Scanning Electron Microscopy

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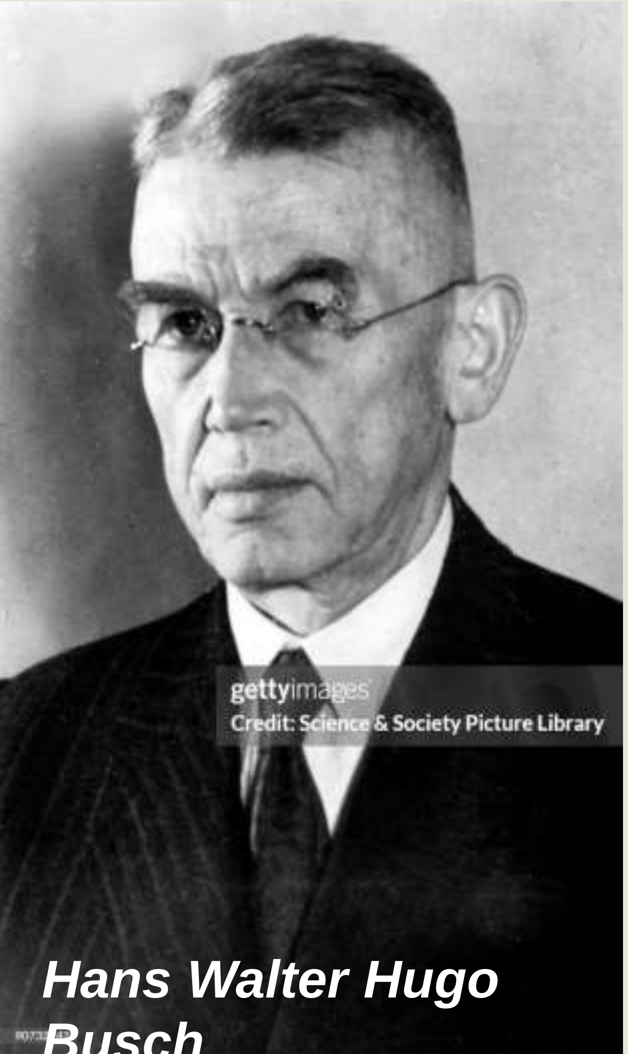
2023UMT0169

Timeline of Electron Microscopy Development

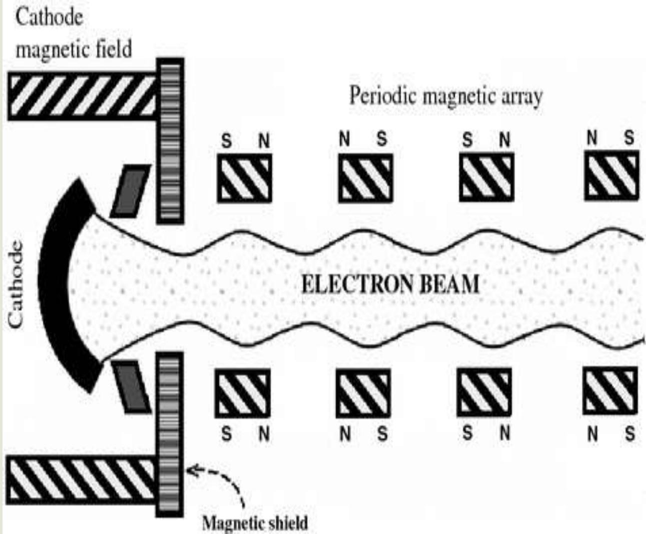
- 1920s – Scientists explore electron beams for imaging. De Broglie's wave hypothesis
- 1926 – Hans Busch demonstrates that magnetic fields can focus electron beams.
- 1931 – Ernst Ruska and Max Knoll build the first Transmission Electron Microscope
- 1935 – Max Knoll conceptualizes Scanning Electron Microscopy (SEM).
- 1937 – Manfred von Ardenne constructs the first experimental SEM.
- 1942 – Manfred von Ardenne builds the first practical SEM with scanning capabilities.
- 1950s-1960s – Charles Oatley and colleagues at Cambridge University improve SEM technology.
- 1965 – Cambridge Instruments releases the first commercial SEM.
- 1970s-1980s – Advancements in detectors and computing enhance SEM imaging.
- 2000s-Present – Development of high-resolution and environmental SEMs.

Beginning concepts of Electron Microscopy

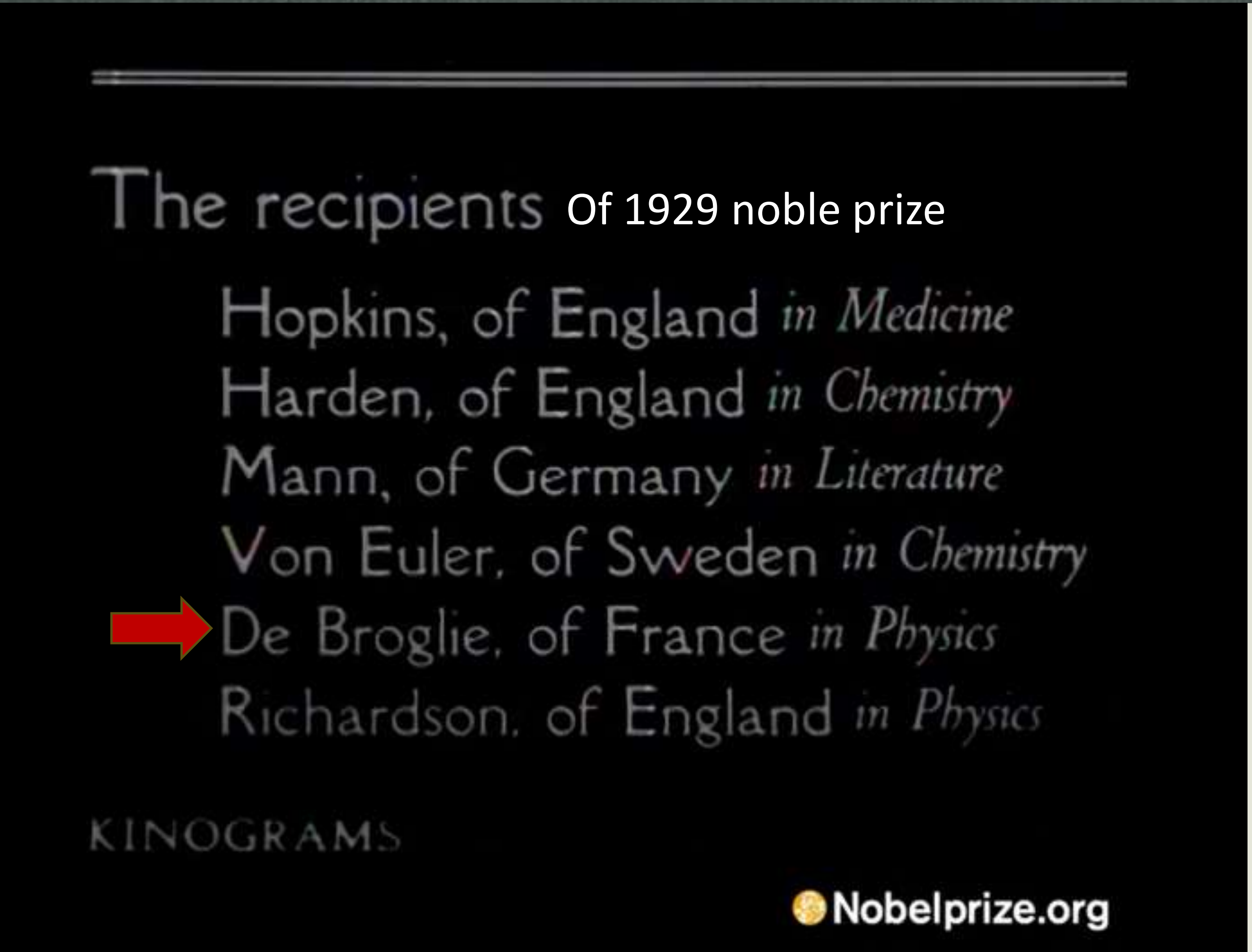


Hans Walter Hugo Busch

- 1920s: Scientists explored electron beams for imaging
- 1928: German physicist Hans Busch showed electron beams could be focused using magnetic fields.
- **This laid the foundation for Electron Microscopy**



1920s : Louis de Broglie's Wave Hypothesis (1924)
The Noble Prize In 1929



- He has been awarded with noble prize **"For his discovery of the wave nature of electrons."**
- He proposed that electrons have wave-like properties, which suggested that electron beams could be used for imaging with much higher resolution than light microscopes.


de broglie

1926 – Hans Busch demonstrates that magnetic fields can focus electron beams.

