International Journal of
Innovative Drug Discovery
e ISSN 2249 - 7609
Print ISSN 2249 - 7617
www.ijidd.com

SCANNING ELECTRON MICROSCOPE – A REVIEW

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ABSTRACT

The Scanning Electron Microscope (SEM) is used for observation of specimen surfaces. When the specimen is irradiated with a fine electron beam (called an electron probe), secondary electrons are emitted from the specimen surface. Topography of the surface can be observed by two-dimensional scanning of the electron probe over the surface and acquisition of an image from the detected secondary electrons.[1].

KEY WORDS: electron beam, emission.

INTRODUCTION

Scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.[2] The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electrons emitted by atoms excited by the electron beam are detected using an Everhart-Thornley detector.

Construction of Instrument

The SEM requires an electron optical system to produce an electron probe, a specimen stage to place the specimen, a secondary-electron detector to collect secondary electrons, an image display unit, and an operation system to perform various operations.

The electron optical system consists of an electron gun, a condenser lens and an objective lens to produce an electron probe, a scanning coil to scan the electron probe, and other components. The electron optical system (inside of the microscope column) and a space surrounding the specimen are kept at vacuum.[3]

Electron Gun

The electron gun produces an electron beam. Thermo electrons are emitted from a filament (cathode) made of a thin tungsten wire (about 0.1 mm) by heating the filament at high temperature (about 2800K). These thermo electrons are gathered as an electron beam, flowing into the metal plate (anode) by applying a positive voltage (1 to 30 kV) to the anode.

If a hole is made at the centre of the anode, the electron beam flows through this hole. When you place an electrode (called a Wehnelt electrode) between the cathode and anode and apply a negative voltage to it, you can adjust the current of the electron beam.[4] At this time, the electron beam is finely focused by the action of the Wehnelt electrode. The finest point of the beam is called the crossover, and this is regarded as an actual electron source with a diameter of 15 to 20 µm.

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Construction of Lens

An electron microscope generally uses a magnetic lens. When you pass a direct electric current through a coil-wound electric wire, a rotationally-symmetric magnetic field is formed and a lens action is produced on an electron beam. To make a strong magnetic lens (with a short focal length), it is necessary to increase the density of the magnetic line. Thus, the surroundings of the coil are enclosed by yokes so that part of the magnetic field leaks from a narrow gap. A portion with a narrow gap, called "polepiece," is fabricated with a high accuracy. The main feature of the magnetic lens is that when you change the current passing through the coil, the strength of the lens is also changed. This is not achieved by an optical lens.

Secondary Electron Detector

The secondary electron detector is used for detecting the secondary electrons emitted from the specimen. A scintillator (fluorescent substance) is coated on the tip of the detector and a high voltage of about 10 kV is applied to it. The secondary electrons from the specimen are attracted to this high voltage and then generate light when they hit the scintillator. This light is directed to a photo-multiplier tube (PMT) through a light guide. Then, the light is converted to electrons, and these electrons are amplified as an electric signal. A supplementary electrode, called the collector, is placed before the scintillator. In general, in order to help the scintillator acquire secondary electrons, a few hundred volts are applied to this collector.

By changing this voltage, you can control the number of secondary electrons to be collected. This type of the detector was originally developed by Everhart and Thornley, so this detector can be called the E-T detector. Many SEMs incorporate this detector in the specimen chamber; however, when a SEM is equipped with a strongly excited objective lens for higher resolution, a secondary electron detector is placed above the objective lens and secondary electrons are detected by utilizing the lens magnetic fields. This detector is often called the TTL (Through the Lens) detector.

Image Display and Recording

The output signals from the secondary electron detector are amplified and then transferred to the display unit. Since the scanning on the display unit is synchronized with the electron-probe scan, brightness variation, which depends on the number of the sec-ondary electrons, appears on the monitor screen on the display unit, thus forming a SEM image. A cathode-ray tube (CRT) was used for many years as a display unit; however in recent years, a liquid-crystal display (LCD) has been widely used. In general, the scan speed of the electron probe can be changed in several steps, an extremely fast scan speed is used for observation and a slow scan speed is used for acquisition or saving of images.To record an SEM image, in the past, the SEM image appearing on the CRT was photographed with a camera. But recently, the image has been recorded in a digital format (electronic file). This is because it is now difficult to get a high-resolution CRT and there are many advantages of electronic file. That is, it is easier to process images and convenient to send or receive image information. Note that an image format with 1M pixels is generally used for the electronic file.

