Scanning Electron Microscope

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Abstract

A discussion of the scanning electron microscope (SEM) and its application is presented along with a brief discussion of the enviromental SEM.

1 Introduction

The Scanning Electron Microscope (SEM) is one of the very important scientific instruments. The discovery of electron in the beginning of the 20th century motivated the development of electron microscope. In SEM electrons are used to increase microscopic resolution. It surpasses the resolution achieved with the optical microscope by orders of magnitude. Some of the pioneers in the development were Knoll, Von Ardenne, Ruska and Oatley. In the early SEM, there were many problems such as lack of high resolution and damage of specimen. Preventing the specimen from being damaged was one of the severest problem. The high point to point nanometer range resolution of the modern SEMcan be successfully used to directly visualize molecules and atoms of a suitable specimen. It is worthwhile to compare the SEM with an optical microscope. A curious difference is that there is a lens with fixed focus and varied distance between specimen and objective lens in an optical microscope, while the separation of lens and the distance between specimen and objective lens in the SEM remain constant. Also, the comparison with STM and AFM is in order. The SEM is better able to deal with specimens having pronounced topography than the STM and AFM, where probe interaction become difficult to control. It is also suitable for understanding the specimen having multiple surfaces.

2 Working of the SEM

The basic components of SEM consists of electron gun, lens system, electron collector, visual and recording CRT and associated electronic kits. A picture of modern SEM is shown in figure below.

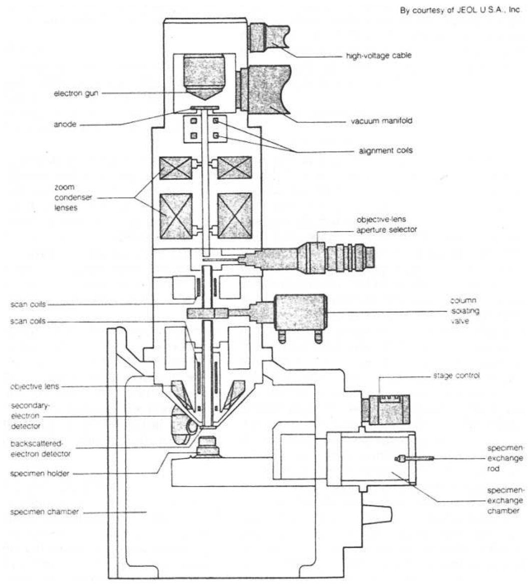

Figure 1: *Components of SEM*

A brief description of various components of the SEM and their functions in production of the image is presented as follows.

2.1 Electron Guns

They are used to produce a large, stable current in a small electron beam. Some of the important electron gun systems are: Thermionic electron emission gun, Conventional triode electron guns, Tungsten Hairpin Electron Gun, Lanthanum Hexaboride (LaB_6) electron guns and Field emission electron guns.

2.2 Minimizing spot sizes by means of electron Lenses

The electron lenses are located just beyond the electron gun and are used to demagnify the electron beam size from the electron gun to the final spot size on the specimen, achieving a demagnification as large as 10,000 for a thermionic source. The lenses used in SEMs operate electromagnetically.
It is necessary to have electron lenses that can produce a small spot. To avoid energy loss due to electron collision with air, it is necessary to have a vacuum and a collimated beam. Electrons are ejected from the electron guns and accelerated to 1-40 keV. The beam diameter produced directly by the conventional electron gun is too large to generate a sharp image at high magnification. The reduction in beam diameter is achieved by electron lenses. It also focuses electron beam on the specimen.

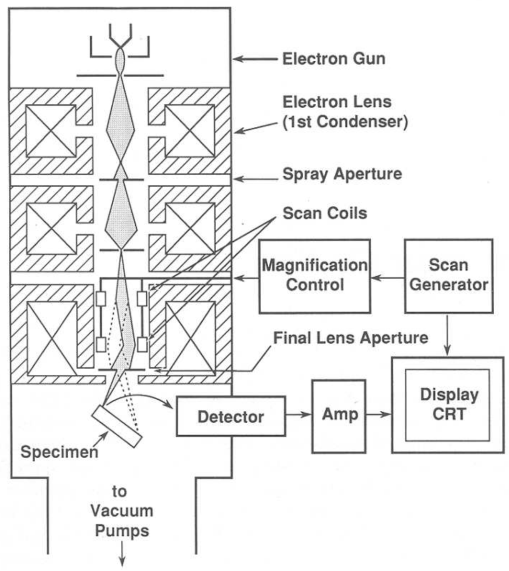

Figure 2: *Schematic drawing showing the electron column, deflection system and detectors*

Most SEMs can generate an electron beam at the specimen surface with a spot size less than 10 nm while still carrying sufficient current to form an acceptable image. The actual formation of an image requires a scanning system to construct the image point by point.

