**Who really invented lenses?**

It is generally held that a Dutch spectacle maker, Hans Lippershey, invented the telescope in 1608. But the origin of the lens itself is shrouded in mystery. In 1850, archeologist John Layard discovered what looks to be a lens at a site he was excavating at the palace of Nimrud in what is now Iraq. So could the first lens date to the ancient Assyrians? That would make lenses about 3000 years older than had been thought. According to Professor Giovanni Pettinato of the University of Rome, this rock crystal "lens", on display in the British museum, could explain why the ancient Assyrians knew so much about astronomy. But this artifact from Nimrud is not totally unique in the ancient world. Another artifact that appears to be a lens dating from roughly the 5$^{th}$ century BC was found in a cave on Mount Ida on Crete. It is more powerful and of better quality than the Nimrud lens. Also, the Roman writers Pliny and Seneca both referred to a lens used by an engraver in Pompeii.

There are many similar lenses from ancient Egypt, Greece and Babylon. The ancient Romans and Greeks filled glass spheres with water to make lenses. Glass lenses were not thought of until the 13th century. This is when Roger Bacon used parts of glass spheres as magnifying glasses and recommended them to be used to help people read. Roger Bacon got his inspiration from Alhazen in the 10th century. He discovered that light reflects from objects and does not get released from them. Between the 11th and 13th century "reading stones" were invented. Often used by monks to assist in illuminating manuscripts, these were primitive plano-convex lenses initially made by cutting a glass sphere in half. As the stones were experimented with, it was slowly understood that shallower lenses magnified more effectively.

**Optics & Science**

The history of optics as a scientific field, begins in Alexandria, around 300 BC. At that time, science was flourishing in Greece, and geometry was the hottest scientific topic (like nuclear physics was in the 1970s). One of Alexandria's biggest geometry hot-shots was a fellow by the name of **Euclid**. He was the man that came up with most of the geometry stuff we're taught in school, but he also observed that light travels in straight lines. The first descriptions on the laws of reflection can be found in his work.

Now let’s look at some of those numerous scientific discoveries and innovations in optics over the centuries that have contributed to mankind’s illumination, vision, and success:

# History of Optics

| | |
|---|---|
| **~300 BC** | Euclid (Alexandria) In his *Optica* he noted that light travels in straight lines and described the law of reflection. He believed that vision involves rays going from the eyes to the object seen and he studied the relationship between the apparent sizes of objects and the angles that they subtend at the eye |
| **Probably between 100 BC and 150 AD** | Hero (also known as Heron) of Alexandria. In his *Catoptrica*, Hero showed by a geometrical method that the actual path taken by a ray of light reflected from a plane mirror is shorter than any other reflected path that might be drawn between the source and point of observation. |
| **~140 AD** | Claudius Ptolemy (Alexandria). In a twelfth-century latin translation from the arabic that is assigned to Ptolemy, a study of refraction, including atmospheric refraction, was described. It was suggested that the angle of refraction is proportional to the angle of incidence |
| **965-1020** | Ibn-al-Haitham ( also known as Alhazen) (b. Basra). In his investigations, he used spherical and parabolic mirrors and was aware of spherical aberration. He also investigated the magnification produced by lenses and atmospheric refraction. His work was translated into latin and became accessible to later european scholars |
| **~1220** | Robert Grosseteste (England). *Magister scholarum* of the University of Oxford and a proponent of the view that theory should be compared with observation, Grosseteste considered that the properties of light have particular significance in natural philosophy and stressed the importance of mathematics and geometry in their study. He believed that colours are related to intensity and that they extend from white to black, white being the purest and lying beyond red with black lying below blue. The rainbow was conjectured to be a consequence of reflection and refraction of sunlight by layers in a 'watery cloud' but the effect of individual droplets was not considered. He held the view, shared by the earlier Greeks, that vision involves emanations from the eye to the object perceived. |
| **~1267** | Roger Bacon (England). A follower of Grosseteste at Oxford, Bacon extended Grosseteste's work on optics. He considered that the speed of light is finite and that it is propagated through a medium in a manner analogous to the propagation of sound. In his Opus Maius, Bacon described his studies of the magnification of small objects using convex lenses and suggested that they could find application in the correction of defective eyesight. He attributed the phenomenon of the rainbow to the reflection of sunlight from individual raindrops |
| **~1270** | Witelo (Silesia). Completed his *Perspectiva* which was destined to remain a standard text on optics for several centuries. Amongst other things, Witelo described a method of machining parabolic mirrors from iron and carried out careful observations on refraction. He recognised that the angle of refraction is not proportional to the angle of incidence but was unaware of total internal reflection |

