
# Introduction

# 1

## 1.1 What Is the SEM

The word microscope is derived from Greek *micros* (small) and *skopeo* (look at). Just like any microscope, the primary function of the scanning electron microscope (SEM) is to enlarge small features or objects otherwise invisible to human sight. It does that by way of using electron beam rather than light which is used to form images in optical light microscopes. The images are obtained by scanning an electron beam of high energy on the sample surface, hence the name scanning electron microscope. By virtue of its smaller wavelength, electrons are able to resolve finer features/details of materials to a much greater extent compared with optical light. A modern day SEM can magnify objects up to one million times their original size and can resolve features smaller than 1 nm in dimension. Similarly, electron beam interaction with the specimen emits x-rays with unique energy that can be detected to determine the composition of material under examination. The SEM is, therefore, a tool used for materials characterization that provides information about the surface or near surface structure, composition, and defects in bulk materials. It allows scientists to observe surfaces at submicron and nano-level to elaborate material properties. It has emerged as one of the most powerful and versatile instruments equally valuable to materials and life scientists working in wide-ranging industries.

## 1.2 Image Resolution in the SEM

A human eye cannot distinguish objects smaller than 200 μm (0.2 mm). In other words, the resolution of a human eye is 200 μm, while a light microscope can typically magnify images up to 1000× to resolve details down to 0.2 μm. Resolution limit is defined as the smallest distinguishable distance separating two objects, i.e., minimum resolvable distance. For instance, two objects separated by a distance of



A. Ul-Hamid, *A Beginners' Guide to Scanning Electron Microscopy*,
https://doi.org/10.1007/978-3-319-98482-7_1

less than 200 μm will appear as one object to the human eye since the latter is not able to resolve details that have dimensions smaller than 200 μm. Hence, 200 μm can be considered to be the resolution limit of the human eye. The same objects viewed under a light microscope will appear as two distinct entities since the light microscope can easily differentiate distances less than 200 μm. In fact, the objects can be brought closer together further to a distance of 0.2 μm and still maintain their separate identities under a light microscope. However, if the distance between the objects is decreased further to less than 0.2 μm, the light microscope will no longer be able to discern them as two separate objects, which will then appear as a single entity. Thus 0.2 μm can be defined as the resolution limit of the light microscope. It follows that the smaller is the value of minimum resolvable distance, the higher is the resolution of a microscope.

Both light microscope and humans use visible light as a means to probe into or interact with an object. The increased ability to observe details in a light microscope compared to the unaided eye is attributed to the lens/aperture system used to magnify the image of an object. It is theoretically possible to keep enlarging the image by increasing the magnification indefinitely. However, it is not possible to keep revealing newer details in an object by simply increasing the magnification. Fine details in an image cannot be resolved beyond a certain magnification. This is due to limitations imposed by the resolving power of the imaging technique as well as that of the human eye. The maximum useful magnification beyond which no further details are revealed is determined by the resolving power of a microscope. The following equation can be used to determine the typical useful magnification of a microscope:

$$\text{Useful Magnification} = \frac{\text{Resolution of the Human Eye}}{\text{Resolution of Microscope}} \tag{1.1}$$

For a light microscope, useful magnification $\left(\frac{200\ \mu m}{0.2\ \mu m}\right)$ is around 1000×. For a scanning electron microscope, useful magnification $\left(\frac{200\ \mu m}{1\ nm}\right)$ is typically 200,000×. Increase in the resolution of the instrument results in the increase of its useful magnification.

The ability of visible light to resolve image details is limited by its relatively large wavelength ($\lambda$ = 380–760 nm) (see Fig. 1.1). Use of light with a shorter wavelength (such as ultraviolet) and a lens immersed in oil (high refractive index) improves resolution to around 0.1 μm. If the image is formed by using a radiation with a smaller wavelength, such as an electron beam, higher resolution limit can be achieved since the smaller the wavelength, the greater the resolving power and the greater the detail revealed in an image. Due to this fact, techniques like the SEM and TEM employ an electron beam to probe the material resulting in an image far superior in resolution compared to that of the light microscope. For example, an electron beam ($\lambda$ of 0.000004 μm) with an accelerating voltage of 100 kV can achieve a resolution of 0.24 nm. The practical limit to resolution is determined by lens aberrations and defects. Modern-day field emission SEM typically operated at