2.3 Controlling magnification by means of deflection system

The contrast in an image is produced by measuring the signal intensity from the beam-specimen interaction from point to point across the specimen surface. A rectangular raster is generated on both the specimen and the viewing screen by scanning the beam along a line and then displacing the line position for next scan. Controlling the raster of the beam is done by two pairs of electromagnetic deflection coils (scan coils). The first pair of scan coils bends the beam off the optical axis of the microscope; the second pair bends the same beam back onto the axis at the pivot point of the scan. The ratio of the linear size of the viewing cathode ray screen (CRT) to the linear size of the raster on the specimen gives us the value of the magnification M of the specimen image. The deflection of a beam is smaller on a specimen for a weakly excited scan coils. For example, a 100 μm wide raster on the specimen gives an image of 1000X magnification when it is displayed on a 10-cm-wide viewing screen.

2.4 Detecting the signal

Many signals generated from interaction of electron beam with the specimen are used to modulate the intensity of the viewing CRT and produce an image. Mostly, signals of secondary electrons and backscattered electrons are used to produce images.

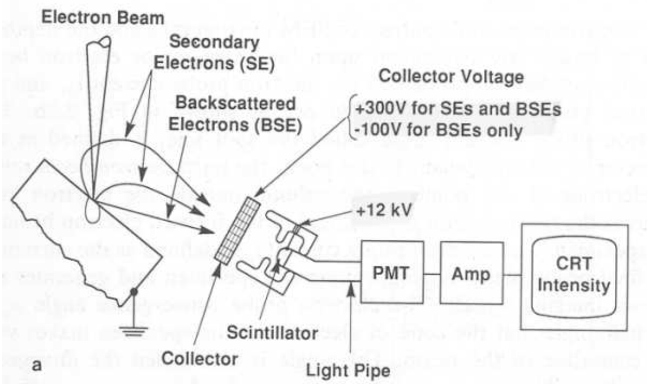

Figure 3: *Diagram showing SEBs and BSEs and E-T detector*

The Everhart-Thornley (E-T) electron detector, used to collect the SEs and BSEs, consists of a scintillator, a light pipe, and a photomultiplier tube and is located to the side of specimen. The formation of image requires the strongest source of SEs to be located at the same point where the beam enters the specimen surface. The photomultiplier tube records the light produced by collision of SEs with the scintillator. The strength of signal varies as the beam sweeps over the specimen surface. This variation in signal strength causes intensity change in image observed on the viewing screen.

2.5 Recording the image

Most SEMs use CRT whose slow-scan image is recorded by a camera on a polaraoid or conventional wet-processed film. The CRT signals can also be converted to the positive image by video printer.

3 Image Formation

Image formation is a very important task of SEM. It is not as easy to understand image formation by the SEM as by light. In our daily life, we are not used to image formation by electron microscope. Although image formation is different to conventional method, it mimics the natural human experience of visualization. The SEM images give 3-d characteristics and are easy to interpret. In the SEM fine beam of focussed high-energy electrons are scanned across the surface of the specimen. The radiation beams produced in interaction are collected by E-T scintillator-detector. Then, the signal is further amplified and displayed on a CRT in synchronism with the scan on the specimen. The SEM imaging process is shown below.

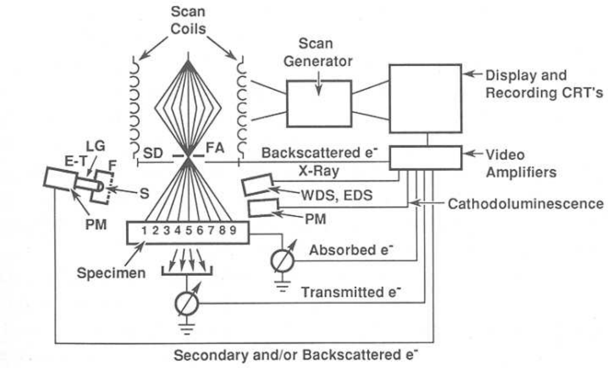

Figure 4: *A schematic illustration of the scanning system of the SEM*

In the SEM, the image formation involves the mapping operation of transmitting information from the specimen space to the display space. In spite of abstract and unconventional method of image formation, it is surprising to find that the image formed is understandable. The image formation mainly involves the following steps.

3.1 Scanning Action

After the scanning is done over the specimen, the magnitudes of SEs and BSEs signal are measured. This determines the local topography of a single location where the beam strikes. The scanning action is done from point to point by means of electromagnetic coils arranged in sets consisting of two pairs, one pair each for deflection in the X and Y directions. It is also necessary to alter the strength of the current in the scan coils, thus moving beam over the sequence of positions on the specimen. Scanning action can be performed analogously and digitally.