| | |
|---|---|
| **1303** | Bernard of Gordon (France). A Physician, he mentioned the use of spectacles as a way of correcting long-sightedness |
| **1304~1310** | Theodoric (Dietrich) of Freiberg. Theodoric explained the rainbow as a consequence of refraction and internal reflection within individual raindrops. He gave an explanation for the appearance of a primary and secondary bow but, following earlier notions, he considered colour to arise from a combination of darkness and brightness in different proportions |
| **~1590** | Zacharius Jensen (Netherlands). Constructed a compound microscope with a converging objective lens and a diverging eye lens |
| **1604** | Johannes Kepler (Germany). In his book *Ad Vitellionem Paralipomena*, Kepler suggested that the intensity of light from a point source varies inversely with the square of the distance from the source, that light can be propagated over an unlimited distance and that the speed of propagation is infinite. He explained vision as a consequence of the formation of an image on the retina by the lens in the eye and correctly described the causes of long-sightedness and short-sightedness |
| **1608** | Hans Lippershey (Netherlands). Constructed a telescope with a converging objective lens and a diverging eye lens |
| **1609** | Galileo Galilei (Italy).Constructed his own version of Lippershey's telescope and started to use it for astronomical observations |
| **1610** | Galileo Galilei (Italy). Using his telescope, Galileo reported several astronomical discoveries including that Jupiter has four moons |
| **1611** | Johannes Kepler (Germany). In his *Dioptrice*, Kepler presented an explanation of the principles involved in the convergent/divergent lens microscopes and telescopes. In the same treatise, he suggested that a telescope could be constructed using a converging objective and a converging eye lens and described a combination of lenses that would later become known as the telephoto lens. He discovered total internal reflection, but was unable to find a satisfactory relationship between the angle of incidence and the angle of refraction |
| **~1618** | Christopher Scheiner. Constructed a telescope of the type suggested by Kepler with converging objective and eye lenses. This type of telescope has since become known as the 'astronomical telescope' but it is uncertain when the first such instrument was constructed |
| **1621** | Willebrord Snell (Leiden). Discovered the relationship between the angle of incidence and angle of refraction when light passes from one transparent medium to another |
| **1647** | B Cavalieri. Derived a relationship between the radii of curvature of the surfaces of a thin lens and its focal length |

| | |
|---|---|
| **1657** | Pierre de Fermat (France). Enunciated his principle of 'least time', according to which, a ray of light follows the path which takes it to its destination in the shortest time. This principle is consistent with Snell's law of refraction |
| **1663** | James Gregory (England). Suggested the use of a converging mirror for the objective of a telescope as a cure for aberrations |
| **1665** | Francesco Maria Grimaldi (Italy). In a book entitled *Physico-Mathesis de lumine, coloribus et iride* published posthumously, Grimaldi's observations of diffraction when he passed white light through small apertures were described. Grimaldi concluded that light is a fluid that exhibits wave-like motion |
| **1665** | Robert Hooke (England). In his treatise, *Micrographia*, Hooke described his observations with a compound microscope having a converging objective lens and a converging eye lens. In the same work, he described his observations of the colours produced in flakes of mica, soap bubbles and films of oil on water. He recognised that the colour produced in mica flakes is related to their thickness but was unable to establish any definite relationship between thickness and colour. Hooke advocated a wave theory for the propagation of light |
| **1666** | Isaac Newton (England). Described the splitting up of white light into its component colours when it is passed through a prism |
| **1668** | Isaac Newton (England). As a solution to the problem of chromatic aberration exhibited by refracting telescopes, Newton constructed the first reflecting telescope |
| **1669** | Erasmus Bartholinus (Denmark). Discovered double refraction in calcite |
| **1672** | Isaac Newton (England). Newton's earlier observations on the dispersion of sunlight as it passed through a prism were reported to the Royal Society. Newton concluded that sunlight is composed of light of different colours which are refracted by glass to different extents |
| **1676** | Olaf Römer (Denmark) Deduced that the speed of light is finite from detailed observations of the eclipses of the moons of Jupiter. From Römer's data, a value of about $2 \times 10^8$ $m.s^{-1}$ is obtainable |
| **1678** | Christiaan Huygens (Netherlands). In a communication to the Academie des Science in Paris, Huygens propounded his wave theory of light (published in his *Traite de Lumiere* in 1690). He considered that light is transmitted through an all-pervading aether that is made up of small elastic particles, each of which can act as a secondary source of wavelets. On this basis, Huygens explained many of the known propagation characteristics of light, including the double refraction in calcite discovered by Bartholinus |
| **1704** | Isaac Newton (England). In his *Optiks*, Newton put forward his view that light is corpuscular but that the corpuscles are able to excite waves in the aether. His adherence to a corpuscular nature of light was based primarily on the presumption that light travels |

