History of the Microscope

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Introduction

The microscope is a powerful tool used widely today by students, teachers, scientists, doctors and researchers. It is used in many fields such as medicine, physics, biology, engineering and countless others. Microscopes are also used in industry and manufacturing. There are many types of microscopes being used and the question arises; how did our high-powered microscopes, such as the Scanning Probe Microscope come into being? The history of the microscope is a fascinating story and this paper will explain the progress and development of the microscope. Here is a list of the types of microscopes that will be discussed.

Types of Microscopes

Optical Microscopes

- Simple Microscope
- Compound Microscope
- Ultraviolet Microscope
- Ultraviolet Fluorescent Microscope

TEM Transmission Electron Microscope

SEM Scanning Electron Microscope

STM Scanning Tunneling Microscope

AFM Atomic Force Microscope

SPM Scanning Probe Microscope

Terms

concave
convex
nanometer
nanolithography
nanotechnology
micron
micrometer
microstructure
photomicrograph
wavelength of light

Microscopes

Named by Giovanni Faber in 1625, the term 'microscope' originally referred to what we know today as a telescope.[2] Simple items such as a magnifying glass or glasses are actually microscopes. A magnifying glass can also be used as a telescope. The common feature of microscopes, telescopes, eyeglasses and magnifying glasses is the lens. Lenses are made of glass or plastic and can be shaped in various ways to make objects appear closer or further away. In order to increase the size of an object, a lens bends light rays away from each other.[3]

Microscopes today come in several forms. These instruments are greatly valued for scientific investigation and research. The first microscope invented was a light microscope, also called the optical microscope, and was invented nearly 500 years ago. The microscope was not immediately appreciated for the contribution it could and would eventually make to science. The microscope has enabled us to learn more about our world than any other instrument.[4] It has enabled us to see what cannot be seen with the naked eye and has contributed to the development of computers, telephones, and cures for disease.

The History of the Lens

Figure 3.
Roman Cage Cup, 300 AD, 12.2 cm[8]

The history of microscopes really begins with the history of lenses. Lenses have always existed. A bead of water acts as a lens. Any transparent and clear object can act as a lens. Man-made lenses began with glassmaking.

The history of glass is ancient. A Roman historian named Pliny credited glassmaking to Phoenician sailors. Phoenicians came from an area we know as Lebanon today. As early as 1300 BC, 3,300 years ago, a group of people in Mesopotamia, now an area of Iraq and Syria, wrote down the instructions for glassmaking on clay tablets (see Figure 2). Tablets from as far back as 2,700 years ago have been recovered.[5] These instructions were passed on through the centuries and with the mixing and mingling of peoples and cultures, glass making was eventually passed on to the Romans. Until approximately 50 BC, glass was made very slowly. The Romans learned to perfect the art of glass making. Romans mass-produced glass vases and goblets (see Figure 3).[7] People began to notice that vases filled with water made objects seem larger.

Figure 2. 2700 year old Mesopotamian Clay Tablet with instructions for Glassmaking[6]

In 1038 AD, an Arabian scholar, Alhazen, published a book called "Opticae Thesaurus Alhazeni Arabius Basil." This book on optics described optics of the eye, including how the eye focuses. In his book, Alhazen also discussed ways to magnify objects by placing these objects in a dense, spherical medium and turning the curved surface of these objects towards the eye.[9] This means that Alhazen had noticed, and had written down that objects could be magnified.

