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2009 Nobel Prizes in Physics: Kao, Boyle and Smith

The Masters of Light

This year the Nobel Prize in physics has been won by Charles K. Kao and Willard Sterling Boyle and George Elwood Smith. Kao had initiated the search for and the development of the low-loss optical fiber 40 years ago; now this techology is used for communication. Willard S. Boyle and George E. Smith invented the charge-coupled device (CCD) used in digital cameras and in medical and scientific instruments. They started to study this kind of technolgy a few years later Kao and their discoveries had substituted films because CCD can capture images electronically.

Their discoveries led to important improvements in telecommunication, but they needed a powerfull source of light, new technologies in the creating process of glass and very small components like trasistors and amplifiers.

Kao's discoveries are based on reflection of light. This proprty has been known from ancient times; in fact Egyptians and Mesopotamians used it for jewells. Later Venecians knew the reflection properties of glass and they were able to create wonderful play of light. In the Universal Exposition of Paris in 1889 water jets combined with coloured light were used to entertain people in special fountains. The first time that total internal reflection was discussed was in 19th century by Babinet and Tyndall that followed a Faraday's idea. Reflection is a property of light that occurs when a sunlight hits the surface of, for exemple, water and light is reflected because water index reflection is higher then the air one.

This property was used by scientists only in 1920's; they guided light in small glass rods, called fibers; they were made of a material whose reflection index is higher than its enviroment, so the ray of light goes on bouncing since the index is higher than its surroundings. This property was used in different fields: for example they applicated optical fibers for televsion, gastroscope and to create flexible periscopes. But these fibers were very fragile and they used to break very easily (for example when one fiber touched each other). In 1950's Hopkins and Kapany in London created a bundle of thousands of fibers and, combining this with the cladding of them, internal reflection of light was faciltated and the trasmission of images was good. From these period this technology was used in communication, even if in 1880 Bell had already patented the "Photophone" based on an easy application of optical fibers.

Then researches on telecommunication were concentrated in shortest radio waves. But telecommunication couldn't be based on radio any longer when TV and telephone spread widely. In fact radiowaves are less fast than infrared. When laser was invented (1960), even if it emitted infrared light, it didn't had practical applications because it needed lot of energy and couln't be used at room temperature. Then the invention of heterostructures permitted the application of laser technology in optical fibers (in fact it could work at room temperatures); but only 1% of light could remain after 20 meters of optical fibers.

Kao, an electronic engineer, made lot of researchs in order to reduce the loss of light; his aim was to make 1% of light remain after 1 km of optycal fiber. The biggest problem were the imperfections of he fibers, so he started to search for a more trasparent glass. So he suggested to produce glass not only with quartz but also with silica; this idea was followed and an important chemical factory (1971) created an ultra-thin threads of fiber 1 km long at a temperature of 2000° C.

Nowdays Kao's goal has been widely achieved, in fact in modern optical fibers 95% of light, that enters in a fiber, remains after 1 km. Some experiments were made in Japan and UK in 1970's. The first optical cable was laid on the Atlantic bottom in 1988 and it was 6000 km long, then other cables were installed and now their global lenght is 1 billion km. The only way to obtain stable trasmissions is to renforce them through transistors, amplifiers, receivers and transmitters. This new generation fibers are made of very thin threads and, even if glass is their main component, they are not fragile because this material changes its properties when its drown out. This fibers can carrie lots of data and telephone communication round the world at a very high speed and in future the amount of them would be higher.

Electronic eye

Willard Boyle and George Smith are the inventors of the image sensor, CCD (charge-coupled device). In September 1969 they outlined the basis of an image sensor. The fact that they got the idea for the CCD can be attributed to the internal politics of their employer. Their boss at Bell Labs outside New York, encouraged them to take on the challenge and enter a competition regarding the development of a better bubble memory. When the basic design for the CCD was finished, it would only take a week before technicians assembled the first prototype. As a memory it is long forgotten, but the CCD has become an indispensable part of modern imaging technology.

A digital image sensor, CCD, is made out of silicon. The size of a stamp, the silicon plate holds millions of photocells sensitive to light. The imaging technique makes use of the photoelectric effect theorized by Einstein: light hits the silicon plate and knocks out electrons in the photocells. The liberated electrons are gathered in the cells which become small wells for them. The larger the amount of light, the larger the number of electrons that fill these wells. When voltage is applied to the CCD array, the content of the wells can be progressively read out; row by row, the electrons slide off the array onto a kind of a conveyor belt. In this manner the CCD transforms the optical image into electric signals that are subsequently translated into digital ones and zeros. Each cell can then be recreated as an image point, a pixel. The image capacity of the sensor is obtained multiplying the width of a CCD, expressed in pixels, with its height. The CCD renders an image in black and white, so various filters have to be used in order to obtain the colors of light.

In 1970 Smith and Boyle could demonstrate a CCD in their video camera for the first time. In 1972, the American company Fairchild constructed the first image sensor with 100 x 100 pixels, which entered production a few years later. In 1975, Boyle and Smith themselves constructed a digital video camera of a sufficiently high resolution to manage television broadcasts. In 1981 the first camera with built-in CCD appeared on the market. Five years later in 1986, the first 1.4 megapixel image sensor (1.4 million pixels) arrived, and in 1995 the first fully digital photographic camera appeared. Camera manufacturers around the world quickly caught on, and soon the market was flooded with ever smaller and cheaper products. With cameras equipped with image sensors instead of film, an era in the history of photography had ended. Lately the CCD has been challenged by another technology, CMOS (Complementary Metal Oxide Semiconductor), invented at about the same time as CCD. Both make use of the photoeffect, but while the electrons gathered in a CCD march in line in order to be read out, every photocell in a CMOS is read out on site. CMOS consumes less energy so batteries last longer, and for a long time it has also been cheaper. However, one also has to take into account its higher noise levels and the loss of image quality, and consequently CMOS is not sufficiently sensitive for many advanced applications. CMOS is currently often used

for everyday cell phone photography, and for other kinds of photography. Both technologies, however, are constantly being developed and for many applications they are interchangeable.
It is thanks to digital technology that the wide-angle camera on the Hubble space telescope can send the most astonishing images back to Earth. The camera's sensor initially consisted of only 0.64 megapixels. However, as four sensors were interconnected, they provided a total of 2.56 megapixels. This was a big thing in the 1980s when the space telescope was designed. Today the Kepler satellite has been equipped with a mosaic sensor of 95 megapixels, and the hope is that it will discover Earth-like planets around stars other than the sun. Early on, astronomers realized the advantages of the digital image sensor. It spans the entire light spectrum, from X-ray to infrared. It is a thousand times more sensitive than photographic film. Out of 100 incoming light particles a CCD catches up to 90, whereas a photographic plate or the human eye will only catch one. In 1974 the first image sensor had already been used to take photographs of the moon the first astronomical images ever to be taken with a digital camera. In 1979 a digital camera with a resolution of 320 x 512 pixels was mounted on one of the telescopes at Kitt Peak in Arizona, USA. Today whenever photo, video or television is used, digital image sensors are usually involved in the process. They are useful for surveillance purposes both on Earth and in space. Furthermore, CCD technology is used in a host of medical applications, e.g. imaging the inside of the human body. The digital image sensor has become a widely used instrument at the service of science both at the bottom of the oceans and in space. In this way, technological and scientific breakthroughs intertwine.