

# Applications Hold the Key to Imager Choice

by Elizabeth M. Lockyer  
Staff Editor

**Application requirements guide users through an alphabet soup of sometimes contradictory imaging technologies.**

**U**nless you know what questions to ask, selecting the right imaging technology for your application can seem more like a crapshoot than a reasoned choice. Worse, it can become an outright nightmare for those unfamiliar with the intricacies of solid-state imaging science.

Besides the multitude of charge-coupled devices (CCDs) available today — themselves difficult to compare without meaningful universal standards — buyers must confront charge-injection devices (CIDs), complementary metal-oxide semiconductor (CMOS) technology and at least one hybrid device. The dilemmas: Are the application strengths for each technology clear? Will one work just as well as another? Will the technologies eventually merge, eliminating the need to choose one over the other? Will whatever choice I make be the right one?

"Each imaging application has parameters to ask about," said Michael McCreary,

assistant general manager of Eastman Kodak, a major CCD manufacturer. "Basically, regardless of the application, there are three global questions: performance, cost and availability."

## Quality, speed and power

Imaging experts — even those who do not manufacture or sell CCDs — agree that CCD image quality is the benchmark for other technologies; when high resolution is the key to an application, the CCD is the

premier choice. For years these detectors have dominated the imaging market, but now other technologies are muscling their way onto the scene. An example is CMOS technology.

"The CMOS vs. CCD problem is a human nature problem; politics, competition and money — that's the unfortunate part," said James Janesick, vice president and chief scientific officer of Pixel Vision Inc. in Huntington Beach, Calif. "It's not simply a black-and-white issue."

Janesick added, "CMOS can't compete with CCDs in the number of pixels, quantum efficiency and noise. Furthermore, CMOS has more pixel inconsistency, that is, pixels that are more sensitive than others. CCD pixels show more uniformity, so in a CMOS camera you see a lot of graininess because the address lines are affecting the sensitivity. You'll see less

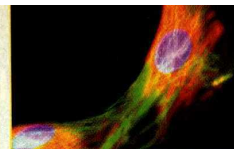
Characteristic	CID	CCD	CMOS (APS)
Pixel Size	★	★★	★
Readout Noise		★★	★★
Fill Factor	★	★★	★
Dynamic Range		★	★★
Quantum Efficiency for Silicon (0.4 - 1.1 μm)	★	★	★
Radiation Hardness	★★		★
System Power	★		★★
System Mass	★	★	★★
System Volume	★	★	★★
Electronic Shutter		★	★★
Electronic Windowing	★★		★★
Electronic Zoom	★★		★★
On-Chip Analog-to-Digital Converter			★★
On-Chip Timing/Control			★★

APS = Active Pixel Sensor  
★★ = excellent, ★ = good, blank = not good

Source: Photobit



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graininess on the CCD image."

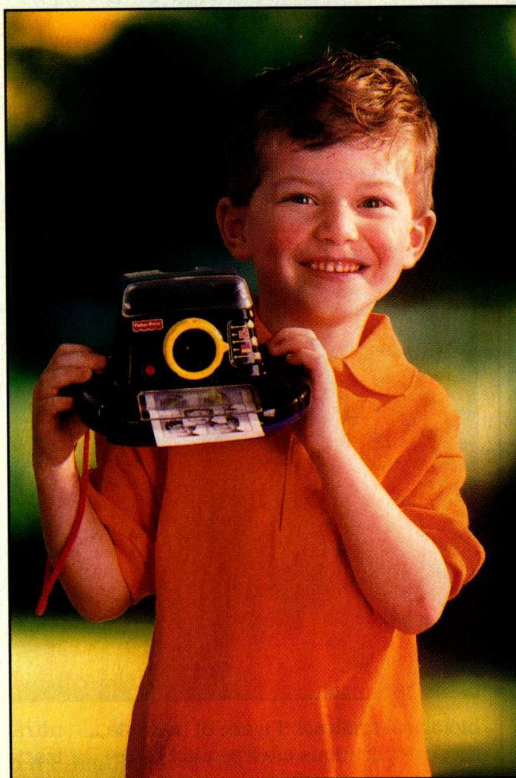
What the CMOS industry touts as an advantage — more circuitry packed on a chip — Janesick belittles as a roadblock: "The more garbage you put in a pixel, the greater the chance of it not working. CMOS hasn't really gone through the scrutiny that CCDs have. Much of the evaluation has been biased because it's been done by the companies that work on the technology."