Figure 4.
Roger Bacon
(1214-1292)[11]

Roger Bacon (Figure 4), a monk who lived in England (1214-1292), studied various aspects of nature for most of his life. He wrote a book called "Opus Majus." He wrote about many things in his book including optics and lenses. Bacon did experiments with lenses and found that putting glass or crystal over letters with the convex side of the crystal or glass towards the eye, made the letters appear larger to him.[10]

By the late 13th century, spectacles, or glasses, were introduced in Florence, Italy. Although it is not clear whom the inventor was, the use of spectacles spread rapidly throughout Europe. The spread of glasses through Europe undoubtedly led to the development of microscopes and telescopes.[12]

The Optical Microscope

Lenses are only one component of the optical microscope. Another element is light. The most obvious source of light is the sun. Today we have artificial light, but when microscopes were first invented, candles were used as a light source; although, eventually sunlight was used as a light source as well.[13] Light normally travels in a straight line; although, when light encounters an object, it will bounce off or bend depending on the type of object that it encounters. For example, if light hits a transparent object such as glass, it will normally pass through the glass, bending a bit. If the quality of the glass is poor, less light will go through, resulting in a distorted view of the world beyond the glass.[14] Optical microscopes capture this light and use it to magnify objects.

There are really two main kinds of optical microscopes: simple and compound. The simple microscope consists of one or two lenses. The lens is placed close to the eye to yield a better view. To focus, the length between the lens and the object is modified. The compound microscope uses more than one lens. The first lens in a compound microscope is called an objective lens. This lens magnifies the object first and then another lens called ocular lens magnifies this already magnified image once again.[15]

By the 1500's, the art of grinding glass into lenses was highly developed, especially in Holland. From the development of lenses, it became apparent that there was more to be seen in the heavens and on earth and someone realized that combining two or more lenses resulted in greater magnification or greater "seeing power." These combinations of lenses were the first microscopes and telescopes.

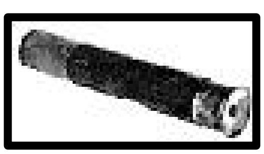

Figure 5. This is thought to be the first microscope, also called the Janssen Microscope[17]

The original inventor of the first microscope is debatable. From records that exist, it seems that the earliest microscopes were made in the 1590`s. The first microscope is thought to have been invented by Hans and Sacharias Janssen (1588-1630),[16] a father and son (respectively) who ran a lens-grinding business in Holland. A friend of Sacharias Janssen named Cornelius Drebbel was able to document his observations of the Janssen microscope. Drebbel described the microscope as having 3 brass sliding tubes that stood vertically from 3 legs. When completely extended this microscope was 18 inches long with a diameter of 2 inches. This microscope invented by the Jannsen's was a compound microscope (see Figure 5).[18]

Nearly half a century passed before the microscope received any attention. In 1663, Robert Hooke (1635-1703), curator of exhibits at the Royal Society of London, began giving weekly lectures on his microscope experiments.[19] He looked at various objects including cork, needles and compound eyes of different bugs. Micrographia, a book written by Hooke, was published in 1665. Micrographia contained information and drawings about the various experiments he did with the compound microscope (see Figure 6). Hooke took common materials and put them under the microscope to look at the microstructure. Although Hook used a two-lens microscope design, he felt a single lens would provide greater magnification; however, Hooke believed that this type of microscope would be very difficult to use. He was correct. The other microscope that Hooke described in his book is called the simple microscope. The distance between the object in the lens has to be very short in order to gain a high magnification.[21]

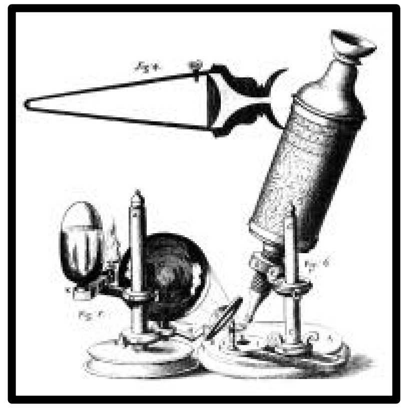

Figure 6. Compound Microscope used by Hooke[20]

Antoni van Leeuwenhoek (1632-1723), a Dutch cloth merchant and a naturalist, was inspired by Micrographia and built over 500 microscopes during his life of the variety that Hooke theorized

Figure 7. Antoni van Leeuwenhoek[2]