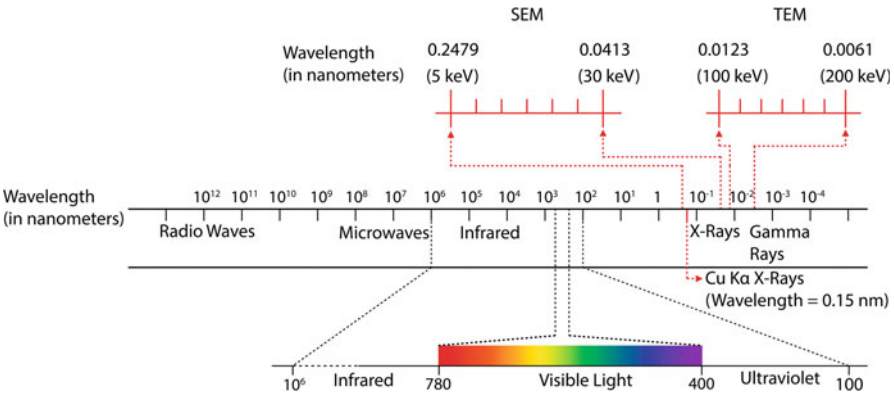


**Fig. 1.1** Electromagnetic spectrum showing the size of the wavelength used in the light, scanning (SEM), and transmission electron microscope (TEM)

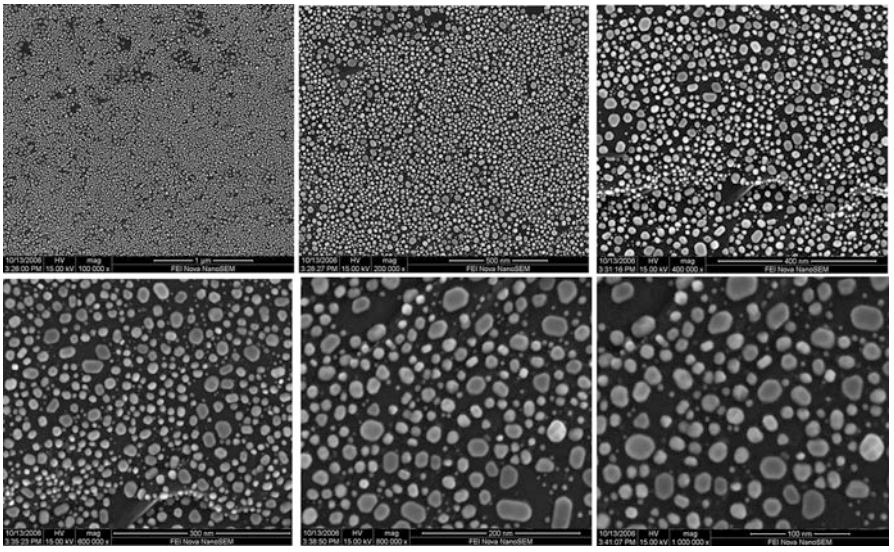

**Fig. 1.2** Secondary electron images of tin balls showing good contrast at low to very high magnifications (100,000× to 1,000,000×)

20–30 kV accelerating voltages can achieve image resolution in the order of 1 nm or better. It is worth noting here that resolving power or resolution (a more commonly used term) of an instrument is demonstrated by manufactures using a specimen *ideally* suited for that instrument. For instance, tin balls/powder is routinely employed for the SEM since the former is conductive and has strong contrast (see Fig. 1.2). Details in real samples, however, are not usually revealed to that level of resolution.

