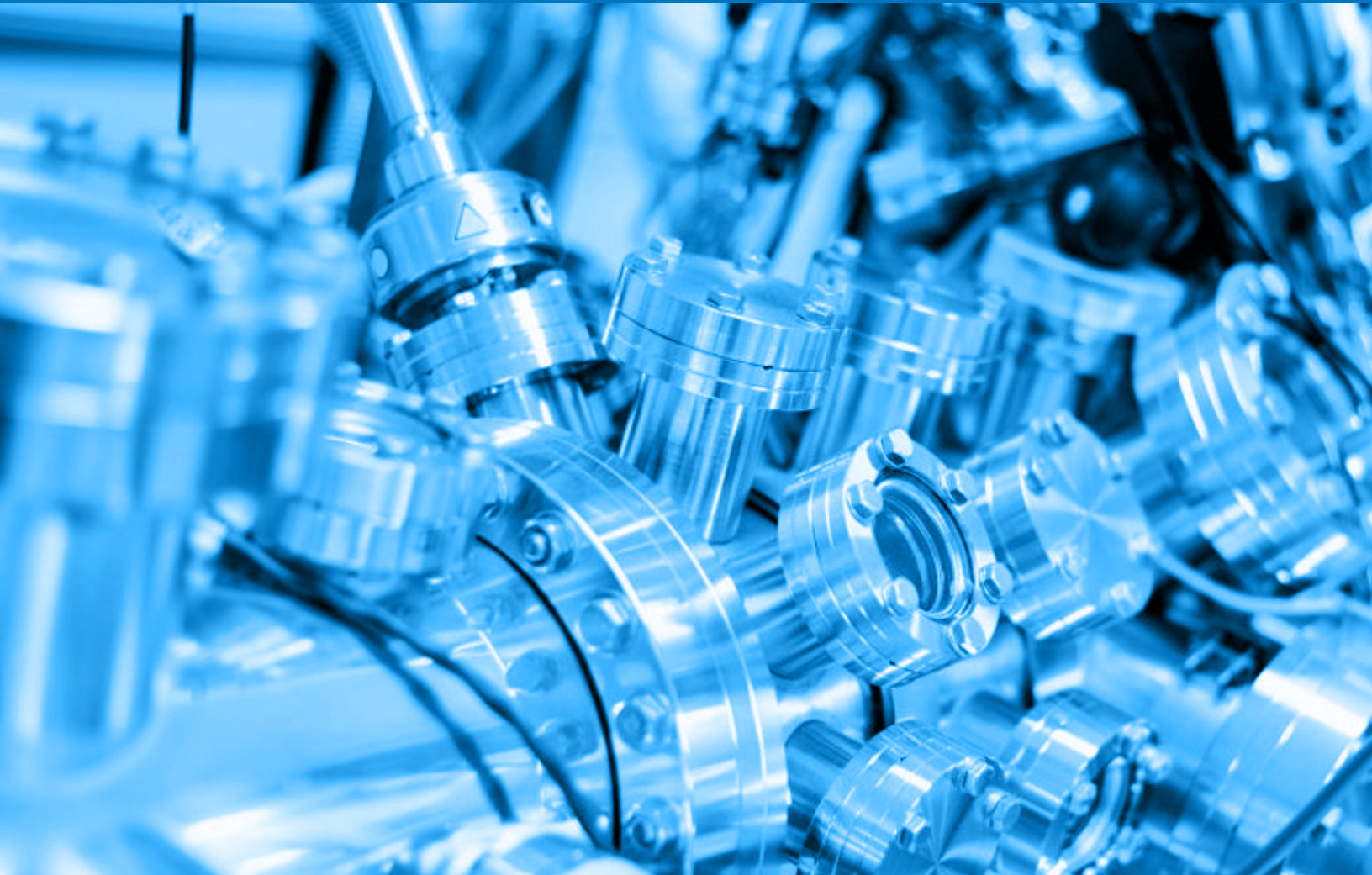


Synchrotron Camera Solutions

The Best For Your Beamline



| Teledyne Princeton Instruments

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Teledyne Princeton Instruments

Providing Synchrotron Solutions Since 1961





Built upon decades of camera design and fabrication, Teledyne Princeton Instruments has provided solutions for multiple synchrotron facilities worldwide. Teledyne Imaging's sensors, cameras, and imaging systems have been addressing many of the requirements needed for multiple techniques since 1961.

As a member of the Teledyne Imaging group, we have an immediate hotline to companies that manufacture cutting edge imaging sensors, such as [Teledyne E2V](#) and [Teledyne Anafocus](#). From pixel and sensor design to fabrication, then camera design – we are involved at every step, enabling quick turnarounds with no sacrifice to quality standards.



X-Ray Sensor Considerations

CCD and CMOS cameras for X-ray measurements use either direct or indirect detection depending on the photon energy.

Direct detection is used for low energy, soft x-rays ($\sim 30 \text{ eV} - 3 \text{ keV}$), where the incoming photons are directly absorbed on the camera sensor and converted into a measurable signal. Illumination from the front of the sensor results in x-ray photons being absorbed by metal and oxide layers on the devices surface. Instead, illumination from the back of the device is used, forging the use of anti-reflection coatings that absorb photons between 30-500 eV. For the same reason, direct detection sensors don't use anti-reflective (AR) coatings as they absorb x-ray photons between $\sim 30-500 \text{ eV}$.

As the absorption length increases with x-ray photon energy, thicker silicon is needed to ensure the photon does not pass through the device undetected. However, thick silicon also increases the size of the field free region, allowing the electrons to drift to neighboring pixels or recombine, resulting in lost signal. High resistivity silicon is used with thicker epitaxial layers to extend the depletion edge, ensuring all photoelectrons are captured.

Indirect detection for high energy, hard x-rays first convert the incoming radiation into a visible signal on a phosphor screen. The screen is fiber optically coupled to the sensor, minimizing signal transfer losses. Both front as well as back-illuminated sensors can be used for indirect detection.

Teledyne Princeton Instruments offers a wide range of direct, and indirect-detection cameras. With technologies from large format sensors to fully in vacuum cameras with both CCD and sCMOS sensors, we can provide the optimal solution for multiple application requirements.

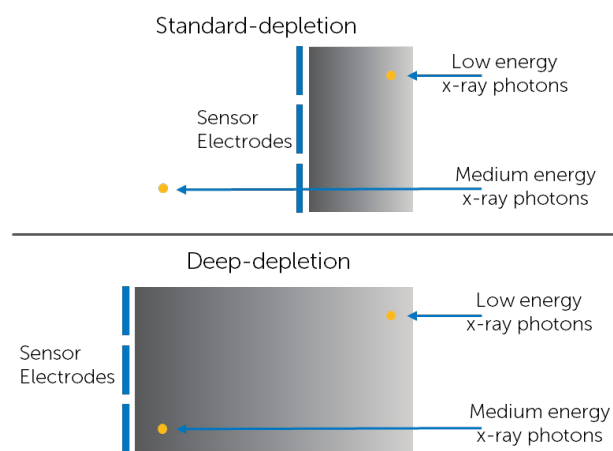
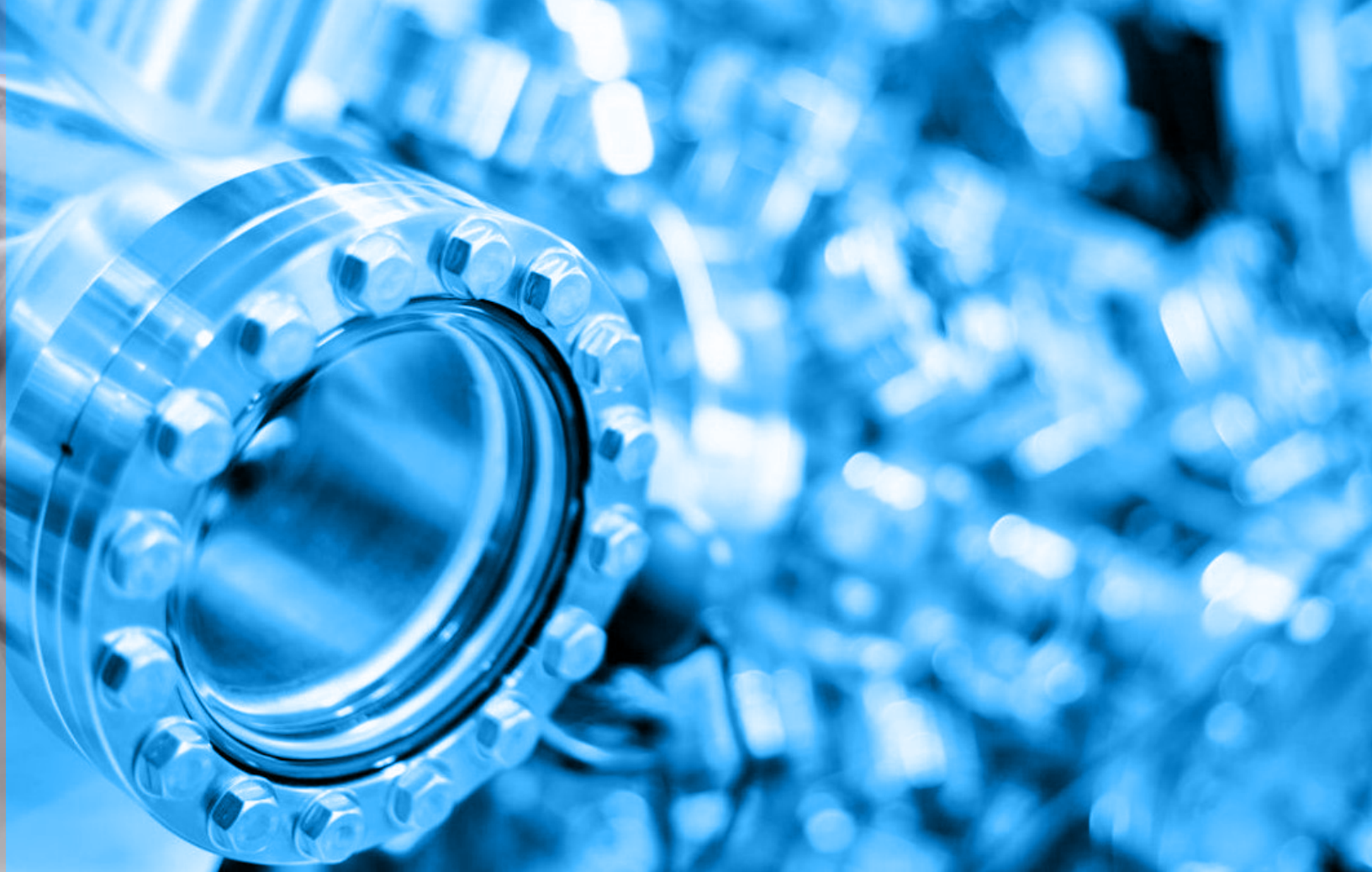


Figure 1: Schematic showing how thicker silicon is required for higher energy x-ray photons to ensure the photon does not pass through the device undetected



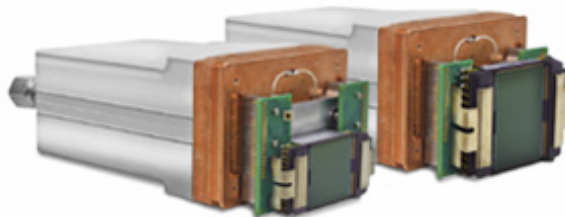
Direct Detection

For Low Energy X-rays

PI-MTE 3

Fully In-Vacuum, Direct Detection CCD Cameras

Large format, fully in-vacuum CCD cameras, offering flexible detector orientation and proximity to sample through sensor and camera design. With back-illumination technology, the PI-MTE 3 delivers >95% peak quantum efficiency over the ~10 eV to 30 keV energy range. Efficient liquid cooling offers low dark current, facilitating long exposure times, with the four-port readout architecture to deliver 7-10x higher frame rates than previous generation two-port cameras.



-
- Fully in-vacuum CCD cameras with scattering angle flexibility
 - Tailored for specific needs, whether speed, sensitivity, or dynamic range
 - Large sensor formats: 2k and 4k
-

Applications

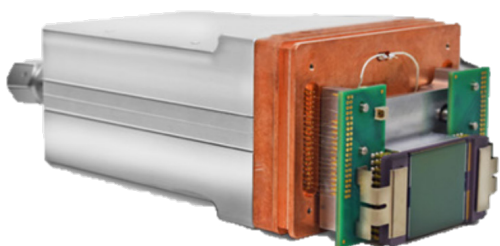
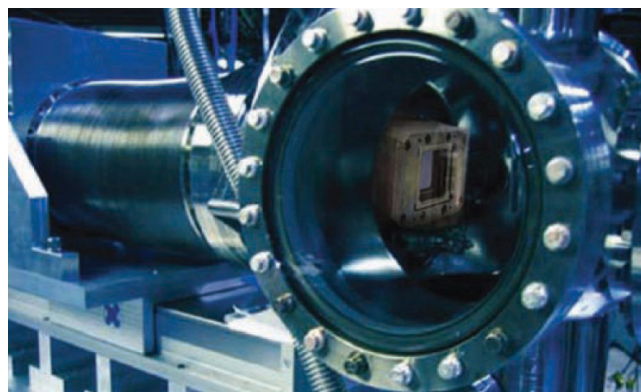
Due to the advanced camera design, high sensitivity, and low noise, the PI-MTE3 is optimal for applications such as:

- Small- and wide-angled x-ray scattering
- X-ray diffraction
- X-ray phase contrast imaging
- Coherent diffraction imaging
- X-ray microscopy
- Semiconductor metrology

Key Features Explored

Fully In-Vacuum

The PI-MTE 3 can be used fully in-vacuum, including the cooling system and all electrical cables. This provides exceptional reliability and flexibility for camera placement within a vacuum chamber, especially for scattering based experiments which rely on varying the distance between the detector and sample to obtain different resolution.

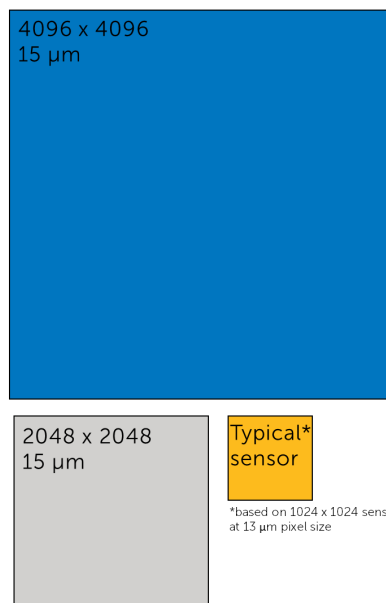


Optimized Sensor Position

The sensor within the PI-MTE 3 is positioned at the base of the camera, allowing for direct detection of ultra-low incident angles, optimal for x-ray diffraction. The PI-MTE 3 is also butttable, offering the advantage of a larger sensor area while providing space for the removal of any primary beam.

Large Format Sensors

The PI-MTE 3 is equipped with large-format, back-illuminated sensors, with either a 2048 x 2048 or 4096 x 4096 resolution CCD sensor, ideal for capturing a range of scattering angles. Both sensors cover the 10 eV to 30 keV range, with a peak quantum efficiency of >95%, owing to the high sensitivity of the PI-MTE3.



