

CMOS Fundamentals

What are CMOS Image Sensors?

CMOS (pr. SEE-moss) stands for complementary metal-oxide semiconductor, the architecture of most computer CPUs and memory modules. Image sensors are silicon chips that capture and read light. High-performance CMOS image sensors use "active-pixel" architectures invented at NASA's Jet Propulsion Laboratory in the mid 1990s. They can perform camera functions on-chip.

CCD vs. CMOS IMAGE SENSORS

Until recently, CCDs were the only image sensors used in digital cameras. Over the years they have been well developed through their use in astronomical telescopes, scanners, and video camcorders. However, there is a new challenger on the horizon, the CMOS image sensor that may eventually play a significant role in some parts of the market. Let's compare these two devices.

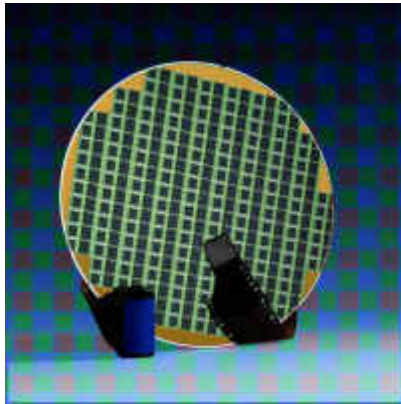
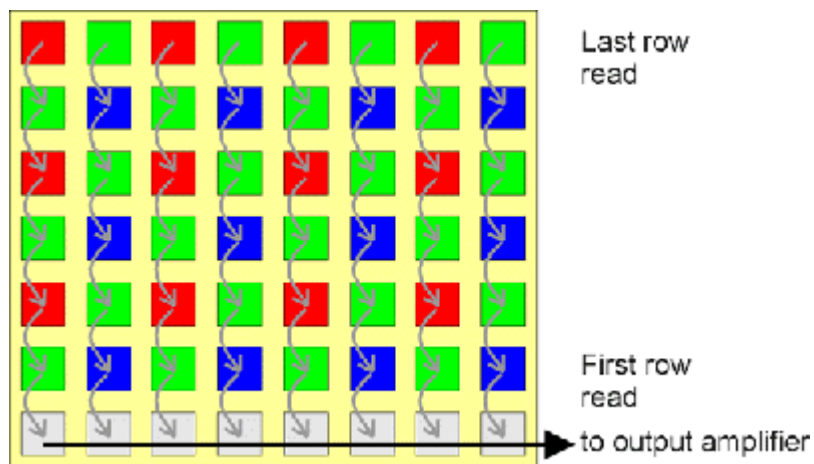


Image sensors are formed on silicon wafers and then cut apart. Courtesy of [IBM](#).

Both CMOS and CCD imagers are constructed from silicon. This gives them fundamentally similar properties of sensitivity over the visible and near-IR spectrum. Thus, both technologies convert incident light (photons) into electronic charge (electrons) by the same photoconversion process. Both technologies can support two flavors of photo element - the photogate and the photodiode. Generally, photodiode sensors are more sensitive, especially to blue light, and this can be important in making color cameras. ST makes only photodiode-based CMOS image sensors. Color sensors can be made in the same way with both technologies; normally by coating each individual pixel with a filter color (e.g. red, green, blue).

CCD Image Sensors

Charge-coupled devices (CCDs) capture light on the small photosites on their surface and get their name from the way that charge is read after an exposure. To begin, the charges on the first row are transferred to a **read out register**. From there, the signals are then fed to an amplifier and then on to an **analog-to-digital converter**. Once a row has been read, its charges on the read-out register row are deleted. The next row then enters the read-out register, and all of the rows above march down one row. The charges on each row are "coupled" to those on the row above so when one moves down, the next moves down to fill its old space. In this way, each row can be read—one row at a time.



The CCD shifts one whole row at a time into the readout register. The readout register then shifts one pixel at a time to the output amplifier.

CCD technology is now about 25 years old. Using a specialised VLSI process, a very closely packed mesh of polysilicon electrodes is formed on the surface of the chip. These are so small and close that the individual packets of electrons can be kept intact whilst they are physically moved from the position where light was detected, across the surface of the chip, to an output amplifier. To achieve this, the mesh of electrodes is clocked by an off-chip source.

