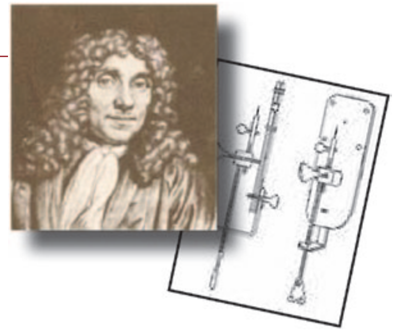


Pioneers in Optics: Joseph von Fraunhofer and Gustav Robert Kirchhoff

Michael W. Davidson
National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL 32306

davidson@magnet.fsu.edu

Joseph von Fraunhofer
(1787–1826)

Joseph von Fraunhofer was the youngest of a poor glass grinder's ten children and was orphaned at the age of 11. He did not receive the luxury of a formal education but was apprenticed to a Munich mirror maker and lens grinder. In 1801, an accident occurred that almost cost von Fraunhofer his life but ultimately worked out to his great benefit. The building that he was working in collapsed and buried him alive for several hours. His dramatic rescue caught the attention of the court prince, as well as Joseph Utzschneider, a politician with an interest in optics. Von Fraunhofer's royal patron bestowed a fair sum of money upon him, which he used to buy himself out of his apprenticeship and to purchase a glass cutting and polishing machine. Utzschneider, however, gave friendship and books to the boy, which fueled his self-education.

Employed at a Munich workshop that made scientific instruments, which was partially owned by Utzschneider, von Fraunhofer continued to develop his skills in optics. During this period, he analyzed lens making, developed new grinding techniques, and invented a polishing machine that rendered lens making more akin to an industrial manufacturing process. Von Fraunhofer also improved the composition of the polishing material and cement used to assemble lenses and introduced the use of an unaltered sheet of glass as a test device to check the shape and concentricity of polished lens surfaces.

Later, at Utzschneider's new glass melting workshop, von Fraunhofer discovered that the quality of glass was a major variable in the process of obtaining perfect optics. Under the tutelage of a Swiss glassmaker, he developed new types of glass suited to making bigger and better optics. By 1809, von Fraunhofer was made partner of the firm, assuming many of the business responsibilities. For a time, he became primarily engaged in designing achromatic objective lenses for telescopes that required the accurate determination of the refractive indices of the optical glasses. Several years later, in 1817, he finally succeeded. With only minor modifications, his design continues to be used in microscopes and other fine optics.

In 1813, von Fraunhofer accomplished what is often considered his greatest achievement. He independently rediscovered William Hyde Wollaston's dark lines in the solar spectrum, which are now known as Fraunhofer lines. He described a great number of the 500 or so lines he could see using self-designed instruments, labeling those most prominent with letters, a form of nomenclature that is still in favor. Fraunhofer lines would eventually be used to reveal the chemical composition of the sun's atmosphere.

Von Fraunhofer is also renowned for building the first diffraction grating, made up of 260 close parallel wires, in 1821. The rudimentary gratings were soon upgraded, possessing up to 10,000 parallel lines per inch, and were ruled by a specially constructed dividing engine. Von Fraunhofer was well versed in the mathematical wave theory of light and used the gratings to measure the wavelengths of specific colors and the dark lines in the solar spectrum. He also used them to develop the laws of diffraction.

The once uneducated apprentice advanced far from what might be expected from his humble beginnings. Von Fraunhofer was honored with membership to the Bavarian Academy of Sciences, given an honorary doctorate from the University of Erlangen, and is considered founder of the German optical industry. He taught at the University of Bavaria and was knighted in 1824. Von Fraunhofer may have achieved even greater heights if he had lived a longer life. However, the self-made man contracted tuberculosis and died prematurely in 1826.

Gustav Robert Kirchhoff
(1824–1887)

Gustav Kirchhoff was a nineteenth-century physicist who is well known for his contributions to circuit theory and the understanding of thermal emission, but who also made significant discoveries in optics. His work in the area spectroscopy, much of which was carried out in conjunction with chemist Robert Bunsen, was foundational to the field, as was his study of black body radiation. Kirchhoff's findings are commonly considered to have been instrumental to Max Planck's quantum theory of electromagnetic radiation formulated at the beginning of the twentieth century.

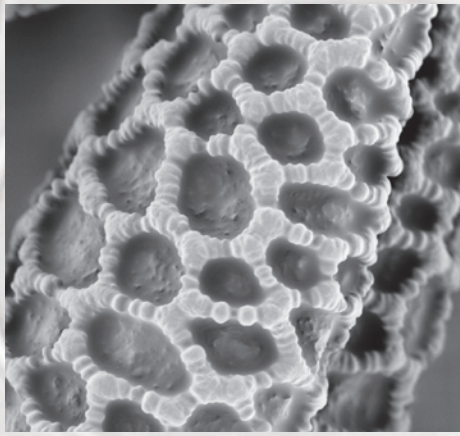
 doi:10.1017/S1551929511000897

View, Analyze, & Create in 3D

with the most powerful FIB and SEM

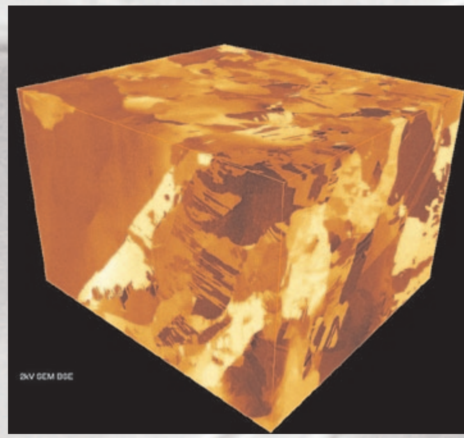
Helios NanoLab™ 50 Series

- Ultra-stable, contamination and damage free imaging of uncoated charging or beam-sensitive samples
- Best in class sample preparation: precise milling of large volume, very low kV polishing, process monitoring
- Most complete and integrated suite of prototyping capabilities with SEM, FIB and beam chemistries
- Robust, reproducible and versatile multi-signal 3D Slice and View automation
- Accurate and flexible sample positioning and handling
- Outstanding application and service support