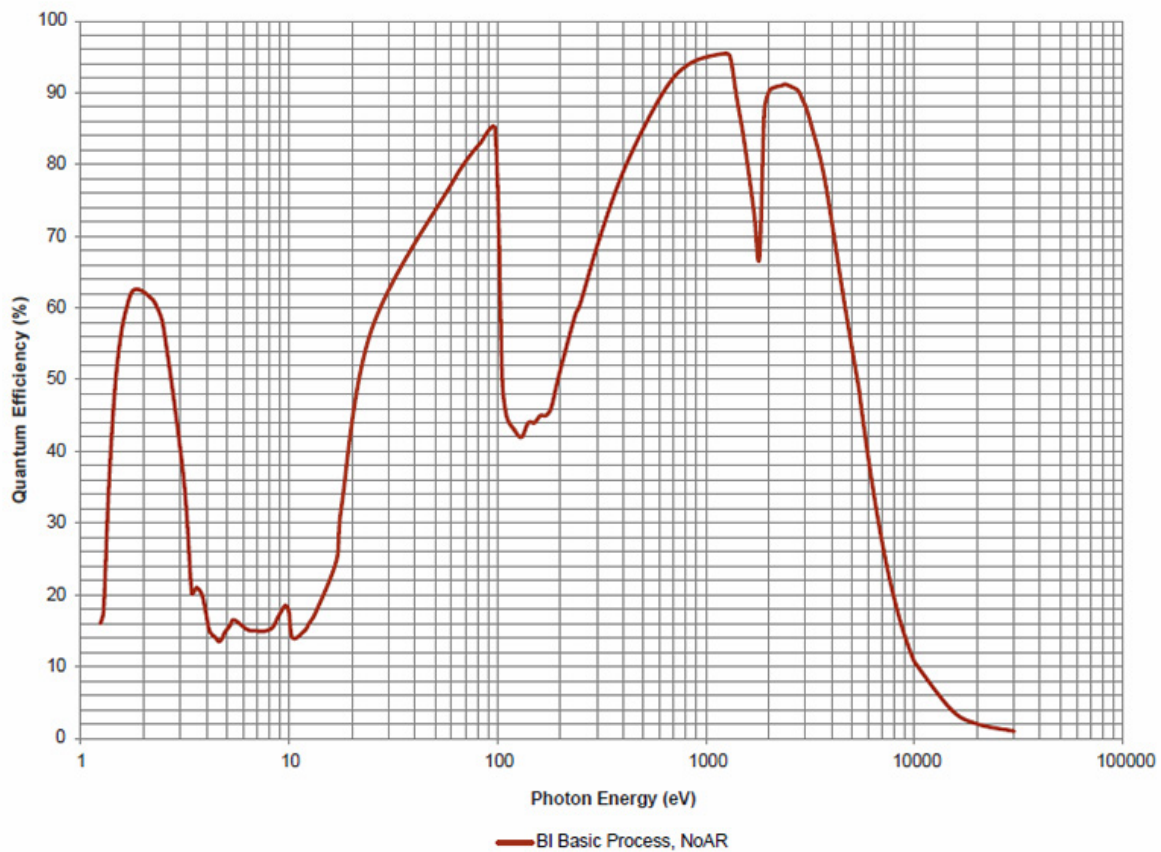
PI-MTE 3

Full Specifications

Feature	PI-MTE3 2048B	PI-MTE3 4096B
CCD image sensor	e2v CCD230-42; scientific grade 1; MPP; back illuminated; no AR coating	e2v CCD231-84 or 230-84; scientific grade 1; MPP; back illuminated; no AR coating
CCD format	2048 x 2048 imaging pixels; 15.0 x 15.0 μm pixels; 100% fill factor	4096 x 4096 imaging pixels; 15.0 x 15.0 μm pixels; 100% fill factor
Imaging area	30.7 x 30.7 mm	61.4 x 61.4 mm
Deepest cooling temperature (@ +20°C)	-55°C (typical) with liquid chiller	-50°C (typical) with liquid chiller
Thermostating precision	$\pm 0.1^\circ\text{C}$	
Dark current (e-/pixel/sec)	0.0015	230-84: 0.0015 231-84: 8.0
Cooling method	Liquid cooling	
Full well, single pixel (typical)	150 ke-	230-84: 150 ke- , 231-84: 300 ke-
ADC speed	16 MHz (4 MHz x 4 ports); 4 MHz (1 MHz x 4 ports); 400 kHz (100 kHz x 4 ports)	12 MHz (3 MHz x 4 ports); 4 MHz (1 MHz x 4 ports); 400 kHz (100 kHz x 4 ports)
ADC bits	16 bits	18 bits
System read noise @100 kHz per Port (e- rms)	6.5	230-84: 6.0 231-84: 3.4
Readout modes	4-port, 2-port, or 1-port readout; Kinetics; External Sync	
Nonlinearity	<2% @ 100 kHz	
Host interface	USB 3.0	
I/O signals (TTL)	Trigger In, Expose Out, Shutter Out/In, Readout, Ready	
Software (optional)	LightField for Microsoft Windows 10 (64 bits); PICam SDK for Microsoft Windows and Linux; EPICS support via automation	
Bake-out temperature	50°C (maximum)	
Vacuum compatibility	10^{-9} Torr	
Certification	CE	
Operating environment	+5°C to +30°C non-condensing	
Feedthrough	DN100 or 6" industry-standard CF flange	
Camera weight	2.31 kg (5.10 lbs)	2.7 kg (5.9 lbs)
Camera head dimensions (L x W x H)	217.6 mm (8.56") x 102.3 mm (4.03") x 73.9 mm (2.91")	220.4 mm (8.68") x 102.3 mm (4.03") x 75.6 mm (2.98")

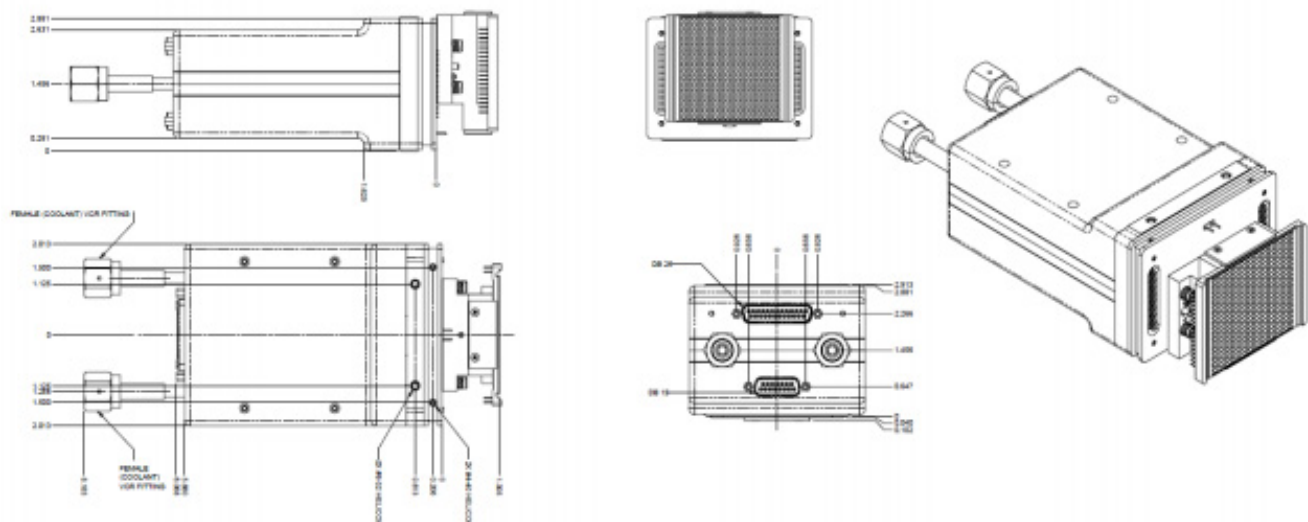
Specifications are subject to change

Quantum Efficiency Curve



Mechanical Drawings

PI-MTE 3 4096B

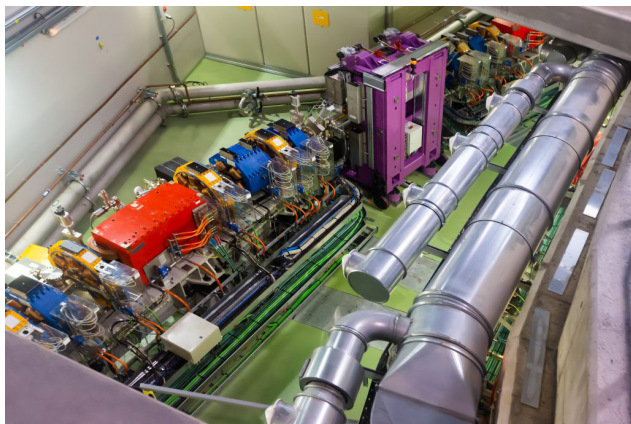


PI-MTE 3

Research Stories

Probing Magnetic Properties Of Materials

An international team of researchers in France, Italy, Slovenia, and the UK reported on their studies into understanding the microscopic magnetic properties of thin film ferromagnetic materials, and sandwich structures of ferromagnets and non-magnetic materials. The researchers were particularly interested in the dynamic formation of magnetic domains showing these complex structures.



To measure the magnetic characteristics, the researchers used magnetic dichroism to measure time resolved x-ray magnetic scattering at the DiProl beamline of the FERMI free-electron laser in Trieste, Italy. The experiment utilizes a pump probe system in which demagnetization is induced in the sample material.

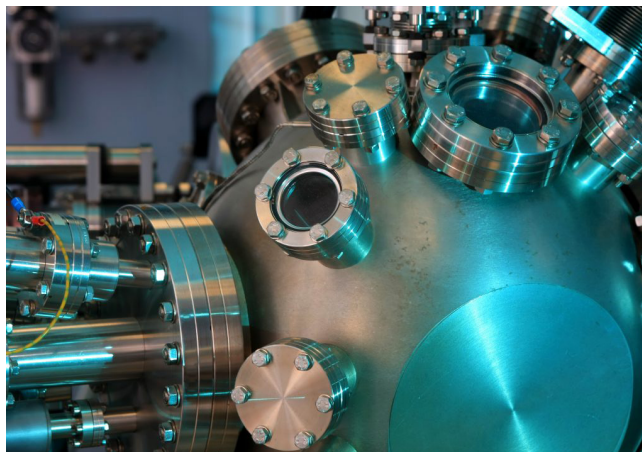
The x-ray reflected diffraction pattern is then recorded via a PI-MTE CCD camera, which sits in close vicinity to the sample. This allows for the detection of a large angular region of diffracted radiation. By imaging the different diffraction patterns of the left and right circularly polarized x-rays, domain wall width and dynamic behavior of the samples can be measured.

Novel soft x-ray spectroscopy on the PAL-XFEL

The PAL-XFEL is a facility in Korea that opened for users in 2017. Not only does the XFEL produce bright x-rays, the facility also provides pulsed beams with a small width below 50fs. This allows the measurement of dynamic processes, relating to atoms and electronics within materials, at energies not available with alternative technologies. The facility operates several beamlines for hard and soft x-ray experiments.

The PAL-XFEL utilizes the PI-MTE on the soft x-ray scattering and spectroscopy beamline, using the large 2048 x 2048 sensor size, and taking advantage of the flexibility of mounting the detector fully in-vacuum. The PI-MTE is also used for coherent x-ray diffraction imaging at the PAL-XFEL facility.

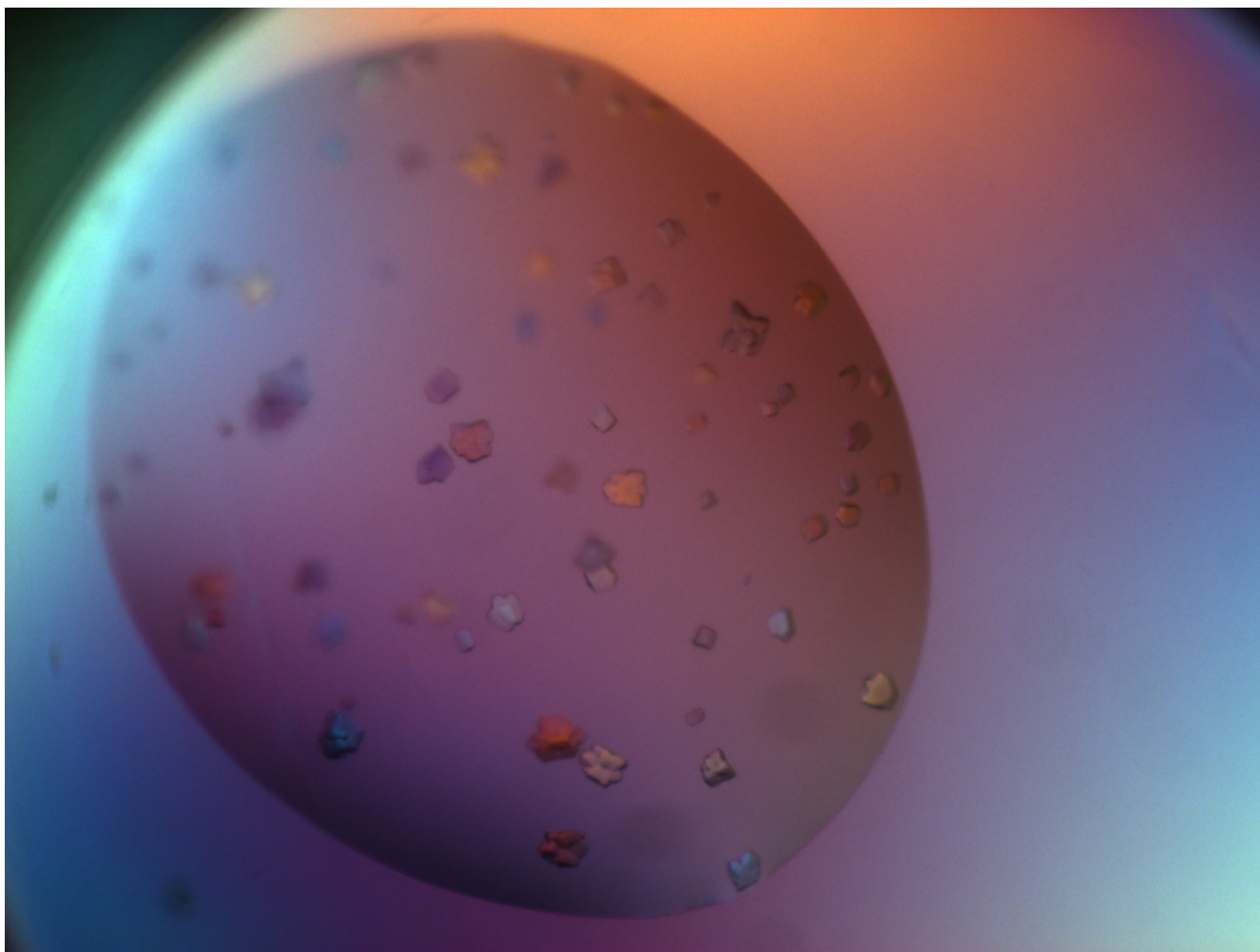
Among other things, researchers at PAL-XFEL investigate the magnetic circular dichroism response in the absorption spectra of Co/Pt multilayers via circular polarized x-rays. These measurements allow researchers to make conclusions about the bulk ferromagnetism of the material.



Liquid Streams of Protein Crystals for X-Ray Diffraction Measurements

X-ray crystallography is an important tool for structure determination in material and biological science. Bright x-ray sources like the Free Electron Laser at DESY in Hamburg can deliver intense x-ray beams on very short timescales that allow probing of crystal structure on very small sample sizes.

Due to the nature of the x-ray sources researchers require new means of sample delivery to the probe region. Here researchers developed means to deliver liquid streams of protein crystals to the interaction region. Researchers utilized the PI-MTE x-ray camera to record coherent x-ray diffraction of the liquid jet and protein crystals within the liquid to establish optimization of the novel sample delivery system.