It is technically feasible but not economic to use the CCD process to integrate other camera functions, like the clockdrivers, timing logic, signal processing, etc. These are therefore normally implemented in secondary chips. Thus most CCD cameras comprise several chips, often as many as 8, and not fewer than 3. Apart from the need to integrate the other camera electronics in a separate chip, the achilles heel of all CCD's is the clock requirement. The clock amplitude and shape are critical to successful operation. Generating correctly sized and shaped clocks is normally the function of a specialised clock driver chip, and leads to two major disadvantages; multiple non-standard supply voltages and high power consumption. It is not uncommon for CCD's to require 5 or 6 different supplies at critical and obscure values. If the user is offered a simple single voltage supply input, then several regulators will be employed internally to generate these supply requirements. On the plus side, CCD's have matured to provide excellent image quality with low noise. CCD processes are generally captive to the major manufacturers.

History The CCD was actually born for the wrong reason. In the 1960s there were computers but the inexpensive mass-produced memory they needed to operate (and which we take for granted) did not yet exist. Instead, there were lots of strange and unusual ways being explored to store data while it was being manipulated. One form actually used the phosphor coating on the screen of a display monitor and wrote data to the screen with one beam of light and read it back with another. However, at the time the most commonly used technology was bubble memory. At Bell Labs (where bubble memory had been invented), they then came up with the CCD as a way to store data in 1969. Two Bell Labs scientists, Willard Boyle and George Smith, "started batting ideas around," in Smith's words, "and invented charge-coupled devices in an hour. Yes, it was unusual—like a light bulb going on." Since then, that "light bulb" has reached far and wide. Here are some highlights:

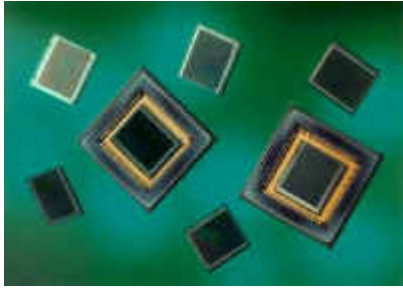
- In 1974, the first imaging CCD was produced by Fairchild Electronics with a format of 100x100 pixels.
- In 1975, the first CCD TV cameras were ready for use in commercial broadcasts.
- In 1975, the first CCD flatbed scanner was introduced by Kurzweil Computer Products using the first CCD integrated chip, a 500 sensor linear array from Fairchild.
- In 1979, an RCA 320x512 Liquid Nitrogen cooled CCD system saw first light on a 1-meter telescope at Kitt Peak National Observatory. Early observations with this CCD quickly showed its superiority over photographic plates.
- In 1982, the first solid state camera was introduced for video-laparoscopy.

CMOS Image Sensors

Image sensors are manufactured in wafer foundries or fabs. Here the tiny circuits and devices are etched onto silicon chips. The biggest problem with CCDs is that there isn't enough economy of scale. They are created in foundries using specialized and expensive processes that can only be used to make CCDs.

Meanwhile, more and larger foundries across the street are using a different process called **Complementary Metal Oxide Semiconductor** (CMOS) to make millions of chips for computer processors and memory. This is by far the most common and highest yielding process in the world. The latest CMOS processors, such as the Pentium III, contain almost 10 million active elements. Using this same process and the same equipment

to manufacturer **CMOS image sensors** cuts costs dramatically because the fixed costs of the plant are spread over a much larger number of devices. (**CMOS** refers to how a sensor is manufactured, and not to a specific sensor technology.) As a result of this economy of scale, the cost of fabricating a CMOS wafer is lower than the cost of fabricating a similar wafer using the more specialized CCD process.



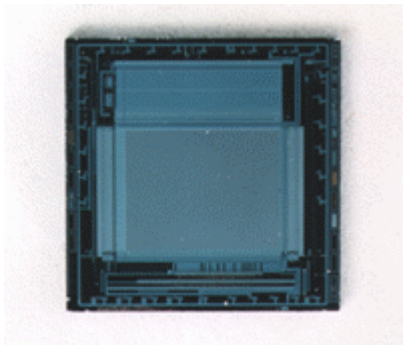
VISION's 800 x 1000 color sensor provides high resolution at lower cost than comparable CCDs. Image courtesy of [VISION](#).

