New Intensified sCMOS Camera Technology Improves High–Speed Analysis

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By Walter Tutsch and Altaf Ramji, PCO-TECH, Inc.

“Blink and you’ll miss it” — the phrase is synonymous with events that may occur too quickly for the human eye to discern. High-speed video has enabled us to record and analyze these events with increasing accuracy and clarity. However, some phenomena encountered in scientific and engineering analysis occur too fast for traditional video or photography to capture, and thus require an approach superior to traditional high-speed video.

Until recently, camera technologies have been limited in their ability to capture high-quality images of these high-speed events across a large field of view — without motion blur (also called “streaks”), damage to the image from light pollution, or exorbitant cost. Fortunately, new intensified scientific CMOS technology greatly enhances what researchers can accomplish, whether in the physical sciences, defense, or any other application requiring a combination of high resolution (greater than 2 megapixels), ultra-short exposure times (a few nanoseconds), low-light imaging (a few photons), or high frame rates (over 100 frames per second).

This article examines the shortcomings of traditional high-speed video and imaging technologies in these roles and introduces readers to a technologically superior method of capturing images under demanding high-speed conditions.

Traditional High-Speed Imaging Applications and Techniques

High-speed video applications — those requiring an extremely short exposure time — serve a variety of tasks, including operation in high-energy environments. When such high energies are involved, changes occur quickly — for example, when something is explosive or discharging plasma.

Examples of such applications include detonation/blasting, hypervelocity impact, particle image velocimetry (PIV), and neutron imaging, among others. Traditional video’s key limitations in these applications are a lack of adequate shutter speed, insufficient extinction ratio, and inadequate resolution. Previous intensification techniques have effectively created an amplifier, wherein photons strike a collector — be it the photo cathode of an image intensifier or the photo diode of a pixel .... where they generate photo electrons that are proportionately amplified.

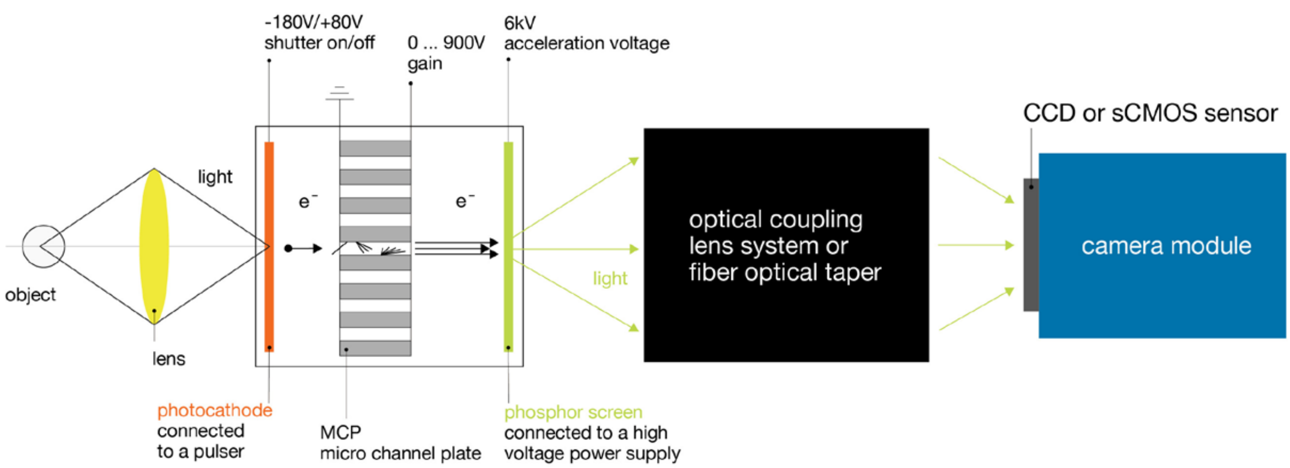
Intensified charge coupled device (ICCD) cameras have been used in some of the applications described above. ICCD operates by utilizing image intensifier tubes coupled optically to a CCD camera readout module. However, this technique is limited by the maximum optical resolution and field of view achievable using an 18-mm image intensifier. ICCD systems in the applications discussed often exhibit an inadequate frame repetition rate, resulting in choppy playback and insufficient dynamic range.

Electron multiplying charge coupled device (emCCD) cameras, meanwhile, have been used in low-light applications, but do not possess fast shuttering capabilities. Thus, the extinction ratios achievable with emCCD are not capable of allowing extremely short gate times (i.e., emCCD is not technologically capable of shuttering a pixel within a few nanoseconds).