3.2 Image Construction

The information flow from the scanning electron microscope consists of the scan location in $X - Y$ space and a corresponding set of intensities from the set of detectors that monitor the beam-specimen interaction. This information can be displayed to the observer in two ways.

3.2.1 Line Scans

In the line-scan mode, the beam is scanned along a single vector on the specimen, e.g; in the X or Y direction. The same scan generator signal is used to drive the horizontal scan of the CRT. The resulting synchronous line scan on the specimen and the CRT produces a one to one correspondence between a series of points in the specimen space and on the CRT or display space. For line scan, the magnification M is given by

$$M = \frac{L_{CRT}}{L_{spec}} \qquad (1)$$

Where L denotes the length of the scan. Line scans are extremely useful for diagnostic work, where the signal profile across a feature is needed.

3.2.2 Area Scan

In area scan the beam is scanned on the specimen in an $X - Y$ pattern while the CRT is scanned in the same $X - Y$ pattern. Again, a one to one correspondence is established between the set of beam location on the specimen and the points on the CRT. The magnification is same as in the line scan.

3.3 Magnification

By appropriately minimizing the scan length on the specimen, it is possible to obtain desired magnification. The following table gives the approximate magnification obtained with respect to change in the sample area.

Table 4.1. Area Sampled as a Function of Magnification[a]

Magnification	Area on sample
10X	$(1\ \text{cm})^2$
100X	$(1\ \text{mm})^2$
1,000X	$(100\ \mu\text{m})^2$
10,000X	$(10\ \mu\text{m})^2$
100,000X	$(1\ \mu\text{m})^2$
1,000,000X	$(100\ \text{nm})^2$

[a] Assumes CRT screen measures 10 cm × 10 cm.

Figure 5: *Area sampled as function of magnification*

4 SEM microscopy modes

The main SEM microscopy modes are: High Depth of Field Images, High resolution Images and High beam current for image quality and X-ray microanalysis.

5 The Enviromental SEM

In spite of some reduction in resolution, ESEM is used to investigate specimens in their natural state. So sample preparation is not necessary. The maximum magnification for the ESEM is 50,000 with a resolution of 100 Angstrom. The investigation of sample at high temperature is possible. In summary, it opens the world of microscopic phenomena hitherto unavailable.

6 Application

The SEM is mainly used for analyzing the structures of objects in the microscopic world. It displays sharp, clear, three dimensional images and enables us to decipher the structure of objects, which is otherwise not possible. For a specimen giving off any type of vapour, SEM can not be used. This disvantage is circumvented by using cryogenic SEM; it involves freezing specimen and coating it with gold. By maintaining a suitable vacuum chamber and keeping the bottom of sample in vacuum, SEM captures the process of crystallization and drying. A revealing SEM produced image is included to illustrate its capability. Because of high resolution, the SEM image gives microstructural characteristics of solid objects. It can be profitably used even when low resolution is necessary.

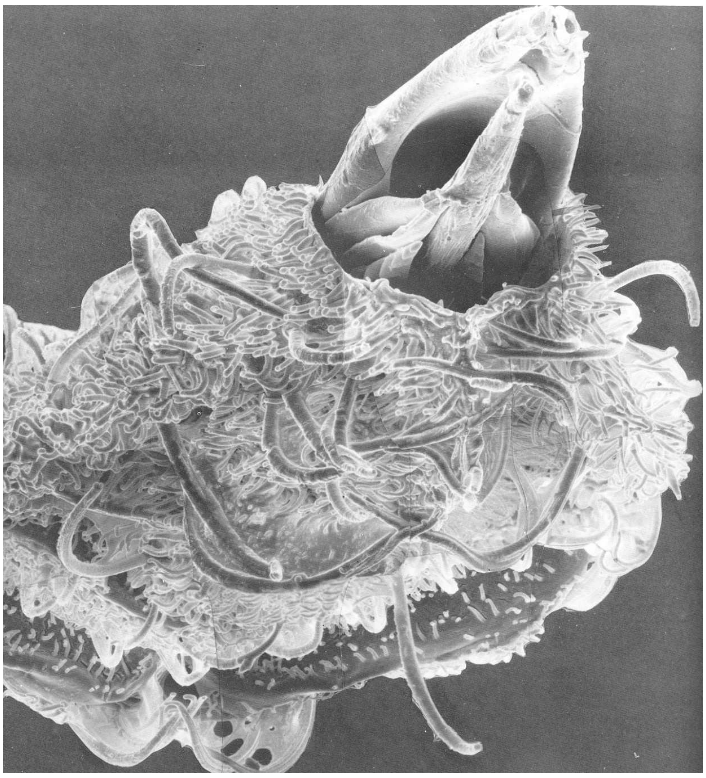

Figure 6: *The picture shows the proboscis of mosquito and blood passage*

References

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