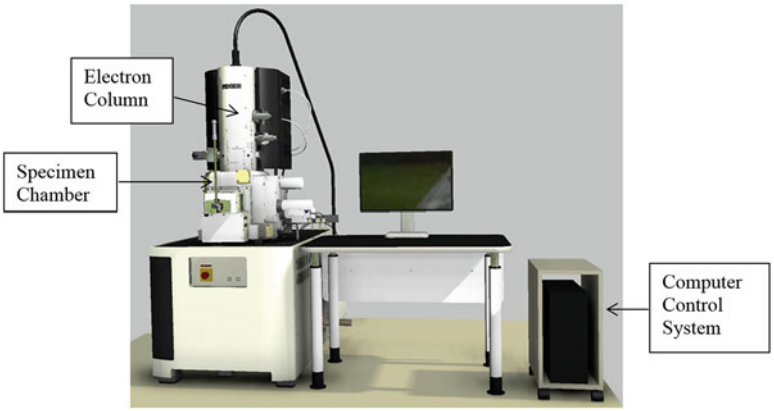


**Fig. 1.3** A photograph showing three major sections of the SEM: the electron column, the specimen chamber, and the computer control system. (Courtesy of T. Siong, JEOL Ltd.)

## 1.3 Image Formation in the SEM

The SEM instrument can be considered to comprise of three major sections: the electron column, the specimen chamber, and the computer/electronic controls, as shown in Fig. 1.3. The topmost section of the electron column consists of an electron gun which generates an electron beam. Electromagnetic lenses located within the column focus the beam into a small diameter (few nanometers) probe. The scan coils in the column raster the probe over the surface of the sample present in the chamber that is located at the end of the column. The gun, the column, and the specimen chamber are kept under vacuum to allow electron beam generation and advancement. The electrons in the beam penetrate a few microns into the surface of a bulk sample, interact with its atoms and generate a variety of signals such as secondary and backscattered electrons and characteristic x-rays that are collected and processed to obtain images and chemistry of the specimen surface. The ultimate lateral resolution of the image obtained in the SEM corresponds to the diameter of the electron probe. Advances in the lens and electron gun design yield very fine probe diameters giving image resolutions of the order of <1 nm. In order to provide a perspective to the way the image is realized in the SEM, a comparison of how light and the transmission electron microscopes work compared to the SEM is shown in Table 1.1 and Fig. 1.4.

## 1.4 Information Obtained Using the SEM

The scanning electron microscope is used to observe and image the micro- and nanostructural surface details of a wide range of materials such as metals, alloys, ceramics, polymers, rock minerals, corrosion deposits, filters, membranes, foils,

**Table 1.1** Comparison of various characteristics of the SEM with light and transmission electron microscope

| Characteristics | Light microscope | Scanning electron microscope | Transmission electron microscope |
|---|---|---|---|
| Radiation used to form an image | Visible light | Electrons | Electrons |
| Wavelength of radiation | 380–760 nm depending on the color of light | 0.008 nm at 20 kV accelerating voltage[a] | 0.0028 nm at 200 kV accelerating voltage[a] |
| Types of lenses used to focus the radiation | Glass | Electromagnetic | Electromagnetic |
| Useful magnification | 1,000× | 200,000× | 2,000,000× |
| Possible magnification | Up to 2,000× | 1,000,000× | 10,000,000 or more |
| Magnification mode | With lenses | Without lenses | With lenses |
| Resolution | 200 nm | 1 nm | 0.1 nm |
| Source of radiation | Tungsten-halogen lamp | Electron gun/emitter | Electron gun/emitter |
| Image formation | Light from the source is scattered by the sample surface and redirected by the objective lens to form an image onto the retina of the human eye. The image can also be displayed on an electronic display | Electrons originating from the source travel in vacuum within a column lined with electromagnetic lenses which focus these electrons into a small probe on the surface of the specimen. Electron-specimen interaction results in information emanating from the specimen which is passed through detectors and reconstituted as an image on an electronic display | Electrons originating from the source travel in vacuum within a column. Electron beam passes through a thin foil of sample and then focused and magnified by electromagnetic lenses to form an image on a fluorescent screen or transferred to an electronic display |
| Type of image | Real image. Color images. Images formed using visible light can be observed directly by the human eye | Processed/ reconstituted image. Grayscale images (black and white). Images formed with electrons cannot be observed directly by humans | The real image is projected onto the screen which can be observed by the human eye. Grayscale images |
| Specimen preparation | Required | Can be omitted (based on specimen type) | Required, tedious |
| Specimen thickness | Thin, bulk | Bulk | Thin (Electron transparent, ≈100 nm) |
| Sample area examined | Large areas of a sample can be examined | Small areas of a sample are examined | Extremely small areas of a sample are examined |