Understanding Intensified sCMOS

The key improvements offered by intensified sCMOS over emCCD and ICCD are greater image resolution and quality, as well as enhanced image repetition speed (how many frames per second it can record in this high image quality).

Figure 1: Components and functional principle of an intensified camera system



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The drastically improved image quality originates from intensified sCMOS' use of a 25-mm intensifier — which almost doubles the optical resolution produced by conventional systems, typically using 18-mm intensifiers — combined with its use of a perfectly matched tandem lens system in lieu of a taper or single lens coupling. Tandem lens coupling (using a collimator lens and an imaging lens) achieves transmission efficiency about six times that of a single lens coupling (30 percent versus 5 percent).

The intensifier's output then is fed into a 4.2-MPix sCMOS sensor, which has the advantage of a high quantum efficiency and almost no readout noise (~one electron), meaning the noise can be all but completely ignored. The sensor also boasts a high dynamic range — up to 16 bits — meaning it can differentiate between very dim and very bright signals (which nearly saturate your sensor) next to one another on the same sensor, in the same image.

In terms of image repetition speed, previous intensified cameras could capture fewer than 10 frames per second (i.e., you could take an image with 10 ns exposure, but only 10 times per second). Therefore, the time difference between each snapshot was always more than 100 ms. Intensified sCMOS offers more than 100 frames per second, and you can repeat the snapshot every 10 ms.

Plus, if you break down the resolution (i.e., apply a region of interest to the sensor), the intensified sCMOS sensor can produce even faster frame rates: 7,000+ frames per second at the small region of interest. This also improves on time resolution — the more images per second you get, the more completely you describe your event, both on the nanosecond scale and on the longer time scale (i.e., a few milliseconds).

At full resolution, intensified sCMOS cameras also can provide this high rate of frames per second alongside fast shuttering (emCCDs are slower unless you use them in a very small region of interest to make them faster).

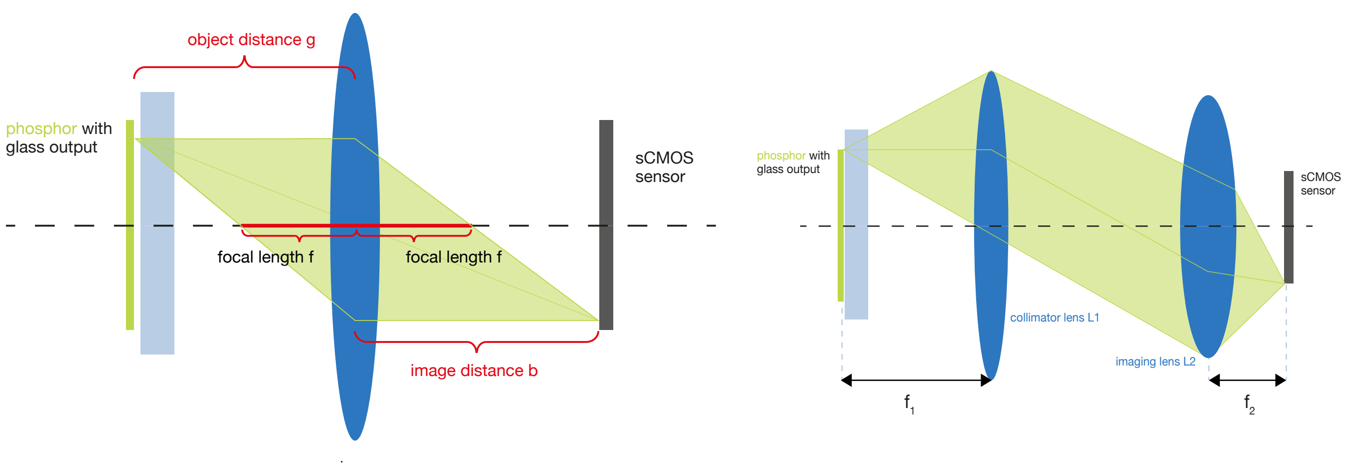
Related, extinction ratio (also called "perfectness of the shutter") takes on increased importance when you're working with short exposure times. For example, if you're acquiring an image in 10 ns, it takes the sCMOS sensor about 10 ms to read out the full 4-megapixel image. During this readout process, if light is impinging on the surface of the sCMOS sensor, it can influence the recorded scene (called a non-perfect extinction ratio).

The image intensifier (i.e., the input device) is in front of the sCMOS sensor and has a near-perfect extinction ratio in the sense that the photo cathode — which acts as the opening and closing device — determines light sensitivity. This photo cathode, in its closed state, allows leaking light at a ratio of 1:10 million. Thus, out of 10 million photons, only one may make it through during readout, generate a signal, and influence the image.