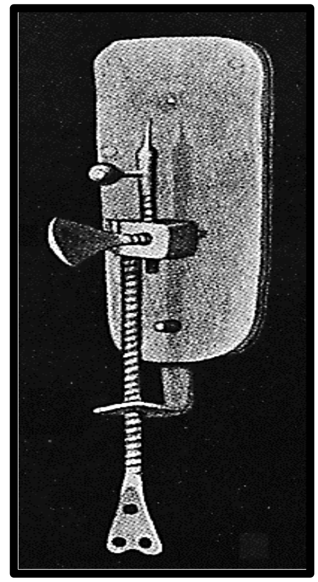

Figure 8.
Leeuwenhoek's
Microscope[24]

about. Leeuwenhoek was able to overcome the obstacle of needing a very short distance between the object and lens. The Leeuwenhoek microscopes were very small, about 3 to 4 inches long or the size of the average human thumb (see Figure 8), with a sharp point where the specimen would attach. The single lens was mounted in a metal plate and could be adjusted by the screws. This microscope enabled Leeuwenhoek to see things that people did not even know existed. For example, he saw bacteria.[23] Like Hooke, Leeuwenhoek wrote down what he saw and drew descriptions. In addition to bacteria, he described spermatozoa and red blood cells. The microscopes could obtain a resolution of 1.4 micrometers or a magnification of about 300 times.[25] A human hair is approximately 50 micrometers wide. So Leeuwenhoek was able to view samples that were about 1/35th the size of the width of a human hair!

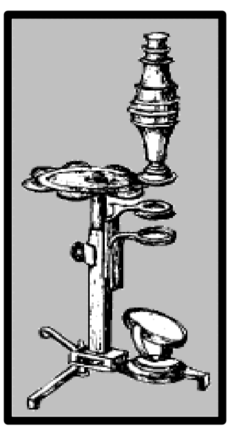

Figure 9.
George Adam's
Universal
Microscope[28]

The earliest microscopy devices were made from simple materials such as cardboard tubing, which often held the lenses. In 1744, John Cuff made a brass microscope with a rotating nosepiece that had 2 or more objective lenses of different magnifications.[26] Many other microscopes were produced based on the Cuff design. In 1746, George Adams came on the scene with a variation that also had two rotating nosepieces and multiple lenses of differing magnification. Though the microscope was sturdier than earlier microscopes, it did not improve the poor quality of the magnified images. The blurry and distorted images were the result of the types of glass used to make the lenses and the defects in the lens grinding process.[27]

During the 1800's, many advances were made with lenses used in light microscopes that improved image quality. Several people produced instruments to measure the quality of lenses. During this century, microscopes improved dramatically with each new model and manufacturers competed fiercely. Because of the improved technology, Theodore Schwann (1810-1882), a Prussian physiologist, was able to study plant and animal tissues. Schwann was able to identify the cell as the basic unit of life.[29]

Other discoveries were made in the 1800's relevant to the improvement of microscopes and microscopic images. In 1836, J.B. Reade took the first primitive photomicrographs, a picture taken through a microscope, with a solar microscope. A solar microscope is a type of microscope that uses the sun as a light source.[30]

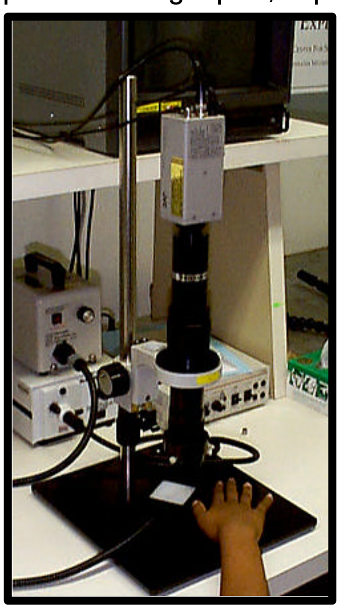

Figure 10. Infinivar High Depth of Field Optical Microscope used today[32]

At the end of the 1800's, August Kohler and Moritz van Rohr designed the ultraviolet microscope which demonstrated how short-wavelength light could improve the resolution (the ability to see smaller objects) of a microscope.[30] The ultraviolet microscope was a forerunner to the ultraviolet fluorescence microscope of today. Ultra-violet wavelengths make different chemicals glow in the dark. Tagging a specimen with fluorescent dye and putting it under this type of microscope allows the specimen to be illuminated. This technique substitutes the special eyepieces needed in the early optical microscopes.[31] Among other things, this microscope allows the observation of different molecules within cells.