- **Magnetic Lens Principle**: Hans Busch demonstrated that magnetic fields a solenoid is able to focus an electron beam and can act as lenses to focus electron beams, similar to how optical lenses focus light.
- **Foundation for Electron Microscopy**: His work provided the theoretical basis for electron microscopes, enabling much higher resolution imaging than optical microscopes by using electron beams.
- **Broad Applications**: The principles of electron beam focusing are applied in technologies like electron microscopes, cathode ray tubes (CRTs), and particle accelerators.

This laid down the foundation for Electron microscopy.

1931 – Ernst Ruska and Max Knoll build the first Transmission Electron Microscope

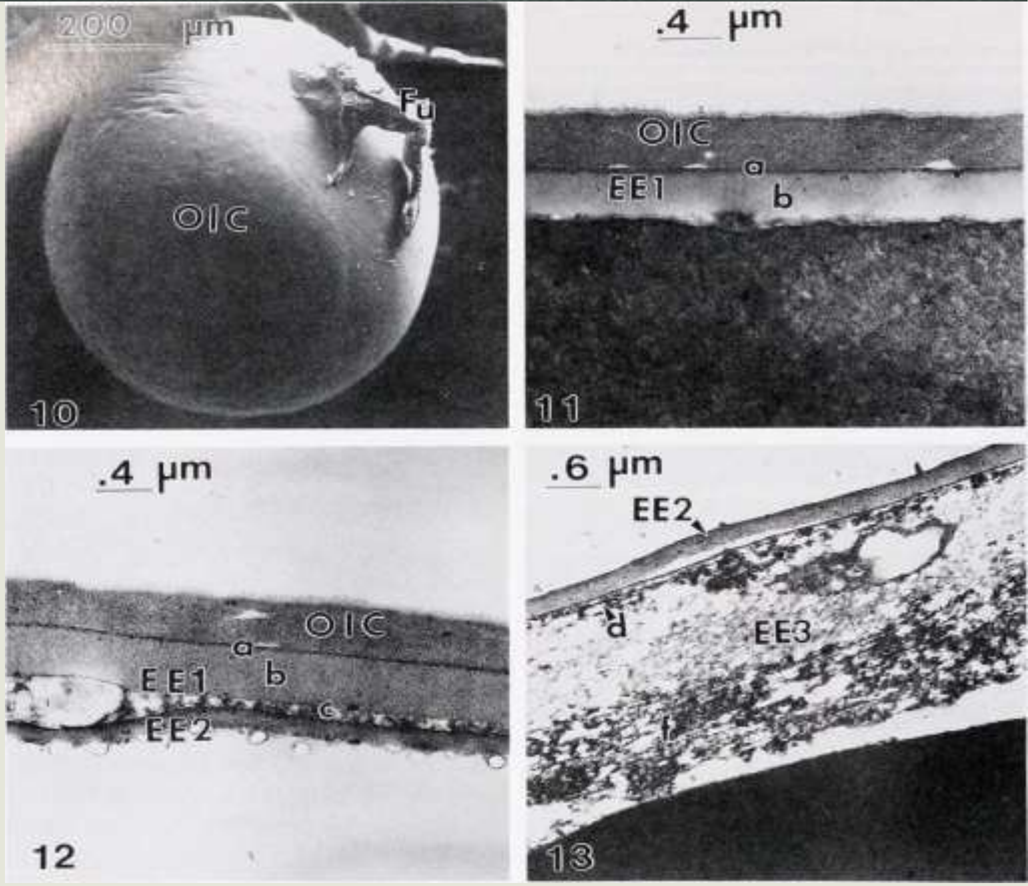
- **First TEM in 1931**: Ernst Ruska and Max Knoll built the first **Transmission Electron Microscope (TEM)**, using electron beams instead of light for imaging.
- **Higher Resolution**: The TEM overcame the limitations of optical microscopes, enabling much greater magnification and the ability to observe atomic-scale structures although during the starting the magnification of tem was 400x but within few years it surpassed light microscope(~1000x - ~2000x)
- **Revolutionized Science**: Their invention transformed fields like biology, materials science, and nanotechnology, earning Ruska the **Nobel**

The electron microscope built by Ruska and Knoll in Berlin in the early 1930s.

Immediate changes and advancements occurred across the field of materials after the invention of TEM :

- **Discovery of Atomic Structures** – Enabled detailed study of metals, crystals, and materials at the atomic level.
- **Advancements in Semiconductors** – Improved transistor research, leading to the electronics revolution.
- **Military & Industrial Impact** – Enhanced metallurgy, weapon development, and aircraft material testing.

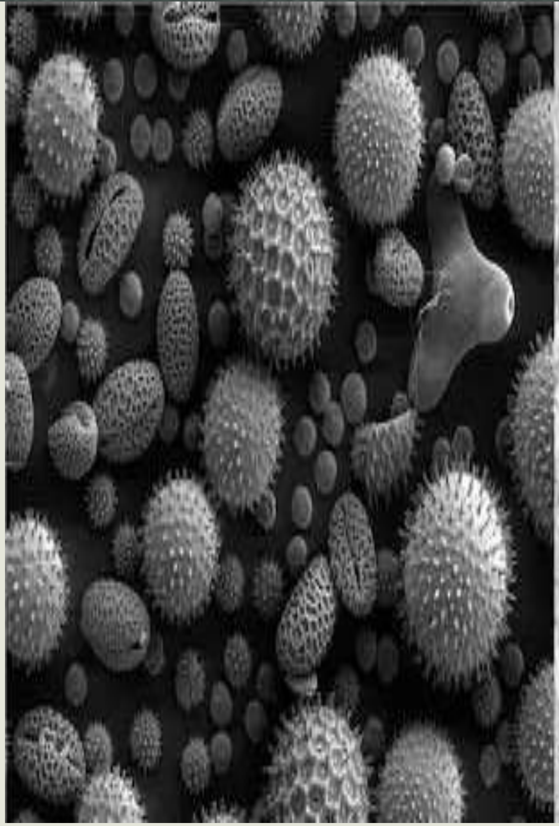
And also there many advancements occurred across different scientific fields (Improved Resolution & Discovery of Cell Structures)-biological research field.



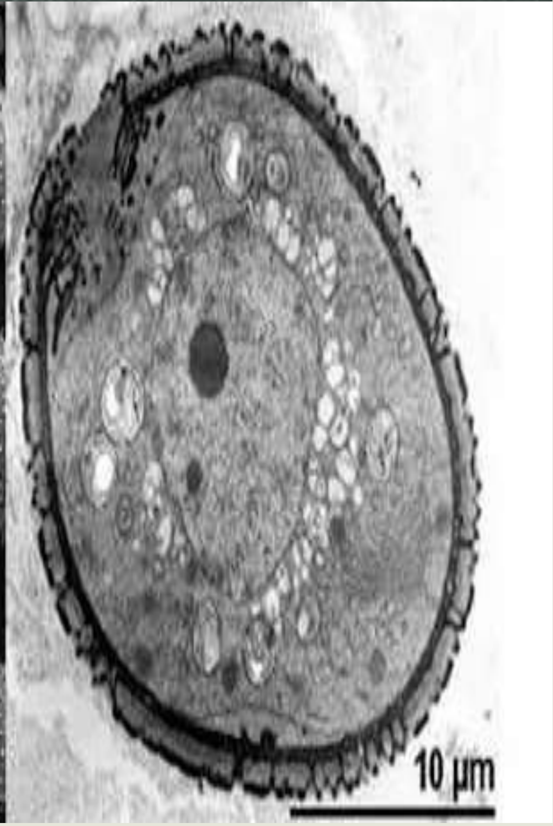
Transmission electron micrograph images of Palaemonetespugio (grass shrimp) embryos showing the development of an embryonic coat, from 1933.

