TECHNOLOGY PRIMER

X-RAY IMAGING

Emerging Digital Technology - CMOS Detectors
In all domains of Medical and Scientific X-Ray imaging, the replacement of film and analog video imaging techniques with a fully digital workflow is underway.

**Digital X-Ray Technology Workflow Benefits:**
- increased operational efficiency resulting in higher patient comfort;
- the adoption of digital information workflow and archival infrastructure;
- opportunity for digital communication and collaboration with peers at remote sites
- advanced digital image processing capabilities;
- and lower X-Ray dose with real-time image availability

There are three primary digital X-Ray technologies in used today, these include:

**Computed Radiography** - uses imaging plates that are converted to digital format in a separate scanning operation (in a similar manner to traditional film-scanning) and cannot be used for real-time X-Ray imaging such as cardio-vascular examinations.

**Direct Detection** - Direct conversion uses an amorphous selenium (aSe) layer to convert X-Ray photons directly to electrons for immediate image capture. An important drawback of selenium is the instability of the material over time and at elevated temperatures, as well as the environmental impact during production and repair or disposal.

**Indirect Detection** - As the most common method, indirect detection uses scintillators (such as Gadolinium Oxides or Cesium-Iodides) to convert X-Rays to visible light. Traditionally, the light generated by the scintillator is imaged onto a CCD sensor using a bulky lens system. In modern flat-panel detectors, the scintillator output is captured by either an amorphous silicon (TFT) panel or CMOS sensor which convert the image to digital format.

DALSA is a leader in the design and manufacture of CCD (Charge Coupled Device) and CMOS (Complementary Metal-Oxide Semiconductor) for digital medical imaging technology.

This technology primer examines the unique engineering features and panel architecture of DALSA’s advanced CMOS detectors.

**CMOS IMAGING TECHNOLOGY**

CMOS image detectors offer numerous advantages including the ability to record smaller image details at higher resolutions – allowing for the diagnostics of medical anomalies at earlier stages, and significantly increasing the probability of early intervention, patient recovery and reduced treatment costs. Current and planned wafer-scale X-Ray CMOS image sensor designs are using pixel pitches ranging from 20 to 100 microns.

Another important benefit of CMOS image sensors is the absence of so-called ‘image lag’, or the presence of residual image information in successive images, that is typical of amorphous TFT technologies. Image lag leads to poor quality images because of small image displacement. The image lag in DALSA’s X-Ray CMOS technology is less than 0.1%.

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**DETECTIVE QUANTUM EFFICIENCY**

High DQE (the efficient use of incoming x-rays) is vital to minimizing patient dose and obtaining the best quality image to support further medical image processing and diagnostics. DALSA’s CMOS detectors deliver industry leading DQE performance as a result of our low readout noise and ability to resolve very small image details at high spatial frequencies.
LOW NOISE, HIGH DYNAMIC RANGE

Active Pixel Sensor technology and expertise in low noise circuit design are the hallmark’s of DALSA’s CMOS X-Ray image sensors. Our CMOS image sensors exhibit unrivalled low readout noise levels and deliver superior Dynamic Range - even at low X-Ray dose, contributing to the high image quality required to support medical diagnostics. DALSA’s active pixel implementation process significantly reduces the read noise which typically dominates system noise when compared with other amorphous silicon (TFT) based detectors.

On system level, the low-noise raw images from DALSA’s CMOS detectors require less pre-processing before the diagnostics image enhancements, preserving image detail, and reducing system processing overhead and complexity.

HIGH-SPEED READOUT

Taking full advantage of the high-speed capabilities of crystalline silicon material, DALSA CMOS X-Ray detectors deliver detailed images at rates exceeding 30fps, at full resolution and each with excellent image quality. Radiologists have a choice to achieve even higher speeds either through defining a specific region of interest (ROI or ‘windowing’) or by selecting one of the flexible pixel binning modes.

COOL-RUNNING IMAGE DETECTORS

High-purity (poly-)crystalline wafer material inherently has low resistivity (or high electron mobility) and offers the opportunity to integrate peripheral circuitry together with the image sensing elements (‘pixels’). As a result, detectors can be driven at higher speeds with increased functionality and lower power consumption than detectors based on amorphous silicon material. Higher frame rates enable the support of procedures that require real-time X-Ray imaging or rely on 3D volume reconstruction techniques (e.g. computed tomography). Low power consumption reduces the need for cooling, which allows the use of detectors in environments with less stringent temperature conditioning. Cooler-running detectors deliver better performance over longer lifetimes.
SCALABILITY

DALSA CMOS X-Ray detectors are created from individual CMOS sensor ‘tiles’. These “buttable” sensors are designed with flexibility in mind for assembly into large two-dimensional arrays with less than one pixel spacing in between individual sensors. This modularity enables multiple detectors with different active areas and resolutions to exist within the same sensor design, leveraging investments while maintaining the high imaging performance for multiple applications.