Vacuum System

The inside of the electron optical system and the specimen chamber must be kept at a high vacuum of 10-3 to 10-4 Pa. Thus, these components are evacuated generally by a diffusion pump. If a user desires an oil-free environment, a turbo molecular pump may be used. When a SEM incorporates an FE gun (explained later), a sputter ion pump is used because the FE gun needs an ultrahigh vacuum.[5]

To exchange a specimen, either of two methods is applied. One vents the entire specimen chamber at the time of specimen exchange. The other uses a specimen pre-evacuation chamber (airlock chamber) while keeping a high vacuum in the specimen chamber.

Magnification of SEM

When the specimen surface is two-dimensionally scanned by the electron probe, a SEM image appears on the monitor screen of the display unit. At this time, if the scan width of the electron probe is changed, the magnification of the displayed SEM image is also changed. Since the size of the monitor screen is unchanged, decreasing the scan width increases the magnification, whereas increasing the scan width decreases the magnification.

For example, when the size of the monitor screen is 10 cm and the scan width of the electron probe is 1 mm, the magnification is 100 times, whereas the scan width is 10 µm, 10,000 times. In terms of historical background, the magnification is expressed for a screen of 12 cm (horizontal) and 10 cm (vertical) as the standard (slightly different depending on a SEM manufacturer). If a display unit has a larger monitor screen compared to the standard size, the magnification of the displayed SEM image becomes larger. In such a case, the magnification and the size of an object are calculated with a scale bar displayed on the screen as a reference.

Detection of secondary electrons

The most common imaging mode collects low-energy (<50 eV) secondary electrons that are ejected from conduction or valence bands of the specimen atoms by inelastic scattering interactions with beam electrons. Due to their low energy, these electrons originate from within a few nanometres below the sample surface. The electrons are detected by an Everhart-Thornley detector, which is a type of collector-scintillator-photomultiplier system. The secondary electrons are first collected by attracting them towards an electrically biased grid at about +400 V, and then further accelerated towards a phosphor or scintillator

positively biased to about +2,000 V. The accelerated secondary electrons are now sufficiently energetic to cause the scintillator to emit flashes of light (cathodoluminescence), which are conducted to a photomultiplier outside the SEM column via a light pipe and a window in the wall of the specimen chamber. [6]

The amplified electrical signal output by the photomultiplier is displayed as a two-dimensional intensity distribution that can be viewed and photographed on an analogue video display, or subjected to analog-to-digital conversion and displayed and saved as a digital image. This process relies on a raster-scanned primary beam. The brightness of the signal depends on the number of secondary electrons reaching the detector.

If the beam enters the sample perpendicular to the surface, then the activated region is uniform about the axis of the beam and a certain number of electrons "escape" from within the sample. As the angle of incidence increases, the interaction volume increases and the "escape" distance of one side of the beam decreases, resulting in more secondary electrons being emitted from the sample. Thus steep surfaces and edges tend to be brighter than flat surfaces, which results in images with a well-defined, three-dimensional appearance. Using the signal of secondary electrons image resolution less than 0.5 nm is possible.

Detection of backscattered electrons

Backscattered electrons (BSE) consist of high-energy electrons originating in the electron beam,that are reflected or back-scattered out of the specimen interaction volume by elastic scattering interactions with specimen atoms. Since heavy elements (high atomic number) backscatter electrons more strongly than light elements (low atomic number), and thus appear brighter in the image, BSEs are used to detect contrast between areas with different chemical compositions.