Why TEM Needed an Upgrade: The Push for a New Microscopy

- **Thin Samples Only**: TEM required ultra-thin samples, which were difficult to prepare and often damaged the material, **demanding a new microscopy** for bulk sample imaging**.**
- **No Surface Details**: TEM couldn't capture surface features, **necessitating a new microscopy** for detailed 3D surface imaging**.**
- **Limited Field of View**: TEM's small field of view made it hard to study large areas, **calling for a new microscopy** with wider imaging capabilities.
- **Complex Preparation**: TEM's lengthy sample preparation process slowed research, **requiring a new microscopy** to simplify and speed up imaging.



Pollen grain under SEM

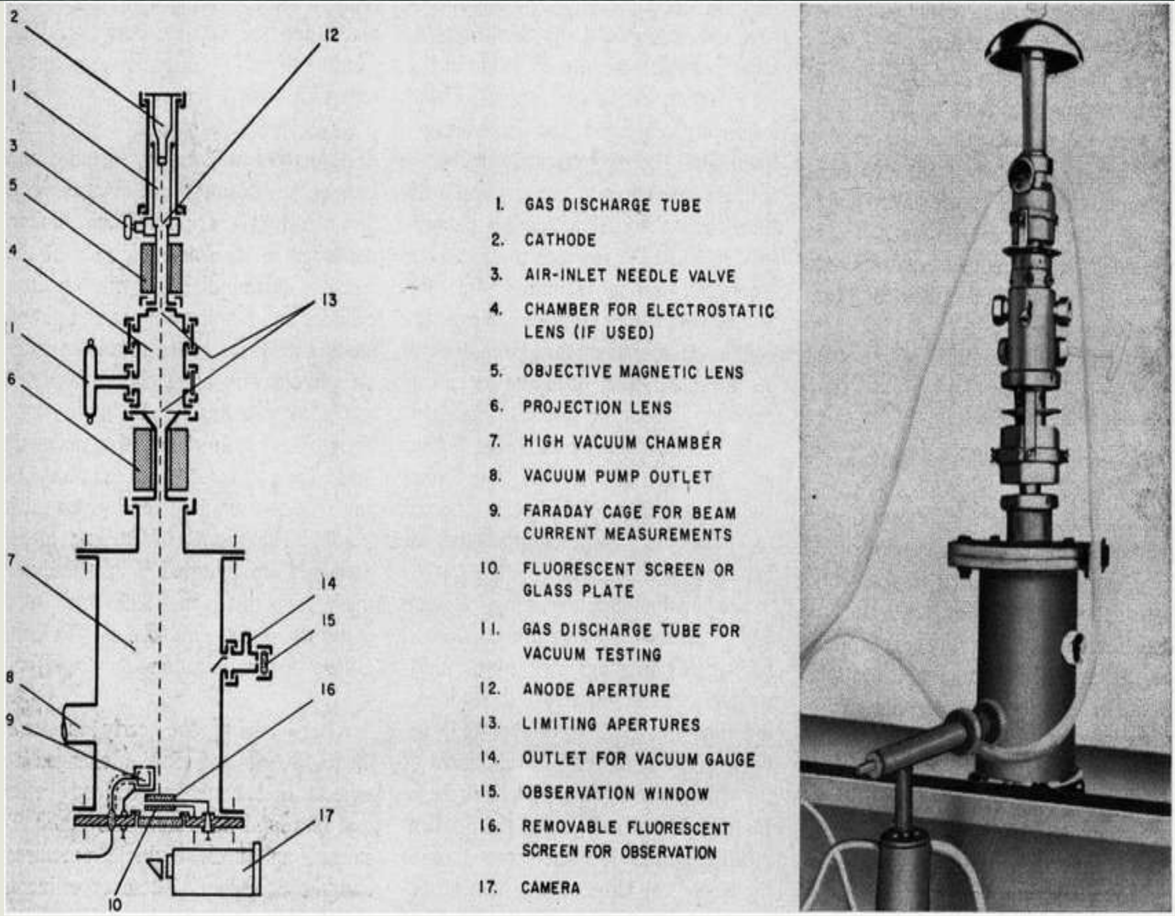


Pollen grain under TEM

These limations of TEM led to the invention of **SEM**

1935 – Max Knoll conceptualizes Scanning Electron Microscopy (SEM).

- **Conceptualization**: In 1935, Max Knoll proposed the idea of the **Scanning Electron Microscope (SEM)**, which uses a focused electron beam to scan and image samples at high resolution.
- **Advantages**: SEM offers significantly higher magnification and detailed 3D surface imaging compared to optical microscopes, enabling nanoscale analysis.
- **Inspiration for Research**: Knoll's work inspired advancements in **electron optics** and led to early experiments, such as Manfred von Ardenne's 1937 scanning transmission electron microscope (STEM), proving the feasibility of electron beam scanning



The first electron microscope demonstrated by Max Knoll and Ernst Ruska in 1931

Manfred von Ardenne constructs the first experimental SEM

- **First Practical SEM Experiment (1937)**:
  Manfred von Ardenne conducted the **first experimental SEM** by modifying a transmission electron microscope (TEM) to include **scanning coils** and a **detector**, enabling the electron beam to scan a sample's surface and capture secondary electrons.

- **Proof of Concept**:
  His experiment successfully produced **scanning electron images**, proving the feasibility of SEM for **surface imaging**, though the resolution was limited by the technology of the time.

- These technical limitations meant that von Ardenne's SEM had **low resolution**, **poor image quality**, and **limited practicality** at the time.

Cross section of the column of von Ardenne's (1938)