(continued)

**Table 1.1** (continued)

| Characteristics | Light microscope | Scanning electron microscope | Transmission electron microscope |
|---|---|---|---|
| Applications | Materials/life sciences | Materials/life sciences | Materials/life sciences |
| Examination of live specimens | Living organisms can be examined | Vacuum usage and high energy electron radiation precludes examination of live samples | Vacuum usage and high energy electron radiation precludes examination of live samples |
| Depth of field | Small[b]<br>15 μm (at 4×)<br>0.2 μm (1000×) | Large (3-D like images)[b]<br>4 mm (at 10×)<br>0.5 μm (500,000×) | Small |
| Lab size requirements | 2 × 2 m | 5 × 5 m | 6 × 6 m |
| Capital and maintenance cost | Low | Medium | High |
| Features studied | Surface | Surface or subsurface | Microstructure |
| Interpretation of images | Easy | Moderate | Difficult |

[a]Electron wavelength is calculated from De Broglie equation: $\frac{1.23\ nm}{\sqrt{\text{accelerating voltage in thousands.}}}$

[b]The exact depth of field depends on the working distance (i.e., the distance between the lens and the imaged surface).

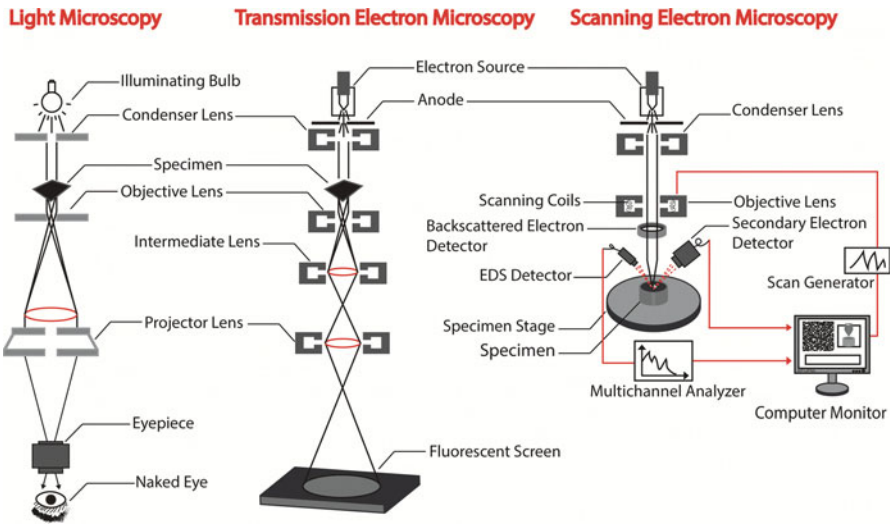


**Fig. 1.4** Schematic comparing the modes of image formation in the light, transmission, and scanning electron microscopes

fractured/rough surfaces, biological samples, etc. The materials can be conductive or non-conductive either in solid or powder form and can be examined in an as-received or prepared (sectioned, ground, polished, etched, coated, etc.) condition. The SEM has the ability to examine materials in the dry or wet state as well as obtain microchemical information from fine structural details. The SEM equipped with a field emission gun can distinguish surface features that are only 1 nm apart (i.e., lateral spatial resolution = 1 nm). Extraordinary ability to depict large depths of field (10–100% of horizontal field width) allows large areas of a sample to remain in focus at one time and thus yield 3-D characteristics in SEM images (see Fig. 1.5). Imaging can be performed using both secondary electrons (for topographic contrast) and backscattered electrons (for topographic and/or compositional contrast). Microchemical information is generally obtained using energy dispersive x-ray spectrometer (EDS) detector attached to the SEM. Both qualitative and quantitative elemental information from microstructural features can be obtained from beryllium to uranium with limits of detection of approximately 0.2–0.5 wt%. The electron beam in the SEM can penetrate as much as a few microns into the sample depending