Finally, intensified sCMOS systems use superior connections. A fiber optic interface (data transmission line) allows the PC or workstation to be far away from camera — necessary at high-energy facilities, because it's usually too dangerous for people or instrumentation to be near the experiment. Previous high-speed imaging technologies have acquired data remotely over gigabit ethernet, a USB cable, or some other copper-based cabling. Each of these options presents difficulties not found when using fiber optics, such as diminished signal, limited cable length, or susceptibility to high electromagnetic fields near the experiment.

External trigger signals (i.e., sending a signal telling the camera to record – and when to record – during an event) also travel along fiber optics in an intensified sCMOS system. Such triggers typically have utilized a coaxial cable (copper line) and, the longer the triggering line, the poorer

Figure 2: Imaging geometry for a single-lens coupling (L) and a tandem lens coupling (R)



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the signal quality. Further, it's likely a copper line will act like an antenna and capture some noise signal from electromagnetic pulses generated by the experiment, which can cause wrong triggering, or at least interfere with triggering.

Next-Generation Ultra-Speed Imaging

Seeking to empower researchers and organizations with all of the advantages intensified sCMOS cameras can provide, PCO AG has introduced the pco.dicam C1, an intensified 16-bit sCMOS camera. Born of PCO AG's decades of experience in intensified cameras, the C1 and its four-channel counterpart – the pco.dicam C4 – prove that ultra-short exposure times, high resolution, a large field of view,and enhanced extinction ratio gating can coexist in the same package.

The pco.dicam C1 starts with a metal housing, shielded with additional copper conductors to protect internal electronics from electromagnetic fields. Inside that housing, a sCMOS-based camera module allows the pco.dicam C1 to produce a sustained frame rate in excess of 100 frames per second at 4.2 MPix resolution and 16-bit dynamic range. The camera's high operational speed even is reflected in its ultra-short reaction time to a trigger signal (i.e., the latency between trigger arrival time and opening of the photocathode to begin exposure): < 50 ns.

Additionally, the pco.dicam C1 represents the first application of the complete optical interface CLHS (Camera Link HS) standard to an intensified camera system. Thus, you can plug your optical fiber into the camera and the other end in a frame grabber in your PC and cover hundreds of meters (both data link and triggering link) without the signal loss or corruption inherent to copper cabling — all of which leads to a staggering 870 Mbyte/s intensified image data rate.

One of the many applications that can take advantage of intensified sCMOS' capabilities is laser-induced breakdown spectroscopy (LIBS), performed using a high-energy laser pulse directed at your sample. The material is evaporated/vaporized within nanoseconds, in that plasma is generated by the high-energy laser pulse's impact, and in this plasma you have an emission spectrum characteristic of the constituent elements. You then can use the camera to analyze parts in the sample.

Conclusion

Intensified sCMOS provides the technical solution when other imaging technology does not meet your application's high-speed requirements, whether you need ultra-short exposure times or higher resolution, and an extinction ratio beyond what non-intensified CCD or CMOS cameras can achieve.

To learn more about intensified sCMOS sensor-based cameras or to discuss how the pco.dicam C1 and pco.dicam C4 could be configured to meet the needs of your particular application, visit www.pco-tech.com/intensified-cameras/ and direct any inquiries to info@pco-tech.com.

About The Authors

Walter Tutsch is a is a physicist working as sales & application engineer at PCO AG with more than 15 years of experience with intensified camera systems.

Altaf Ramji is a Regional Manager at PCO-TECH Inc. He was hired as High-Speed Imaging Specialist in 2001 and has over 18 years of experience with various imaging systems. He holds Bachelor of Engineering (B.Eng.) from McGill University and Master Of Business Administration (MBA) from Wilfrid Laurier University.

find us

europe
PCO AG
Donaupark 11
93309 Kelheim, Germany

+49 9441 2005 50
info@pco.de
pco.de

america
PCO-TECH Inc.
1000 N West Street, Suite 1200
Wilmington, DE 19801

+1 866 678 4566
info@pco-tech.com
pco-tech.com

asia
PCO Imaging Asia Pte.
3 Temasek Ave
Centennial Tower, Level 34
Singapore, 039190

+65 6549 7054
info@pco-imaging.com
pco-imaging.com

china
Suzhou PCO Imaging Technology Co., Ltd.
Room A10, 4th Floor, Building 4
Ascendas Xinsu Square, No. 5 Xinghan Street
Suzhou Industrial Park, China 215021

+86 512 67634643
info@pco.cn
pco.cn

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