The ultraviolet microscope was an improvement in microscopy but still did not allow the observation of things smaller than 0.5 microns (1/100 the size of a hair). This obstacle was overcome in the 20th century with the development of the Transmission Electron Microscope (TEM) and the Scanning Probe Microscope (SPM).

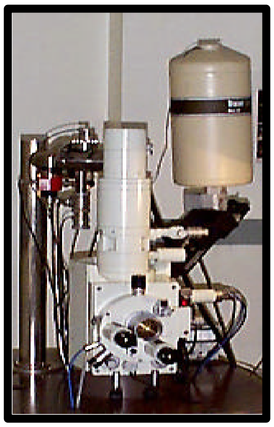

Figure 11. JSM-840 Scanning Electron Microscope [36]

The Electron Microscope

In 1897, an English physicist, J.J. Thompson, discovered the electron. In 1924, a French physicist, Louis de Broglie found that electrons could behave in a wave-motion like light does. The length of this electron wave was determined to be much smaller than the wavelength of light. This means that by using an electron beam, instead of a light beam, it might be possible to view those objects smaller than the wavelength of light.[33] These important discoveries ushered in the next technological breakthrough in microscopes: the Transmission Electron Microscope or TEM and Scanning Electron Microscopes or SEM (see figure 11).

In 1931 a young Russian Ph.D. student, Max Ruska, produced the first electron microscope that could see an object that was 50 nanometers in size! If we return to the hair example, this would be 1/100 the width of the average human hair. This microscope was 4 times more powerful than a light microscope. Ruska (see Figure 12)[35] was awarded the Nobel Prize in Physics for this achievement in 1986.

Figure 12.
Max Ruska[34]

With an optical microscope, light bounces off an object and produces an image. Once lens-manufacturing technology improved and ultraviolet microscopes took advantage of short wavelength light to increase resolution, microscopists had finally come close to the limits of resolution possible for optical microscopes. With the electron microscope (instead of light bouncing off an object and producing an image) electrons were focused on a very thin specimen (100 nanometers in thickness or 1/10,000 of a millimeter). These electrons were focused in a vacuum so they would not bounce off molecules of air. Electron microscope technology improved over the next 30 years. Modern electron microscopes can achieve a resolution of 0.2 nanometers. This is one thousand times better than the resolution of the light microscope. The transmission electron microscope was an incredible advancement, but the need for a specimen to be very thin made it difficult to examine surfaces and to be able to study the 3-dimensional relationships within a specimen. The limit of the TEM created a need for another type of microscope: the Scanning Electron Microscope or SEM.[37]

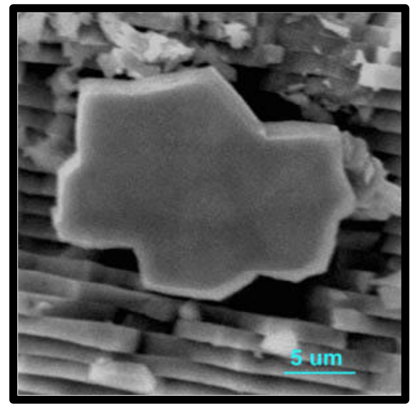

Figure 13. Structure of Mother of Pearl shell, imaged by the scanning electron microscope.[39]

With the SEM, the electrons are reflected from a specimen instead of passing through. The specimen is coated in a metallic conductor such as gold to produce an image (see Figure 13). Max Knoll first developed the scanning principle in 1935 while working for a company called Telefunken at the Department of Television. The SEM was developed by Dennis McMullan, a Ph.D. student in England, under the supervision of an engineer, Charles Outlay, in 1948.[38]

Improvements in electron microscopy continue today, allowing a better vision of the microstructure of biological and non-biological specimens and creating new forms of the microscope. Even so, the electron microscope has its constraints and this gave rise to a need for a new type of microscope technology: the Scanning Probe Microscopes or SPM.

