X-ray Technology Bets on the Blue Chips

CCDs are available for most applications, each with its own unique requirements. With new applications appearing almost daily, CCD makers must find improved processes and designs to make their imagers better fit customers' needs...

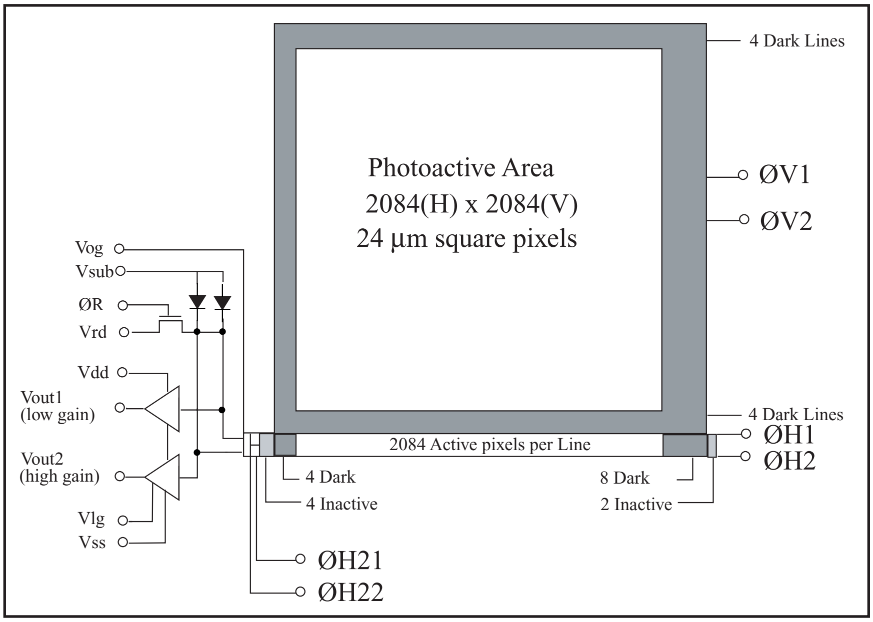

Figure 1: CCD Sensor Functional Diagram—Many imaging apps require a large format full-frame transfer style CCD image sensor. Fewer clocks are required for true two-phase sensors, compared to three and four-phase. (Photo: William Des Jardin, et al.)

by Keith Wetzel

Critical parameters common to all CCD chips include resolution, dynamic range, quantum efficiency (QE), responsivity (sensitivity), readout speed, and dark current. Some parameters, however, are more critical for certain applications than for others. For example, CCD chips for astronomy require a large dynamic range, high S/N ratio and low dark current over a wide color spectrum. This is necessary in order to detect a faint star as well as a bright cluster without saturating the photosensitive pixels.

Medical diagnostics CCDs, on the other hand, receive images from an X-ray scintillation plate that emits predominantly green and blue light. The CCD should have the highest QE and sensitivity in this band and a sufficient resolution in order to find the smallest pathogen possible in the X-ray image.

THREE BASIC TECHNOLOGIES

CCD manufacturers have unique, proprietary processes, designs and materials intended to maximize these parameters and help keep the firms competitive—which is, of course, a benefit to users. Kodak, for example, has been in the CCD business for decades and has developed two basic architectures: full frame and interline. Full-frame CCDs make the entire image-capturing surface active for light sensing, charge storage and image readout.

This makes the fill factor—the ratio of active to inactive pixel area—100%, so the entire pixel area is light sensitive. Strobe lights that illuminate the subject or mechanical shutters typically determine the exposure time for these sensors. By contrast, interline CCDs partition each pixel into an image-active area and an opaque charge-transport area. This allows for electronic exposure control, but because the active pixel area shares space with the inactive area, the fill factor for interline imagers is much lower, as little as 20%. In a standard full-frame CCD architecture, two or more polysilicon gates are placed over each pixel. The polysilicon absorbs some light and limits the QE (ability of a sensor to convert light into electrical energy).