PI-MTE 3

Customer Story

High-Repetition Rate Laser-Matter Interactions for Solid Targets

ELI Beamlines

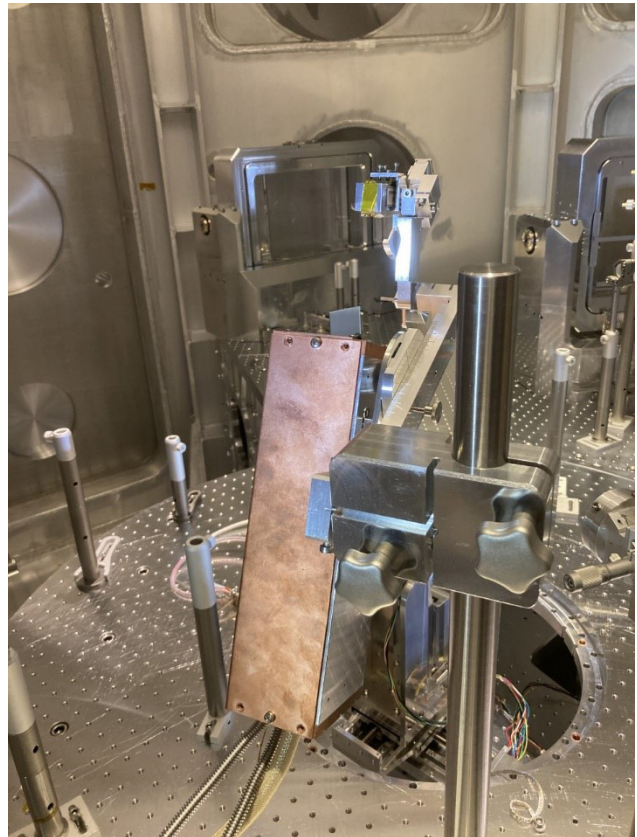
Dr. Florian Condamine works at the Extreme Light Infrastructure (ELI) Beamlines, a European research institute offering highly intense laser systems and high energy radiation to enable research in the fields of physical, biomedicine, material science and more.

Dr Condamine and his team have developed a high-repetition rate solid samples delivery system for PW-class laser-matter interaction. This instrumentation can measure 1000s of interactions within one experiment without having to replace the target, increasing the data quality and statistical reliability, while reducing overall experimental time. These solid laser-matter interactions provide essential data but can encounter experimental limitations.

Challenge

To overcome the common limitations of high-repetition rate laser-matter interactions on solid targets, the experiment utilizes a tape target system, moving the target material on spools. This allows the target to remain aligned and produce a fresh surface of material throughout the entire experiment while moving the solid target at the same rate as the high-repetition laser.

The instrument provides 300° of freedom around the target, as well as flexible locations of diagnostic systems. A lot of the phenomena being researched by this method is angle dependent, and often requires close proximity between the target and diagnostic system. To achieve this, a detector that allows for versatile geometry is essential. The detector would also need to be fully in-vacuum and protected from surrounding electromagnetic pulses, while allowing for high intensity laser experiments.





The PI-MTE, in association with the tape target system, allows us to use the laser at its maximum repetition rate.



Solution

The PI-MTE is a fully in-vacuum CCD camera, featuring a large sensor and high soft x-ray sensitivities. The ability of the PI-MTE to remain inside the vacuum at all times allows for essential flexible geometries to be preserved. By encasing the PI-MTE within a faraday cage, any damage from surrounding electromagnetic pulses is minimized, while still allowing high intensity laser experiments.

With higher frame rates than previous generations, deep cooling to minimize noise, and large formats, the PI-MTE is ideal for these fast rate, single shot spectra, typical of these experiments.

Resources

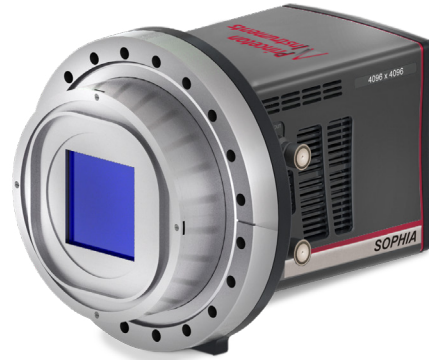
F. P. Condamine, et al. High-repetition rate solid target delivery system for PW-class laser-matter interaction at ELI Beamlines. Review of Scientific Instruments 92 (2021).

SOPHIA-XO

LARGE FORMAT CCD CAMERAS FOR SOFT X-RAY, VUV AND EUV APPLICATIONS

SOPHIA®-XO is a large format, back-illuminated CCD camera with a peak quantum efficiency of >95% over the widest range of direct VUV and soft x-ray energies. The SOPHIA-XO offers fast frame rates, alongside a unique thermoelectric cooling design for temperatures as low as -90°C for low dark current noise.

With a rotatable, industry standard CF flange, available in both six (6) or eight (8) inch interfaces, and a high-vacuum seal design, the software-selectable gains and readout speeds of the SOPHIA-XO make it well suited for ultra-high vacuum applications.



-
- Fully in-vacuum CCD cameras with scattering angle flexibility
 - Tailored for specific needs, whether speed, sensitivity, or dynamic range
 - Large sensor formats: 2k and 4k
-

Applications

With high sensitivity, broad x-ray energy coverage, deep cooling for low dark current noise, and a high-vacuum seal design, the SOPHIA-XO is designed for applications such as:

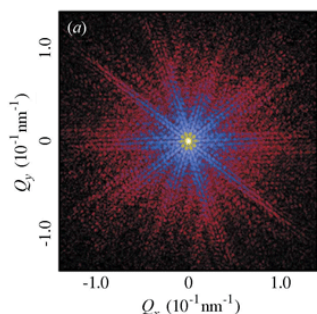
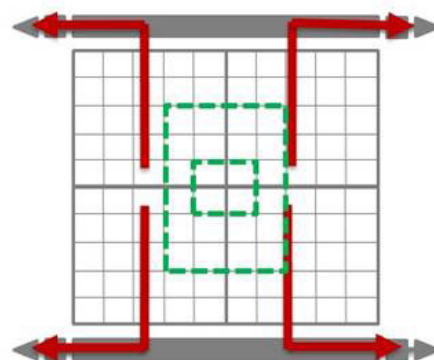
- VUV/EUV/XUV imaging
- X-ray diffraction
- X-ray microscopy
- X-ray spectroscopy
- X-ray holography
- X-ray plasma studies

Key Features Explored

When Speed is Paramount

With the option of 1-, 2-, or 4- port simultaneous readout, the SOPHIA-XO can capture ultrafast events. The flexible multiple-readout-port design supports custom sensor readout or kinetic readout each with 4.2 fps at 12 MHz.

The SOPHIA-XO also comes with complete triggering support, independently optimized clocking for each combination alongside a field-replaceable internal mechanical shutter.

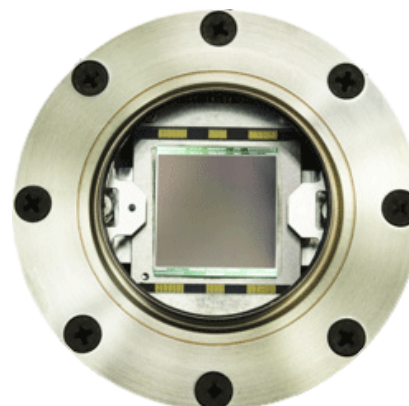


Designed for Low-Flux Applications

The SOPHIA-XO is a back-illuminated CCD camera providing a peak quantum efficiency of >95% over a broad photon energy range. Alongside deep cooling to reduce dark current noise, and low read noise, the SOPHIA-XO offers a wide dynamic range with up to 18-bit readout.

Ultra-High Vacuum Compatibility

Using an all-metal, hermetically seal vacuum design, the SOPHIA-XO prevents outgassing or long-term degradation typical with epoxy designs. The ArcTec™ cooling technology further prevents degradation and outgassing, alongside ensuring efficient thermal dissipation from the sensor and electronics via a custom heat sign design. ArcTec™ cooling is available as air cooling only, liquid cooling only for vibration-sensitive environments, or a combination of both.



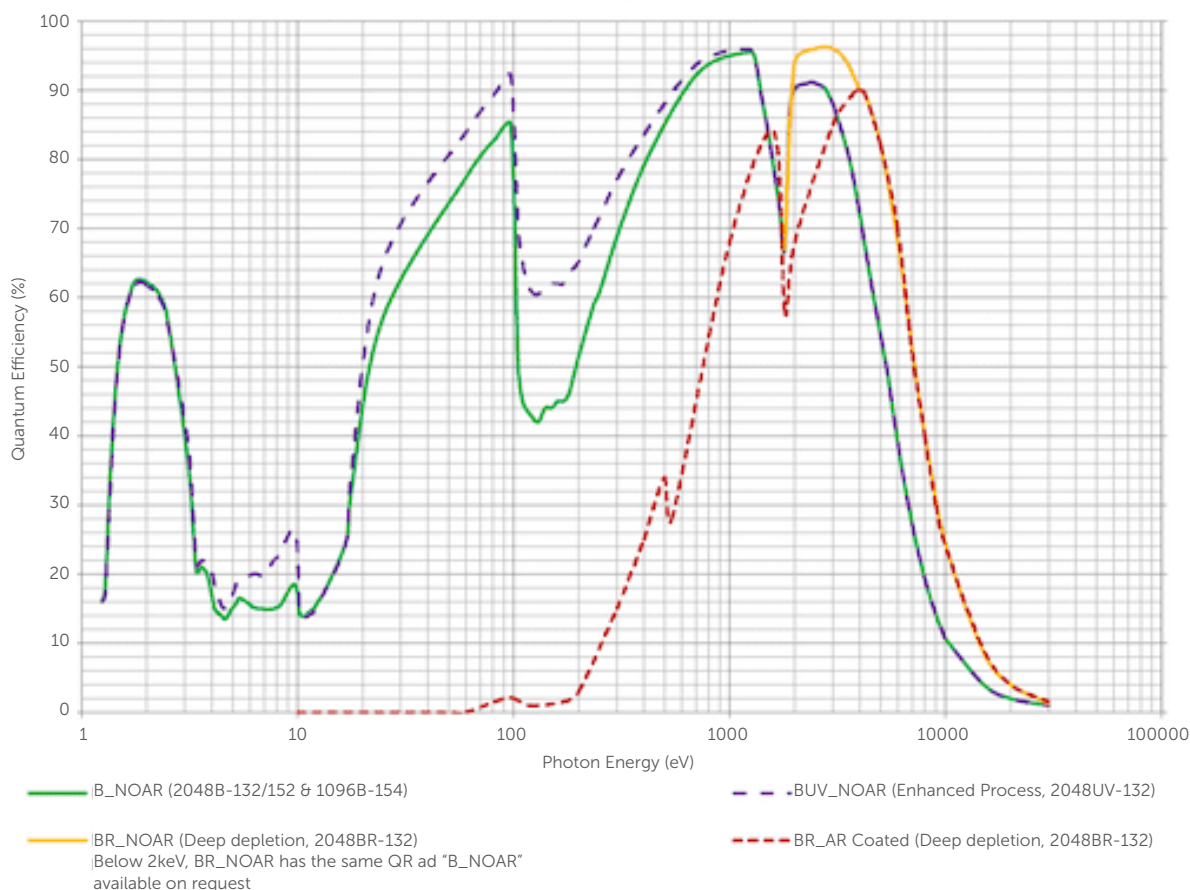
SOPHIA-XO

Full Specifications

Feature	SOPHIA-XO 2048B - 132	SOPHIA-XO 2048B - 152	SOPHIA-XO 4096B - 154
CCD image sensor	e2v CCD42-40; UV-enhanced grade 1; NIMO; back illuminated	e2v CCD230-42; scientific grade 1; AIMO; back illuminated; no AR coating	e2v CCD230-84; scientific grade 1; AIMO; back illuminated; no AR coating
CCD format	2048 x 2048 imaging pixels; 13.5 x 13.5 μm pixels; 100% fill factor	2048 x 2048 imaging pixels; 15.0 x 15.0 μm pixels; pixels; 100% fill factor	4096 x 4096 imaging pixels; 15.0 x 15.0 μm pixels;100% fill factor
Imaging area	27.6 x 27.6 mm	30.7 x 30.7 mm	61.4 x 61.4 mm
Deepest cooling temperature (@ +20°C)	< -90°C (typical) with liquid chiller; < -90°C (typical) with air	< -90°C (typical) with liquid chiller; < -90°C (typical) with air	< -80°C (typical) with liquid chiller; < -60°C (typical) with air
Thermostating precision	±0.05°C		
Dark current (e-/pixel/sec)	0.0001	0.00025	0.005
Cooling method	Thermoelectric air or liquid cooling		
Full well	Single pixel: 100 ke- (typical)	Single pixel: 150 ke- (typical)	Single pixel: 150 ke- (typical)
ADC speed	8 MHz (4 MHz x 2 ports) 2 MHz (1 MHz x 2 ports) 200 kHz (100 kHz x 2 ports)	12 MHz (3 MHz x 4 ports) 4 MHz (1 MHz x 4 ports) 400 kHz (100 kHz x 4 ports)	
ADC bits	16 bits	16 bits	18 bits
System read noise	3.5 e- rms @ 200 kHz 7.0 e- rms @ 2 MHz	3.6 e- rms @ 400 kHz 8.5 e- rms @ 4 MHz	
Readout modes	2-port or 1-port readout; Kinetics; External Sync	4-port, 2-port, or 1-port readout; Kinetics; External Sync	
Nonlinearity	<2% @ 100 kHz		
Data interface	USB 3.0 (5 m interface cable provided); Optional fiberoptic interface available for remote operation		
I/O signals	Two MCX connectors for programmable frame readout, shutter, trigger in		
Software (optional)	LightField for Microsoft Windows 10 (64 bit); PICam SDK for Microsoft Windows and Linux; EPICS support via automation		
Bake-out temperature	70°C (maximum)		
Vacuum compatibility	10 ⁻⁸ Torr		
Certification	CE		
Operating environment	+5°C to +30°C non-condensing		
Camera head dimensions (L x W x H)	DN100 or 6" industry-standard CF flange: 251.6 mm (9.91") x 129 mm (5.08") x 142.8 mm (5.62")	DN100 or 6" industry-standard CF flange: 251.6 mm (9.91") x 129 mm (5.08") x 142.8 mm (5.62")	DN160 or 8" industry-standard CF flange: 251.6 mm (9.91") x 129 mm (5.08") x 142.8 mm (5.62")

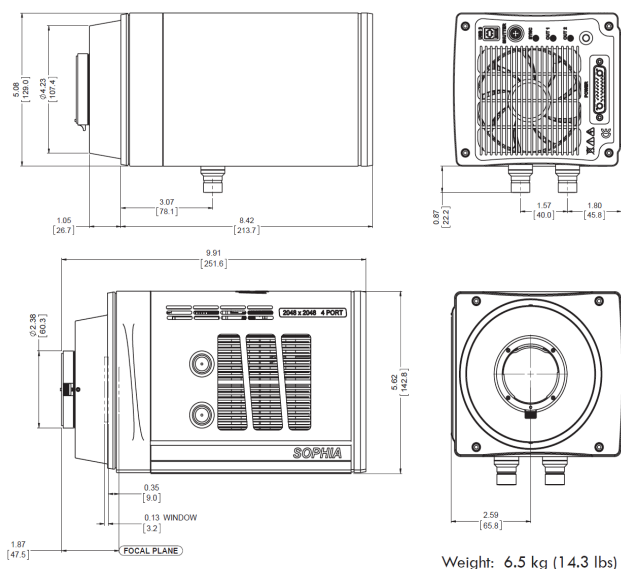
Quantum Efficiency Curve

SOPHIA-XO Quantum Efficiency

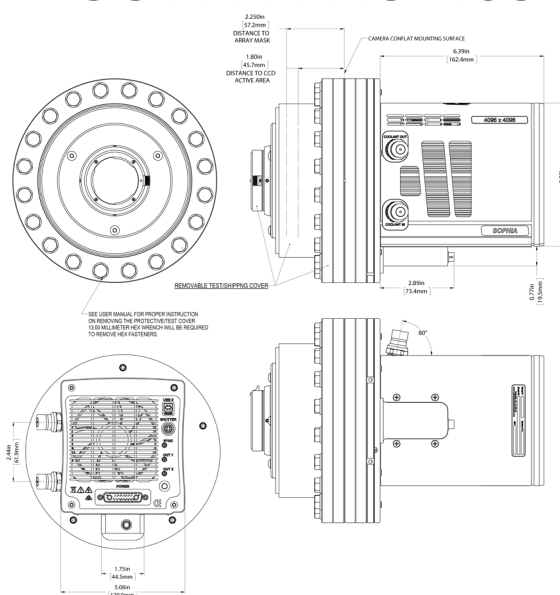


Mechanical Drawings

SOPHIA-XO 2048B



SOPHIA-XO 4096B



SOPHIA-XO

Research Stories

Utilizing A Laser Wakefield Accelerator to Produce 27 nm Radiation

X-ray free electron lasers (XFELs) are a great source of coherent, intense radiation achieving sub-angstrom wavelengths. They are advantages in a range of applications from chemistry to structural biology. However, they are costly, large and require advanced technology to achieve these radiation beams.