The Scanning Probe Microscopes

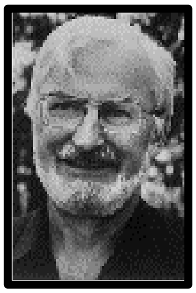

Figure 14. Heinrich Rohrer[41]

The next step in microscopy came in 1982 with the development of Scanning Tunneling Microscopy (STM) by two Swiss Scientists, Heinrich Rohrer and Gerd Binnig. For this achievement they were awarded the Nobel Prize in Physics in 1986 (see Figures 14 and 15).[40] They developed a microscope that probes the surface of specimens instead of looking through them.

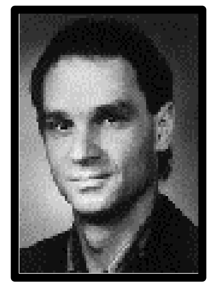

Figure 15. Gerd Binnig[42]

The probe has a tip that is 1 atom in thickness and moves up and down over the surface of an object. The probe scans the object producing image information of a small area of the object. The STM requires an electrically conductive sample because the tip itself carries a small voltage. When it comes near the surface of the sample, a small current will flow between the sample and the tip. The current changes with the height of the sample and an image is produced based on this change. The limits in STM, mainly the need for an electrically conductive sample, created a need for another type of microscope: the Atomic Force Microscope or the AFM.[43]

Figure 16. Atomic Force Microscope[44]

The AFM (see Figure 16) was developed in 1985 with components of the STM by Binnig, Quate and Gerber and works in a similar fashion to the STM. Instead of reading the change in current to produce an image, the probe of the AFM moves over the surface of the sample and reads the repulsive force between the sample and the probe tip (see Figure 17). As with the STM, there is not much space between the probe tip and sample surface. The AFM can be used to look at non-conductive samples like bacteria, viruses, and cells (see image 18) as well as samples such as CDs and computer chips.[45]

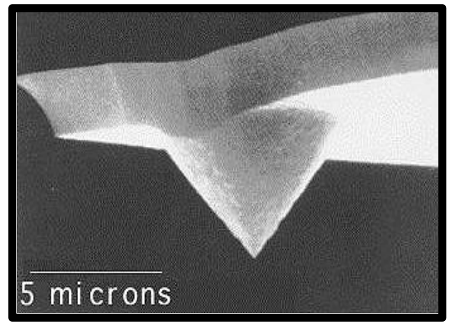

Figure 17. Probe tip of the AFM[46]

Since STM and AFM are still fairly young, the possibilities for the use of these microscopes are still in development. Even so, STM and AFM technology have opened the door to an entirely new area of science called nanotechnology. The computer industry uses these microscopes to produce smaller and smaller electrical circuits and to control the quality of products that they are making.[47] Probes are also used to write on circuit boards. This is called nanolithography. Scientists are also using these microscopes to learn more about DNA.

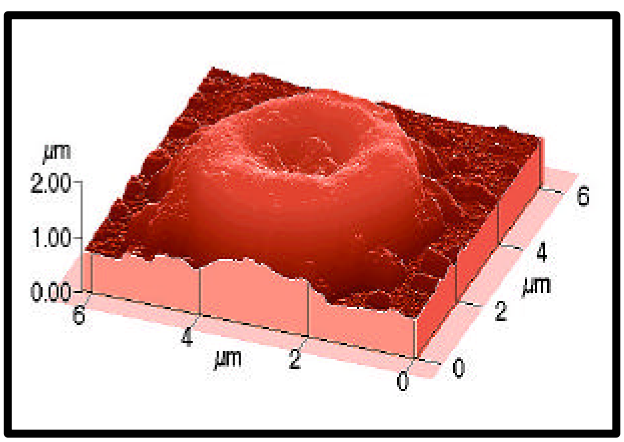

Image 18. Red Blood Cell image taken with the AFM.[48]