Passive- and Active-pixel sensors

There are two basic kinds of CMOS image sensors—passive and active.

- **Passive-pixel sensors** (PPS) were the first image-sensor devices used in the 1960s. In passive-pixel CMOS sensors, a photosite converts photons into an electrical charge. This charge is then carried off the sensor and amplified. These sensors are small—just large enough for the photosites and their connections. The problem with these sensors is noise that appears as a background pattern in the image. To cancel out this noise, sensors often use additional processing steps.
- **Active-pixel sensors** (APSs) reduce the noise associated with passive-pixel sensors. Circuitry at each pixel determines what its noise level is and cancels it out. It is this active circuitry that gives the active-pixel device its name. The performance of this technology is comparable to many charge-coupled devices (CCDs) and also allows for a larger image array and higher resolution.

Inexpensive CMOS chips are being used in low-end digital cameras. There is a consensus that while these devices may dominate the low-end of the camera market, more expensive active-pixel sensors will become dominant in niches.



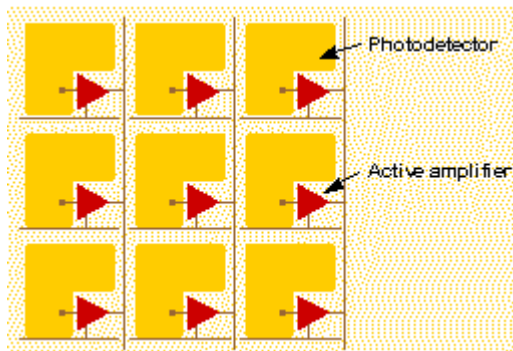
Toshiba Corporation fabricates a 1,300,000 pixel complementary metal oxide semiconductor (CMOS) image sensor. Courtesy of [Toshiba](#).

CMOS image sensor facts

Here are some things you might like to know about CMOS image sensors:

- CMOS image sensors can incorporate other circuits on the same chip, eliminating the many separate chips required for a CCD. This also allows additional on-chip features to be added at little extra cost. These features include anti-jitter (image stabilization) and image compression. Not only does this make the camera smaller, lighter, and cheaper; it also requires less power so batteries last longer. It is technically feasible but not economic to use the CCD manufacturing process to integrate other camera functions, such as the clock drivers, timing logic, and signal processing on the same chip as the photosites. These are normally put on separate chips so CCD cameras contain several chips, often as many as 8, and not fewer than 3.

- CMOS image sensors can switch modes on the fly between still photography and video. However, video generates huge files so initially these cameras will have to be tethered to the mothership (the PC) when used in this mode for all but a few seconds of video. However, this mode works well for video conferencing although the cameras can't capture the 20 frames a second needed for full-motion video.
- While CMOS sensors excel in the capture of outdoor pictures on sunny days, they suffer in low light conditions. Their sensitivity to light is decreased because part of each photosite is covered with circuitry that filters out noise and performs other functions. The percentage of a pixel devoted to collecting light is called the pixel's **fill factor**. CCDs have a 100% fill factor but CMOS cameras have much less. The lower the fill factor, the less sensitive the sensor is and the longer exposure times must be. Too low a fill factor makes indoor photography without a flash virtually impossible. To compensate for lower fill-factors, micro-lenses can be added to each pixel to gather light from the insensitive portions of the pixel and "focus" it down to the photosite. In addition, the circuitry can be reduced so it doesn't cover as large an area.



Fill factor refers to the percentage of a photosite that is sensitive to light. If circuits cover 25% of each photosite, the sensor is said to have a fill factor of 75%. The higher the fill factor, the more sensitive the sensor. Courtesy of [Photobit](#).

- CMOS sensors have a higher noise level than CCDs so the processing time between pictures is higher as these sensors use digital signal processing (DSP) to reduce or eliminate the noise. The DSP is one early camera (the Svmimi), executes 600,000,000 instructions per picture.

IMAGE SIZES

The quality of any digital image, whether printed or displayed on a screen, depends in part on the number of pixels it contains. More and smaller pixels add detail and sharpen edges.