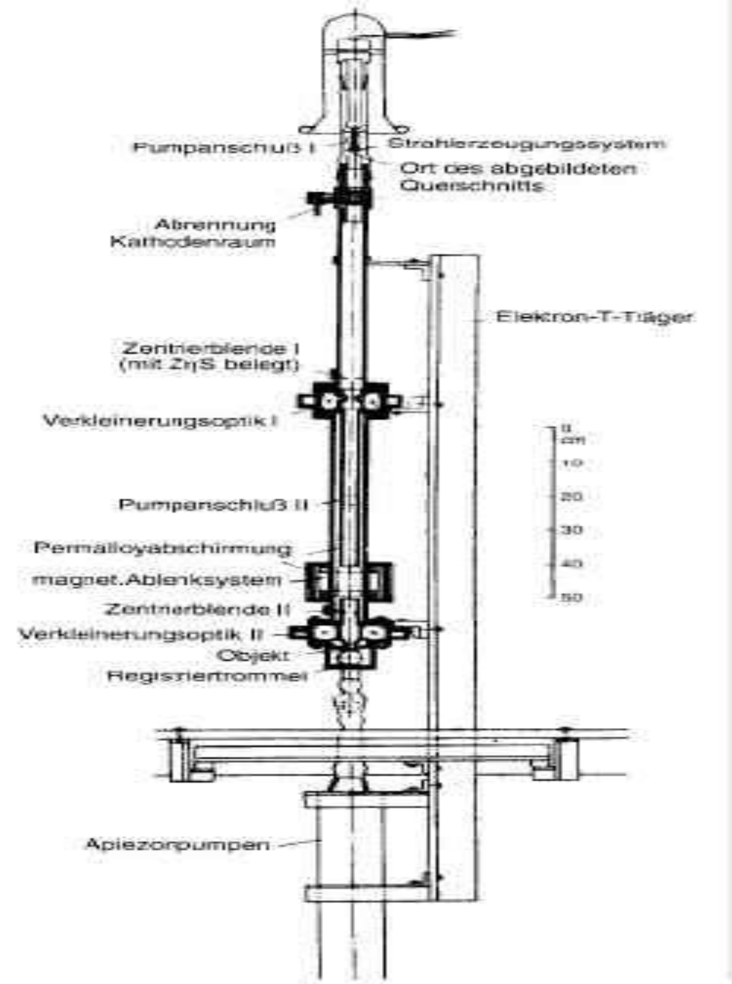
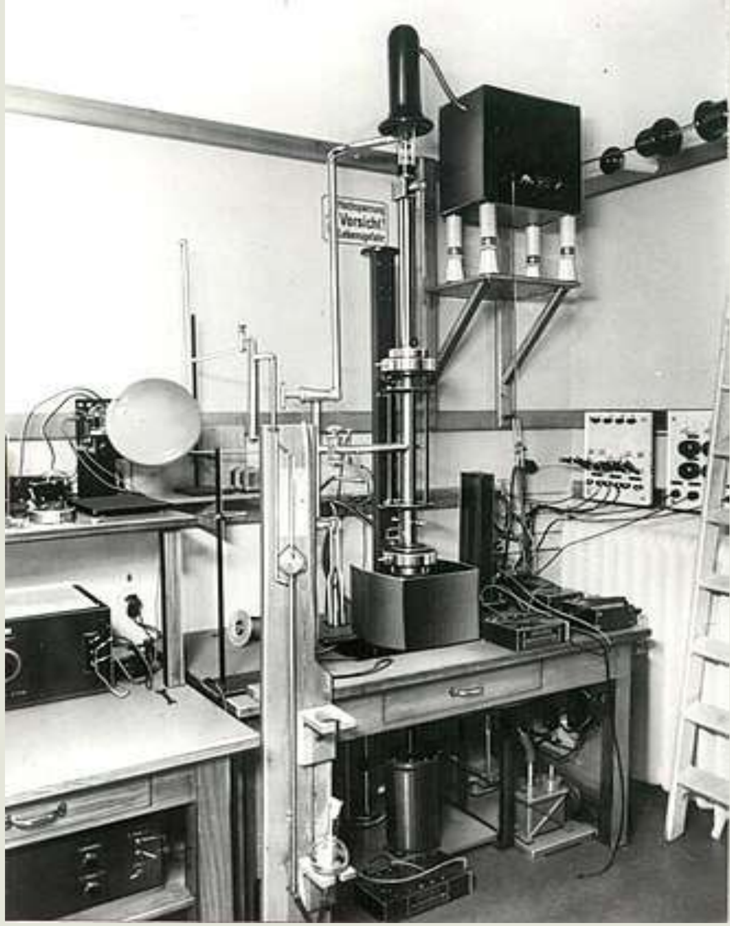


Fig. 4 Cross section of the column of von Ardenne's (1938b) STEM

1942 – Manfred von Ardenne builds the first practical SEM with scanning capabilities

- **Advanced Scanning Mechanism**: The 1942 SEM introduced **scanning coils** to systematically move the electron beam in a **raster pattern**, enabling precise and controlled scanning of the sample surface—a major improvement over the rudimentary beam control in the 1937 experiment.
- **Enhanced Image Quality**: With **better detectors** and **improved vacuum systems**, the 1942 SEM achieved **higher resolution** and clearer images compared to the low-quality output of the 1937 prototype.

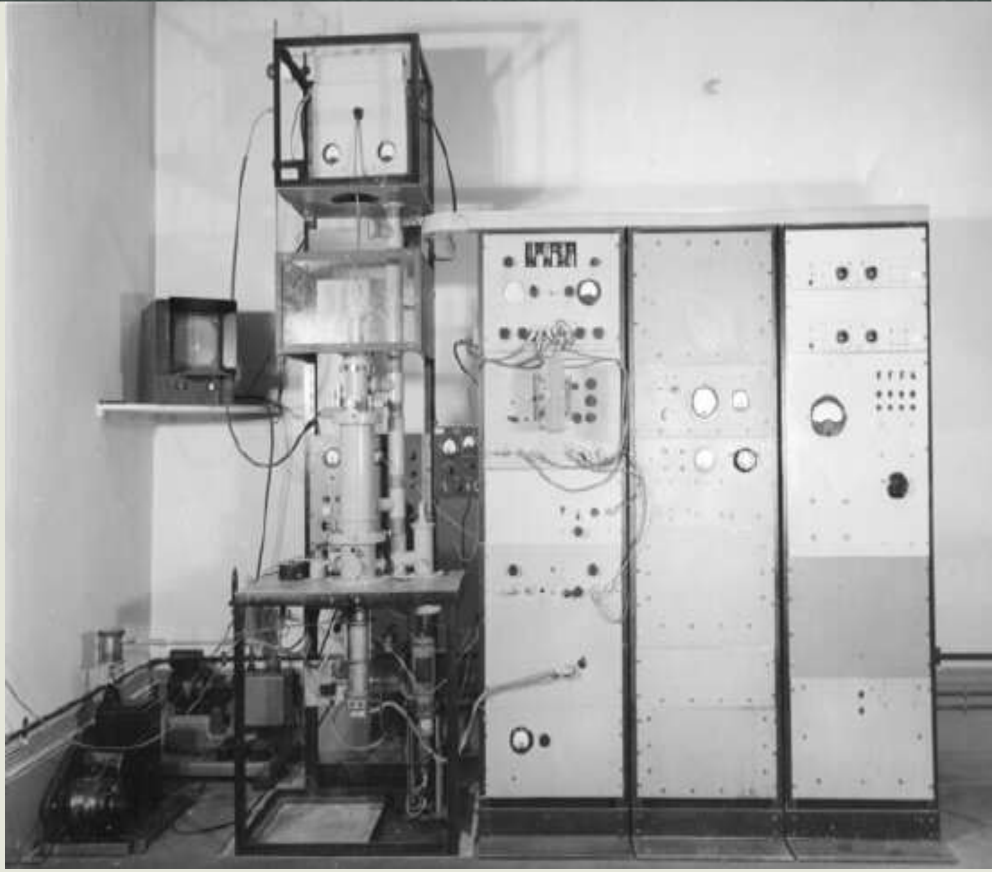
3. **Transition to Practical Use**: The 1942 SEM evolved from a **theoretical demonstration** (1937) into a **functional instrument** capable of producing usable images, marking a critical step toward its application in scientific research.



The first SEM by von Ardenne in 1942

1950s-1960s – Charles Oatley and colleagues at Cambridge University improve SEM technology.

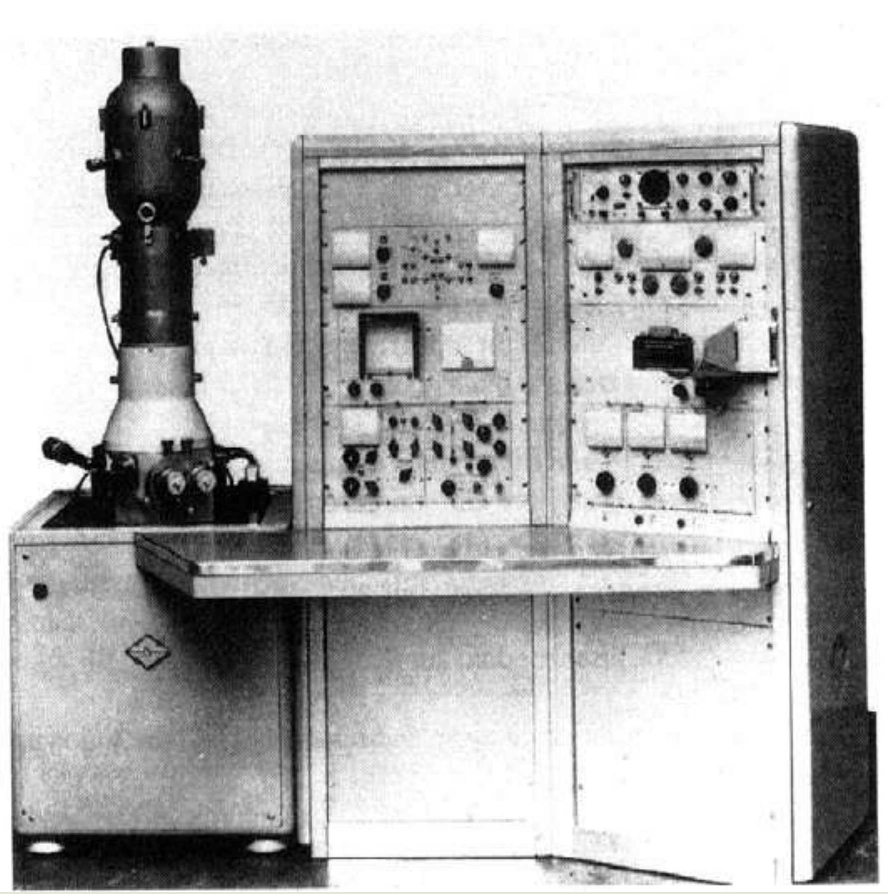
- **Key Advancements**: In the 1950s-1960s, Charles Oatley and his team at Cambridge University improved SEM technology by enhancing **electron detection**, **electron optics**, and **vacuum systems**, leading to higher-resolution and more stable imaging.
- **Development of Practical SEMs**: During this period, Oatley's group built advanced SEM prototypes, refining the technology and demonstrating its practicality for scientific research, paving the way for the first commercial SEM in 1965.
- **Scientific and Industrial Impact**: Their work made SEM a powerful tool for **surface imaging** and **microstructural analysis**, revolutionizing fields like **materials science**, **biology**