| | |
|---|---|
| | in straight lines whereas waves can bend into the region of shadow |
| **1727** | James Bradley (England). Bradley calculated the speed of light from observations of the 'aberration' of light from stars, an apparent motion of a star arising from the value of the speed of light in relation to the speed of the earth in its orbit |
| **1733** | Chester More Hall. Constructed an achromatic compound lens using components made from glasses with different refractive indices |
| **1752** | Thomas Melvill (Scotland). Observed that the spectra of flames into which metals or salts have been introduced show bright lines characteristic of what has been introduced into the flame |
| **1801** | Thomas Young (b. England). Provided support for the wave theory by demonstrating the interference of light |
| **1802** | William Hyde Wollaston (England). Discovered that the spectrum of sunlight is crossed by a number of dark lines, but he did not interpret them in accordance with current explanations [Phil.Trans.Roy.Soc., London. p365, 1802] |
| **1808** | Etienne Louis Malus (France). As a result of observing light reflected from the windows of the Palais Luxembourg in Paris through a calcite crystal as it is rotated, Malus discovered an effect that later led to the conclusion that light can be polarized by reflection |
| **1814** | Joseph Fraunhofer (Germany). Fraunhofer rediscovered the dark lines in the solar spectrum noted by Wollaston and determined their position with improved precision |
| **1815** | David Brewster (Scotland). Described the polarization of light by reflection |
| **1816** | Augustin Jean Fresnel (France). Presented a rigorous treatment of diffraction and interference phenomena showing that they can be explained in terms of a wave theory of light |
| **1816-1817** | As a result of investigations by Fresnel and Dominique Francois Arago on the interference of polarized light and their subsequent interpretation by Thomas Young, it was concluded that light waves are transverse and not , as had been previously thought, longitudinal |
| **1819** | Joseph Fraunhofer (Germany). Described his investigations of the diffraction of light by gratings which were initially made by winding fine wires around parallel screws |
| **1821** | Augustin Jean Fresnel (France). Presented the laws which enable the intensity and polarization of reflected and refracted light to be calculated |
| **1823** | Joseph Fraunhofer (Germany). Published his theory of diffraction |

**1828** William Nicol (Scotland). Invented a polarizing prism made from two calcite components. The device became known subsequently as a "nicol prism"

**1834** John Scott Russell (Scotland). Observed a 'wave of translation' caused by a boat being drawn along the Union Canal in Scotland, and noted how it travelled great distances without apparent change of shape. Such waves subsequently became known as 'solitary waves' and their study led to the idea of solitons, optical analogues of which have been propagated in optic fibres [Report of the 14th meeting of the British Association for the Advancement of Science, p311, 1844]

**1835** George Airy (England). Calculated the form of the diffraction pattern produced by a circular aperture

**1845** Michael Faraday (England). Described the rotation of the plane of polarized light that is passed through glass in a magnetic field (the Faraday effect)