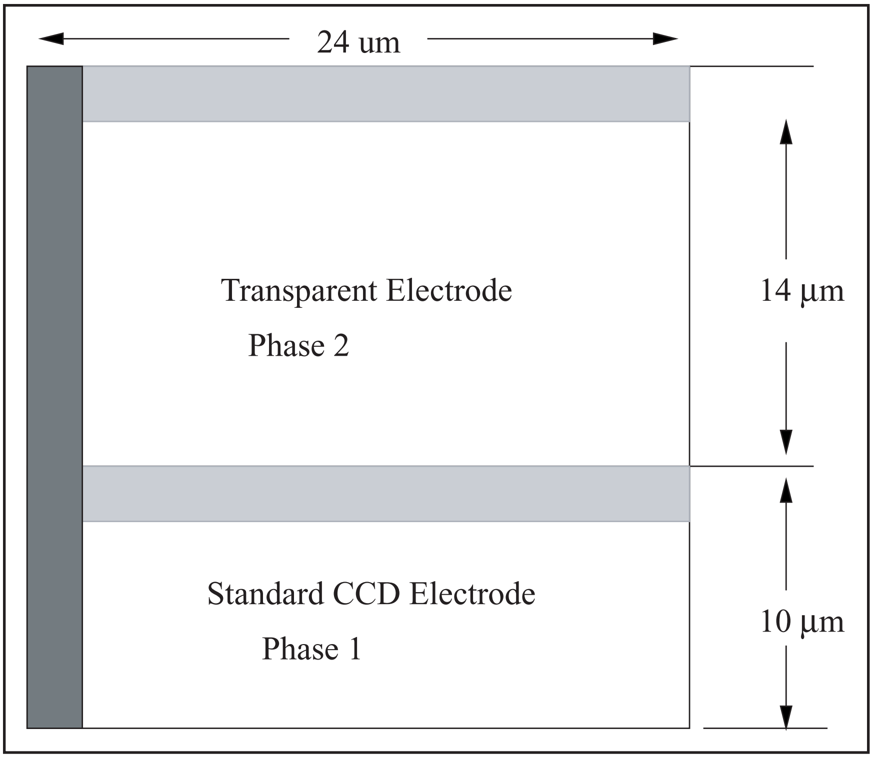

Figure 2: Details of Pixel Design—The transparent gate process replaces the second polysilicon gate with indium-tin-oxide and improves the spectral response. (Photo: William Des Jardin, et al.)

In a move to increase the sensitivity of the full-frame CCD chip, Kodak replaced one of the polysilicon gates with a higher sensitivity material called indium-tin-oxide (or ITO) and named this technology Blue Plus. This technology, according to the manufacturer, offers nearly a 50% improvement in QE at 550 nm, an important wavelength in medical X-ray, with a near 2X improvement in QE when integrating light over the entire visible spectrum.

Kodak Blue Plus CCDs produce larger signals in the blue and green band, and increase overall responsivity with higher S/N ratios as compared to sensors without ITO. Kodak is still in development with the Blue Plus line and will offer further improvements in QE in the near future.

A third CCD technology used by some scientific CCD manufacturers is called back-side illumination. These CCDs were developed to increase sensitivity and are intended for demanding applications that require reliable performance, where cost is not an important factor. The chips are polished on the back-side to remove most bulk silicon and are imaged through the back surface. Because the polysilicon gates are on the opposite side, they do not interfere with the sensor's QE. This type of imager costs more to develop, is difficult to manufacture and tends to have higher dark current than front-illuminated CCDs like th Blue Plus.

MEDICAL X-RAY SYSTEMS

The continuously escalating cost of health care is driving medical equipment makers to find less expensive ways to make their products without sacrificing new technology breakthroughs that can benefit patients. And X-ray imaging systems are among the diagnostic instruments getting a lot of attention.

Traditional X-ray machines use film for capturing the image and are still widely used, even after 100 years—principally because of their low initial capital cost.

