OEMs: EXPAND YOUR PRODUCT PORTFOLIO WITH sCMOS SENSORS

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For decades, high-end digital imaging has been commonplace in science and engineering. Technology has allowed researchers in biology, biomedicine, physics, astronomy, materials science, and other fields to measure and record experiments and tests for later detailed analysis.

And like any other technology, the imaging equipment researchers have come to depend on has changed with the times. The most foundational aspect — the semiconductor sensors that collect images — has seen massive improvements in sensitivity, speed, dynamic range, and resolution. Sensors have advanced in the form of charge-coupled devices (CCD) and complementary metal-oxide semiconductors (CMOS), with CMOS seeing a more recent and rapid progression in technology.

But original equipment manufacturers (OEMs) that integrate cameras and, therefore, sensors into their products have frequently stayed with older versions of technology.

This may in part owe to habit, as engineers can become comfortable with components they know well and prefer to use them. Another reason for staying with older technology might be a misunderstanding about how newer versions have become price competitive. Or engineers and product designers may not realize the developments in advanced sensor capabilities.

For all those reasons, it makes sense for OEMs to step back, look at the most modern sensor technology (scientific CMOS, or sCMOS), and consider how its capabilities could enhance their products and attract customers. A bonus is that in many applications, the more advanced sensors and cameras cost no more, and often less, than the older technologies OEMs currently use.

CCD-BASED SOLUTIONS

The CCD was initially developed in 1969 at AT&T Bell Labs and is still commonly used for imaging applications. A semiconductor is produced that has tiny light-sensitive spaces called pixels. When photons impinge onto the surface of a pixel, the semiconductor generates and then stores a proportionate number of electrons in an area of the pixel called a well. The higher the intensity of the light, the more photons strike the surface, and the more electrons are released and then collected.

After the sensor is exposed to light, the CCD shifts rows of these packages of electrons to one edge of the sensor. At the edge, an analog-to-digital (A-to-D) converter changes the total charge of the electrons into a predetermined associated digital value. Eventually, the CCD has turned all the electrons that were formerly captured in wells into a pattern of digital levels. Software then transforms the final array of digital levels into an image.

Unfortunately, the basic design of CCD sensors meant they had to be used in a pick-two-out-of-three strategy: Given high speed, high resolution, and high sensitivity, designers and engineers could choose two out of the three.

Binning, or grouping together pixels on the sensor for processing, provided high speed and sensitivity but at the expense of high-spatial resolution. Cropping — cutting down the area on the sensor used for an application — provided speed and high-spatial resolution. However, it still had a decreased field of view and lacked an increase in sensitivity. Long exposures provided sensitivity and high resolution, but not speed.

A variation of CCD called electron multiplying CCD (EMCCD) can increase sensitivity up to a thousand-fold, but at the cost of dynamic range. That, in turn, could interfere with observation and analysis. The solution generally worked at slower speeds and came with a high price tag and the need for frequent maintenance due to the nature of the amplification process.

MORE FLEXIBILITY WITH CMOS

To attain more flexibility, researchers began to use versions of CMOS image sensors, originally developed at NASA's Jet Propulsion Laboratory in the 1990s and now prevalent in consumer electronics like cell phone cameras, helping to fuel the technology improvements. Each pixel has transistors that amplify the signal of the electrons collected in the pixel's well. Also, each column has its own A-to-D converter rather than waiting for its turn at the single converter on a CCD sensor. That allows a CMOS sensor to process images much more quickly. Because of the greater volume afforded by the consumer electronics industry, CMOS sensors are in many cases less expensive than CCDs.

The sCMOS sensor, a variation developed 10 years ago, is even more well-suited to scientific applications. This new generation of sensor offers important advantages. An sCMOS sensor has lower inherent noise and higher quantum efficiency, or the percentage of photons striking the sensor that result in the generation of an electron. The combination offers greater sensitivity to low light levels. In addition, sCMOS offers a larger field of view, increased frame rates, higher resolution, and greater dynamic range.

A newer development in CMOS sensors is the change from what is called front or front-side illumination to back or backside illumination. (There is a similar approach for CCD sensors called back-thinned.)