Much of CMOS (active-pixel) technology is still in the development stage. Indeed, critics maintain that the industry is not to the point where customers can just call up and order 1000 chips.

#### Chips abound — almost

Peter Denyer, managing director of VLSI Vision Ltd. of Edinburgh, UK, disagrees on the availability of CMOS chips. "In fact we do very high volume production of CMOS chips," said Denyer. "We may be one of the few companies that are doing it, but an order of 500 active-pixel CMOS chips would not be a problem. Last year we produced nearly one million. They were used mostly in domestic security products, toys and PC video applications, but there are no real technological limits that would prevent their being used in high-end scientific applications in the future. Both CMOS and CCDs sense light with silicon, so fundamentally there isn't a technological limitation there."

The primary difference between CCDs and charge-transfer devices (which include CIDs and CMOS devices) is that in CCDs, photoelectrically generated charge packets move sequentially to an amplifier. CMOS and CID technology, on the other hand, can access specific pixel information without reading out the whole image, an important feature for applications such as missile tracking and some rapid inspection applications that cannot wait to read an image pixel by pixel.

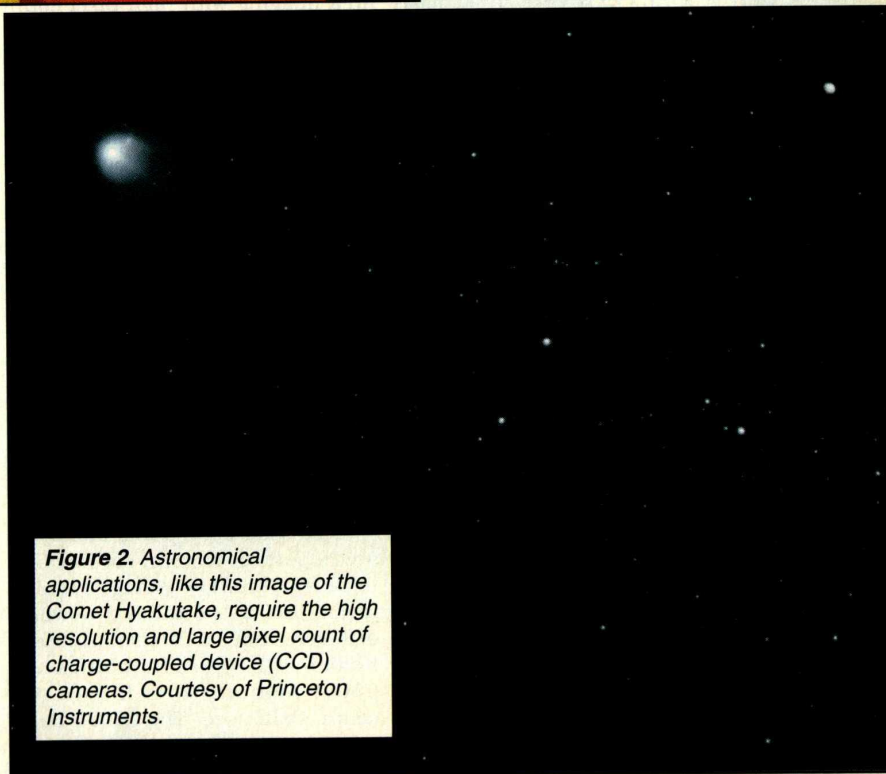


CMOS technology is the basic stuff of computers, and it promises high levels of integration. Its chips can accommodate added circuitry, offer cost advantages in high-volume production and operate at very low voltages (5 V or less, whereas CCDs in modern camcorders require 10 to 30 V). Experts expect the CMOS devices will find their way into electronic imaging applications and high-volume consumer applications such as video-conferencing for PCs and digital still cameras (Figure 1).