**Fig. 1.5** Secondary electron SEM image of an ant showing detailed three-dimensional details. (Image courtesy of TESCAN)

on sample density, beam accelerating voltage, etc. Typical applications include observation of metallographically prepared samples (such as steel) to study surface morphology, grain size/shape, inclusions, precipitates, dendrites, grain boundaries, etc. It is also employed to observe materials in an unprepared (as-received) condition, e.g., fracture surfaces for metallurgical failure analysis, electronic devices for electronic failure analysis, corrosion deposits, catalyst shape, size and surface structure, polymer additives, rock mineral samples, etc. Apart from bulk samples, it is also used to examine coatings and thin films deposited on substrates. Table 1.2 highlights various applications and the range of information obtained using SEM and related techniques.

A combination of factors such as good resolution, large depth of field, compositional information, time-efficient analysis, as well as relative ease of use and image interpretation in both materials and life sciences has made the SEM one of the most heavily used instruments in academia, research, and industry. Although the SEM can generate rich morphological and compositional data for a wide variety of materials, it is often necessary to employ various other analytical tools to undertake complete materials characterization. Selection of these tools will depend on the type of material under study and the nature of information required. For instance, if the objective is to reveal true microstructure (not surface topography) of a material, transmission electron microscopy is employed. This technique can also extract chemical information from features at the nanometer scale. Likewise, if the bulk composition is desired, x-ray fluorescence is a better choice as it analyzes large volumes of material. Phase identification at a macro level is often carried out using x-ray powder diffraction analysis. Analysis of structure and composition of a thin surface constituting a few atomic monolayers is undertaken with Auger and x-ray photoelectron spectroscopy. All these techniques are tools available to a scientist to carry out essential materials characterization and information obtained from one complements the others. A brief comparison of the imaging and analytical abilities of these techniques is shown in Table 1.3.

## 1.5 Strengths and Limitations of the SEM

Strengths of the SEM include:

1. A wide variety of specimens can be examined.
2. Relatively easy and quick sample preparation.
3. Ease of use due to user-friendly and automated equipment.
4. Rapid imaging, quick results, time-efficient analysis, and fast turnaround time.
5. Relatively straightforward image interpretation.
6. Large depth of field (ability to focus large depths of samples at one time and produce 3-D like images)
7. Microchemical analysis capability from Be to U.
8. Samples can be dry or wet.
9. Nondestructive (some beam damage may result).

**Table 1.2** Summary of capabilities of the SEM and related techniques

| | |
|---|---|
| Information obtained using SEM and related techniques | Morphology (grain shape, precipitate size, dimension, texture and volume fraction, and phase distribution of physical features) [using secondary electron (SE) imaging]<br>Surface topography (distribution/arrangement of features at the surface of a sample, defects, cracks, voids, structure) [using secondary electron imaging]<br>Atomic number or compositional contrast, grain boundaries, domains in magnetic materials [using backscattered electron (BSE) imaging]<br>Microanalysis, elemental identification and quantification, line scans, x-ray maps [using energy dispersive x-ray spectroscopy (EDS)]<br>Kikuchi maps of bulk samples—crystallographic orientation of grains, phase identification [using electron backscattered diffraction (EBSD)]<br>Pore size/shape/distribution in rock minerals, organic samples [using cryogenic techniques]<br>Image non-conductive charging samples such as polymers, rocks, etc., without coating [using low vacuum (LV) mode]<br>Imaging fine details of surface structures [using low accelerating voltage]<br>Preparation of precise plan and cross-sectional view TEM samples, fabrication of nano devices [using SEM combined with focused ion beam]<br>In situ experiments under hydration, thermal cycling, or gaseous environment [using environmental SEM (ESEM)]<br>Printing of circuit boards in the electronics industry [using E-beam lithography] |
| Applications | Materials identification, materials science, forensic science, metallurgical and electronic materials failure analysis, corrosion science, rock mineralogy, geo sciences, nano devices, polymer science, catalysis, semiconductor design, desalination, life sciences, oil and gas, mining |
| Types of samples examined | Metals, alloys, semiconductors, polymers, coatings, ceramics, rocks, sand, corrosion products, catalysts, membranes, carbon nanotubes, nanopowders, tissues, cells, insects, leaves |
| Industry | Academic and research, oil and gas, power generation, metals and alloys, industrial manufacturing, automobile, aero, aerospace, petrochemical, geosciences, nanotechnology, semiconductor, computer, chemical process industry, mining |
| Sample form/state/size | Form: Solid, bulk, thin, nanostructured, powder, pellet, organic, inorganic<br>State: Dry, wet<br>Sample size: 1 mm to 150 mm (typically 10–20 mm) |
| Spatial resolution | 1 nm |
| Sampling depth | 1–5 μm (depends on sample density and electron beam accelerating voltage) |
| Sample area analyzed | Submicron to >100 μm (depends on electron probe size, magnification) |
| Detection limit of elements | ≈ 0.2 wt% (depends on relative elemental content and atomic weight) |