Laser wakefield accelerators (LWFAs), which accelerate particles to high energies by utilizing the enormous electrostatic field of an excited plasma wakefield, are able to produce radiation over just a few millimeters – centimeters. This makes them a promising compact, economically viable alternative to XFELs for laboratory settings.

However, the relatively poor quality of electron beams based on LWFAs makes them challenging, as typical FEL configurations rely on a high-quality, stable electron beam. Researchers from the Chinese Academy of Sciences have demonstrated an FEL using a LWFA as proof-of-principle.

Through the use of an LWFA accelerated electron beam, they are able to generate undulator radiation with an exponential amplification. This radiation is centered on 27 nm, with a maximum photon number of $\sim 10^{10}$ per shot.

In order to evaluate the on-axis undulator radiation produced, the researchers used a SOPHIA-XO. By measuring the number of photons collected by the SOPHIA-XO, they were able to determine the energy of the undulator radiation. The researchers also installed a transmission grating in front of the SOPHIA-XO to spectral diagnostics of the radiation.



Improving the Speed of Soft X-ray Hyperspectral Mapping

X-ray mapping is an important tool for non-destructively assessing the chemical composition of solid samples. With the recent development in both computational technology and detector technology, hyperspectral x-ray maps can now be used to further analysis.

Soft x-ray emission spectrometers are one of the most recent hyperspectral detectors, and can measure very low energy x-rays, increasing chemical analysis through the use of direct lithium measurements and spectral mapping of L, M, and N lines of certain elements.

Typically, these spectrometers utilize a 2048 x 2048, x-ray sensitive CCD camera for measurement. However, CCDs of this size are limited by the amount of time taken to readout a spectrum, even with on-chip binning.

Researchers from Australia attached a SOPHIA-XO onto a soft x-ray emission spectrometer, alongside other detector types, to optimize the experimental configuration of x-ray hyperspectral mapping. With the four-port readout of the SOPHIA-XO, the researchers were able to achieve readout speeds 10x faster than that of traditional CCD cameras. The researchers were concerned that the faster readout would result in a lower signal-to-noise ratio, due to the reduction of signal accumulation. However, the improved electronics of the SOPHIA-XO improved the noise characteristics, increasing the signal-to-noise ratio in comparison to other models.



PIXIS-XO

HIGHLY SENSITIVE, THERMOELECTRICALLY COOLED DIRECT DETECTION CAMERAS

The PIXIS-XO series of fully integrated imaging cameras utilizes back-illuminated CCDs for direct detection of x-rays between ~ 30 eV and 20 keV. The PIXIS-XO has a wide range of sensor size options allowing for the ultimate experimental flexibility.

Alongside fast readout speeds, the PIXIS-XO is thermoelectrically cooled up to -70°C , with air- or water-cooling system options, minimizing dark current noise. The high-vacuum-seal rotatable conflat flange design, as well as software selectable gains makes the PIXIS-XO suitable for ultra-high vacuum applications.



-
- 30 eV - 20 keV x-ray energy sensitivity to cover a wide range of applications
 - Multiple sensor size options for ultimate experimental flexibility
 - Rotatable high-vacuum-seal CF flange design for ultra-high vacuum applications
-

Applications

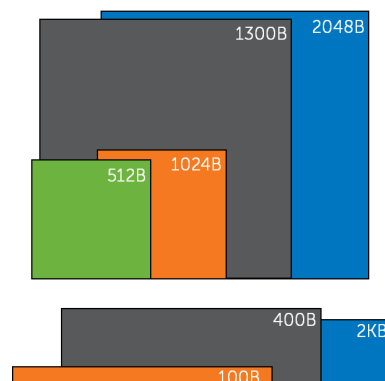
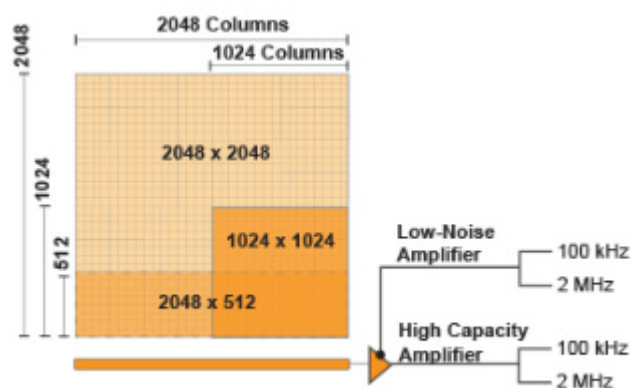
With multiple sensor options, deep cooling, dual amplifier readout design, and a rotatable conflat flange, the PIXIS XO is suitable for techniques such as:

- EUV lithography
- X-ray microscopy
- X-ray spectroscopy
- X-ray plasma diagnostics

Key Features Explored

Experimental Flexibility

The PIXIS-XO offers high x-ray sensitivity over the 30 eV – 20 keV energy range, offering flexibility for a wide range of applications. With multiple sensor and pixel sizes, including both square and rectangular configurations, allows for simple experimental optimization.



Dual amplifier readout design

The exclusive dual-amplifier configuration provides two (2) independent amplifiers whose electronics are optimized for high-capacity readout and high-sensitivity readout, respectively.

The high-capacity amplifier provides wider dynamic range by increasing full well capacity, optimal for applications with high levels of incident light. The high-sensitivity amplifier, however, is designed to deliver the lowest possible read noise at a given readout rate. This is ideal for applications involving low-energy x-rays or low levels of incident light.

Reliable Axis Alignment

The PIXIS-XO camera utilizes a ConFlat flange design, with a high-vacuum-seal, to provide an ultra-high vacuum-compatible interface that can achieve vacuum levels below 10⁻⁶ Torr. This flange design is rotatable, allowing the ability for CCD x-axis alignment with the image or spectral axis.



PIXIS-XO

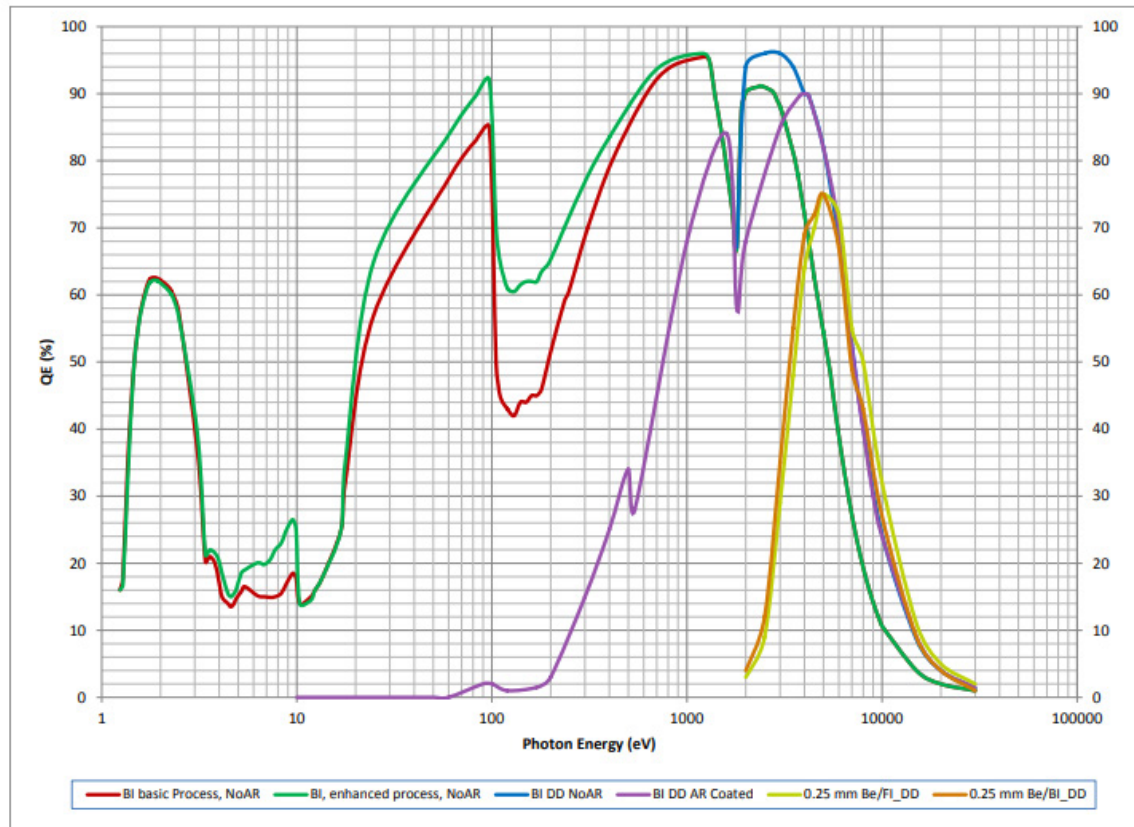
Full Specifications

Features	PIXIS-XO: 100B	PIXIS-XO: 100BR	PIXIS-XO: 400B	PIXIS-XO: 400BR
CCD image sensor	Princeton Instruments exclusive; scientific grade 1; MPP; back illuminated (BI); no AR coating (B) for sensitivity between ~10 eV to 20 keV.	Princeton Instruments exclusive; scientific grade 1; NIMO; back illuminated (BI); deep-depletion (BR); no AR coating for sensitivity between ~10 eV to 30 keV.	Princeton Instruments exclusive; scientific grade 1; MPP; back illuminated (BI); no AR coating (B) for sensitivity between ~10 eV to 20 keV.	Princeton Instruments exclusive; scientific grade 1; NIMO; back illuminated (BI); deep-depletion (BR); no AR coating for sensitivity between ~10 eV to 30 keV.
CCD format	1340 x 100 imaging pixels; 20 x 20 μm pixels; 100% fill factor; 13.3 x 13.3 μm (optically centered)		1340 x 400 imaging pixels; 20 x 20 μm pixels; 100% fill factor; 13.3 x 13.3 μm (optically centered)	
Deepest cooling temperature	TE air cooling* (with ambient ar @ +20° C); -90° C typical; -75° C guaranteed			
Thermostating precision	±0.05° C			
Dark current (e ⁻ /pixel/sec)	@-75° C 0.001 @+20° C 0.005	@-75° C 0.03 @+20° C 0.065	@-75° C 0.001 @+20° C 0.005	@-75° C 0.03 @+20° C 0.065
Cooling method	Thermoelectric air or liquid cooling (CoolCUBE II required)			
Full well	Single pixel: 100 ke ⁻ (typical), 60 ke ⁻ (minimum) High Sensitivity node: 250 ke ⁻ (typical), 220 ke ⁻ (minimum) High Capacity node: 1000 ke ⁻ (typical), 750 ke ⁻ (minimum)			
ADC speed	100 kHz/16-bit and 2 MHz/16-bit			
System read noise	@100 kHz 3.0 e ⁻ rms (typical), 5 e ⁻ rms (max) @2 MHz 11 e ⁻ rms (typical), 16 e ⁻ rms (max)			
Nonlinearity	<1% @ 100 kHz <2% @ 2 MHz			
Software-selectable gains	1, 2, 4 e ⁻ (high sensitivity); 4, 8, 16 e ⁻ (high capacity); available at all speeds			
Data interface	USB2.0 (5m interface cable provided); Optional Fiberoptic interface is available for remote operation			
I/O signals	Two MCX connectors for programmable frame readout, shutter, trigger in			
Bake-out temperature	70° C (maximum)			
Vacuum compatibility	10 ⁻⁸ Torr			
Certification	CE			
Operation environment	+5° C to +30° C non-condensing			
Camera dimensions (L X W X H)	16.59cm (6.53")x 11.81 cm (4.65")x 11.38cm (4.48")			

* The minimum temperature attainable is dependent on the vacuum condition - temperature can be lowered w/lower vacuum