Conclusion

The microscope evolved over the past 500 years branching into different directions, all with the same purpose, to enable the exploration of the microworld and nanoworld. From the earliest Janssen microscope to the Electron and Scanning Probe microscopes of today, microscopy has revolutionized the world we live in, allowing us to see a part of the world that our eyes alone cannot. The possibilities for the use of microscopes are beyond our wildest dreams and many more microscopes exist today than could be discussed in this historical account. The Phoenicians making glass on a beach 3000 years ago probably had no idea of what was to come!

Acknowledgements

I would like to thank the following people for their assistance in preparing this history: Leanne Bosson, Laurie Luckenbill and Lorna Stulen-Glaunsinger.

Footnotes

1. Ford, Brian J. (1992), p166.
2. Burgess, et al. (1990), p 186.
3. Klein. (1980), p24.
4. Klein. (1980), p14.
5. Corning Museum of Glass
6. Clay Tablet from the Corning Museum of Glass
7. Corning Museum of Glass
8. Roman Cage Cup from the Corning Museum of Glass
9. Clay and Court. (1975), p4.
10. Clay and Court. (1975), p5.
11. Picture of Roger Bacon from Compton's Encyclopedia On-line
12. Jones, Chapter 1.
13. Burgess, et al. (1990), p187.
14. Klein. (1980), p23-24.
15. Comptom's Encyclopedia On-Line
16. Jones, Chapter 2.
17. Picture of what is thought to be a Janssen microscope from Jones, Chapter 2.
18. Ruestow. (1996), p7.
19. Burgess, et al. (1990), p186.
20. Picture of Hooke's microscope from Fournier. (1996), p17.

21. Burgess, et al. (19990), p186.
22. Picture of Antoni van Leeuwenhoek from Antoni van Leeuwenhoek, UC Berkeley.
23. Antoni van Leeuwenhoek, UC Berkeley.
24. Picture of Antoni van Leeuwenhoek's microscope from Antoni van Leeuwenhoek, UC Berkeley.
25. Burgess, et al. (1990), p186.
26. Clay and Court. (1975), p140.
27. Burgess, et al. (1990), p187.
28. Jones, Chapter 4.
29. Burgess, et al. (1990), p188.
30. Ford. (1973), p108.
31. Burgess, et al. (1990), p188.
32. WISE image taken by Lillian Owen at ASU Optical Microscopy Lab, thanks Dr. Michael McKelvy.
33. Burgess, et al. (1990), p189.
34. Picture of Max Ruska from The Nobel Prize Internet Archive.
35. Press Release: 1986 Nobel Prize in Physics.
36. WISE image taken by Lillian Owen at ASU Electron Microscopy Lab, thanks Dr. Michael McKelvy.
37. Burgess, et al. (1990), p189-190.
38. Burgess, et al. (1990), p189-190.
39. Mother of Pearl image taken by Velavan Varadarajan, courtesey of Dr. B.L. Ramakrishna.
40. Press Release: 1986 Nobel Prize in Physics.
41. Picture of Rohrer from 1986 Nobel Prize in Physics web site.
42. Picture of Binnig from 1986 Nobel Prize in Physics web site.
43. Martin. (1996).
44. WISE picture taken by Lillian Owen at ASU IN-VSEE Lab, thanks Dr. Ed Ong.
45. Martin. (1996).
46. AFM probe tip image taken by Dr. Ed Ong at ASU, courtesy of Dr. Ed Ong.
47. Wickramasinghe. (1989).
48. Red Blood Cell Image courtesy of Dr. B.L. Ramakrishna.

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