A scintillation screen in the film cassette emits light when the X-rays hit it projecting the image onto the film plate. While film systems are inexpensive, several exposures of a patient may be required to ensure that a reliable picture with enough detail has been recorded. These additional exposures increase the amount of time needed to process a patient and increase the patient X-ray dose. The advent of an X-ray camera using CCD technology to replace the film cassette now allows

Figure 3: CCD Sensors in Astronomy—Long exposures with blue camera lens filters obtain correct color balance for full-color photos, but exposure times can be reduced with Blue Plus CCDs because of increased sensitivity at this wavelength. (Photo: Kodak)

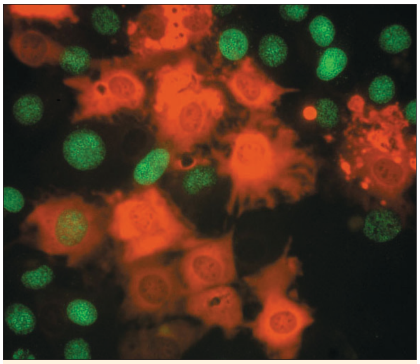

Figure 4: CCD Sensors in Biology—Fluorescent dyes monitor calcium activity in cells for DNA sequencing, excited with UV lights to make them visible. Blue Plus CCDs are highly sensitive to detecting the faint signals emitted, and exposure times are low. (Photo: Kodak)

the radiologist to view the image immediately on a CRT screen eliminating the need for unnecessary X-ray exposures and increasing the number of patients a radiology department can process. This new technology is often called digital radiography or direct digital radiography, ddR.

Kodak's full-frame Blue Plus line is geared toward digital radiography X-ray imaging because of its high QE in the green and blue spectrum (540 nm), the predominate band of light provided by the scintillation plate. High QE chips require relatively short exposure times for high quality images.

Swissray, a Swiss X-ray firm with offices in Elmsford, N.Y., developed an X-ray machine based on Blue Plus CCD technology. The company uses a modular approach to designing the camera.

Swissray exposes an array of four sensors in symmetrical quadrants that merge into one image. Each of the four CCDs images one scintillator quadrant with a 10% overlap to adjacent quadrants. The final image is a single composite of the four overlapping images without a seam or dead zone between quadrants. The assembly comprises a modular frame that can be field replaced. This offers an advantage in another regard: the ability to upgrade the camera when lower noise, higher resolution and higher QE chips become available.

All told, such enhancements allow for relatively fast and economical changes in the field, including adjustments and upgrades to its signal processing circuits. Replacing a module is less expensive and quicker than having to scrap an entire digital detector. The use of standard off-the-shelf components is key. For example, Kodak CCDs are manufactured using standard integrated circuit (IC) wafer processing, a relatively inexpensive process. Kodak uses the same manufacturing facility to create imagers for multiple markets including digital still cameras, machine vision, scanners, and others.

The Blue Plus line is helping X-ray manufacturers reach their goal of achieving quality images at low radiation dosages. Swissray reports that doses administered with their equipment are substantially less than computerized radiography and other digital radiography imaging technologies. The company's direct digital radiography system using high-resolution CCDs with high QE offer such new benefits as simultaneous display of bone and soft tissue with image quality improvement in the extremities and chest images, where mediastinal and peripheral lung structures are both seen.

Kodak full-frame CCDs use a proprietary true 2-phase architecture. Kodak KAF-1301E CCD pixels measure 16 micrometers on a side and contain two gates per pixel, a polysilicon gate called phase 1 and an ITO gate called phase 2. The ITO material replaces the second level of polysilicon typical in previous designs. Horizontally running barrier regions implanted under a portion of each gate isolate the vertically aligned pixels during image integration and readout.

Horizontally aligned pixels are isolated with a vertical field or channel stop region. Each pixel is 100% photoactive, and each frame contains 1280 by 1024 pixels. The total device area measures 16.5 by 11.4 mm, and is housed in a 24-pin DIL ceramic package.