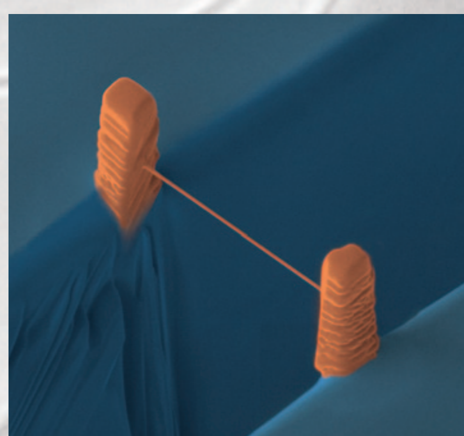


Surface of uncoated pollen, imaged using SEM at very low kV (50 V).

The horizontal field width is 51 µm. *Courtesy of FEI NanoPort.*



Austenic-ferritic duplex steel, 16 x 12 x 18 μm^3 volume acquired with the AutoSlice and View™ application. A series of top-down high energy, high angle SEM-BSE images were collected automatically. The distance between each slice is 30 nm. *Courtesy of FEI NanoPort.*



Platinum nanowire deposited and milled to about 50 nm diameter for use as a gas sensor *Courtesy of Peter Heard, Bristol University, United Kingdom.*

Learn more at www.fei.com/research

FEI™ Explore. Discover. Resolve.

The son of a lawyer, Kirchhoff was born and educated in Königsberg, Prussia (now the Russian city Kaliningrad). He graduated from Albertus University in 1847 and soon after married Clara Richelot, the daughter of his mathematics professor. The couple immediately relocated to Berlin, where Kirchhoff had obtained an unpaid teaching position. In 1850, at the unusually young age of 26, he received an appointment as Professor Extraordinarius in Breslau (now Wroclaw), Poland. In Breslau, Kirchhoff became acquainted with Bunsen, who urged Kirchhoff to follow him to Heidelberg, Germany, which he did in 1854. As a professor of physics at the university there, Kirchhoff was very successful, but he did suffer personal adversity when his wife died in 1869, leaving him alone to finish raising their four children, a task made more difficult by a disability that often confined him to a wheelchair or to the use of crutches. He remarried, however, in 1872 to Luise Brömmel, and his family remained in Heidelberg until 1875, at which point his failing health inspired him to accept the chair of mathematical physics at the University of Berlin because experimental work was becoming increasingly difficult.

Most of Kirchhoff's early research was related to electrical currents. While still only a graduate student, he published a paper that included a pair of rules for the analysis of circuits, which are widely used in the field of electrical engineering and are now known as Kirchhoff's laws of circuits. Then, by 1850, Kirchhoff determined that Georg Ohm's suggestion that electrical flow is analogous to the flow of heat was incorrect and misleading, lending itself to the mistaken assumption that a static current could be present in a conductor. Kirchhoff made another important contribution in this area around 1857, when he noted that an electrical current traveled at approximately the same speed as light. However, he did not make the connection, which was deduced by James Clerk Maxwell in 1862, that light was an electromagnetic phenomenon.

Kirchhoff's important work on thermal radiation was primarily carried out in the late 1850s and early 1860s. In 1859, his studies led him to propose what is commonly referred to as Kirchhoff's law in thermodynamics. Proven in 1861, this law holds that at thermal static equilibrium, the emissivity of an object or surface is equivalent to its absorbance at any given wavelength and temperature. In the course of his studies of radiation, Kirchhoff coined the term black body to describe a hypothetical perfect radiator that absorbs all incident light and, therefore, emits all of that light when maintained at a constant temperature in order to preserve equilibrium. The concept of black body radiators is key to the determination of color temperature in the field of photography, but even more importantly, questions raised about black body radiators could not be explained using traditional views of statistical mechanics and electromagnetism. In his attempts to solve these problems, Max Planck made history by discarding contemporary scientific notions and hypothesizing that a black body radiator could only absorb or emit energy in the form of packets he called quanta.

In addition to formulating laws of electrical currents and thermal radiation, Gustav Kirchhoff developed a spectroscope with Robert Bunsen, and the pair pioneered the field of analytical spectroscopy (the study of the emission and absorption of light and other radiation by matter in terms of their relationship to the wavelength of the radiation). Underlying this achievement was Kirchhoff's demonstration in 1859 that all pure substances display their own characteristic spectrum. Prior to that time, other scientists had postulated that each element had a unique spectrum, but impurities in their samples impeded the discovery because they resulted in the appearance of multiple spectra simultaneously. Equipped with this knowledge, Kirchhoff and Bunsen discovered the elements cesium and rubidium, analyzed the chemical composition of the sun, and explained the dark lines in the solar spectrum generally referred to as Fraunhofer lines—an achievement often considered an important turning point in astronomical studies.

MT

https://doi.org/10.1017/S1551929511000897 Published online by Cambridge University Press

https://doi.org/10.1017/S1551929511000897 Published online by Cambridge University Press