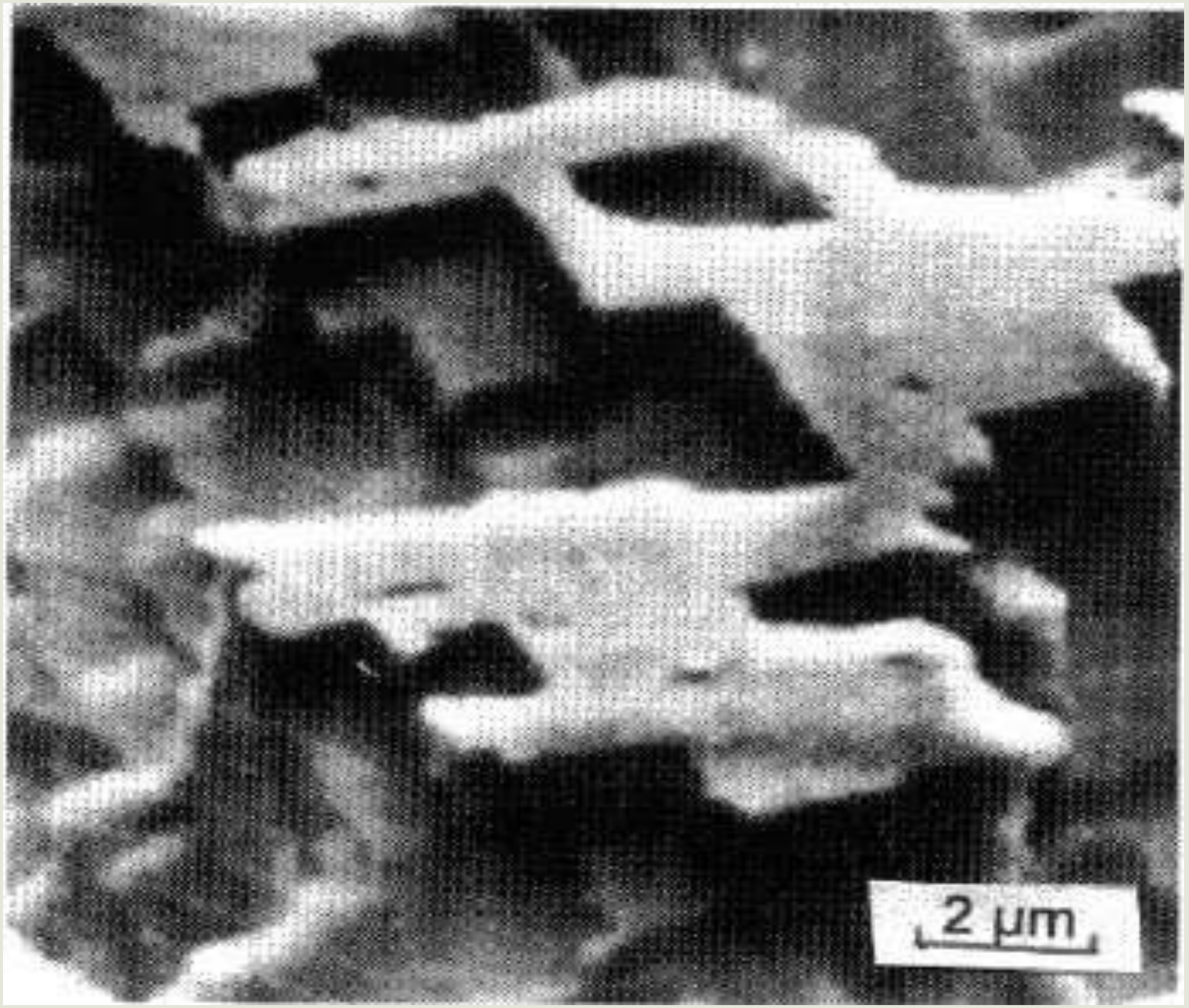
The photogragh of 1st SEM in 1953 at Cambridge

1965 – Cambridge Instruments releases the first commercial SEM.

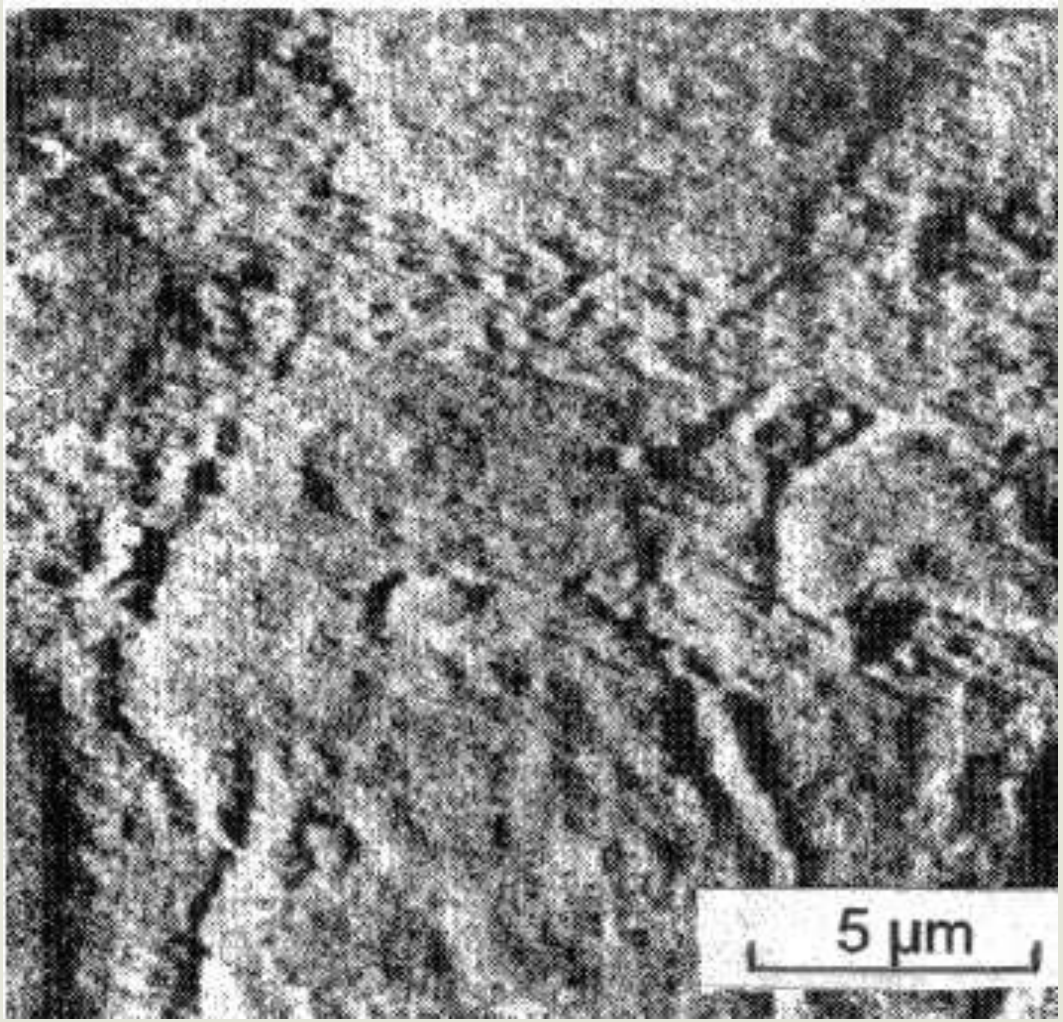
- **First Commercial SEM (1965)**: Cambridge Instruments released the **Stereoscan**, the first commercial SEM, offering **high-resolution, 3D surface imaging** and making the technology accessible to researchers and industries
- **Transformative Applications**: The Stereoscan enabled groundbreaking research in **materials science**, **biology**, and **geology**, while industries adopted it for **quality control**, **failure analysis**, and **materials characterization**, transforming both scientific and industrial practices.
- **Legacy of Innovation**: The Stereoscan's success spurred further advancements in SEM technology, paving the way for tools like **EDS**, **ESEM**, and **FIB-SEM**, and establishing SEM as a cornerstone of modern microscopy