In front illumination, light passes through the pixel, where layers of embedded transistors and other electronics reside, before eventually striking the silicon photodiode, where light is converted to electronic charges. The configuration absorbs or reflects a significant number of photons, reducing the sensors' sensitivity.

A back-illuminated sensor is essentially flipped 180 degrees, so it has light entering from the other side. Because there are no electronic components between the light source and the photodiode, more photons can be utilized to generate electrons, making the sensor more sensitive. As a result, the newest sCMOS cameras, as developed by PCO, can achieve quantum efficiencies of 95 percent and also offer 16-bit dynamic range to capture more information than the human eye can recognize without aid.

CHOOSE BETWEEN CCD AND sCMOS

CCD and EMCCD sensors still have a place in scientific imaging, especially where a longer exposure and lower dark current is required. EMCCD sensors are particularly good for extreme low-light imaging, astronomy, and both bioluminescence and chemiluminescence. They can cost between $25,000 and $40,000.

On the other hand, back-illuminated sCMOS cameras, which run between ~$10,000 and $30,000, excel at total internal reflection fluorescence microscopy, super-resolution or spinning disk microscopy, general fluorescence, and live-cell imaging. Not only does improved performance address such areas, but the sensors come at a price that makes them more cost-effective.

While in many applications sCMOS sensors offer better performance, features, and price, many staff scientists, product managers, and chief science officers at life science and physical science related companies have not fully realized the advantages they could gain.

There are some additional practical considerations in a choice between CCD and sCMOS. The latter requires more power and, in the process, generates more heat than CCD sensors, which could necessitate a cooling strategy for system integration.

If an application requires binning, which is the process of combining pixel signals to increase signal-to-noise ratio or decrease data volumes with the trade-off of lower resolution, the two types of devices perform the operation differently. A CCD performs binning in hardware on the sensor itself before digitization, while sCMOS does so with software, after the digitization step. The difference means CCD binning can offer both a better signal-to-noise ratio and speed, while sCMOS binning typically results in only lower spatial resolution and smaller file sizes.

MAKING THE SHIFT TO sCMOS

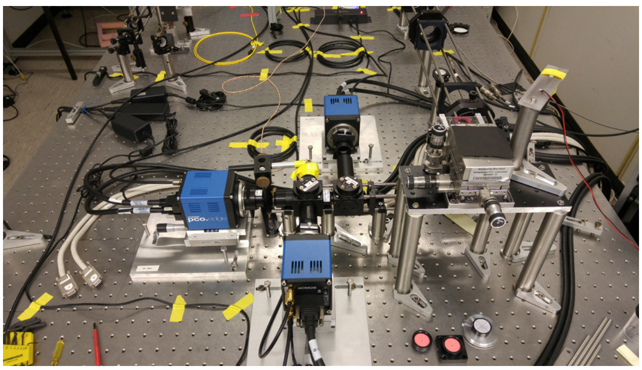
Although sCMOS is nearing 10 years old, that is a relatively short time in the adoption of imaging technology. The changes have been so relatively recent and swift, it is understandable how many OEMs have not yet adopted the devices.

Some OEMs, though, have more likely avoided sCMOS sensors because they have misperceptions about the difficulty of switching from CCD. The transition is not nearly as technically challenging as it would seem. Image data remains in the same format (generally TIFF), which most applications support. The files can be larger than those from an equivalent CCD device, due to the potentially higher frame rates and array sizes, and so may require more memory and storage schemes than before, but they as well enable higher throughputs.

Companies like PCO have developed extensive and sophisticated sets of drivers to support a wide variety of OEM applications. If no compatible driver is available, the design of a custom driver is possible. A free software developer's kit then handles any complexities of the switch and allows rapid integration with existing software.

In addition, product managers should remember that increased speed, sensitivity, and resolution are important to their customers and can provide competitive advantages.

For more information on sCMOS sensors and cameras, visit www.pco-tech.com and direct any inquiries to info@pco-tech.com.



Experimental set-up for structured illumination microscopy (SIM) simultaneously with three different fluorescent markers using three sCMOS cameras. The researchers named this set-up fairSIM (https://www.fairsim.org/). They achieved a very fast image processing and display.
-Courtesy of Prof. Thomas Huser, University of Bielefeld, Germany