**1849** Armand Hypolite Louis Fizeau (France). Using a rotating toothed wheel to break up a light beam into a series of pulses, Fizeau made the first non-astronomical determination of the speed of light (in air). Obtained a value of 313,300 $km.s^{-1}$

**1850** J L Foucault (France). Foucault determined the speed of light in air using a rotating mirror method. Obtained a value of 298,000 $km.s^{-1}$.In the same year, Foucault used a rotating mirror method to measure the speed of light in stationary water and found that it was less than in air

**1855** David Alter (USA). Described the spectrum of hydrogen and other gases

**1859** H L Fizeau (France). Performed an experiment to determine whether the velocity of light in water is affected by flow of the water. He found that it is, the change in the velocity of light being about a half the velocity of the flowing water

**1860** Robert Wilhelm Bunsen and Gustav Kirchoff. Observed the emission spectra of alkali metals in flames and also noted the presence of dark lines arising from absorption when observing the spectrum of a bright light source through the flame. The origin of these dark lines was similar to that of dark lines in the solar spectrum observed by Wollaston and Fraunhofer and attributed to the absorption of light by gases in the solar atmosphere that are cooler than those emitting the light [Annalen der Physik und der Chemie. **110**, 1860]

**1865** James Clerk Maxwell (Scotland). From his studies of the equations describing electric and magnetic fields, it was found that the speed of an electromagnetic wave should, within experimental error, be the same as the speed of light. Maxwell concluded that light is a form of electromagnetic wave

**1869** John Tyndall (Ireland). Described experimental studies of the scattering of light from aerosols
[Phil. Mag. **37**, 384; **38** , 156, 1869]

| | |
|---|---|
| **1871** | John William Strutt, third Baron Rayleigh (England). Presented a general law which related the intensity of light scattered from small particles to the wavelength of the light when the dimensions of the particles is much less than the wavelength. He also made a 'zone plate' which produced focussing of light by Fresnel diffraction [Phil. Mag. **41**, 107,274,447, 1871] |
| **1873** | Ernst Abbe (Germany). Presented a detailed theory of image formation in the microscope |
| **1874** | Marie Alfred Cornu (France). Described a graphical approach (the Cornu spiral) to the solution of diffraction problems |
| **1875** | John Kerr (Scotland). Demonstrated the quadratic electro-optic effect (the Kerr effect) in glass |
| **1879** | Josef Stefan (Austria). Presented an empirical relationship which asserted that the total radiant energy emitted from a body per unit time is proportional to the fourth power of the absolute temperature of the body |
| **1879** | Joseph Swan (England). Demonstrated an electric lamp with a carbon filament |
| **1879** | Thomas Alvin Edison (USA). Developed the electric lamp using cotton as the source of the carbon filament and produced it as a practical device |
| **1882** | Albert Abraham Michelson (USA, b. Poland). Described the Michelson interferometer |
| **1885** | Johann Jakob Balmer (Switzerland). Presented an empirical formula describing the position of the emission lines in the visible part of the spectrum of hydrogen |
| **1887** | Albert A Michelson and Edward W Morley (USA). Described their unsuccessful attempts to detect the motion of the earth with respect to the 'Luminiferous Aether' by investigating whether the speed of light depends upon the direction in which the light beam moves (The Michelson-Morley experiment) |
| **1887** | Heinrich Hertz (Germany). Accidentally discovered the photoelectric effect |
| **1890** | O Wiener. Observed standing waves in light reflected at normal incidence from a silver mirror. Nodes and antinodes in the standing wave were detected photographically and it was concluded that a node exists at the mirror surface. From this it is concluded that, at least as far as photographic effects are concerned, the electric component of the electomagnetic wave has the more important effect |
| **1891/92** | L Mach and L Zehnder separately described what has become known as the Mach-Zehnder interferometer which could monitor changes in refractive index, and hence density, in compressible gas flows. The instrument has subsequently been applied in the field of aerodynamics |