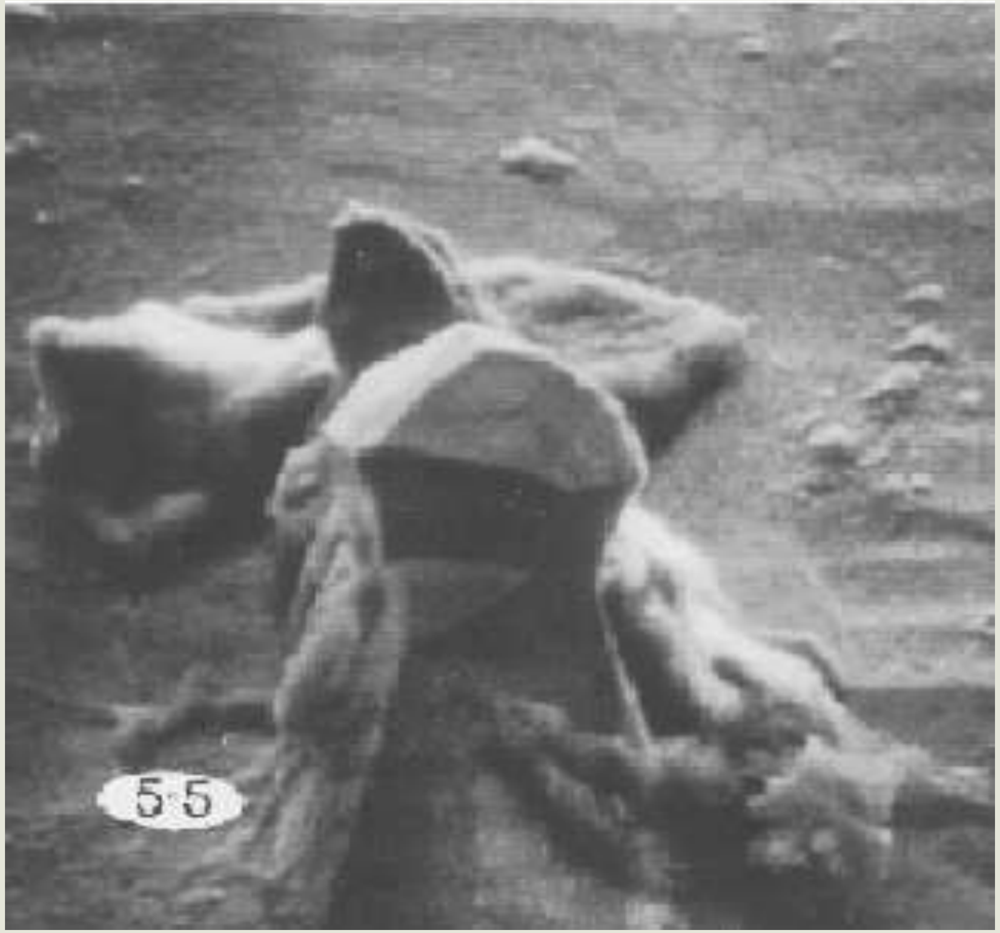
Cambridge Instrument Company: prototype of the first Stereoscan SEM, 1965



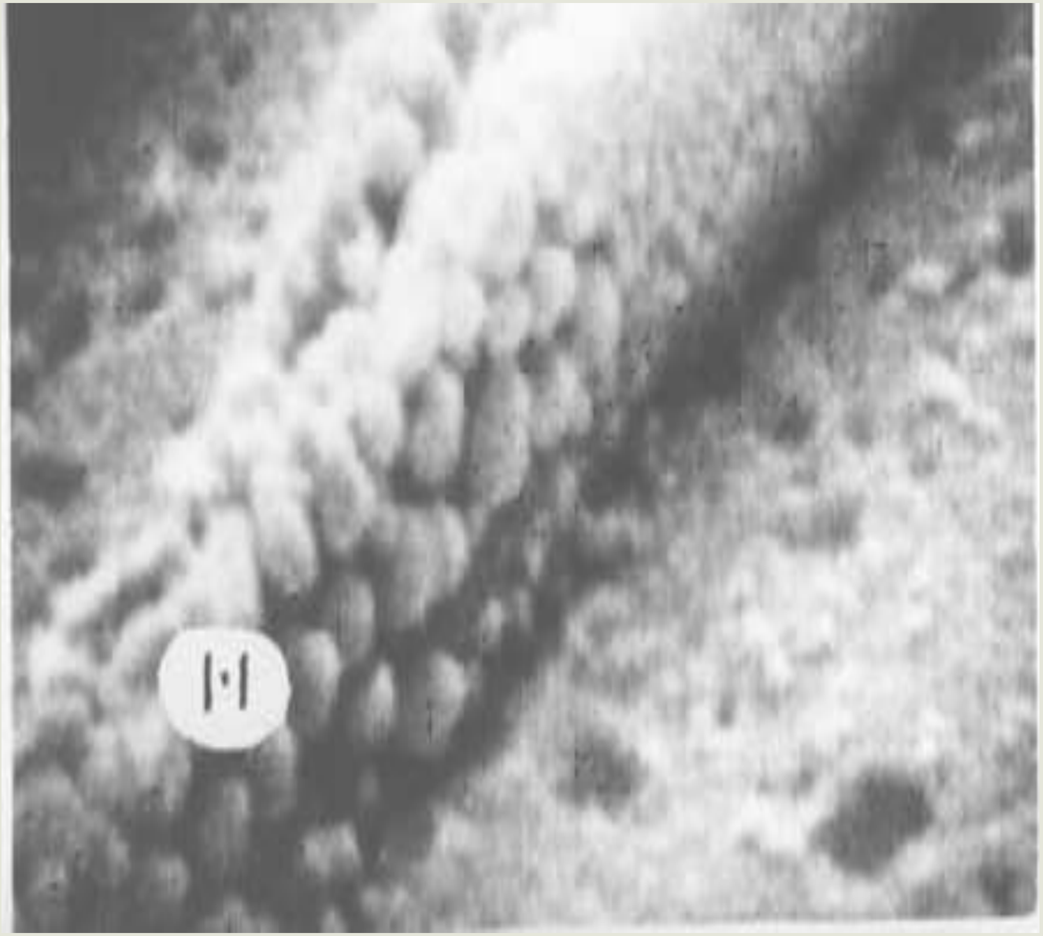
Cambridge SEM 1: First micrograph of etched aluminium



Micrograph of etched brass produced by the SEM



SEM1: a feature on the etched surface of a zone-grown single crystal of germanium



SEM1: micrograph of a partly decomposed needle Fig. 8. SEM1: micrograph of a portion of an intact of silver azide.

