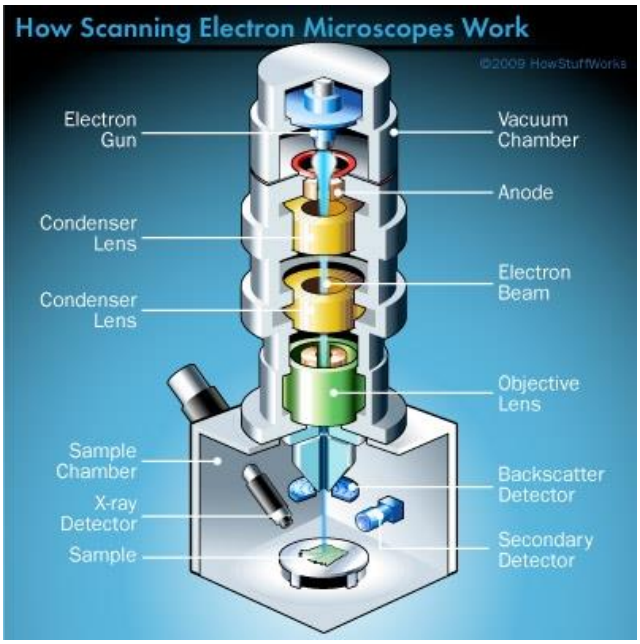
The SEM

SEM stands for scanning electron microscope. The SEM is a microscope that uses electrons instead of light to form an image. Since their development in the early 1950's, scanning electron microscopes have developed new areas of study in the medical and physical science communities. The SEM has allowed researchers to examine a much bigger variety of specimens.

The scanning electron microscope has many advantages over traditional microscopes. It has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels. Because the SEM uses electromagnets rather than lenses, the researcher has much more control in the degree of magnification. All of these advantages, as well as the actual clear images, make the scanning electron microscope one of the most useful instruments in research today.

A **scanning electron microscope** produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with electrons in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern (A **raster scan**, or **raster scanning**, is the rectangular pattern of image capture and reconstruction in television) and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, low vacuum and in environmental SEM specimens can be observed in wet conditions.

To the bottom is a picture of our Hitachi S-4700. Consist of the microscope column, specimen chamber, and vacuum system are on the left; the computer, monitor, and many of the instrument controls on the right. As an operator you will need to understand what is happening inside the "black box" (microscope column and specimen chamber) when an instrument control is manipulated to produce a change in the monitor image.



A look inside the black box reveals quite a bit of complexity; however, we can simplify at this point. We have:

1- a source (**electron gun**) of the electron beam which is accelerate down the column;

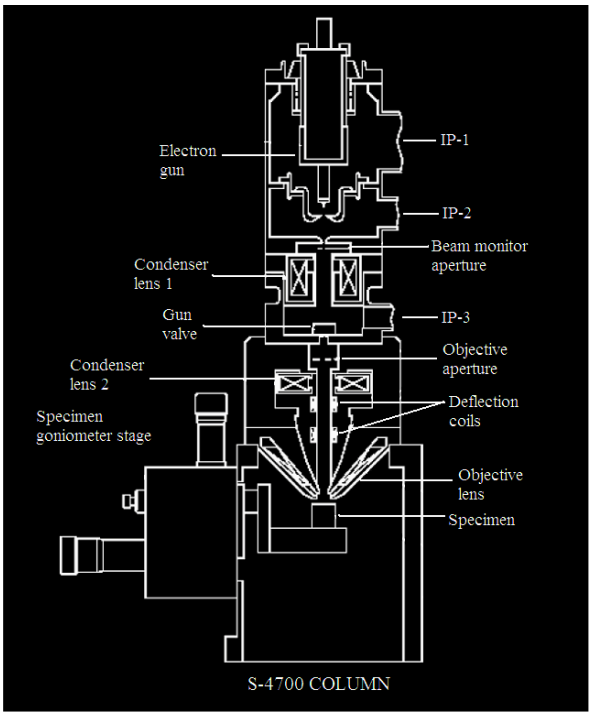
2- a series of **lenses (co**ndenser and **objective)** which act to control the diameter of the beam as well as to focus the beam on the specimen.

3- A series of **apertures** (micron-scale holes in metal film) which the beam passes through and which affect properties of that beam.

4- Controls for **specimen position** (height) and orientation (tilt, rotation).

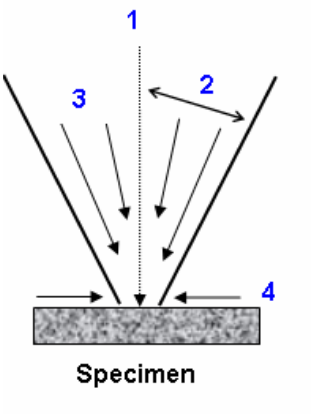
5- An area of **beam/specimen interaction** that generates several types of signals that can be detected and processed to produce an image or spectra.