#### Star struck

CCDs dominate high-end scientific imaging applications like astronomy (Figure 2) as well as

**Figure 1.** Complementary metal-oxide semiconductor (CMOS) detectors have found some early success in low-end applications, such as the Creative Effects Instant Camera from Fisher-Price. Courtesy of VLSI Vision Ltd.



**Figure 2.** Astronomical applications, like this image of the Comet Hyakutake, require the high resolution and large pixel count of charge-coupled device (CCD) cameras. Courtesy of Princeton Instruments.



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**Figure 3.** Biologists need a CCD's high resolution to discern fluorescently labeled fibroblasts. Courtesy of the Fryer Co. and Princeton Instruments.

biological analysis (Figure 3) because those applications often require large-area imaging with high pixel count and long integration periods.

"If your goal is to take direct images of Halley's comet or of the stars, you may want to use a CCD because of its lower noise baseline," said Joseph Carbone of CID Technologies Inc. in Liverpool, N.Y.

In addition to its Earth-bound astronomical applications, the CCD has long owned the lion's share of imaging applications aboard satellites and other space-borne devices. However, as radiation became more of a factor, CCDs came under scrutiny and industry looked to CMOS for its low-voltage requirements and its radiation-hard qualities. For this, CMOS is now earning consideration in the most far-flung applications.

"On a spaceship, power and space are important factors, so CMOS — because of its low voltage requirements and its portability — would definitely be favored," said Sabrina E. Kemeny, CEO of Photobit Inc., a CMOS manufacturer in La Crescenta, Calif. (see "The CMOS Saga" on page 84). "NASA is now [testing] a CMOS sensor because of its

ultralow power needs and miniaturization — two factors that are important to their space information gathering."

CID and CMOS technologies offer advantages in other scientific imaging applications as well. In CID technology, for example, the charge remains intact at each pixel even after it has been read out; thus, a user can read pixels more than once. Unfortunately, the structure that enables this type of nondestructive random readout also creates more noise, so the CID's baseline noise is not as low as a CCD's (or even a CMOS'). But in applications where noise is not an issue, CIDs are very efficient.

#### Noise is not the real issue

For example, Thermo Jarrell Ash Corp. of Franklin, Mass., employs a CID detector in its plasma optical emission mass spectrometer. The device views a sample's entire emission spectrum simultaneously, using an eschelle optical design to focus a high-resolution two-dimensional image onto the detector's surface. Reading out the light at specific areas of the detector, the device can identify the primary elemental

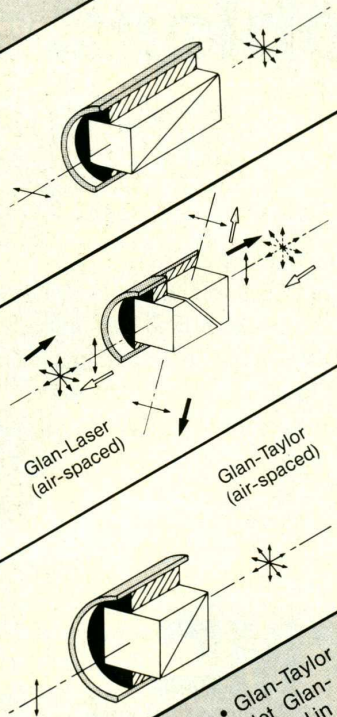
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### The CMOS Saga

Within CMOS technology there are three options: two types of active-pixel sensors and a passive-pixel sensor, which is a photodiode with a pass transistor. The term active pixel, which originated in Japan, refers to any pixel that has an active element — at least one amplifier.

"Passive pixel is what gave CMOS a bad name," said Sabrina Kemeny, CEO of Photobit Inc. in La Crescenta, Calif. "It generated poor-quality black-and-white images that critics of the technology still hold on to."

#### Enter active-pixel sensors

The active-pixel sensor uses very large scale integration to incorporate all necessary camera functions onto one chip. Each pixel contains not only the photodetector element, but also active transistor circuitry for reading the pixel signal. Unlike CCDs, which need to add antiblooming circuitry, the CMOS active-pixel sensor is inherently not

prone to blooming (charge leaking from one pixel to another) in the face of a very bright light.