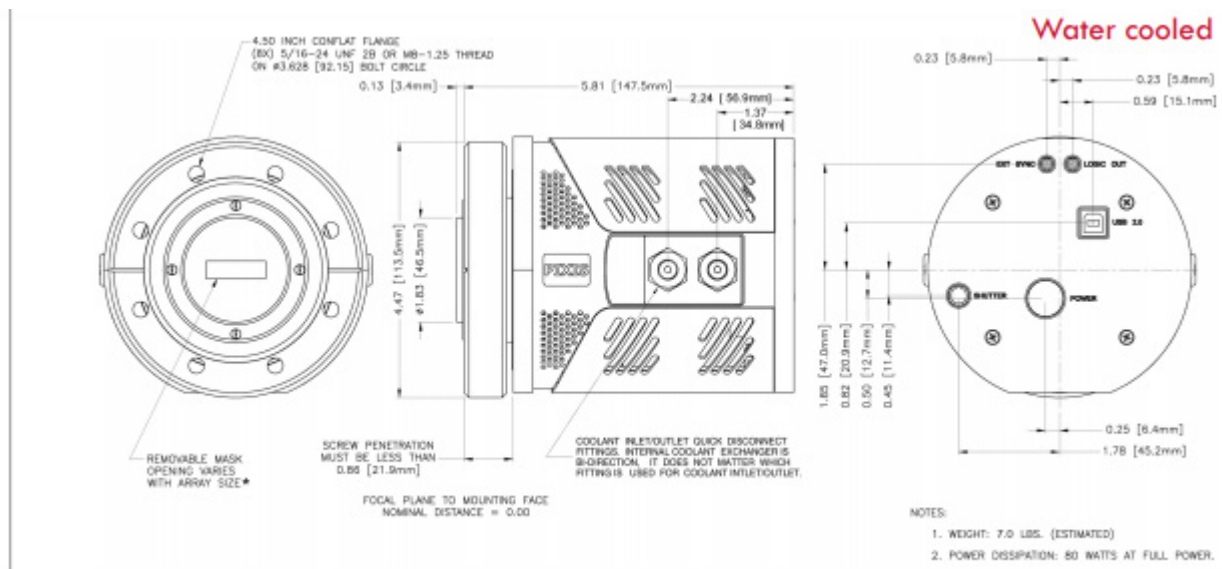
PIXIS-XO: 1024B/BUV	PIXIS-XO: 1024BR	PIXIS-XO: 2KB/2KBV	PIXIS-XO: 2048B	PIXIS-XO: 2048BUV/BR
e2v CCD47-10; scientific grade 1; MMP; BI-basic process (B); BI-enhanced process (BUV), no AR coating, for sensitivity between ~10 eV to 20 keV	e2v CCD47-10; scientific grade 1; NIMO; BI-deep depletion (BR); no AR coating, for sensitivity between ~10 eV to 30 keV.	e2v CCD42-10; scientific grade 1; MMP; BI-basic process (B), BI-enhanced process (BUV); no AR coating; for sensitivity between ~10 eV to 30 keV	e2v CCD42-40; scientific grade 1; MMP; BI-basic process (B); no AR coating; for sensitivity between ~10 eV to 30 keV	e2v CCD42-40; scientific grade 1; NIMO; BI-enhanced process (BUV), BI-deep depletion (BR); no AR coating; for sensitivity between ~10 eV to 30 keV
1024 x 1024 imaging pixels; 13 x 13 μm pixels; 100% fill factor; 13.3 x 13.3 μm (optically centered)		2048 x 512 imaging pixels; 13.5 x 13.5 μm pixels; 100% fill factor; 13.3 x 13.3 μm (optically centered)	2048 x 2048 imaging pixels; 13.5 x 13.5 μm pixels; 100% fill factor; 27.6 x 27.6 μm (optically centered)	
TE air cooling* (with ambient air @ +20° C); -70° C typical; -65° C guaranteed		TE air cooling* (with ambient air @ +20° C); -75° C typical; -70° C guaranteed	TE air cooling* (with ambient air @ +20° C); -70° C (typical); -60° C (guaranteed) with CoolCUBE II liquid circulator	-60° C (typical); -50° C (guaranteed) with air
$\pm 0.05^\circ\text{C}$				
@ -75° C 0.0004 (typical) @ +20° C 0.001 (max)	@ -75° C 0.02 (typical) @ +20° C 0.07 (max)	@ -75° C 0.001 (typical) @ +20° C 0.006 (max)	@ -60° C 0.002 (typical) @ +20° C 0.006 (max)	@ -60° C 0.2 (typical) @ +20° C 2 (max)
Thermoelectric air or liquid cooling (CoolCUBE II required)				
Single pixel: 100 ke ⁻ (typical), 60 ke ⁻ (minimum) Output node: 250 ke ⁻ (typical), 220 ke ⁻ (minimum)		Single pixel: 100 ke ⁻ (typical), 60 ke ⁻ (minimum) High Sensitivity node: 250 ke ⁻ (typical), 220 ke ⁻ (minimum) High Capacity node: 750 ke ⁻ (typical), 600 ke ⁻ (minimum)	Single pixel: 100 ke ⁻ (typical), 80 ke ⁻ (minimum) High Sensitivity node: 250 ke ⁻ (typical), 220 ke ⁻ (minimum) High Capacity node: 1000 ke ⁻ (typical), 800 ke ⁻ (minimum)	
100 kHz/16-bit and 2 MHz/16-bit				
@100 kHz 3.1 e ⁻ rms (typical), 5 e ⁻ rms (max) @2 MHz 9 e ⁻ rms (typical), 15 e ⁻ rms (max)		@100 kHz 3.5 e ⁻ rms (typical), 6 e ⁻ rms (max) @2 MHz 14 e ⁻ rms (typical), 20 e ⁻ rms (max)	@100 kHz 3.5 e ⁻ rms (typical), 5 e ⁻ rms (max) @2 MHz 12 e ⁻ rms (typical), 16 e ⁻ rms (max)	
<1% @ 100 kHz		<1% @ 100 kHz <2% @ 2 MHz	<2% @ 100 kHz	
1, 2, 4 e ⁻ /ADU; available at all speeds		1.5, 3, 6 e ⁻ (high sensitivity); 3, 6, 12 e ⁻ (high capacity); available at all speeds	1, 2, 4 e ⁻ /ADU (low noise input); 3.5, 7, 14 e ⁻ /ADU (high capacity output)	
USB2.0 (5m interface cable provided); Optional Fiberoptic interface is available for remote operation				
Two MCX connectors for programmable frame readout, shutter, trigger in				
70° C (maximum)				
10 ⁻⁸ Torr				
CE				
+5° C to +30° C non-condensing				
16.59cm (6.53")x 11.81 cm (4.65")x 11.38cm (4.48")		15.1 cm (5.95") x 11.81 cm (4.65") x 11.45 cm (4.50") (L x W x H)	15.1 cm (5.95") x 15.24 cm (6.00") x 15.24 cm (6.00")	

Quantum Efficiency Curve



Mechanical Drawings

Mechanical drawing of the PIXIS-XO: 1024B (water cooled)*

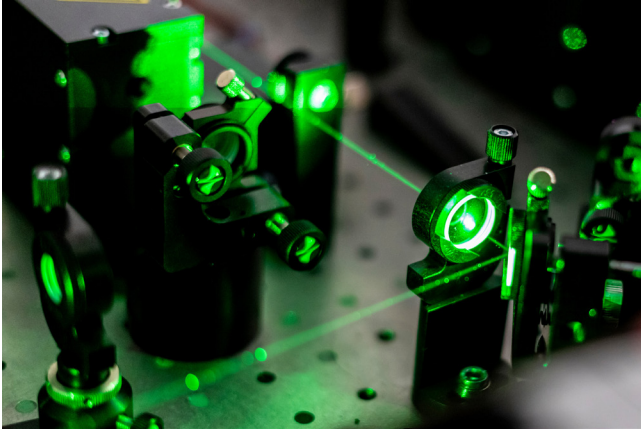


PIXIS-XO

Research Stories

Improving the Use of Strong Laser Fields in Plasmas for Synchrotrons

Particle accelerators and synchrotrons are our most perfect and brilliant light sources of visible to x-ray radiation for scientific research and development, from material to life science. Recently techniques using strong laser fields in plasmas have emerged as an alternative for acceleration because of their much smaller size (<1 meter vs. 100s of meters for synchrotrons).



However, the emerging particle beams still have significant quality issues compared to the currently used beams. Researchers at the Synchrotron SOLEIL in France report on work of improving the beam quality where they monitor the quality and shape of the radiation that is produced from them. The vacuum compatible PIXIS-XO allowed for sensitive detection of radiation from UV to soft x-rays in this application.

EUV Microscope for Plasma Scattering and Absorption Investigations

An international team of researchers centered in Germany designed and built a new EUV microscope with sufficient magnification for imaging of scattering and absorption of plasmas created with sub picosecond EUV pulses created from cryogenic hydrogen jets. The EUV radiation is created in a free electron laser (FEL, FLASH in Hamburg Germany) built to provide short pulsed, high quality radiation at extremely short wavelengths.

Understanding the physics of plasmas has important applications in other fields. Higher resolution of plasma dynamics will improve understanding and modelling of processes in planetary science and fusion research. EUV light can penetrate deeply into plasmas (unlike visible light) so it is well suited to study inner workings of plasmas.

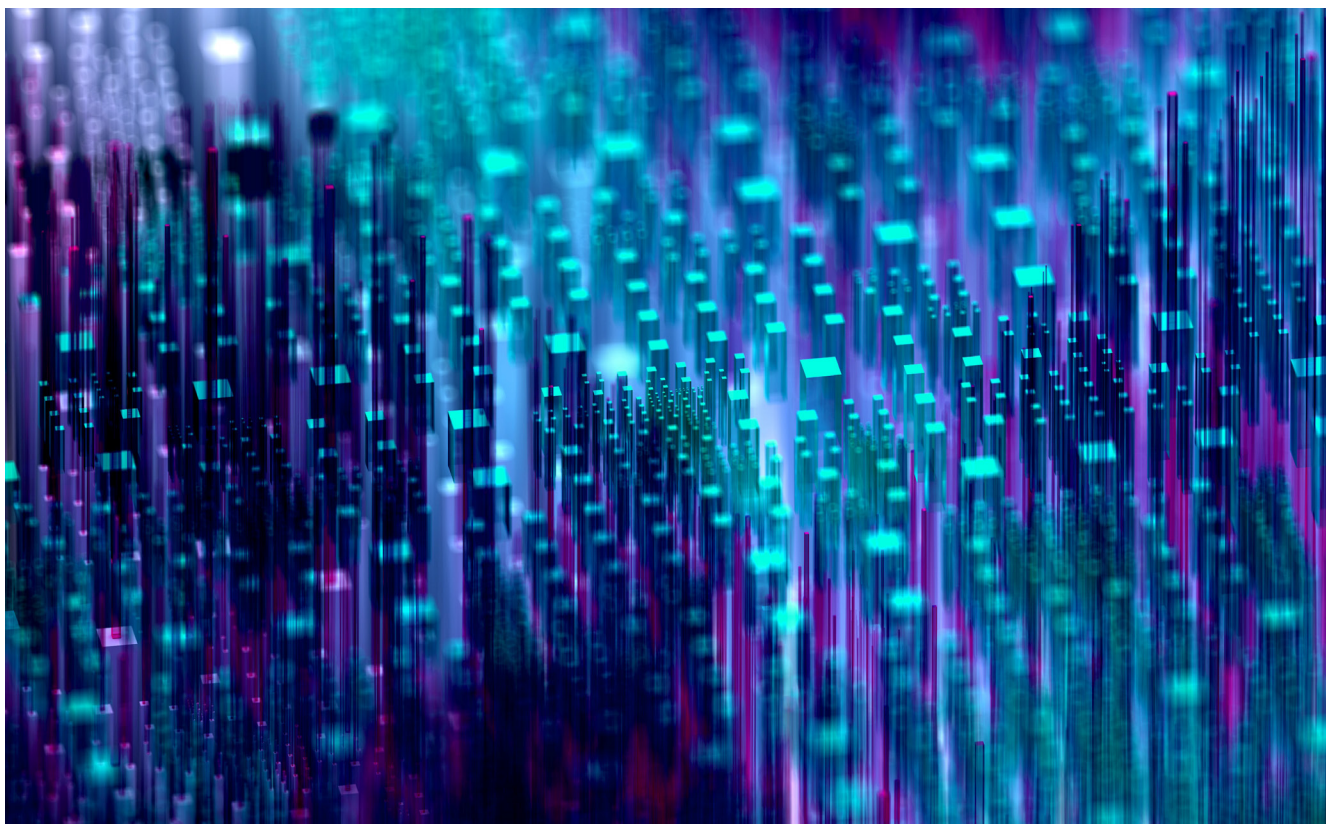


For their setup the team created proper objective, designed for right magnification (practical FOV size with highest resolution given 13.5 μm pixel pitch of CCD). The high sensitivity of the PIXIS-XO allowed for fast imaging of scattering from single radiation pulses.

New Gratings for Suppression of Higher Diffraction Orders

Diffraction gratings are used as the dispersive element in spectral analysis from the infrared to the soft x-ray range. A common problem in any wavelength range is the influence of higher diffraction orders that can either overlap with the main signal or complicate calibration of the measurement instruments. A research team in China has developed new grating types based on nanotechnology fabrications techniques that show much larger suppression of higher diffraction orders than blazed diffraction gratings.

Interestingly, the new gratings do not have periodic, repeatable structure, but are made of millions of nanometer sized pillars arranged in a quasi-random fashion. To test the gratings in an x-ray monochromator, the researchers used the sensitive PIXIS-XO to detect the very low signals, via long integration. While the suppression of higher orders is very high in the nanopillar gratings, the overall efficiency is low, yet it is still comparable to the efficiency achieved by conventional methods of higher order suppression.



PIXIS-XB

HIGH PERFORMANCE, LOW NOISE CAMERAS WITH BERYLLIUM WINDOW DESIGN

The PIXIS-XB camera utilizes a beryllium window design, present within the vacuum chamber, to filter out visible light and low energy x-rays, reducing any background. In addition, this camera can be used within a laboratory setting and does not need to be installed on a vacuum chamber.

With multiple sensor format and illumination options, dual-amplifier readout design, deep thermoelectric cooling, and plug-and-play USB 2.0 computer connectivity, the PIXIS-XB offers simple operation and integration.



-
- Beryllium window design to filter visible and low x-ray energies
 - Multiple sensor format options for flexibility over various applications
 - Easy compatibility and integration with Linux operation and USB 2.0 plug-and-play computer connectivity
-

Applications

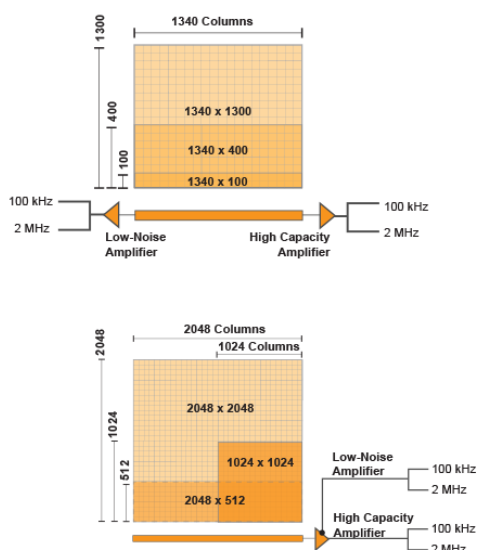
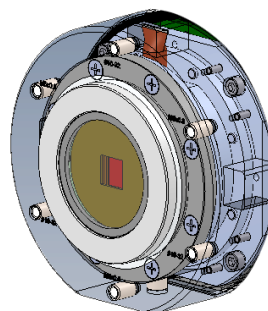
With multiple sensor formats, dual-amplifier readout for low noise, high dynamic range, and linearity, and the incorporation of a beryllium window, the PIXIS-XB can be utilized for multiple applications such as:

- X-ray photon correlation spectroscopy (XPCS)
- X-ray intensity fluctuation spectroscopy (XIFS)
- X-ray diffraction
- X-ray lithography
- X-ray spectroscopy

Key Features Explored

Beryllium Window Design

With a thin, maintenance free Beryllium window design present within the vacuum chamber, the PIXIS-XB blocks visible light, protecting the CCD sensor from contamination. It also reduces background signal by filtering low energy x-rays.



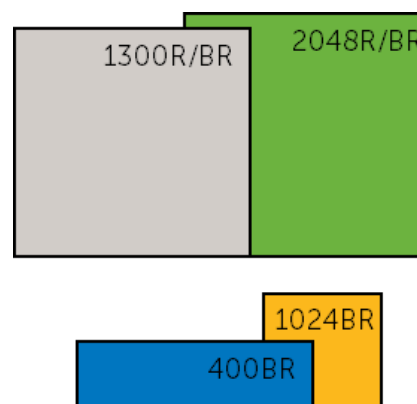
Ultimate Flexibility

The dual-amplifier readout design of the PIXIS-XB allows for optimization of system performance, with the lowest possible read noise, highest dynamic range and linearity.

With multiple sensor formats, including both square and rectangular design, the PIXIS-XB offers the ultimate flexibility. In both front- or back-illuminated deep-depleted CCD options, up to 2048 x 2048 pixels, and deep thermoelectric cooling, the PIXIS-XB can fit into multiple experimental set-ups.

Varying Sensor Formats

The PIXIS-XB has multiple sensor formats and pixel sizes, providing flexibility for each specific experiment. With both square and rectangular sensor formats, the PIXIS-XB can be utilized for imaging or spectroscopy. Offering either 13 μm or 20 μm pixels, the PIXIS-XB provides up to 27.65 x 27.65 mm imaging area, ideal for a wide range of applications.