The Everhart-Thornley detector, which is normally positioned to one side of the specimen, is inefficient for the detection of backscattered electrons because few such electrons are emitted in the solid angle subtended by the detector, and because the positively biased detection grid has little ability to attract the higher energy BSE. Dedicated backscattered electron detectors are positioned above the sample in a "doughnut" type arrangement, concentric with the electron beam, maximizing the solid angle of collection. BSE detectors are usually either of scintillator or of semiconductor types. When all parts of the detector are used to collect electrons symmetrically about the beam, atomic number contrast is produced.

However, strong topographic contrast is produced by collecting back-scattered electrons from one side above the specimen using an asymmetrical, directional BSE detector; the resulting contrast appears as illumination of the topography from that side. Semiconductor detectors can be made in radial segments that can be switched in or out to control the type of contrast produced and its directionality. Backscattered electrons can also be used to form an electron backscatter diffraction (EBSD) image that can be used to determine the crystallographic structure of the specimen.

Influence of Accelerating Voltage

When the accelerating voltage is changed, the penetration depth of the incident electrons changes. As the accelerating voltage is higher, the penetration depth is larger. If the accelerating voltage is increased, information from the inside of the specimen gives rise to the background, degrading the contrast on the specimen surface. The electron probe broadens within the specimen. Thus, if a structural object exists inside the specimen, a higher accelerating voltage causes an unclear image of this object that overlaps on the surface image. In addition, as the accelerating voltage is higher, the edge effect is larger. Accordingly, in order to clearly observe surface structures, it is better to use a lower accelerating voltage.

Electron Gun

Field-Emission Electron Gun

An electron gun that is used for a high-resolution SEM is the FE gun. The FE gun utilizes the field-emission effect that takes place when a high electric field is applied to a metal surface. The cathode is made of a thin tungsten wire. A tungsten single crystal is welded to this tungsten wire, and the tip of the tungsten single crystal is shaped to be a curvature radius of about 100 nm. This is called the emitter. When a positive voltage (a few kV) is applied to a metal plate (extracting electrode), the tunneling effect occurs and electrons are emitted from the emitter. If a hole is made at the center of the extracting electrode, the emitted electron beam flows through this hole. Then, when you apply a voltage to the electrode (accelerating electrode) located below the extracting electrode, you can obtain an electron beam having certain energy. In order to generate a field emission, the tip of the emitter must be very clean. Thus, the FE gun needs to be placed in an ultrahigh vacuum of about 10-8 Pa.

The electron beam emitted from the emitter behaves as if the beam was emitted from a small electron source with a diameter of 5 to 10 nm. In the case of the TE gun, its electron source is 10 to 20 μm in diameter, indicating that the FE gun produces a much smaller electron source than the TE gun, thus suitable for high-resolution SEMs. In addition, another advantage of the FE gun is that the energy spread of the electron beam is small because the FE gun requires no heating of the emitter. In low-accelerating voltage observation, this energy spread determines the resolution (chromatic aberration); therefore, this advantage is very important.

Resolution of the SEM

A video illustrating a typical practical magnification range of a scanning electron microscope designed for biological specimens. The video starts at 25x,

about 6 mm across the whole field of view, and zooms in to 12000×, about 12 μm across the whole field of view. The spherical objects are glass beads with a diameter of 10 μm, similar in diameter to a red blood cell.

SEM is not a camera and the detector is not continuously image-forming like a CCD array or film. Unlike in an optical system, the resolution is not limited by the diffraction limit, fineness of lenses or mirrors or detector array resolution. The focusing optics can be large and coarse, and the SE detector is fist-sized and simply detects current. Instead, the spatial resolution of the SEM depends on the size of the electron spot, which in turn depends on both the wavelength of the electrons and the electron-optical system that produces the scanning beam. The resolution is also limited by the size of the interaction volume, the volume of specimen material that interacts with the electron beam. The spot size and the interaction volume are both large compared to the distances between atoms, so the resolution of the SEM is not high enough to image individual atoms, as is possible with transmission electron microscope (TEM). The SEM has compensating advantages, though, including the ability to image a comparatively large area of the specimen; the ability to image bulk materials (not just thin films or foils); and the variety of analytical models available for measuring the composition and properties of the specimen. Depending on the instrument, the resolution can fall somewhere between less than 1 nm and 20 nm. As of 2009, the world's highest resolution conventional (≤30 kV) SEM can reach a point resolution of 0.4 nm using a secondary electron detector.