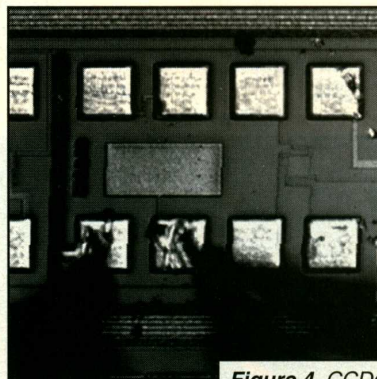
#### From whence they came

Scientists at NASA's Jet Propulsion Laboratory (JPL) developed active-pixel technology with noise performance on a par with CCDs. Eventually, some members of the JPL group left and formed Photobit to commercialize the technology.

Others firms developing CMOS technology include:

- VLSI Vision Ltd. of Edinburgh, UK, has a high-resolution color sensor for digital photography. The company says the sensor operates under normal lighting, bringing it — at least on one level — up to par with CCDs.

- Sound Vision of Framingham, Mass., introduced a CMOS active-pixel digital camera that combines Internet teleconferencing capability with portable high-quality image capture. □



**Figure 4.** CCDs are the predominant imaging detector for machine vision and inspection applications, but other technologies may make inroads. Here, a CCD images semiconductor device failure analysis. Courtesy of Princeton Instruments.

components in any sample.

Because it can provide independent access to each detector element, the detector can analyze and recalculate stored spectral information, thus reducing the number of repeat analyses made

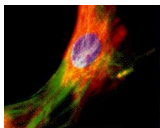
when questions arise about unusual samples.

"In spectroscopy, if you're energizing a sample to extreme temperatures with ... plasma, the temperature gets up to about the temperature of the sun," Carbone explained. "You've got a bright background. In this type of spectroscopy, sensitivity (that is, the sensor's ability to pick up light) is not an issue, so noise is not a factor because performance becomes source-limited. Then CID technology is a very efficient choice."

On the other hand, Carbone said, sensitivity is crucial in Raman spectroscopy, where the CID may not be as appropriate. "You need a very low noise level, so you'd

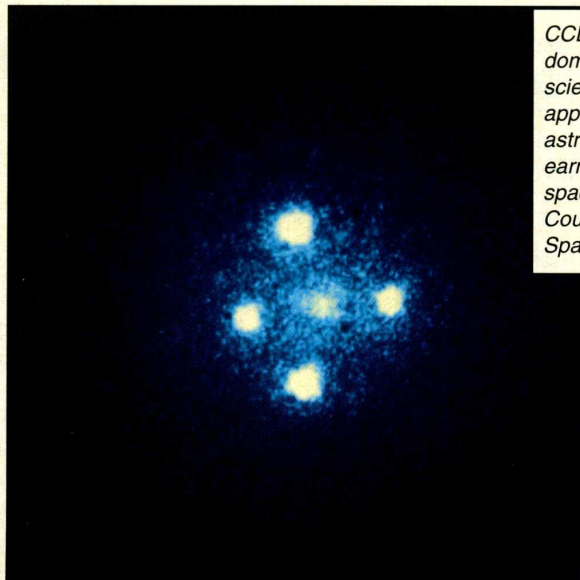
have to stick with CCDs. CID Technologies is in the process of





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*CCDs have long dominated high-end scientific imaging applications like astronomy. Now CMOS is earning consideration for space-borne applications. Courtesy of the European Space Agency.*

the spectroscopy arena as promising in the near future. However, Paul Suni, president of Suni Imaging Microsystems Inc. in Mountain View, Calif., recently commercialized a hybrid CMOS-CCD technology and

developing lower-noise CIDs to fit this application."

CMOS manufacturers do not see

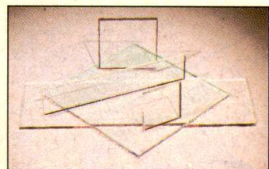
predicts that as portable spectroscopic chemical analysis grows in applications such as roadside auto

pollution monitoring, hybrid technology may offer a low-power, low-cost detection solution.