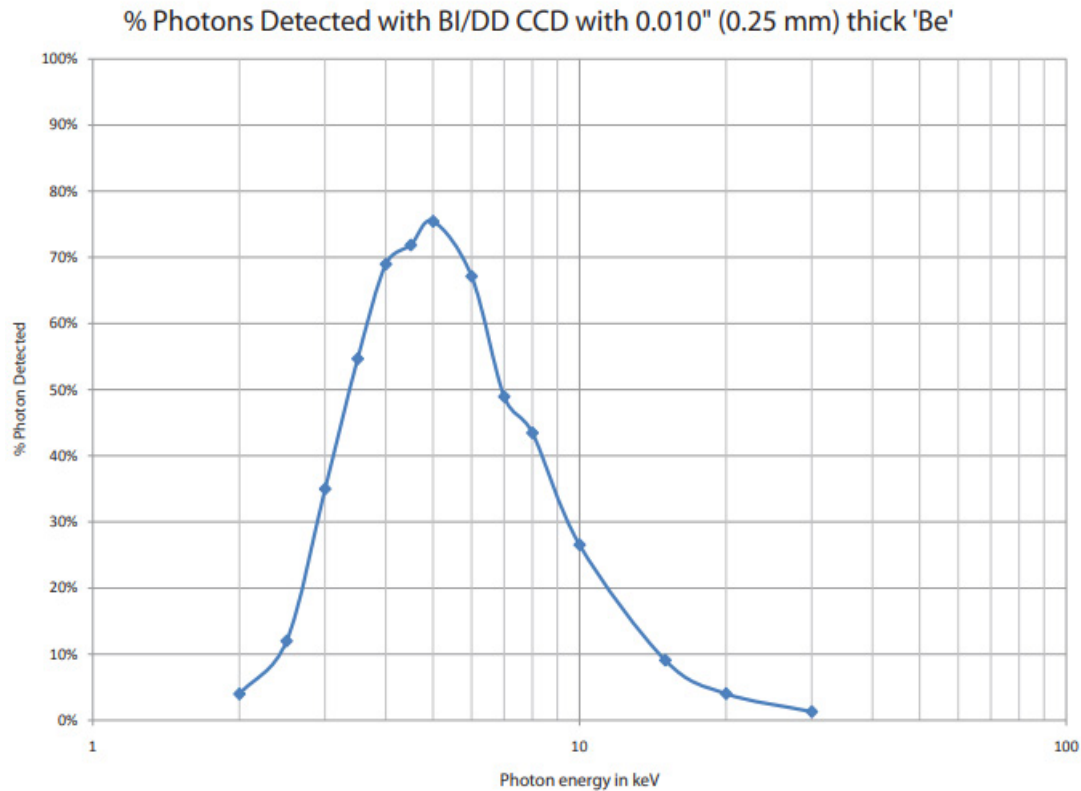
PIXIS-XB

Full Specifications

Features	PIXIS-XB: 400BR	PIXIS-XB: 1024BR	PIXIS-XB: 1300R	PIXIS-XB: 1300BR
CCD image sensor	Princeton Instruments' proprietary CCD, back-illuminated, deep depletion, grade 1, NIMO	e2v CCD47-10, back-illuminated, deep depletion, grade 1, NIMO	Proprietary CCD, front-illuminated, deep depletion, grade 1, NIMO	Proprietary CCD back-illuminated, deep depletion, grade 1, NIMO
CCD format	1340 x 400 imaging pixels; 20 μm x 20 μm pixels; 100% fill factor	1024 x 1024 imaging pixels; 13 x 13 μm pixels; 100% fill factor	1340 x 1300 imaging pixels; 20 μm x 20 μm pixels; 100% fill factor	
Deepest cooling temperature	-90° C typical; -75° C guaranteed, specified at ambient temperature of +20° C		< -70° C (typical), -60° C (guaranteed) with CoolCUBEII liquid circulator < -65° C (typical), -55° C (guaranteed) with air	
Thermostating precision	±0.05° C			
Dark current (e ⁻ /pixel/sec)	@ -75° C, 0.03 (typical), 0.065 (max)	@ -70° C, 0.02 (typical), 0.07 (max)	@ -60° C 0.32 (typical) 0.65 (max)	
Cooling method	Thermoelectric air or liquid cooling (CoolCUBE II liquid circulator available)			
Full well	Single pixel 250 ke ⁻ (typical), 200 ke ⁻ (min) Output node 1 Me ⁻ (typical), 750 ke ⁻ (min) (high capacity mode)	Single pixel 100 ke ⁻ (typical), 60 ke ⁻ (min) Output 250 ke ⁻ (typical), 220 ke ⁻ (min)	Single pixel 250 ke ⁻ (typical), 200 ke ⁻ (min) Output node 1000 ke ⁻ (typical), 800 ke ⁻ (min)	
ADC speed	100kHz/16-bit and 2MHz/16-bit			
System read noise	@ 100 kHz 3.0 e ⁻ rms (typical), 5 e ⁻ rms (max) @ 2 MHz 11 e ⁻ rms (typical), 16 e ⁻ rms (max)	@ 100 kHz 3.0 e ⁻ rms (typical), 5 e ⁻ rms (max) @ 2 MHz 9 e ⁻ rms (typical), 15 e ⁻ rms (max)		
Nonlinearity	<1% @ 100 kHz			
Software-selectable gains	1, 2, 4 e ⁻ (high sensitivity); 4, 18, 16 e ⁻ (high capacity); available at all speeds	1, 2, 4 e ⁻ /ADU (typical); available at all speeds	1, 2, 4 e ⁻ (high sensitivity); 4, 8, 16 e ⁻ (high capacity); available at all speeds	
Data interface	USB2.0 (5m interface cable provided); Optional Fiberoptic interface is available for remote operation			
I/O signals	Two MCX connectors for programmable frame readout, shutter, trigger in			
Certification	CE			
Operation environment	+5° C to +30° C non-condensing			
Camera dimensions (L X W X H)	16.59 cm (6.53") x 11.81 cm (4.65") x 11.38 cm (4.48")			

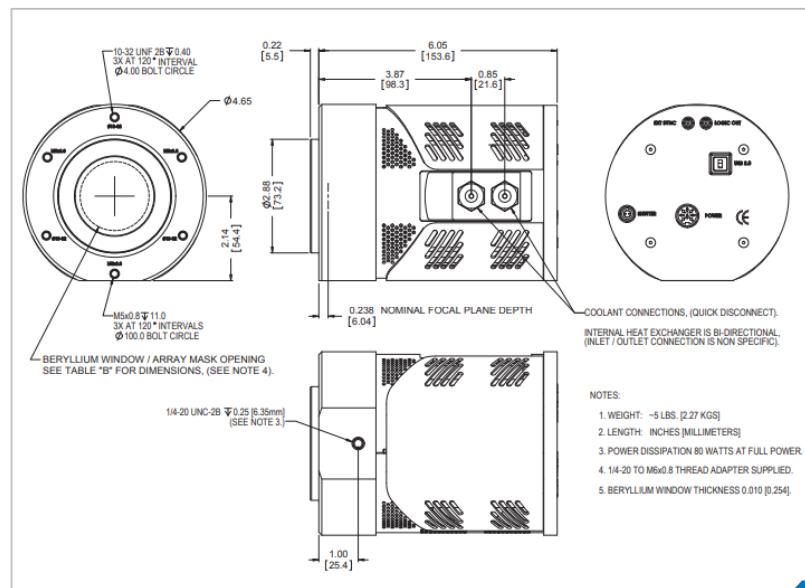
* The minimum temperature attainable is dependent on the vacuum condition - temperature can be lowered w/lower vacuum

Quantum Efficiency Curve



Mechanical Drawings

Mechanical drawing of the PIXIS-XB: 1024BR (water cooled)*



PIXIS-XB

Research Stories

X-ray Imaging of Hydrogen for Fusion Experiments

Researchers at the Laboratory for Laser Energetics in Rochester are using X-Ray imaging to characterize frozen hydrogen shells that are used as fuel in fusion experiments. The lab develops and conducts experiments, materials and technologies as part of a national program on inertial confinement fusion. This process uses spherical shells consisting of deuterium and tritium. The fusion process is initiated by an intense laser beam, leading to the explosion of the outer layer of the micrometer sized spheres and driving compression and heating of fuel inside the shells.



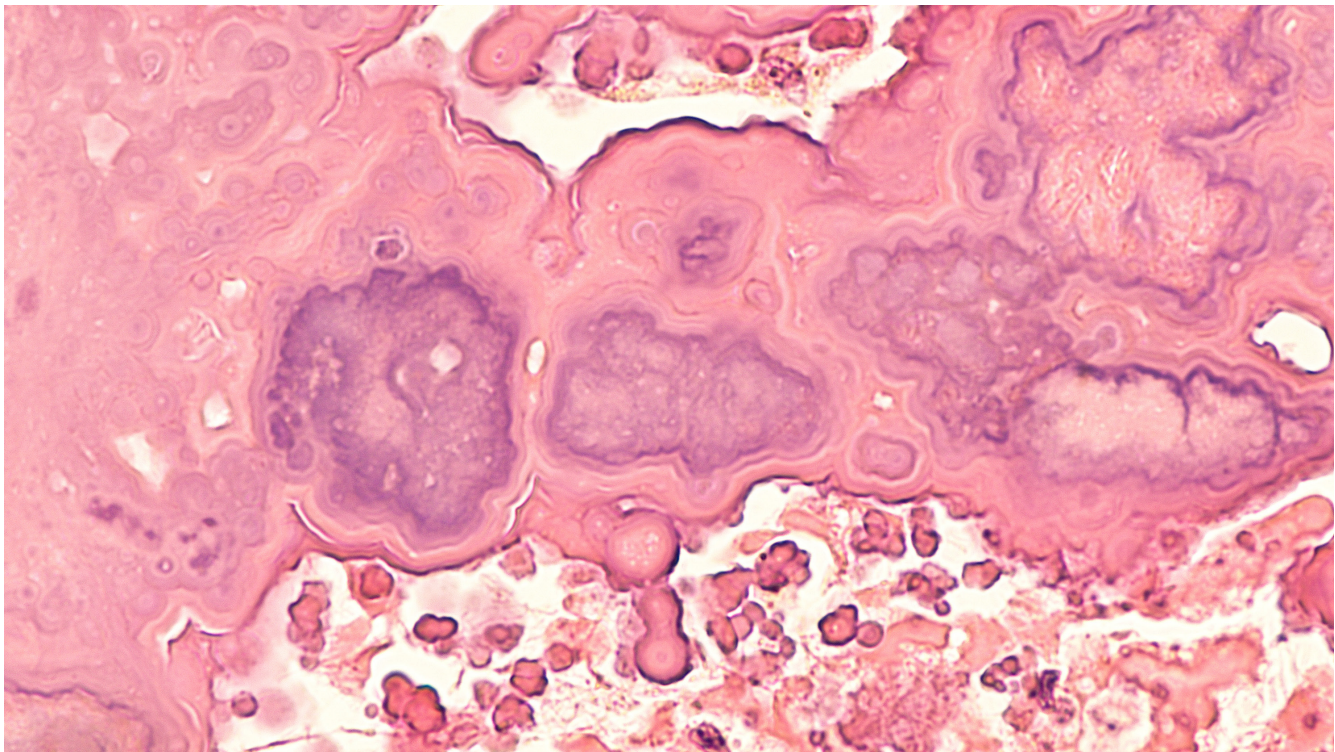
X-Ray phase contrast imaging is a useful technique to analyze structure in materials. It observes interference due to phase differences created by different index of refraction in materials. Phase contrast imaging can even be applied to materials like hydrogen where X-Ray absorption is low.

The X-Ray phase imaging setup at LLE uses a microfocus X-Ray source in 165 mm distance from the sample and a PIXIS-XB direct detection camera in 1140 mm distance. The large distance of the detector is chosen to magnify the image to a resolution of 1.6 $\mu\text{m}/\text{pixel}$. The X-Ray measurements are compared to visible light shadowgraphy measurements to figure out which technique is best suited for measuring specific properties of the ice shells.

The X-Ray measurements show the suitability of the technique to measure the thickness and defects in the deuterium-tritium layers, in particular for measuring longer wavelength fluctuations, as the X-Rays are less affected by small defects compared to the visible measurements. Combined with the visible imaging techniques, X-Ray phase imaging can help to identify highest quality ice layers where the results of both measurements techniques give the most similar results.

Quantifying Calcifications to Diagnose Cardiovascular Disease with CT

Cardiovascular disease is one of the most common causes of death worldwide. One of the typical indicators of this disease is calcifications within the coronary artery. The most established method for measuring these calcifications is computed tomography (CT). Within the clinic, these CT scanners rely on energy-integrating detectors, which utilize a scintillator to convert high energy photons into visible light. However, they are limited in spatial resolution which can result in either an overestimated diagnosis or an underestimated one. In comparison, photon-counting detectors, currently not used in clinic, use a semiconductor to convert x-ray photons to electrical signals, allowing for smaller signals and improved spatial resolution.



Researchers from Linköping University and the Mayo Clinic in Rochester (USA) have compared a photon-counting detector CT with an energy-integrating detector CT to determine which method is more accurate at quantifying calcifications on the coronary artery. They relied on micro-CT measurements as the reference standard.

These researchers found that the photon-counting detector CT was not only able to quantify coronary calcifications much more accurately, but also produce lower noise than the standard energy-integrating detectors. The researchers utilized a PIXIS-XB within their micro-CT set up, creating a custom-built micro-CT scanner to create the standard reference. By accumulating hundreds of images over 360° sample rotation they were able to reconstruct the sample for referencing.



Indirect Detection

Current Capabilities

PIXIS-XF

LOW-NOISE CCD CAMERA WITH INTEGRATED PHOSPHOR SCREEN

PIXIS-XF low-noise cameras have a unique fiberoptic design with multiple phosphor screen options for the direct detection of x-rays. With an exclusive mechanical design, where the fiberoptic faceplate extends outside the vacuum, the PIXIS-XF offers flexibility for optimizing performance at specific medium-energy x-rays.

Having multiple CCD sensor types, alongside complete control either by our powerful LightField software, or via a Linux driver and PICAM/PVCAM DLLs (64/32 bits) for custom software development, the PIXIS-XF provides further optimization and flexibility.



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- Unique fiberoptic design and several phosphor screen options for optimization and specificity
 - Multiple sensor and illumination options for further optimization and flexibility
 - Custom software development and long-distance interfaces for easy integration into experimental set-ups
-

Applications

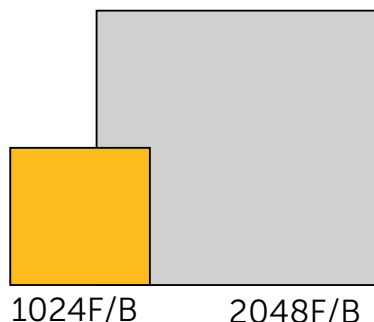
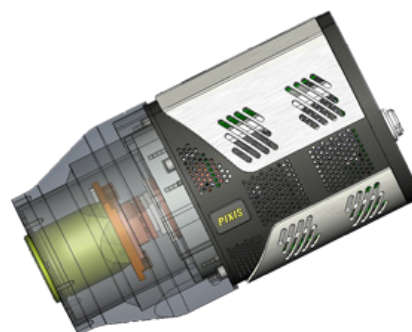
With an integrated and easy replacement phosphor screen, multiple sensor options, and dual amplifier readout design, the PIXIS-XF is suitable for techniques such as:

- X-ray computed microtomography
- Streak tube and CRT readout
- Industrial imaging
- Medical imaging

Key Features Explored

Unique Phosphor Screen Design

The PIXIS-XF is designed for medium-energy x-ray applications. With a unique fiberoptic design and several phosphor options, including GdOS:Tb for 8-17 keV coverage and CsI:Tl, the PIXIS-XF can be easily optimized for specific x-ray energies. The mechanical design, with fiberoptic extended outside the vacuum, allows performance optimization with custom phosphor screens.