| | |
|---|---|
| **1895** | D J Korteweg and G deVries (Netherlands). Korteweg and his student, deVries, derived a non-linear partial differential equation governing the propagation of waves in shallow water that described the soliton wave described by John Scott Russell. Study of the Korteweg-deVries (KdV) equation has had an important role in the development of the mathematical description of solitons |
| **1896** | Wilhelm Wien (Germany). Described how the spectral distribution of radiation from a black body varies with the temperature of the body [Annalen der Physik **38**, 662, 1896] |
| **1896** | Pieter Zeeman (Netherlands). Observed that the spectral lines emitted by an atomic source are broadened when the source is placed in a magnetic field |
| **1899** | Lord Rayleigh (England). Explained the blue colour of the sky and red sunsets as being due to the preferential scattering of blue light by molecules in the earth's atmosphere. [Phil. Mag. **47** , 375, 1899] |
| **1899** | Marie P A C Fabry and Jean B G G A Perot (France). Described the Fabry-Perot interferometer which enabled high resolution observation of spectral features [C Fabry and A Perot. Ann.Chim.Phys. **16**, p115, 1899] |
| **1900** | Max Karl Planck (Germany). In his successful explanation of the spectrum of radiation emitted from a hot black body, Planck found it necessary to introduce a universal constant described as the quantum of action, now known as Planck's constant. A consequence is that the energy of an oscillator is the sum of small discrete units, each of which has a value that is proportional to the frequency of oscillation |
| **1905** | Albert Einstein (Germany). Explained the photoelectric effect on the basis that light is quantized, the quanta subsequently becoming known as photons [Annalen der Physik **17**, p132, 1905] [Annalen der Physik **20**, p199, 1906] |
| **1908** | Gustav Mie (Germany). Presented a description of light scattering from particles that are not small compared to the wavelength of light, taking account of particle shape and the difference in refractive index between the particles and the supporting medium |
| **1913** | Neils Henrik David Bohr (Denmark). Bohr advanced a theory of the atom in which the electrons were presumed to occupy stable orbits with well-defined energy. According to this theory, the absorption and emission of light by an atom occurs as a result of an electron moving from one orbit to another of different energy. This allowed an explanation of the observation that atoms absorb and emit light at particular frequencies that are characteristic of the atom |
| **1915** | William David Coolidge (USA) Patented a method of making electric lamp filaments from tungsten |
| **1916** | Albert Einstein (Germany). Proposed that the stimulated emission of light is a process that should occur in addition to absorption and spontaneous emission |

| | |
|---|---|
| **1919** | Sir Arthur Eddington (England). Observed the eclipse of the Sun on 29th May from Principe Island off the west coast of Africa with the intention of determining the apparent position of stars that appeared close to the Sun's disk. He concluded that the path of light is bent by the Sun's gravitational field in accordance with predictions of Einstein's theory of General Relativity |
| **1926** | A A Michelson (USA). Performed a series of experiments to determine the speed of light using a rotating mirror method with a light path from the observatory at Mount Wilson to a reflector on Mount San Antonio, a distance of 22 miles (35 km). Obtained an average value of 299,796 $km.s^{-1}$ |
| **1926** | John Logie Baird (England) gave the world's first public demonstration of a working television system that transmitted live moving images with tone graduation (grayscale) on 26 January 1926 at his laboratory in London |
| **1927** | Paul Adrien Maurice Dirac (England). Presented a method of representing the electromagnetic radiation field in quantized form [Proceedings of the Royal Society A, **114**, 243, 710, 1927] |
| **1928** | Chandrasekhara Raman (India). Observed weak ineleastic scattering of light from liquids, an effect arisng from the scattering of light by vibrating molecules and now known as Raman scattering [Indian J. Phys. **2** ,p387, 1928] |
| **1929** | Edwin Powell Hubble (USA). Devised a classification system for the various galaxies he observed, sorting them by content, distance, shape, and brightness; it was then he noticed red-shifts in the emission of light from the galaxies, seeing that they were moving away from each other at a rate constant to the distance between them. From these observations, he was able to formulate Hubble's Law, helping astronomers determine the age of the universe, and proving that the universe was expanding. |
| **1932** | P Debye and F W Sears and also R Lucas and P Biquard independently observed the diffraction of light by ultrasonic waves |
| **1932** | E H Land (USA). Invented "polaroid" polarizing film |
| **1934** | Frits Zernicke (Netherlands). Described the phase-contrast microscope |
| **1939** | Walter Geffcken (Germany). Described the transmission interference filter |
| **1941** | W C Anderson. Measured the speed of light using a Kerr cell to modulate a light beam that passed through a Michelson interferometer. Obtained a value of 299,776 $km.s^{-1}$ |
| **1946** | First space photographs from V-2 rockets. |
| **1947** | RCA introduced the rear projection 648PTK television to overcome the small size of CRT's at that time. This set had a "giant" 15 by 20 inch rectangular screen. |

