lenses are used:
- The **condenser** lens is the first lens that electrons meet as they travel towards the sample. This lens converges the beam before the electron beam cone opens again and is converged once more by the **objective** lens before hitting the sample. The condenser lens defines the size of the electron beam (which defines the resolution), while the main role of the objective lens is to focus the beam onto the sample.
- The scanning electron microscope's lens system also contains the **scanning coils**, which are used to raster the beam onto the sample. In many cases, **apertures** are combined with the lenses in order to control the size of the beam. These main components of a typical SEM instrument are shown in Figure 1.

What kind of electrons are there?

- The interaction of electrons with a sample can result in the generation of many different types of electrons, photons or irradiations. In the case of SEM, the two types of electrons used for imaging are the backscattered (BSE) and the secondary electrons (SE).
- Backscattered electrons belong to the primary electron beam and are reflected back after elastic interactions between the beam and the sample. On the other hand, secondary electrons originate from the atoms of the sample: they are a result of inelastic interactions between the electron beam and the sample.

What kind of electrons are there?

- BSE come from deeper regions of the sample (Figure 2), while SE originate from surface regions. Therefore, BSE and SE carry different types of information. BSE images show high sensitivity to differences in atomic number: the higher the atomic number, the brighter the material appears in the image.

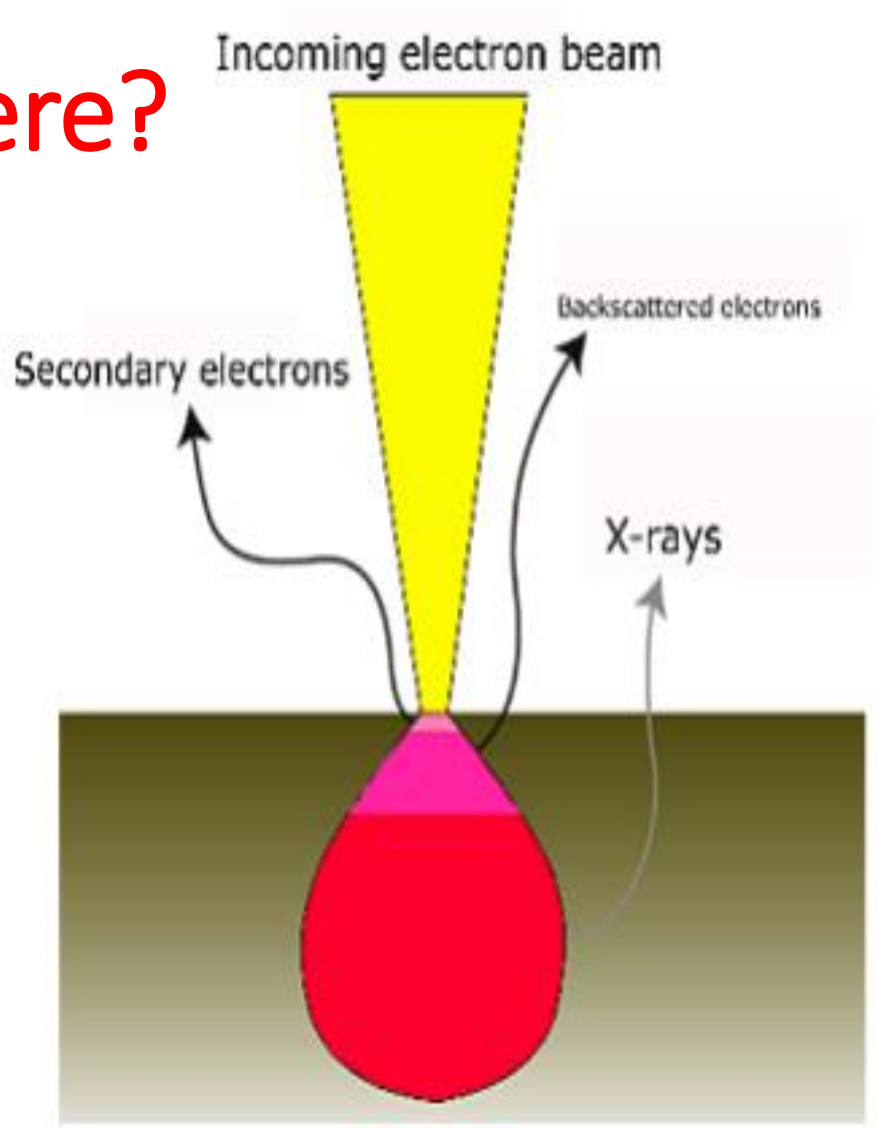

Figure 2: Different types of signals used by a SEM and the area from which they originate

What kind of electrons are there?