Multiple Sensor Options

For further optimization and flexibility, the PIXIS-XF comes with both front- and back-illuminated CCD sensors. The PIXIS-XF also has sensors with multiple resolution options, ranging up to 2048 x 2048 pixels (imaging area: 27.6 x 27.6 mm). By considering the 1:1 fiberoptic ratio and 13 μm pixel size, the 1 MP CCD camera model offers resolution of ~ 38 lp/mm.

Simple Experimental Integration

The PIXIS-XF camera can be completely controlled by the powerful and intuitive LightField software. Full control of the PIXIS-XF can also be achieved via a Linux driver and PICAM DLLs (64 bits) for custom software development. The USB 2.0 plug-and-play computer connectivity, alongside fiberoptic and ethernet interfaces for long-distance camera control, allows the PIXIS-XF to easily fit into already existing experimental set-ups.



USB 2.0 to Fiberoptic



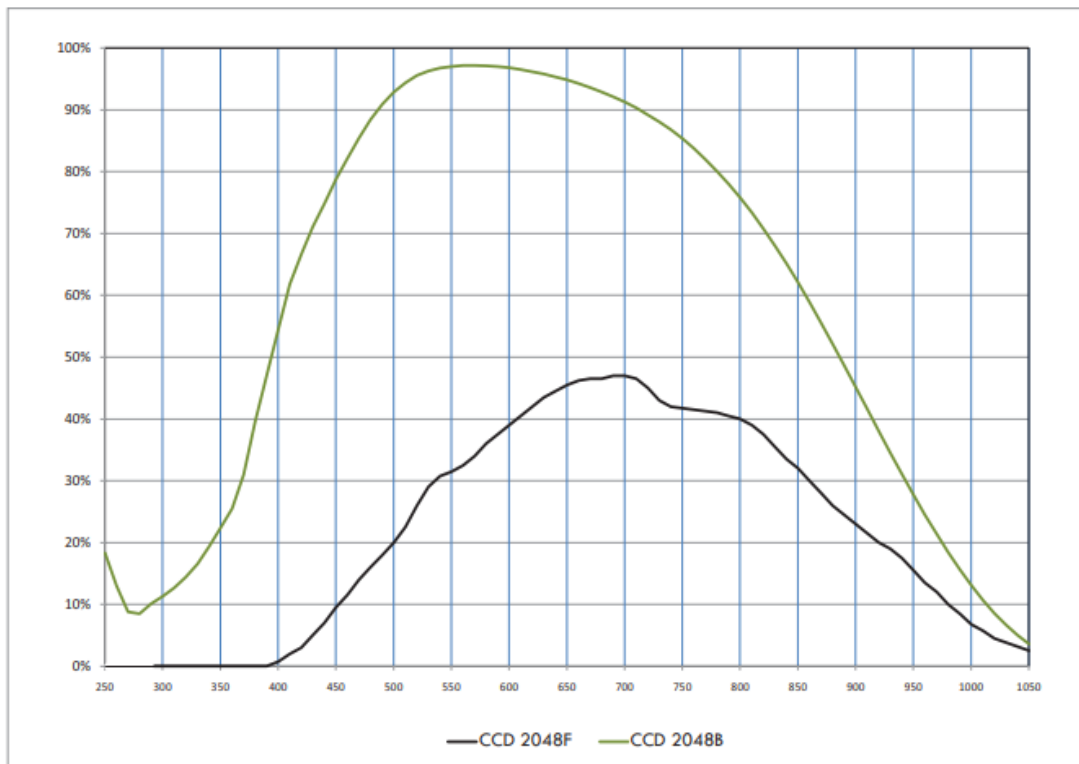
USB 2.0 to Ethernet

PIXIS-XF

Full Specifications

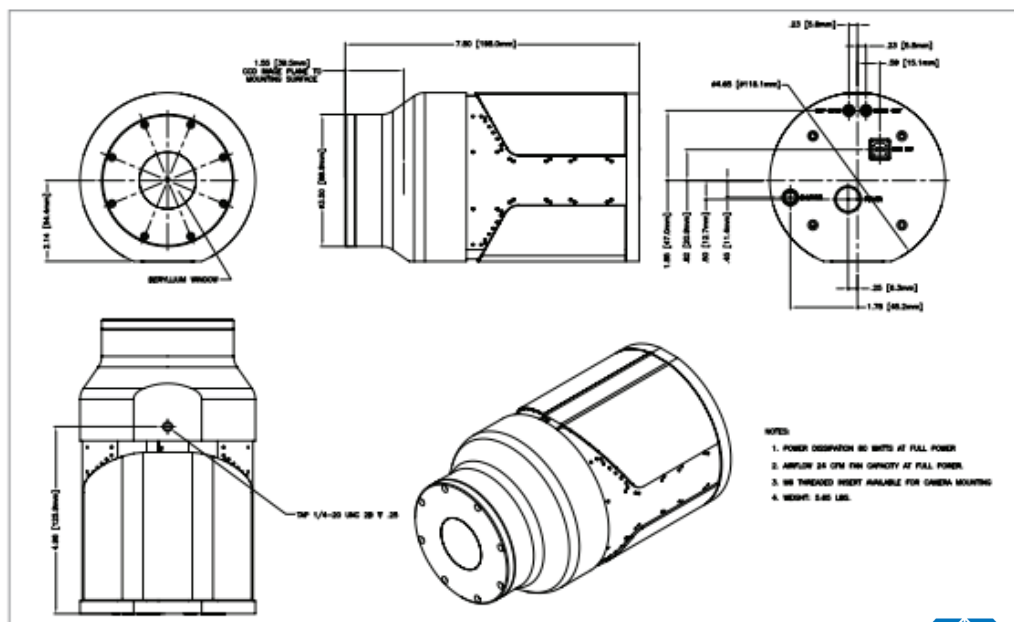
Features	PIXIS-XF: 1024F	PIXIS-XF: 1024B	PIXIS-XF: 2048F	PIXIS-XF: 2048B
CCD image sensor	e2v CCD47-10; front-illuminated; scientific grade 1; AIMO	e2v CCD47-10; back-illuminated; scientific grade 1; AIMO	e2v CCD42-40; front-illuminated; scientific grade 1; AIMO	e2v CCD42-40; back- illuminated; scientific grade 1; AIMO
CCD format	1024 x 1024 imaging pixels; 13 x 13- μ m pixels; 100% fill factor; 13.3 x 13.3 μ m (optically centered)		2048 x 2048 imaging pixels; 13.5 x 13.5- μ m pixels; 100% fill factor; 27.60 x 27.60 μ m (optically centered)	
Deepest cooling temperature	(with ambient air @ +20° C) -40° C typical; -35° C guaranteed		(with ambient air @ +20° C) -30° C typical; -25° C guaranteed	
Thermostating precision	$\pm 0.05^\circ$ C			
Dark current (e ⁻ /pixel/sec)	@ -40° C 0.035 e ⁻ /p/sec (typical) 0.2 e ⁻ /p/sec (max)		@ -30° C 0.035 e ⁻ /p/sec (typical) 0.1 e ⁻ /p/sec (max)	
Cooling method	Thermoelectric air (standard) or liquid cooling (CoolCUBE II required)		Thermoelectric liquid cooling - Standard (CoolCUBE II required). Contact factory for air-cooled option.	
Full well	Single pixel: 100 ke ⁻ (typical), 60 ke ⁻ (minimum) Output node: 250 ke ⁻ (typical), 200 ke ⁻ (minimum)		Single pixel: 125 ke ⁻ (typical), 100 ke ⁻ (minimum) Output node: 270 ke ⁻ (typical), 250 ke ⁻ (minimum)	
ADC speed	100 kHz/16-bit and 2 MHz/16-bit			
System read noise	@100kHz 4.5 e ⁻ rms (typical), 6.5 e ⁻ rms (max) @2MHz 12.5 e ⁻ rms (typical), 16 e ⁻ rms (max)		@100kHz 4.0 e ⁻ rms (typical), 5.5 e ⁻ rms (max) @2MHz 12.75 e ⁻ rms (typical), 16.5 e ⁻ rms (max)	
Nonlinearity	< 1% @ 100 kHz			
Software-selectable gains	1, 2, 4 e ⁻ /ADU; available at all speeds			
Data interface	USB2.0 (5m interface cable provided); Optional Fiberoptic interface is available for remote operation			
I/O signals	Two MCX connectors for programmable frame readout, shutter, trigger in			
Certification	CE			
Operation environment	+5° C to +30° C non-condensing			
Camera dimensions (L X W X H)	19.8 cm (7.80") x 11.81 cm (4.65") x 11.38 cm (4.48")		20.45 cm (8.05") x 11.81 cm (4.65") x 11.38 cm (4.48")	

Quantum Efficiency Curve



Mechanical Drawings

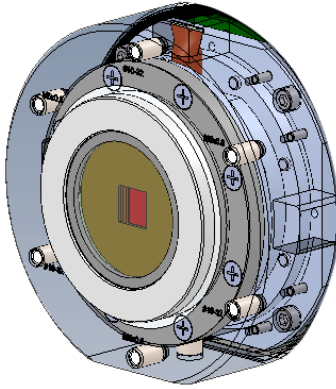
Mechanical drawing of the PIXIS-XF: 1024 with phosphor kit*



PIXIS-XF

Research Stories

Quantitatively Evaluating Scintillators for the Few-Ten-keV Energy Range



Different x-ray energies can be beneficial for different applications. Applications such as phase-contrast imaging, and small-animal imaging, and increasingly relying on high-spatial-resolution imaging over the few-ten-keV energy range. Both the sensor and scintillator quality drastically determine the quality of high-spatial-resolution imaging.

Researchers from Sweden quantitatively evaluated 3 scintillators to determine which qualities are optimal for this type of imaging. They investigated the noise, resolution, and overall performance over the few-

ten-keV energy range, at a rate of 37 cycles/mm to obtain high-spatial-resolution imaging. Various thickness of structured, microcolumnar, and unstructured scintillators were measured to determine their detective quantum efficiency, noise power spectrum, and modulation transfer function, all which influence image quality.

To ensure that only the scintillator parameters were being investigated, it was imperative that the researchers used the same camera. The PIXIS-XF was the ideal CCD camera as it accommodates exchangeable scintillators. The researchers coupled the scintillator to the CCD at 1:1 via fiber optic plate. The 13.5 mm pixel pitch and 100% fill factor of the PIXIS-XF provided the researchers with an active area of 27.6 x 27.6 mm².

The researchers found that scintillator thickness reduces resolution and relative noise, and that for lower energies thin scintillators have better performance. They also found that structured scintillators are the most efficient in reducing the diffusion of light within the scintillator, however they still have limitations. Overall, careful consideration must be taken when choosing the right scintillator for each imaging experiment.

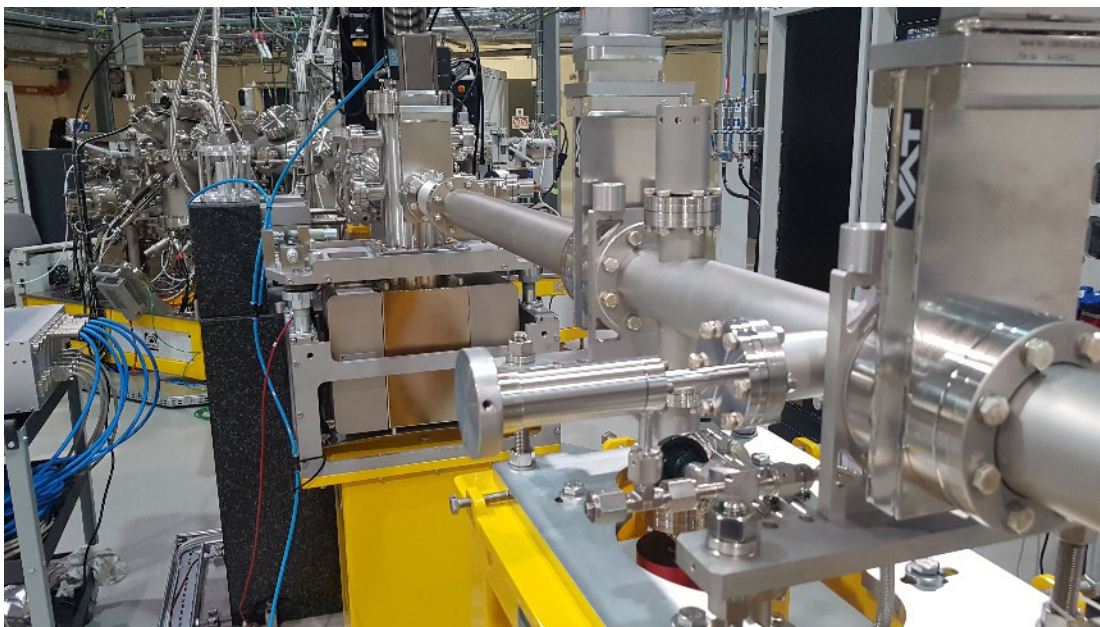
Hard X-ray Test Facility Based on a Single Crystal Monochromator

In order to calibrate x-ray detectors, they need to be tested at how well they respond to different x-ray energy levels at dedicated x-ray test facilities. Researchers from China developed a hard x-ray test facility to test various hard x-ray detectors based on a single crystal monochromator.

They utilized 3 single crystals within the monochromator to cover the energy range 21-301 keV. The system was comprised of 4 parts, an x-ray source, a collimating structure, a single crystal monochromator, and two detectors. These detectors were a high-purity Germanium detector, and the PIXIS-XF CCD camera.

The researchers found there to be a good linear relationship between the x-ray tube current and the monochromatic light flux. However, the energy resolution worsened with increasing energy value, as the spectra broadened. Overall, they found the x-ray test facility to accommodate a wide energy range with good stability, and therefore suitable for multiple testing experiments.

The low noise of the PIXIS-XF made it a great option for monitoring the x-ray light spot. The researchers found the dual speed operation suitable for both steady state as well as for high speed applications, and therefore an ideal option for monitoring their new system.



Kinetix

HIGHLY SENSITIVE sCMOS WITH FAST FRAME RATES

The Kinetix is a back-illuminated scientific CMOS (sCMOS) camera that delivers fast frame rates up to 498 full frame fps, while maintaining near perfect 95% quantum efficiency in the visible wavelength region.

With a low read noise of 0.7 e-, and the latest sCMOS fabrication technology, the Kinetix ensures pattern-free images with minimal artifacts and pixel defects, delivering improved image quality for challenging indirect detection x-ray applications.



-
- 498 frames per second, allowing for high speed data acquisition and minimized experimental time
 - 0.7 e- read noise for improved image quality at reduced frame rates
 - 95% visible quantum efficiency for highly sensitive imaging
-

Applications

The Kinetix offers unbeatable sensitivity at extremely fast frame rates, while maintaining low read noise, making the Kinetix optimal for x-ray imaging applications which rely on fast data acquisition for maximizing experimental time. These applications include:

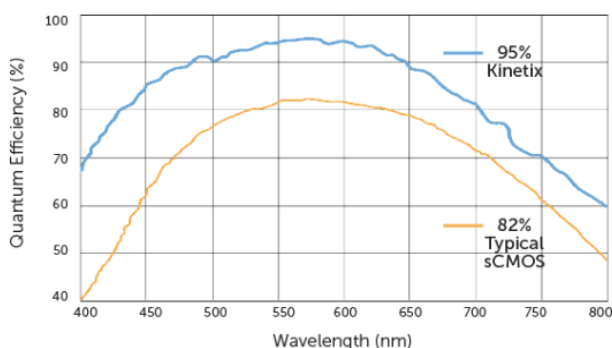
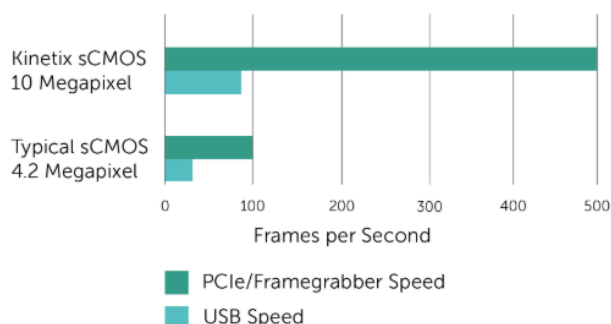
- Tomography
- X-ray microscopy
- Micro computational tomography
- Phase contrast x-ray imaging

Key Features Explored

Extreme Speed

With an 8-bit readout mode, the Kinetix sCMOS delivers a tremendous 498 full frame fps over a 29.4 mm diagonal field of view.