INTEGRATED DOSE-SENSING

To facilitate medical diagnostics, it’s important to have access to correctly exposed X-Ray images. However, to minimize patient dose and to maximize equipment utilization, it is neither practical nor allowable to take multiple X-Ray exposures to determine the optimal X-Ray setting. Ion chambers are most often used to achieve a better X-Ray exposure on the first attempt, but ion chambers can only report the average exposure of an area through a single analog signal.

DALSA CMOS X-Ray detectors offer a unique way to ensure optimal X-Ray exposure for every image. A grid of dose-sensing pixels is embedded in the full active image area and can be read repeatedly throughout the X-Ray exposure period. Because dose sensing pixels are exactly the same as the pixels in a final image, the low-resolution dose sensing image delivers a highly accurate preview of the final X-Ray image.

Read-out of these dose-sensing pixels is non-destructive and facilitates real-time auto exposure and contrast control algorithms during the actual X-Ray exposure. By using this information to shut down the X-Ray generator at exactly the right moment, the highest possible image quality is achieved while the patient is exposed to the lowest possible X-Ray dose in a first-time-right procedure. This is critically important for single-shot applications like mammography screening.
SWITCHABLE CHARGE CAPACITY

More and more medical modalities make use of both static (still) and dynamic (real-time) imaging. As the total X-Ray dose to which a patient can be exposed is strictly regulated, the amount of X-Ray dose available per image in dynamic mode is much less when compared to static images.

A pixel with a fixed charge capacity, optimized to handle the large amount of charge required for still images, will only utilize a fraction of the full well capacity in dynamic mode. Readout noise is one of the most limiting factors when creating low dose images with dynamic panels. Low dose results in lower signal which necessitates the application of higher gain to the output signal. In this case both the X-Ray signal and the readout noise are amplified which lowers the signal-to-noise ratio.

The advanced Dalsa X-Ray CMOS pixel design offers the ability to switch between different pixel charge capacities, each optimized for a specific imaging mode. This eliminates the need for additional gain that amplifies readout noise. Switching is done via software and can be programmed in between consecutive frames. Dynamic images for video analysis are crisp and clear, and do not suffer from low signal-to-noise ratio (SNR) after the required contrast stretching.

The switchable pixel full well capacity also has advantages for binned mode operation when higher frame rates and higher sensitivity are desired. Pixel binning can be used to increase the frame rate, but generally the sensitivity is not increased since the saturation charge is increased by the binning factor. An improvement of the SNR in binned operation would be very welcome. The Dalsa switchable pixel achieves higher frame rates and higher sensitivity when operated in binned mode. A sensitivity increase of up to a factor of 4 is within reach of the technology.
RELIABILITY

Similar to human bone and tissue, image sensor structures suffer damage from high-energy X-Ray photons, which results in increased noise (or reduced signal-to-noise ratio). This will become increasingly more apparent throughout the lifetime of the detector.

Through many years of experience and a thorough understanding of the basic processes in CMOS manufacturing, DALSA has created a proprietary pixel design that is far less susceptible to damage from X-Ray radiation. By isolating and protecting critical structures within the basic pixel cell design, the pixel performance remains constant even after high total ionization dose.

DALSA CMOS detectors deliver constantly high imaging performance every day of use, and throughout their extended product lifetime. Extended equipment lifetime and reduced maintenance downtime deliver more efficient equipment utilization and increased patient throughput without the need to reschedule appointments.
We offer OEMs more than just a technology advantage, we provide a comprehensive consultation program to meet your business model and a single point of accountability for service, support and manufacturing. Our imaging technology is backed by a field proven track record and an extensive install base; propelled by next generation R&D and delivered by a dedicated and highly trained team of imaging engineers.

DALSA X-Ray detectors and sensors are designed to deliver the highest imaging quality for improved diagnostics, while optimizing patient comfort and safety including:

- The ability to offer lower noise and higher image quality which in-turn facilitates earlier diagnostics and potentially contributes to higher patient survival rates and lower treatment costs.

- Implementation of dose-sensing to optimize image quality in first-time-right exposures, resulting in reduced patient dose, increased patient comfort and workflow efficiency.

- Optimized imaging modes for static and dynamic procedures, "best of both worlds", offering true integration of modalities and more effective utilization of capital investments without sacrificing diagnostic quality.

- Provides radiation hard pixel technology which delivers constant and reliable operation throughout extended periods of daily use, reducing periodic re-calibration and system down-time to a minimum, optimizing patient throughput.

DALSA knows the highly regulatory stringent quality requirements for medical and scientific imaging applications.