Hoe Philips Research naast de Nobelprijs greep.

De Nobelprijs 2009 voor Natuurkunde werd voor de helft toegekend aan Charles K. Kao voor zijn diepgravend onderzoek aan de transmissie van licht in fibers voor optische communicatie.
De andere helft werd toegekend aan Willard S. Boyle and George E. Smith van Bell Labs voor de uitvinding van een 'imaging semiconductor circuit' - de CCD sensor.

De uitvinding van het charge-coupled device (CCD) zou waarschijnlijk niet gerealiseerd zijn zonder de belangrijke doorbraken die Philips Research had gedaan, nl. in 1969 hadden F. Sangster en K. Teer het emmertjesgeheugen (Bucket Brigade Device, BBD) uitgevonden, de voorganger van de CCD.
F. Sangster en K. Teer publiceerden in 1969 hun uitvinding van een compleet nieuw device: het emmertjesgeheugen. Het principe bestond uit het transporteren van ladingspakketjes door middel van een combinatie van transitoren en condensatoren.
Hun oorspronkelijke toepassing was een analoge vertragingslijn, maar al gauw realiseerden zij zich dat hun uitvinding ook geschikt zou zijn als solid-state beeld sensor.

Een jaar later breidden W. Boyle en G. Smith van Bell Laboratories dit ladings-transport uit door een transport mechanisme van de ene capaciteit naar de andere capaciteit te bedenken.
Dit nieuwe device noemden zij CCD (Charge Coupled Device). Deze CCD dekte dezelfde toepassingsgebieden van het emmertjesgeheugen, nl.: analoge vertragingslijnen, (programmeerbare) analoge filters, analoge geheugens, digitale geheugens en beeld sensors. In feite was het emmertjesgeheugen een twee-traps CCD.

Ontworpen als een geheugen device, werden er al snel andere applicaties voorgesteld. Omdat de CCD-chip lichtgevoelig was kon het ook worden gebruikt als beeld sensor. Astronomen waren de eersten die de mogelijkheden van de CCD voor hoge kwaliteit beelden herkenden. Met een gevoeligheid die meer dan 100 keer groter was dan die van film, verdrong de CCD binnen een paar jaar alle andere sensoren. De CCD heeft vele nieuwe consumenten toepassingen voortgebracht, zoals camcorders en digitale fotografie.
In wetenschappelijke, industriële en medische toepassingen worden CCD's gebruikt voor hoge resolutie opnames of licht detectie.

F. Sangster en K. Teer zullen zich waarschijnlijk niet gerealiseerd hebben, hoe hun pionierswerk de wereld heeft veranderd, maar ook niet dat zij bijna de Nobelprijs in ontvangst hadden kunnen nemen.

Vrije vertaling van een artikel van Dr. M.J. van Bommel

16-10-2009

Electronic eye

Sometimes inventions appear totally unanticipated. The image sensor, CCD, or charge-coupled device, is such an invention. Without the CCD, the development of digital cameras would have taken a slower course. Without CCD we would not have seen the astonishing images of space taken by the Hubble space telescope, or the images of the red desert on our neighboring planet Mars.

This was not what the inventors of the CCD, Willard Boyle and George Smith, had imagined when they began their work. One day in September 1969, they outlined the basis of an image sensor on a blackboard in Boyle's office. At that time they did not have photographic images in

mind. Their aim with the CCD was to create a better electronic memory. As a memory device it is now forgotten. However, they did come up with an indispensable part of modern imaging technology. The CCD is yet another success story of our electronic era.

Images become digital

Just like many other devices in the electronics industry, 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 which was first theorized by Albert Einstein and earned him 1921's Nobel Prize. The effect occurs when 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 (figure 3). So for example, an array of 10 x 10 image points is transformed into a 100 points long chain. In this manner the CCD transforms the optical image into electric signals that are subsequently translated into dig
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ital ones and zeros. Each cell can then be recreated as an image point, a pixel. When the width of a CCD, expressed in pixels, is multiplied with its height, the image capacity of the sensor is obtained. Thus a CCD with 1280 x 1024 pixels yields a capacity of 1.3 megapixels (1.3 million pixels).

The CCD renders an image in black and white, so various filters have to be used in order to obtain the colors of light. One kind of filter that contains one of the base colors red, green or blue, is placed over every cell in the image sensor. Owing to the sensitivity of the human eye, the number of green pixels needs to be twice that of the blue or red pixels. For more advanced imaging, a number of filters may be used.

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Figure 3.
Digital images.
CCD, the electronic
image sensor, converts
the optic image to
electronic signals that
are translated into digital
ones and zeros.
Photo: A-C Reibekiel

Challenges at work

The fact that Boyle and Smith got the idea for the CCD during their short brainstorming session 40 years ago 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 regard
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ing the development of a better bubble memory, another one of the Bell Labs' inventions. 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 the center of many digital imaging techniques.

The American George Smith was hired at Bell Labs in 1959, and took out 30 patents during his time at the company. When he retired in 1986, he could at last dedicate himself fully to his life-long passion – sailing on the great seas, which has brought him around the globe many times.

By 1969, Willard Boyle had made many important discoveries, for instance in relation with the development of the world's first continuous red light laser. Boyle was born in a distant part of Nova Scotia in Canada, and was educated at home by his mother until the age of 15. He began to work at Bell Labs in 1953, and in the 1960s he joined the 400 000 scientists in the USA whose efforts were to put the first man on the moon on 20 July 1969.

A photographic camera for everyone

The advantages of the electronic image sensor quickly became evident. In 1970, just about a year after the invention, 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.

It would not be until 1981 before the first camera with built-in CCD appeared on the market. Not withstanding its bulky and primitive characteristics, when compared to contemporary cam
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eras, it initiated a more commercially oriented digitalization in the field of photography. Five years later in 1986, the first 1.4 megapixel image sensor (1.4 million pixels) arrived, and a fur
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ther nine years on in 1995, the world's 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.

Figure 4. Original notes from the Boyle and Smith's brainstorm meeting

on September 8 1969, when they made the first sketch of a CCD.
Photo: Janesick (2001) “Scientific Charge-Coupled Devices”. SPIE Press Monograph Vol. PM83, p. 4.

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With cameras equipped with image sensors instead of film, an era in the history of photography had ended. It had begun in 1839 when Louis Daguerre presented his invention of photographic film before the French Académie des Sciences.
When it comes to everyday photography, digital cameras have turned out to be a commercial success. Lately the CCD has been challenged by another technology, CMOS, or Complementary Metal Oxide Semiconductor; a technology that was 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 appli
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cations. 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.
Three years ago, CCD breached the limit of 100 megapixels, and although the image quality is not only dependent on the number of pixels, surpassing this limit is seen to have brought digital photography a further step into the future. There are those that predict that the future belongs to CMOS rather than to CCD. Others still, maintain that the two technologies will continue to