- SE imaging can provide more detailed surface information — something you can see in Figure 3.
- In many microscopes, detection of the X-rays, which are generated from the electron-matter interaction, is also widely used to perform elemental analysis of the sample. Every material produces X-rays that have a specific energy; X-rays are the material's fingerprint. So, by detecting the energies of X-rays that come out of a sample with an unknown composition, it is possible to identify all the different elements that it contains.

SEM IMAGE

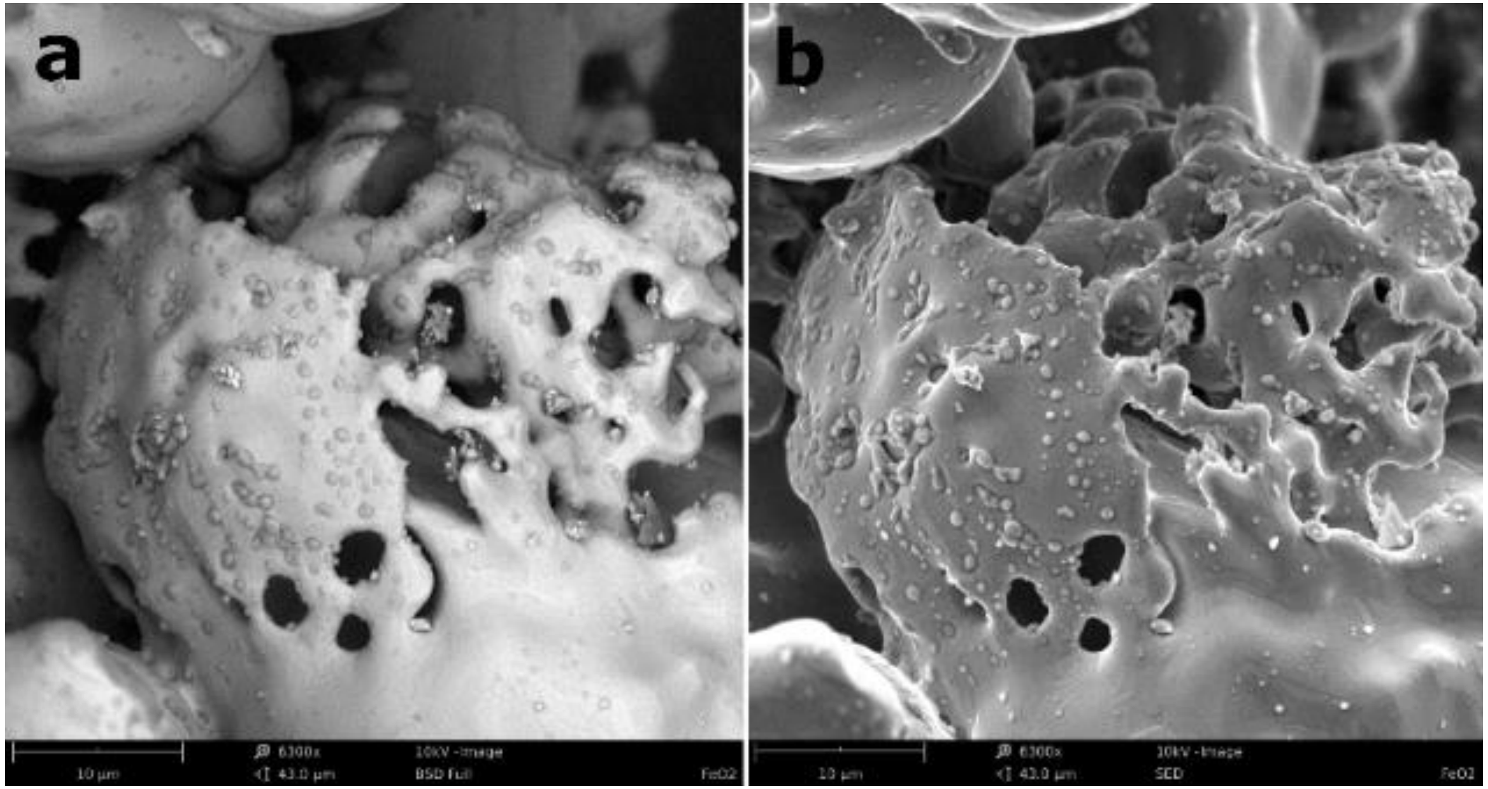

Figure 3: a) BSE and b) SE image of the FeO_2 particles

How are electrons detected?