**Table 1.3** Comparison of imaging and analytical techniques generally used to study materials structure, chemical composition, and defects

| Technique | Information/ applications | Spatial resolution | Sampling depth | Typical sample area analyzed | Elemental detection limits |
|---|---|---|---|---|---|
| Light microscopy | Imaging/materials and life sciences | 200 nm | Surface | Millimeters | – |
| Scanning electron microscopy | Imaging, microchemical analysis/materials, and life sciences | 1 nm | Submicron to several microns | Micron to millimeters | 0.2–0.5 wt% |
| Transmission electron microscopy | Imaging, microchemical analysis, crystal structure/materials and life sciences | 0.1 nm | <100 nm (thin foils) | <1 to few microns | 0.01–0.1 wt% |
| Atomic force microscopy | Imaging, topography/ materials, and life sciences | Sub nanometer | Sub-nanometer | Tens to hundreds of microns | – |
| Electron probe microanalysis with wavelength dispersive x-ray spectroscopy | Imaging, microchemical analysis/materials science | 1 nm | Submicron to several microns | Micron to millimeters | 0.01 wt% |
| X-ray diffraction | Structural analysis, lattice parameters, phase constitution, crystal structure, crystallite size, pore size, stress, texture, lattice distortion, thin film analysis/materials science | – | Tens to hundreds of microns | Sq. cm | – |
| X-ray fluorescence | Bulk chemical analysis/materials science | – | Tens to hundreds of microns | Sq. cm | ppm |
| X-ray photoelectron spectroscopy | Surface chemistry (binding energy, chemical state)/ materials science | – | 0.5–5 nm | Tens of sq. μm | 0.001 wt% to ppm |
| Auger electron spectroscopy | Surface chemistry, imaging (electronic structure, depth profiling)/materials science | 8 nm | <5 nm | Nanometers to microns | 0.01–0.1 at% |

10. High spatial resolution (1 nm) achieved by modern equipment.
11. A versatile platform that lends support to other sophisticated tools, devices, and techniques.
12. Capable of several modes of imaging, spectroscopy, and diffraction analysis.
13. Affordability and availability compared to more expensive equipment.

Limitations can be summarized as follows:

1. The sample size is limited.
2. Samples are solid.
3. EDS detector cannot detect H, He, or Li.
4. Poor detectability limit of elements (with EDS) compared to wet analytical methods.
5. Samples need to be examined under vacuum.
6. The instrument typically requires an installation space of 5 × 5 m.
7. Non-conductive samples need to be coated.

## 1.6 Brief History of the SEM Development

Limitation of light microscope in resolving fine details of organics cells provided the impetus to develop an electron microscope in the early twentieth century. The first electron microscope was a transmission electron microscope developed by German scientist Max Knoll and electrical engineer Ernst Ruska in Germany in 1931. It employed a working model similar to light microscope except that a beam of electrons, instead of visible light, was made to pass through the body of a sample to form an image on a fluorescent screen. Use of electrons as an imaging medium afforded a resolution of 10 nm compared to a resolution of 200 nm achievable by a light microscope. The resolution achieved at the time might seem modest today, but the real breakthrough was the fact that for the first time in history, electrons had been successfully employed to create images of matter. Subsequent improvements in the accelerating voltage, lens technology, vacuum systems, electron guns, power supplies, and overall design of the microscopes in the next few decades led to the imaging of atoms (i.e., atomic resolution was achieved). Due to his "fundamental work in electron optics and for the design of the first electron microscope," Ernst Ruska received a Nobel Prize in physics in 1986.