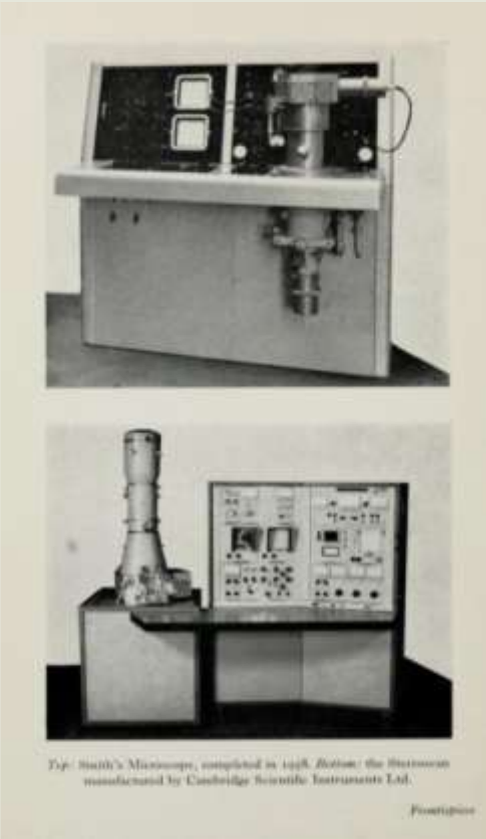
1970s-1980s – Advancements in detectors and computing enhance SEM imaging.

- **Enhanced Detectors**: Advancements in **secondary electron detectors (SED)**, **backscattered electron detectors (BSED)**, and **energy-dispersive X-ray spectroscopy (EDS)** improved image quality, enabled compositional contrast, and allowed for chemical analysis.

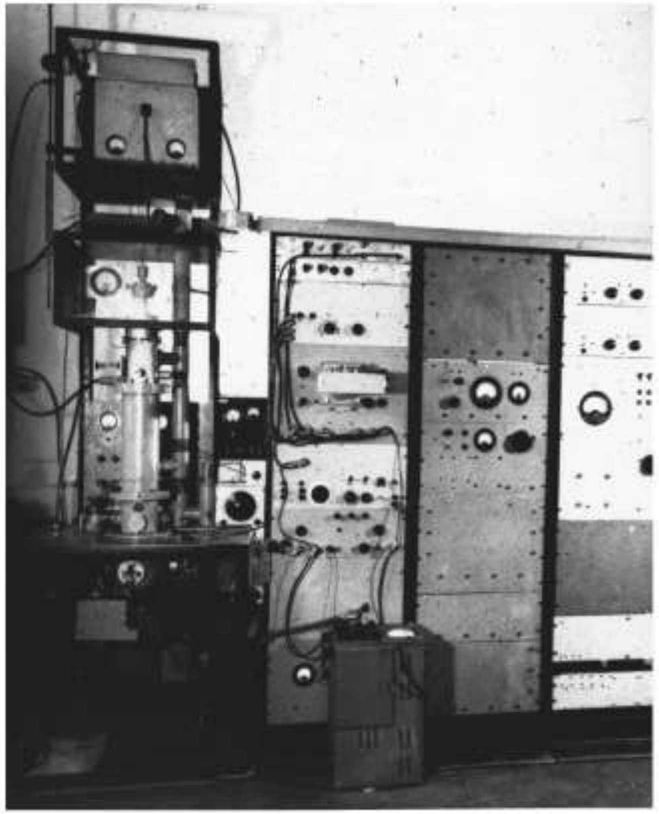
- **Computing and Digital Imaging**: The integration of **computers** brought **digital image processing**, **automation**, and **data storage**, making SEMs more efficient, user-friendly, and capable of complex analysis.

- **New Imaging Modes and Applications**: Innovations like **environmental SEM (ESEM)** and **cathodoluminescence (CL)** expanded SEM's use to **wet, non-conductive, and light-emitting samples**, revolutionizing fields of**materials science**.

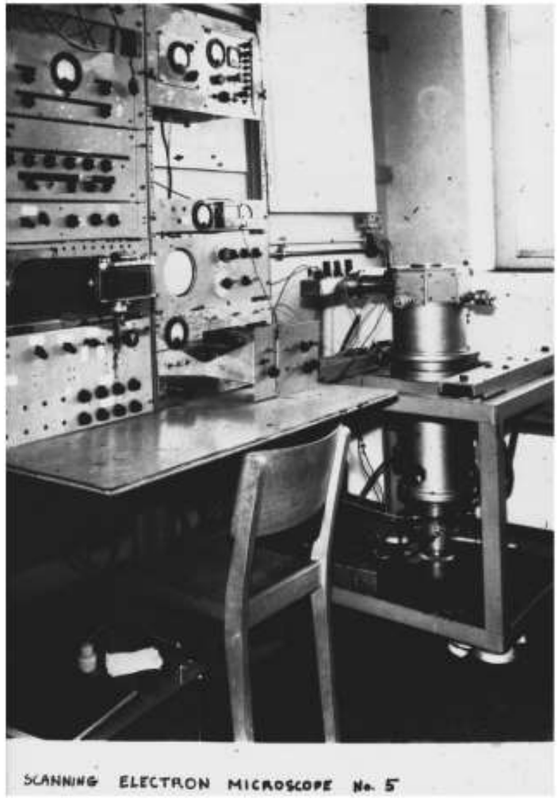
Pictures of early stages of Scanning Electeon microscope



The first SEM in Cambridge university



D. McMullan’s scanning electron microscope, as modified by K. C. A. Smith. Photograph taken about 1955.

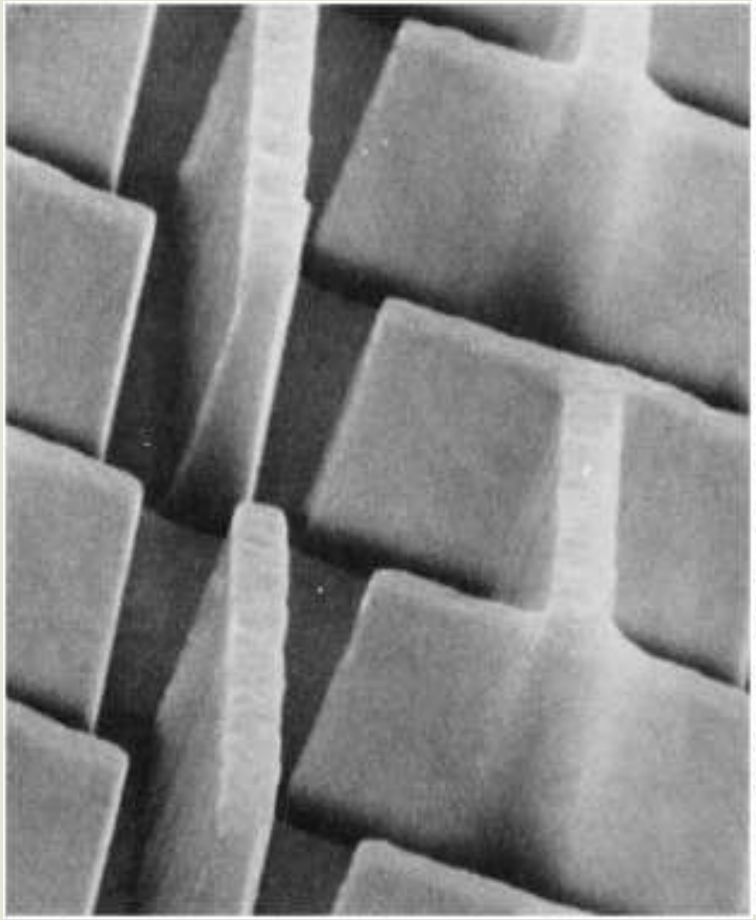


High resolution SEM constructed by R. F. W. Pease. Photograph taken in 1963 by Les Peters