- The types of electrons mentioned above are detected by different types of detectors. For the detection of BSE, solid state detectors are placed above the sample, concentrically to the electron beam, in order to maximize the BSE collection.
- On the other hand, for the detection of SE, the **Everhart-Thornley detector** is mainly used. It consists of a scintillator inside a Faraday cage, which is positively charged and attracts the SE. The scintillator is then used to accelerate the electrons and convert them into light before reaching a photomultiplier for amplification. The SE detector is placed at the side of the electron chamber, at an angle, in order to increase the efficiency of detecting secondary electrons. These secondary electrons are used to form a 3D-image of the sample, which is shown on a PC monitor.

SEM IMAGE

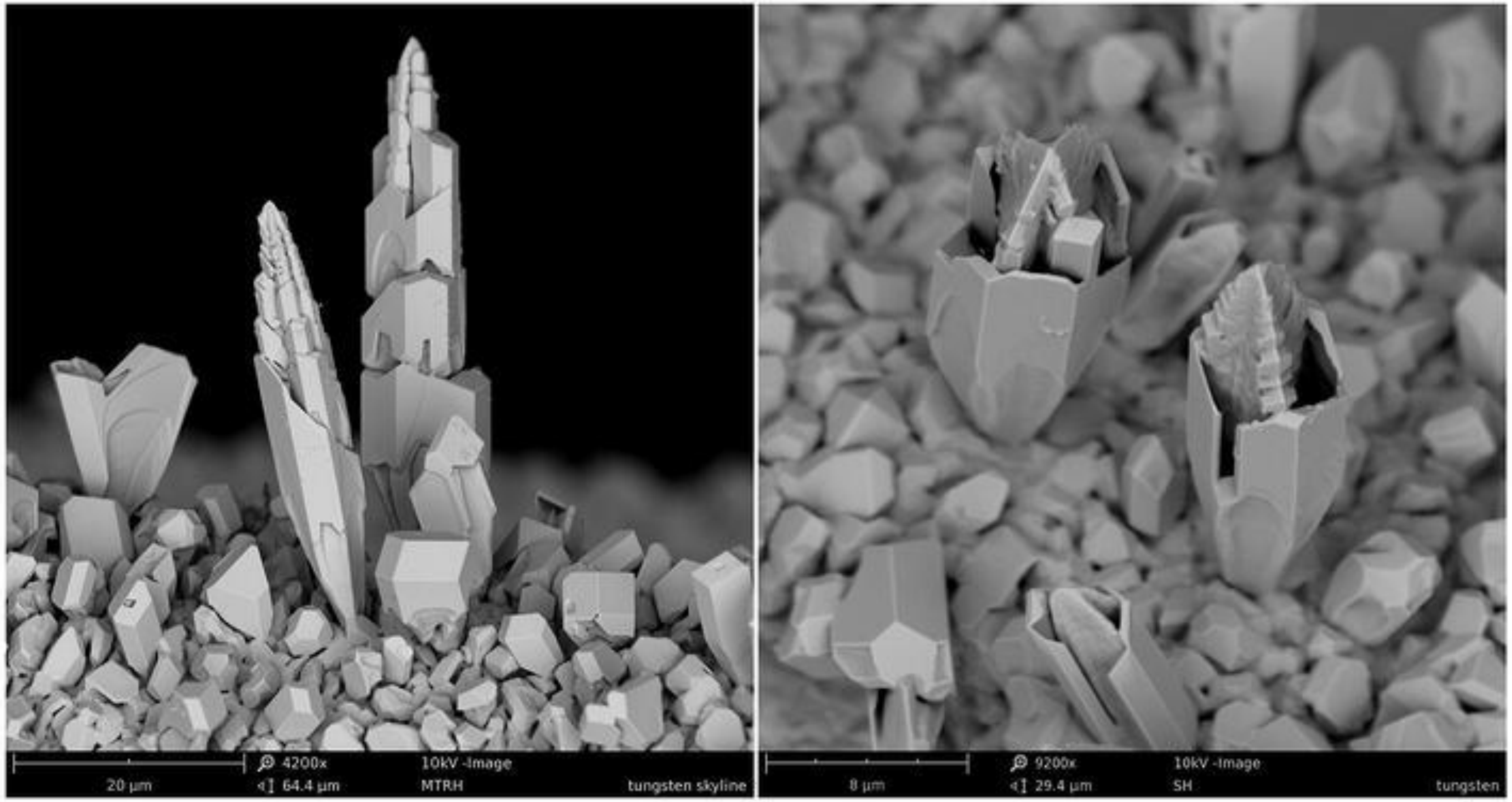

Figure 4: Backscattered electron image of Tungsten particles