| | |
|---|---|
| **1948** | Dennis Gabor ( b.Hungary). Described the principles of wavefront reconstruction, later to become known as holography |
| **1948** | Lord Partick Maynard Stuart Blackett (England), Imperial College, London, Awarded the Nobel Prize for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation. |
| **1953** | Frits (Frederik) Zernike – Nobel Prize in Physics "for his demonstration of the phase contrast method, especially for his invention of the phase contrast microscope" |
| **1954** | C H Townes, J P Gordon and H J Zieger (USA). In a paper entitled "Molecular microwave oscillator and new hyperfine structures in the microwave spectrum of $NH_3$", they described a maser built at Columbia University which used ammonia to produce coherent microwave radiation. [Physical Review. **95**, p 282, 1954] |
| **1955** | On July 1, 1955 the Society of Photographic Instrumentation Engineers (SPIE) is founded to specialize in the application of photo-optical instrumentation. The Society's first local technical meeting is held in Los Angeles on August 8. |
| **1957** | Soviets launch the first orbiting satellite, “Sputnik”, starting the space race. |
| **1958** | Arthur L Schawlow and Charles H Townes (USA). Published a paper entitled "Infrared and Optical Masers" in which it was proposed that the maser principle could be extended to the visible region of the spectrum to give rise to what later became known as a 'laser' [Physical Review. **112(6)**, p1940, 1958] |
| **1960’s** | US begins collection of intelligence photography from Earth orbiting satellites, CORONA. |
| **1960** | Theodore H Maiman (USA). Described the first laser. The laser was built at the Hughes Research Laboratories and used a rod of synthetic ruby as the lasing medium [Nature. **187**, p493, 1960] |
| **1960** | American U-2 spy plane is "shot down" over Sverdlovsk, USSR while taking photographs of military installations in the USSR. |
| **1961** | P A Franken, A E Hill, C W Peters and G Weinreich. Demonstrated harmonic generation from light by passing the pulse from a ruby laser through a quartz crystal |
| **1961** | Ali Javan, W R Bennett and Donald R Harriott (USA). Described the first gas laser. Built at the Bell Laboratories, the lasing medium was a mixture of helium and neon and emitted at wavelengths in the near infrared, the most intense beam being at a wavelength of 1.153 um ["Population inversion and continuous maser oscillation in a gas discharge containing He-Ne mixtures", Physical Review Letters, **6**, p106, 1961] |
| **1962** | Four groups in the United States described the observation of stimuated emission from homojunction gallium arsenide semiconductor diodes [M I Nathan *et al*, (IBM). Applied |

Physics Letters. **1**, p62, 1962] [R N Hall *et al*, (GEC). Physical Review Letters. **9**, p366, 1962] [T M Quist *et al*, (MIT). Applied Physics Letters. **1**, p91, 1962] [N Holonyak and S F Bevacqua, (GEC). Applied Physics Letters. **1**, p82, 1962]

**1962** Zaitor and Tsuprun construct prototype nine lens multispectral camera permitting nine different film-filter combinations Also during this year our country came very close to nuclear war when military intelligence photography was brought into the lime light by the Cuban Missile Crisis.