Fig 1 SEM line diagram

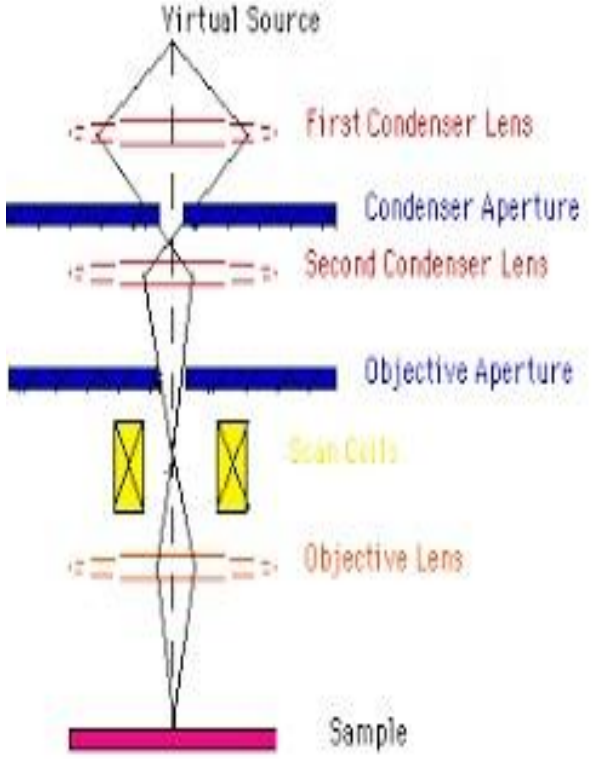
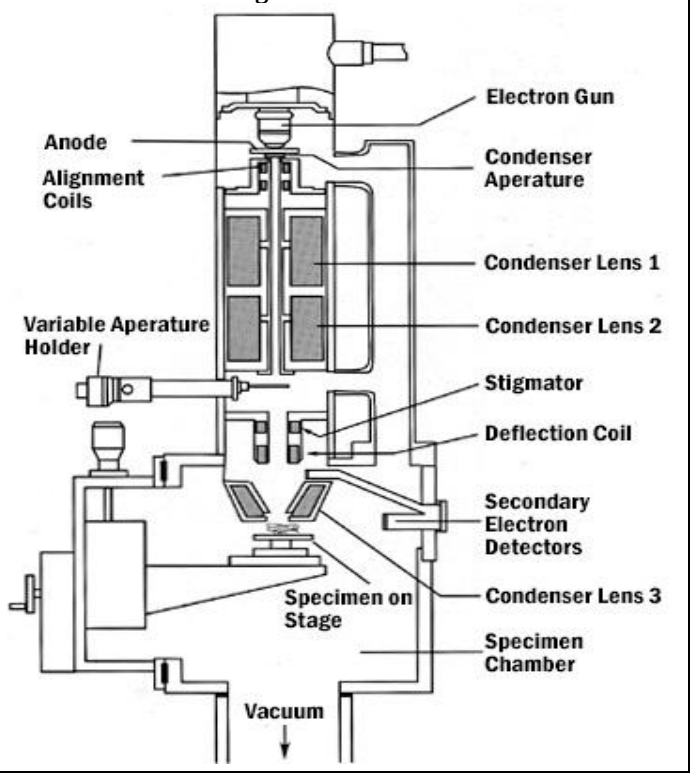


Fig 2 Parts of SEM



CONCLUSION

SEMs are used in medical science to compare blood and tissue samples in determining the cause of illness and measuring the effects of treatments on patients (while contributing to the design of new treatments). Common uses include, identifying diseases and viruses, testing new vaccinations and medicines, comparing tissue samples between patients in a control and test group, testing samples over the lifespan of a patient etc. Within the fields of industrial application and research, there is an increasing focus on quality control at microscopic scales. Achieving high resolution imagery with a scanning electron microscope can provide insight into many fields, making SEMs indispensable tools across many fields.

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