Similarly, CMOS' voltage requirements could benefit some military applications, particularly those requiring soldiers to carry battery-powered devices into the battlefield. But it is CMOS' and CID's shared ability to randomly access sections of a detector that make them a potentially important military tool.

In the so-called Star Wars technology, detectors were to track incoming missiles so that defensive missiles could intercept them high in the atmosphere. The ability to randomly access pixels is important in tracking applications because an incoming missile with an 8- to 10-in. diameter may be traveling at a speed from Mach 12 to 15. The CID's ability to read out parts of the detector — and read them quickly — becomes a greater advantage than the extra sensitivity and resolution that a CCD

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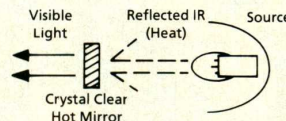


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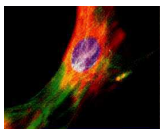
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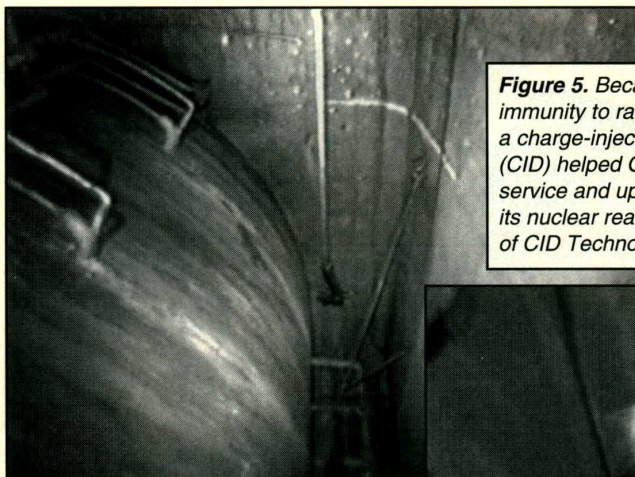
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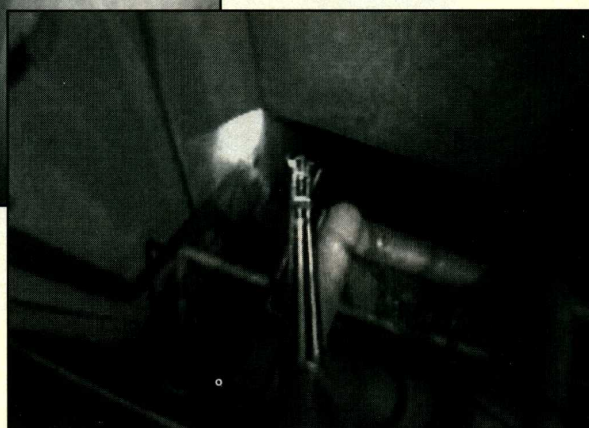
**Figure 5.** Because of its immunity to radiation effects, a charge-injection device (CID) helped Ontario Hydro service and upgrade one of its nuclear reactors. Courtesy of CID Technologies.

would offer. After all, CID boosters point out, we are not trying to read a message or serial number on the side of the missile.