6- All of the above maintained at high **vacuum levels.**



To define the major parameters associated between the electron beam (probe) and the specimen surface. These parameters are ones that we can control as an operator and define the major modes of imaging in the SEM. They are:

1. **Beam accelerating voltage (kV)**: the voltage with which the electrons are accelerated down the column;
2. **Probe convergence angle (α_p)**: the half-angel electrons converging onto the specimen.
3. **Probe current (i_p)**: the current that impinges and generates the various imaging signals.
4. **Probe diameter or spot size (d_p)**: the diameter of the final beam at the surface of the specimen.



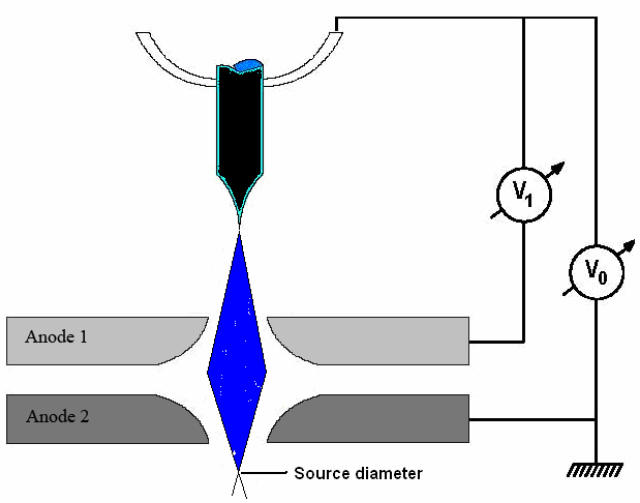
Looking at the diagram it would seem that all we would have to do to maintain adequate probe current in a small probe diameter would be to increase the probe convergence angle. But this is not the case due to aberrations in the optic system. A small probe diameter always comes with a decrease in probe current. These parameters are interrelated in other ways. For example, a decrease accelerating voltage will result in a decrease in probe current as well as an increase in probe size.

Electron Guns

The purpose of the electron gun is to provide a stable beam of electrons of adjustable energy. There are three main types of electron guns: Tungsten hairpin; Lanthan hexaboride (LaB_6); and Field emission gun (FEG).

Tungsten is normally used in thermionic electron guns because it has the highest melting point and lowest vapour pressure of all metals, thereby allowing it to be heated for electron emission, and because of its low cost.

The FEG cathode consists of a sharp metal (usually Tungsten) tip with a radius of less than 100 nm. A potential difference (V_1 = extraction voltage) is established between the first anode and the tip. The result is an electric field, concentrated at the tip, which facilitates electron emission (**emission current**). **See the figure below.**



The potential difference between the tip and the second grounded anode determines the **accelerating voltage** (V_0) of the gun. The higher the accelerating voltage the faster the electrons travel down the column and the more penetrating power they have.

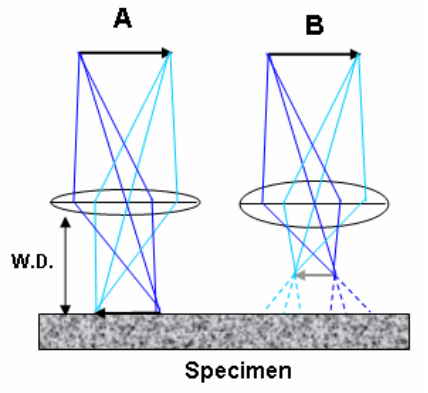
- Field emission require that the tip remain free of contaminants and oxide and thus they require Ultra High Vacuum conditions (10^{-10} to 10^{-11} Torr). (Torr: A unit of pressure equal to 0.001316 atmosphere; named after Torricelli).
- Although the FEG has a moderate emission current, its **"Brightness"** value is orders of magnitude greater than the thermionic Tungsten and LaB_6 sources. Brightness is the beam current per unit area, unlike current; it is conserved down the column. Brightness increases linearly with accelerating voltage.
- The ability to have enough probe current (and thus potential signal) in a probe of small diameter allows the FEGSEM to obtain the highest resolution of SEM**.**

Electron lens

Electron lens is use to focus the electron beam on the specimen. Tow type of lens are there Condenser lenses are involved in demagnification; the objective lens focuses on the specimen as well as demagnifies. The source size of the FEG is comparatively small so that the amount of demagnification necessary to produce small probe sizes is less than that of other electron sources.