One key advantage to this technology is the manufacturing efficiencies produced by true 2-phase architecture. As pixel sizes shrink, the true 2-phase architecture demands less from photolithography processes than 3 or 4-phase devices. ◆

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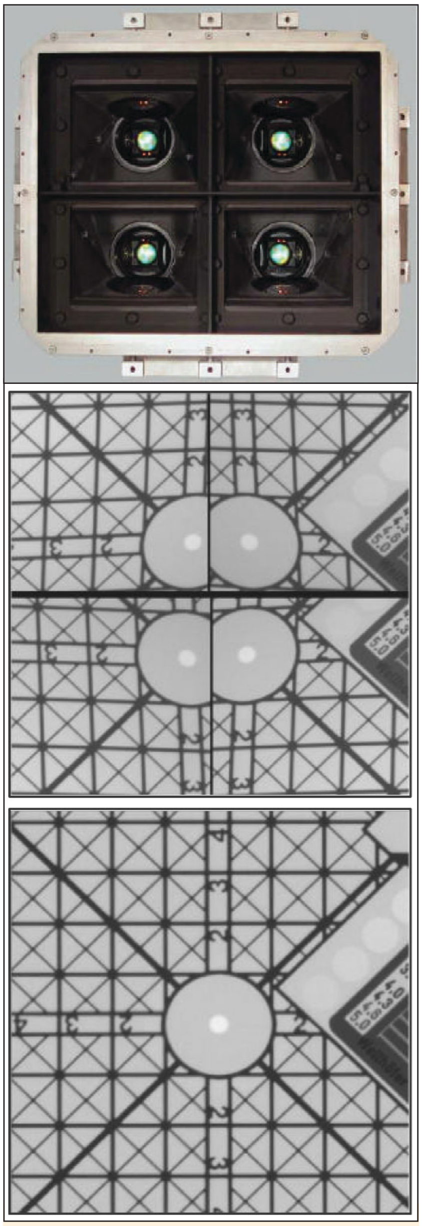
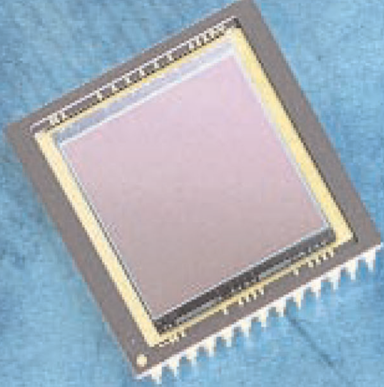


Figure 5: Swissray Digital Optical Detector—This digital optical design detector (above) uses mirror optics to focus four high-res CCD cameras on a cesium iodide scintillator screen. Each full-frame CCD with 100% fill factor captures the image of one scintillator quadrant with 10% overlap. The final image (below) composites the four images without a seam or dead zone. (Photo: Rex Harmon, SwissRay International)



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The Blue Plus Image Sensor significantly boosts response in the blue, and also in the green, yellow and red portions of the spectrum. In fact, with responsivity as low as 300 nm, the Blue Plus Image Sensor delivers Kodak's highest QE ever... along with the robustness of a front-illuminated architecture!

The bottom line? Blue Plus Image Sensors provide more imaging options—with fewer compromises*.

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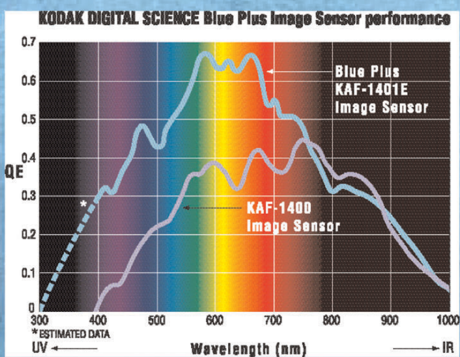
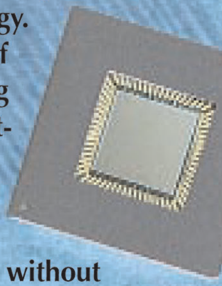


Key to the breakthrough performance of the Blue Plus Image Sensor is its new transparent gate technology. Instead of absorbing or reflecting light, more light is captured without increasing the image sensor noise.



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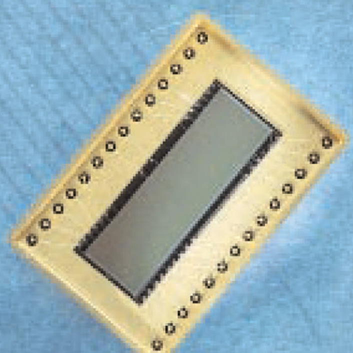

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*As compared to KODAK DIGITAL SCIENCE KAF-1400 Image Sensor.