German physicist Max Knoll introduced the concept of a scanning electron microscope in 1935 [1]. He proposed that an image can be produced by scanning the surface of a sample with a finely focused electron beam. Another German physicist Manfred von Ardenne explained the principles of the technique and elaborated upon beam-specimen interactions. He went on to produce the earliest scanning electron microscope in 1937 [2–4] as shown in Fig. 1.6.

Later, the SEM with a resolution of 50 nm was built by American scientists Zworykin, Hillier, and Snijder in 1942 [5] and later by Professor Sir Charles W. Oatley and his postgraduate student D. McMullan at the University of Cambridge

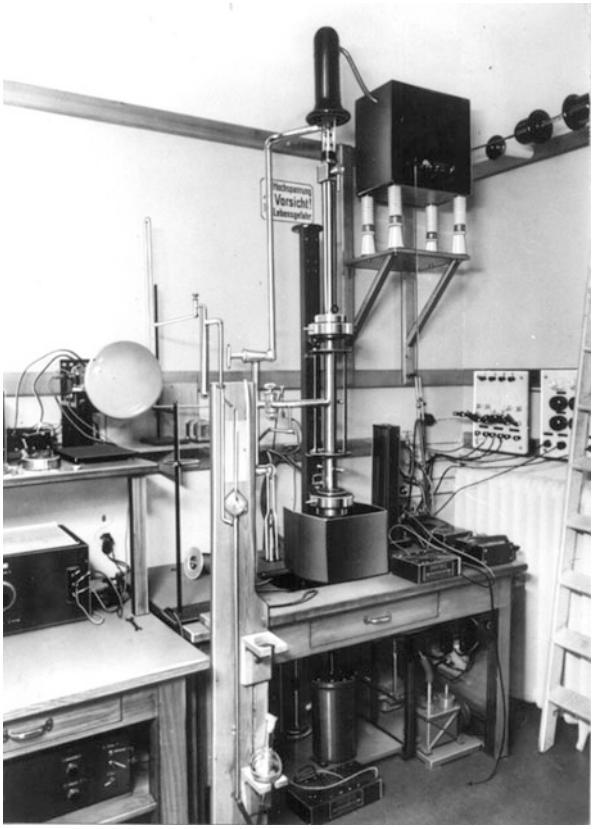


**Fig. 1.6** First scanning electron microscope built by Manfred von Ardenne in 1937

in 1952 [6]. Scintillator-based secondary electron detector was developed by Everhart and Thornley in 1960 [7]. Further improvements in the technology led to the development of first commercial SEM known as "Stereoscan" by Cambridge Scientific Instruments in 1965 [8, 9]. The SEMs built in the 1960s had a resolution of about 15–20 nm. In the 1970s and 1980s, the resolution was improved to 7 nm and 5 nm (at 1 kV), respectively. Next couple of decades saw resolution improvements down to 3 nm and then to 1 nm. Currently, manufacturers claim resolutions of 0.5 nm in the SEM. Although the scanning electron microscope was developed subsequent to the transmission electron microscope, the former quickly became popular due to its ease of use, simple sample preparation, and ability to generate 3-D like images of the sample topography. A detailed history of the SEM development has been documented by some authors [10–13]. Main events in the development of SEM techniques and instrumentation are listed in a chronological order in Table 1.4 [10–14]:

**Table 1.4** Development of SEM instrumentation and techniques in a chronological order [10–14]

| Year | Key developments | Contributors |
|---|---|---|
| 1935 | The concept of the SEM | M. Knoll (1935) |
| 1938 | Concept and development of the scanning transmission electron microscope (STEM) | M. von Ardenne |
| 1942 | Development of the SEM with 50 nm resolution | Zworykin et al. |
| 1952 | Development of the SEM with 50 nm resolution | D. McMullan and Prof. C. Oatley |
| 1956 | Signal processing, double deflection scanning, stigmator (improved image quality) | K. C. A. Smith [15] |
| 1960 | Scintillating secondary electron detector, photomultiplier tube (improved signal-to-noise ratio) | Everhart and Thornley [7] |
| 1957 | Observation of voltage contrast | Oatley and Everhart [16] |
| 1960 | Stereographic 3-D SEM images | O. C. Wells [17] |
| 1963 | Development of "SEM V" microscope with three magnetic lenses and Everhart-Thornley (ET) detector | R. F. W. Pease [8] |
| 1963–1965 | Development of first commercial SEM "Stereoscan" | R. F. W Pease and Nixon [8, 9] |
| 1970s | Microchemical analysis using energy dispersive x-ray spectrometer (EDS) coupled with the SEM | Contributions from various individuals and commercial manufacturers |
| 1970s | Lanthanum hexaboride ($LaB_6$) cathode gun | |
| 1970s | Field emission gun | |
| 1970s | Electron backscattered diffraction (crystal structure and grain orientation) | |
| 1970s | Cathodoluminescence in the SEM | |
| 1973 | Hot stage to examine samples at elevated temperatures | |
| 1970s,1980s | Large specimen stages to hold sample sizes up to 23 cm | |
| 1980s | Auto focus and auto stigmator functions | |
| 1980s | Yttrium doped silicate scintillator as backscattered electron detector | |
| 1980s | Low temperature (Cryo) stage | |
| 1990s | Variable pressure SEM (for charging samples) | |
| Since 1990s | Improved automation and analysis due to computers | |
| 2000 to date | High resolution microscopes to study nanomaterials | |

## References


1. Knoll M (1935) Aufladepotentiel und Sekundäremission elektronenbestrahlter Körper. Z Tech Phys 16:467–475
2. von Ardenne M (1937) Improvements in electron microscopes. GB Patent No. 511204
3. von Ardenne M (1938) Das Elektronen-Rastermikroskop, Practische Ausführung. Z Tech Phys 19:407–416
4. von Ardenne M (1939) Das Elektronen-Rastermikroskop, Theoretische Grundlagen. Z Phys 108(9–10):553–572
5. Zworykin VK, Hiller J, Snyder RL (1942) A scanning electron microscope. ASTM Bull 117:15–23
6. McMullan D (1952) Ph.D. Dissertation, University of Cambridge, Cambridge, UK
7. Everhart TE, Thornley RFM (1960) Wide-band detector for micro-microampere low-energy electron currents. J Sci Instr 37(7):246–248
8. Pease RFW (1963) Ph.D. Dissertation, University of Cambridge, Cambridge, UK
9. Pease RFW, Nixon WC (1965) High resolution scanning electron microscopy. J Sci Instr 42:31–35
10. Oatley CW (1972) The scanning Electron microscope. Cambridge University Press, Cambridge
11. Thomas G (1999) The impact of electron microscopy on materials research. In: Rickerby D, Valdre G, Valdre U (eds) Proceedings of the NATO advanced study institute on impact of electron and scanning probe microscopy on materials research (1999). Springer Science+Business Media, Dordrecht. Originally published by Kluwer Academic Publishers in 1999, pp 1–24. https://doi.org/10.1007/978-94-011-4451-3
12. McMullan D (2006) Scanning electron microscopy 1928–1965. Scanning 17(3):175
13. McMullan D (1988) Von Ardenne and the scanning electron microscope. Proc Roy Microsc Soc 2:283
14. Goldstein J et al (2003) Scanning Electron microscopy and X-ray microanalysis, 3rd edn. Kluwer Academic/Plenum Publishers, New York
15. Smith KCA (1956) Ph.D. Dissertation, University of Cambridge, Cambridge, UK
16. Oatley CW, Everhart TE (1957) The examination of p-n junctions with the scanning electron microscope. J Electron 2:568–570
17. Wells OC (1960) Correction of errors in stereomicroscopy. Br J Appl Phys 11:199–201