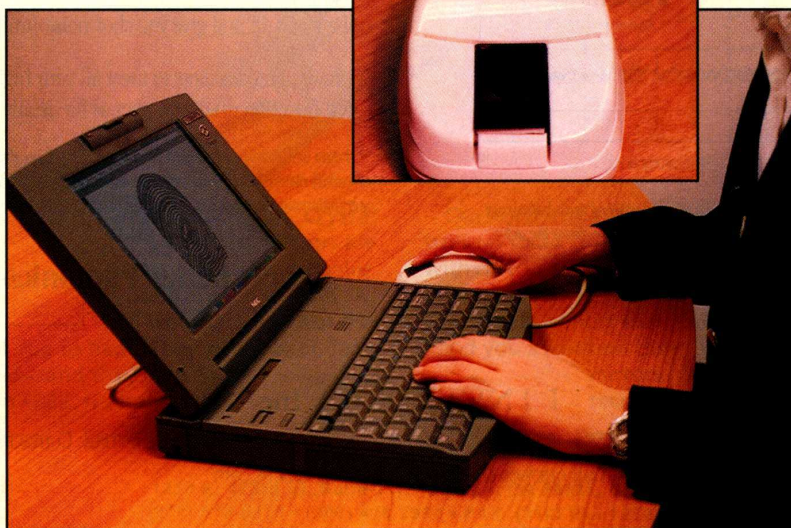
#### On top of the heap, for now

CCDs have a predominant place in the industrial machine vision market (Figure 4), and they are expected to maintain an important share of that market. Here again, however, CMOS and CID offer the potential for ultrahigh-speed inspection because of their random access abilities. According to Carbone, "CCDs are riding the coattails of commercial camcorder productions and they're expected to retain a significant portion of that market."

"With CID technology, you can electronically 'window,' " Carbone said. "This buys faster parts-rate inspection. And, there is an advantage of greater pixel accuracy because there's no embedded charge-coupled register. The



**Figure 6.** A hybrid CCD/CMOS detector enables fingerprint recognition on a computer mouse-size device for bank-at-home applications. Courtesy of Suni Imaging Microsystems.



pixels provide a truer indication of the image, which allows us to compute the position of edges and points

more accurately. The CID's pixel accuracy is also a plus with laser interferometry, where exact (subpixel) measurement of the fringe pattern is important."

Probably the main inspection area where the CCD is not the preferred choice is in radiation-harsh environments. CID and CMOS can both provide high-quality images in the

presence of high levels of radiation. (Suni notes that there are exceptions, such as intraoral dental x-ray imaging, in which radiation-hardened CCDs have been the winner over the years.)

"CCDs have been used with radiation-resistant tubes, but purportedly these

tubes will not be manufactured much longer," Carbone said.

"There is a movement to develop solid-state CCD cameras that will work in harsh radiation environments, but as it stands they can tolerate only 10 to 20 krad total dose," he said.

CID Technologies manufactures radiation-hardened cameras, designed to provide sharp, crisp video images at dose rates of 500 krad/h (gamma) and total dose capability greater than 1 million rads, a level at which CCD cameras typically cannot operate.

The company targets applications in nuclear power generation, decommissioning, monitoring and inspection (Figure 5), machine vision and process control, waste



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management and instruments for high-energy physics.

### Low-end applications

Surveillance and consumer applications have traditionally been less demanding than industrial, military and scientific applications. CCDs have dominated in this area, but with cost

and size advantages, the CMOS detector is showing some promise.

Initial consumer markets accepting CMOS images were those driven by cost; the main markets were for toys. In the future, CMOS will enable users to call home via videophone to check up on things. One current example of this technology

is the Mv-Net CMOS camera from Active Imaging of Incline Village, Nev. With a built-in video Web server, it includes all the technology needed to transport video over digital networks. In use, the system provides imagery for applications such as atmospheric studies (live video from unmanned weather stations verifies and complements instrument data) and surveillance (guards at the main facility could watch a remote plant or warehouse, or you could keep an eye on your dog at home).

Granted, the new CCD cameras are very small, but CMOS and CCD/CMOS technology can yield an even smaller camera than CCD technology alone. In addition to lower power requirements, such a camera could be more economical because it would not require separate chips, thus reducing production and assembly costs.

Hybrid detectors offer solutions in high-speed, high-volume CD-ROM, digital video disk and other applications that require highly integrated image sensors and sensor systems. According to Suni Imaging, one promising application is fingerprint identification systems for home banking (Figure 6).

### And the winner is?

CCD technology, once king of the imaging mountain, is meeting with increasing competition in several application areas, especially from the newer CMOS (active-pixel and CID) and CMOS/CCD hybrid technologies. Indeed the technologies are merging, but most industry observers believe that each technology will find or maintain its own market niche according to its application strength.

"Personally, I think there's always going to be room for the various technologies," Suni said. "They'll remain application-specific. CID's going to be the answer to the radiation-hardened, random-access applications. CMOS will meet the needs of the low-end, low-voltage, portable applications. CCDs will be the choice for the scientific and astronomical. People will move toward the CMOS/CCD combination when they want the advantages of CMOS and the high performance of the CCD." □

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