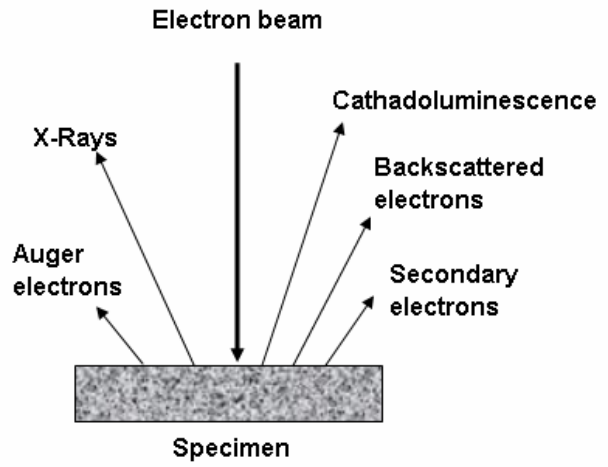
The type of lens used in SEMs is stationary electromagnetic lenses which we can vary the strength of by altering the amount of current running through them. SEMs have more than one electromagnetic lens. Under this circumstance the image plan of the first lens becomes the object plane of the second. The total magnification is the product of the magnification of lens one with lens two.

The objective lens is used to focus the beam on the specimen. Coarse focusing of the specimen is done choosing the working distance (WD = distance betweenthe bottom of the objective lens and the specimen); focusing the objective lens to coincide with this valuand then changing the physical height of the specimen to bring it into focus. Fine focusing is subsequently done solely with the objective lens. See figure below.



detectors and capacities

The types of signals produced by a SEM include secondary electron (SE), back scattered electron (BSE), characteristic X-ray light (cathodoluminescence) (CL), specimen current and transmitted electrons.

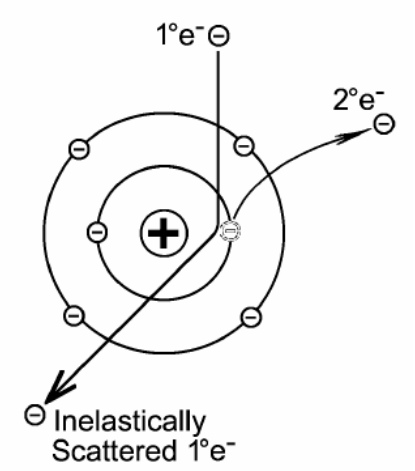


Secondary electron detectors are standard equipment in all SEMs, but it is rare that a single machine would hav e detectors for all possible signals. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details less than 1 nm in size.

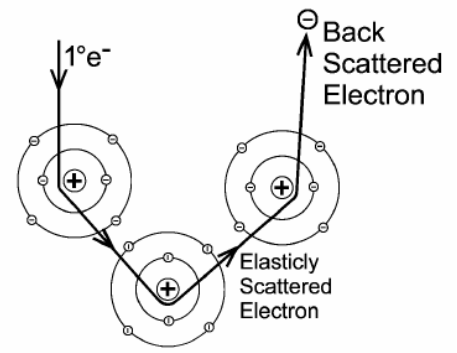
Due to the very narrow electron beam, SEM micrographs have a large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample. A wide range of magnifications is possible, from about 10 times (about equivalent to that of a powerful hand-lens) to more than 500,000 times, about 250 times the magnification limit of the best.

Back-scattered electrons (BSE) are beam electrons that are reflected from the sample by elastic scattering.

Elastic events occur when a beam electron interacts with the electric field of the nucleus of a specimen atom, resulting in change of the direction of that electron without significant change of its energy elastically scattered beam electron is deflected back out of the specimen the electron termed back scattered electron.



Inelastic event: Occure when electron beam interacts with the electric field of specimen atom and a potential expulsion of an electron from that atom as a **secondary electron (SE)**. SEs by definition are less than 50 eV. If the vacancy due to the creation of a secondary electron is filled from a higher level orbital, an X-Ray characteristic of that energy transition is produced.



BSE are often used in analytical SEM along with the spectra made from the characteristic X-rays, because the intensity of the BSE signal is strongly related to the atomic number (Z) of the specimen. BSE images can provide information about the distribution of different elements in the sample. For the same reason, BSE imaging can image colloidal gold immuno-labels of 5 or 10 nm diameter, which would otherwise be difficult or impossible to detect in secondary electron images in biological specimens. Characteristic

X-ray are emitted when the electron beam removes an inner shell electron from the sample, causing a higher energy electron to fill the shell and release energy. These characteristic X-rays are used to identify the composition and measure the abundance of elements in the sample.