**1963** Kumar Patel (USA, b India). Announced the development of the first carbon dioxide laser at Bell Laboratories

**1964** William B Bridges (USA). Built the first ion lasers at Hughes Research Laboratories ["Visible and uv laser oscillation at 118 wavelengths in ionized neon, argon, krypton, oxygen and other gases" W B Bridges and Arthur N Chester, Applied Optics, **4**, p573, 1965]

**1964** Jerome V V Kasper and George C Pimentel (USA). Described the photodissociation Iodine laser, built at the University of California, Berkeley, in which a population inversion in atomic iodine was produced by the photodissociation of either $CF_3I$ or $CH_3I$. The laser output was in the near infrared at a wavelength of 1.315 um [Applied Physics Letters. **5(11)**, p231, 1964]

**1966** Sorokin and J R Lankard. Built the first organic dye laser

**1967/69** S L McCall and E L Hahn (USA). Described studies of the propagation of very short optical pulses through a medium consisting of resonant two level atoms, developing in the process the criteria to be satisfied by the shape of the pulse so that it would propagate as an optical solution (the area theorem) and describing the propagation mechanism of self-induced transparency (SIT) [Physical Review Letters, **18**, p908, 1967] [Physical Review, **183**, p457, 1969]

**1971** John M J Madey (USA). In a paper entitled "Stimulated emission of bremsstrahlung in a periodic magnetic field", Madey outlined the principles of the free electron laser [Journal of Applied Physics, **42**, p1906, 1971]

**1975** Hänsch and Schawlow made the important suggestion that it was possible to use the strong velocity dependence of the scattering force due to Doppler shift for the optical cooling or damping of atomic motions.

**1976** John M J Madey (USA). A group at Stanford University demonstrated the first free electron laser (FEL)

**1984** R E Fischer (USA). Elected President of SPIE, The International Society for Optical Engineering .

**1985** D L Matthews *et al* (USA). Described x-ray laser experiments at the Lawrence

Livermore National Laboratory in which amplified spontaneous emission was observed at wavelengths around 20nm ["Demonstration of a soft x-ray amplifier", Physical Review Letters. 54, p110, 1985]

**1986** Gerd Binnig (Germany). Awarded the Nobel Prize in Physics for his scanning tunneling microscope. With this invention, the nanotech era in imaging was launched by Gerd Binnig and Heinrich Roher from the IBM Zurich Research Laboratory.

**1987** R E Fischer (USA), established Optics 1, Inc. as an optics research and development company at Westlake Village California

**1990** The Hubble space telescope was positioned in a low Earth orbit on 25th April, 1990

**1990** Bell Labs transmitted a 2.5 Gb/s signal over 7,500 km of optical fiber without regeneration.

**1993** Texas Instruments creates the "DLP Display", Digital Light Processor, a matrix of microscopic mirrors using semiconductor manufacturing techniques.

**1995** A new class of intelligence satellite is being developed. The new satellite code named 8x is said to be a major upgrade of the KH-12 spy satellite. The satellite which may weight as much as twenty tons will be able to acquire "intricately detailed images of areas as large as 1,000 square miles of the Earth's surface.

**1997** Steven Chu awarded the 1997 Nobel Prize in Physics for his work in optical tweezing in his work on cooling and trapping atoms. Steven Chu described how Askhin had first envisioned optical tweezing as a method for trapping atoms. Ashkin was able to trap larger particles (10 to 10,000 nanometers in diameter) but it fell to Chu to extend these techniques to the trapping of atoms (0.1 nanometers in diameter).

**2000** R E Fischer (USA), first publication of "Optical System Design" by McGraw Hill, the industry's "easy to use" text on optics and system design.

**2001** I. Hartl, X. D. Li, C. Chudoba, R. K. Ghanta, T. H. Ko, J. G. Fujimoto, J. K. Ranka, and R. S. Windeler, experiments demonstrate Ultrahigh-resolution OCT (optical coherence tomography) for the first time , Opt. Lett. **26**, 608-610 (2001)

**2003** Optical Camouflage System invented by Susumu Tachi, Masahiko Inami, and Naoki Kawakami

**2004** After the Columbia disaster, NASA desperately needed a boost, a success that would restore people's faith in space exploration. This year the agency got two: the twin Mars Exploration rovers returned spectacular pictures.

**2005** Optics 1, Inc. ships commercial "Holographic Optical Tweezing" (HOT) box.

**2006** The new Optical SETI telescope at the Oak Ridge Observatory in Harvard, Massachusetts, was inaugurated on April 11, 2006.

**2007** Optics 1, Inc. celebrates $20^{th}$ Anniversary