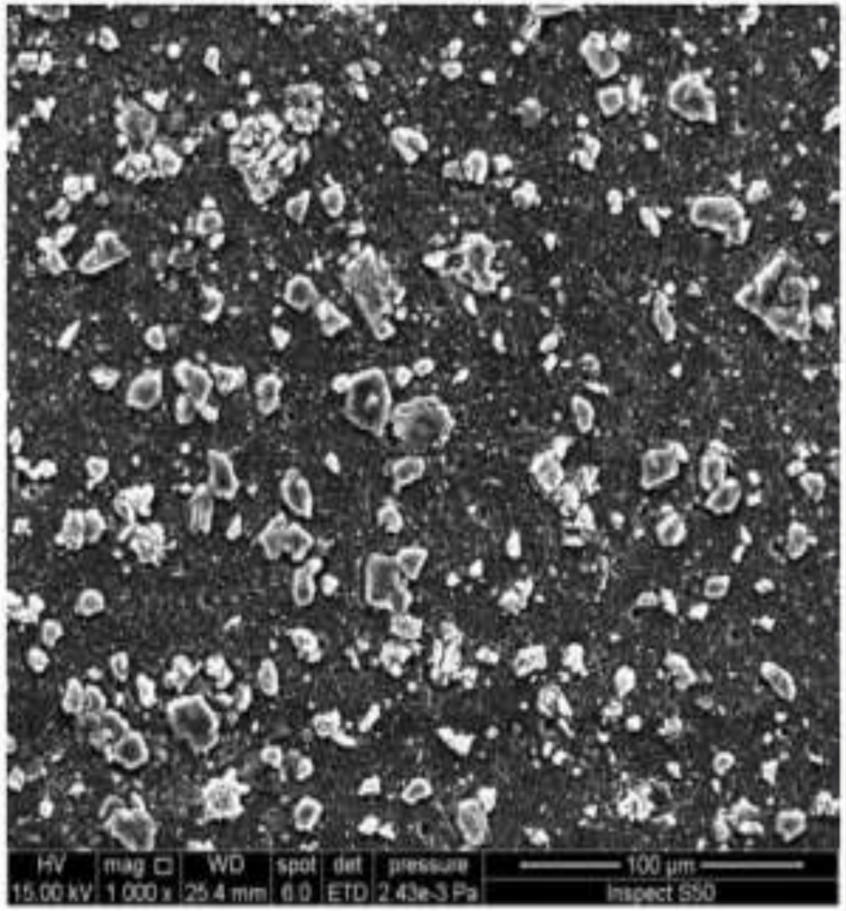
SEM, constructed by Dr. K. C. A. Smith at Cambridge University engineering laboratory about 1957 or 1958.

Major Achievements Using Scanning Electron Microscopy (SEM) Since 1965 in the field of material sciences

- **1965-1980: Early Metallurgy & Industrial Applications** – Improved metal fracture analysis, failure detection in aerospace, and polymer development.
- **1980s-1990s: Semiconductor & Coatings Advancements** – Enhanced microchip quality control, thin-film coatings, and superalloy development for high-performance industries.



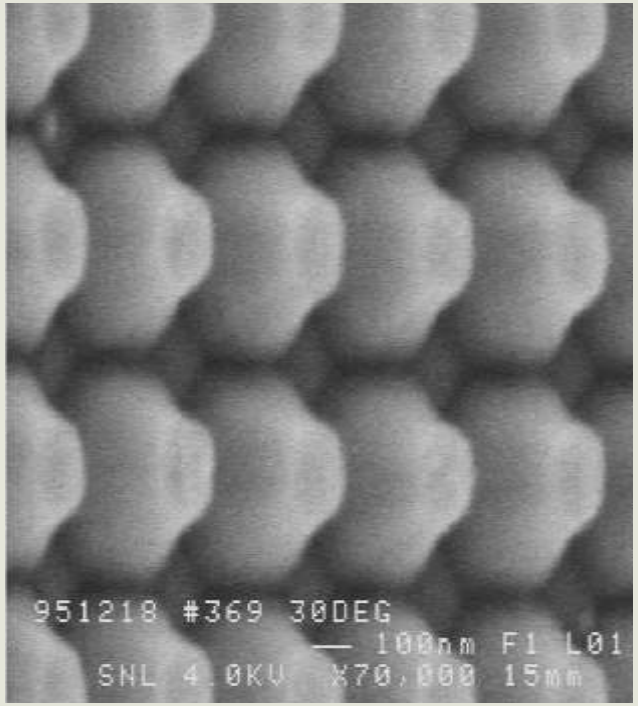
Semi conductors and coatings



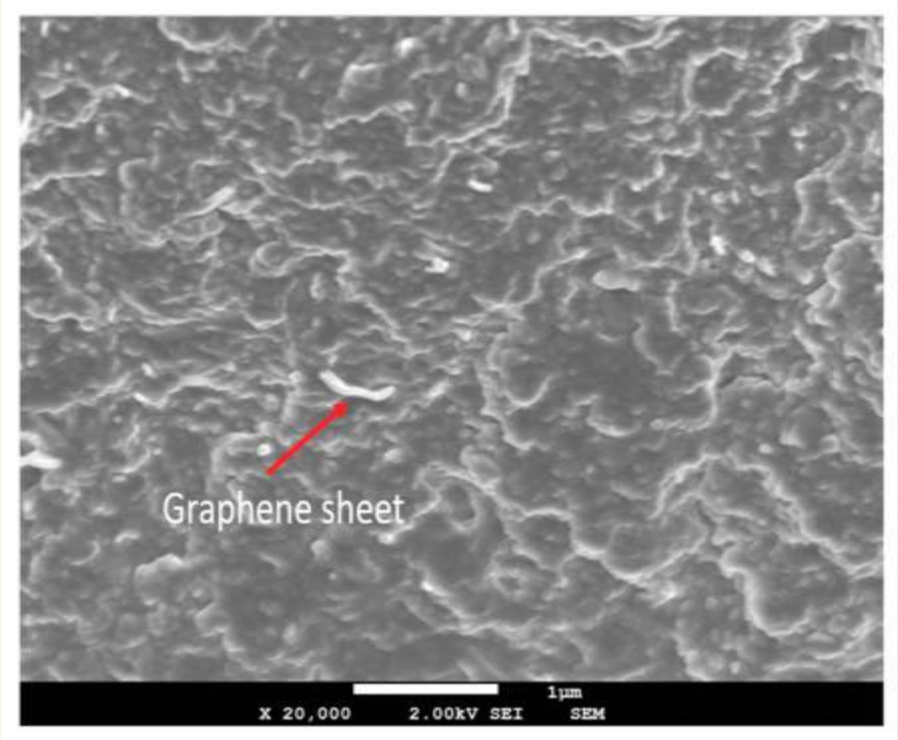
Polymers development

Major Achievements Using Scanning Electron Microscopy

- **2000s: Nanotechnology & Smart Materials** – Enabled graphene discovery, nanomaterial imaging, self-cleaning surfaces, and lightweight composites for aerospace.
- **2010s-Present: Cutting-Edge Innovations** – Advanced battery research, quantum dots for electronics, optimized 3D-printed materials, and space-grade materials.



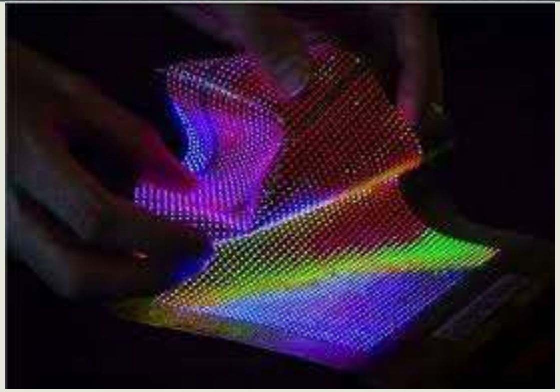
Qauntum Dots under SEM



First Graphene sheet under SEM

Role of SEM in Graphene Research

- **Discovery & Early Studies (2004)** – SEM helped confirm graphene's structure after its isolation by Geim & Novoselov.
- **Structural Analysis** – Used to examine **layer thickness, defects, and morphology** of graphene sheets.
- **Quality Control in Production** – Ensures **purity, uniformity, and defect detection** in industrial-scale graphene synthesis
- **Advanced Applications** – Supports graphene-based **electronics, batteries, coatings, and composites**



THANK YOU

Yours,
Snehith