By optimizing the line time, the speed significantly outperforms typical sCMOS devices, delivering over 5000 megapixels/second. This overall minimizes the total experimental time, or maximizes data acquisition within a given time.



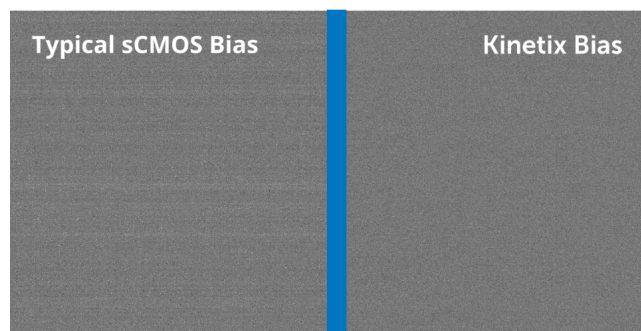
Ultimate Sensitivity at High Speeds

The Kinetix takes advantage of back-illuminated sCMOS technology, achieving 95% visible quantum efficiency. By illuminating the back of the sensor, photons land directly onto the light receiving surface, maximising light collecting capability.

The Kinetix combines 95% quantum efficiency with a low 0.7 e⁻ read noise to deliver the most sensitive sCMOS camera at 498 frames per second.

Reduced Fixed-Pattern Noise

The latest sCMOS fabrication technology ensures the Kinetix delivers clean, pattern-free images with minimal pixel defects, ideal for low light conditions. This allows the Kinetix to deliver improved image quality for challenging x-ray applications.



Kinetix

Full Specifications

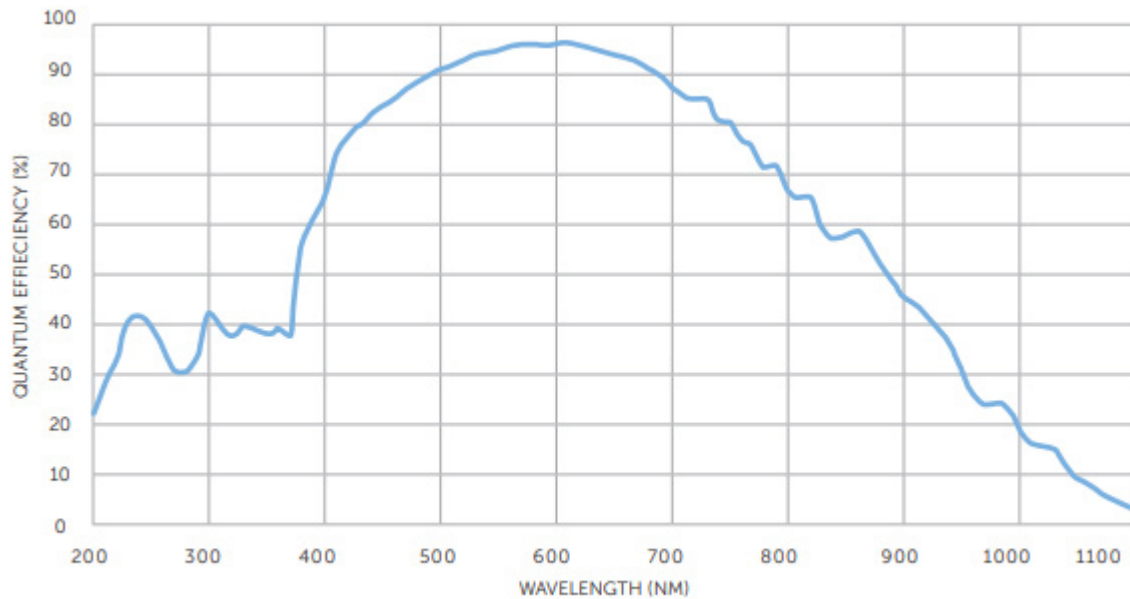
Specifications	Camera Performance
Sensor	Teledyne Photometrics Kinetix Sensor
Active Array Size	3200 x 3200 (10.24 Megapixel)
Pixel Area	6.5µm x 6.5µm (42.25µm ²)
Sensor Area	20.8mm x 20.8mm 29.4mm diagonal
Peak QE%	>95%
Readout Mode	Rolling Shutter Effective Global Shutter Programmable Scan Mode
Digital Binning	Symmetrical and Asymmetrical Binning up to 4x4 pixels
Linearity	>99%
Cooling Options	Air Cooled Liquid Cooled

Camera Modes				
Specifications	Dynamic Range	Speed	Sensitivity (CMS)	Sub-Electron (8x CMS)
Bit-Depth	16-bit	8-bit	12-bit	16-bit
Frame Rate (Full Frame)	83 fps	498 fps	88 fps	5.2 fps
Read Noise	1.6e ⁻	2.0e ⁻	1.2e ⁻	0.7e ⁻
Cooling	0° C	0° C	0° C	0° C
Line Time	3.749 µsec/line	0.625 µsec/line	3.53125 µsec/line	60.1 µSec/line
Dark Current	1.27 e ⁻ /p/sec	3 e ⁻ /p/sec	1.03 e ⁻ /p/sec	0.477 e ⁻ /p/sec
Conversion Gain	0.23 e ⁻ /count	0.85 e ⁻ /count	0.25 e ⁻ /count	0.015 e ⁻ /count
Full Well Capacity	15000 e ⁻	200 e ⁻	1000 e ⁻	1000 e ⁻

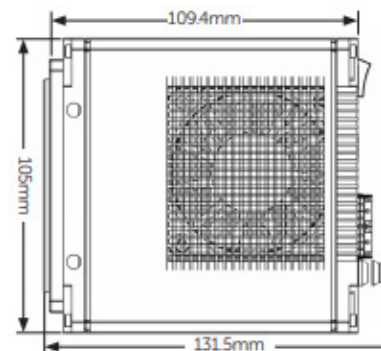
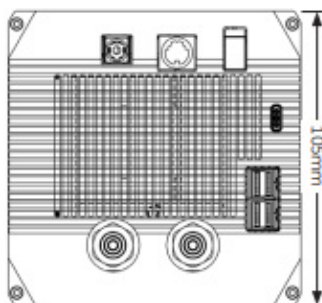
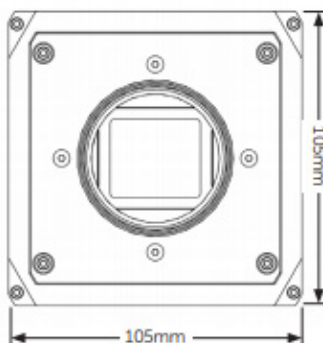
Specification	Camera Interface
Digital Interface	PCI-Express Gen 3 USB 3.2 10 Gbps
Lens Interface	T-Mount F-Mount C-Mount Swappable Mounts
Mounting Points	2x 1/4" mounting points per side
Camera Weight	1.8 Kg, 4 lbs

Triggering Mode	Function
Input Trigger Modes	Trigger First: Sequence triggered on first rising edge
	Level Trigger: Exposure time is controlled by length of high trigger signal
	Edge Trigger: Each frame in sequence triggered by rising edge
	SMART Streaming: Fast iteration through multiple exposure times works with the 4 trigger outs to control multiple sources at multiple exposure time
Output Trigger Modes	Any Row: Expose signal is high while any row is acquiring data
	First Row: Expose signal is high while first row is acquiring data.
	Line Output: Expose signal provides rising edge for each row advanced by the rolling shutter readout
Effective Global Shutter Trigger Modes	All Rows: Expose out signal is high for Exposure time this keeps exposure time but drops frame rate
	Rolling Shutter: Expose out signal is high for Exposure time - readout time this keeps frame rate but drops exposure time
Output Trigger Signals	Expose Out (up to four signals), Read Out, Trigger Ready

Quantum Efficiency Curve



Mechanical Drawings



KURO

BACK-ILLUMINATED SCIENTIFIC CMOS CAMERA

The KURO is a back-illuminated scientific CMOS (sCMOS) camera. With high sensitivity and fast frame rates, the KURO is optimal for indirect detection, in applications such as high-speed imaging and spectroscopy.

Latest sCMOS fabrication technology allows the KURO to provide a significantly better noise profile, in particular with relation to background quality, than any previous-generation, front-illuminated sCMOS camera.



-
- Fast frame rates minimizing overall experimental time
 - 1.3 e- (rms) read noise allowing for a faster frame rate while maintaining a high signal-to-noise
 - Reduced fixed-pattern noise, improving image quality
-

Applications

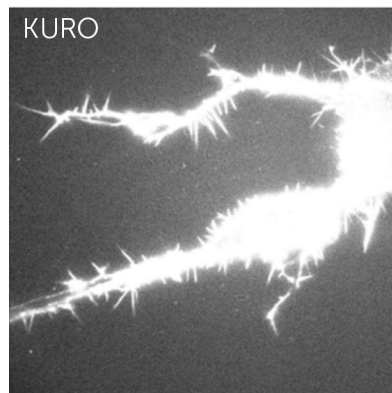
With low read noise, high frame rates, and large pixel size, the KURO is ideal for a range of indirect detection applications that would benefit from sCMOS technology, such as:

- Tomography
- X-ray microscopy
- Micro computational tomography
- Phase contrast x-ray imaging

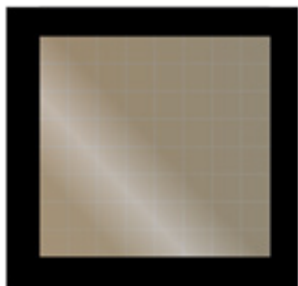
Key Features Explored

Superior Background Quality

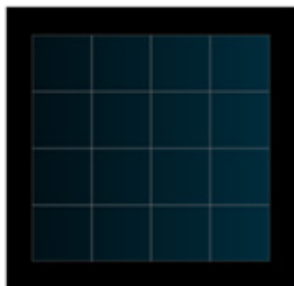
With Pattern Noise Reduction Technology and Correlated Noise Reduction Technology, the KURO delivers clean, pattern-free background images with minimal pixel defects. This allows the KURO to deliver improved image quality for challenging x-ray applications.



Traditional Pixel Size



KURO Pixel Size



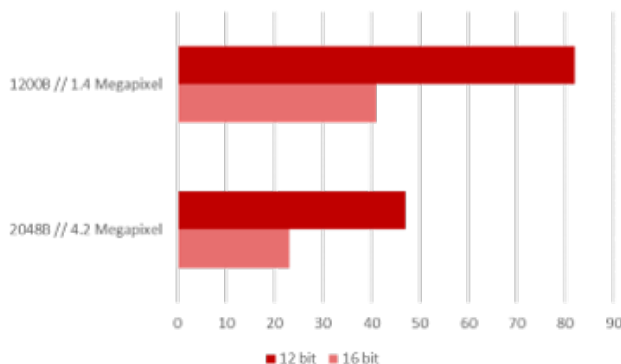
Highly Sensitive Imaging

The KURO utilizes back-illuminated technology, providing a near-perfect 95% visible quantum efficiency, offering optimal sensitivity.

Taking advantage of an $11 \mu\text{m}^2$ pixel pitch the KURO sensor captures 2.8x more photons than previous generation sCMOS sensors. Each pixel is also capable of handling a large full well of 80,000 electrons, allowing for excellent dynamic range. This makes the KURO ideal for x-ray imaging applications that require high speeds.

High Speeds and Low Noise

With an extremely low read noise of 1.3 e⁻ (rms), the KURO is able to deliver high quality images at high speeds. The KURO delivers up to 82 fps, minimizing total experimental time, allowing for more data to be captured within a given amount of time on a beamline.

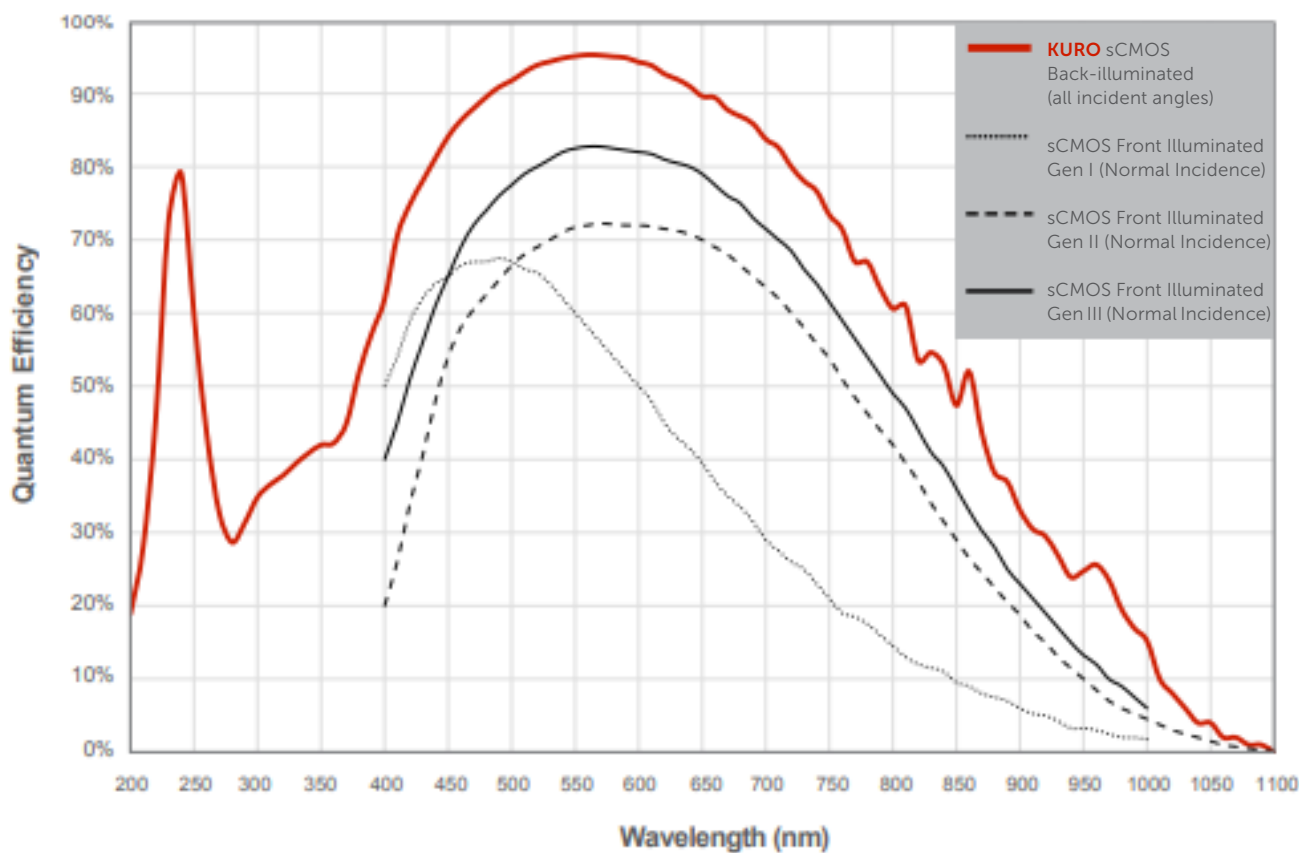


KURO

Full Specifications

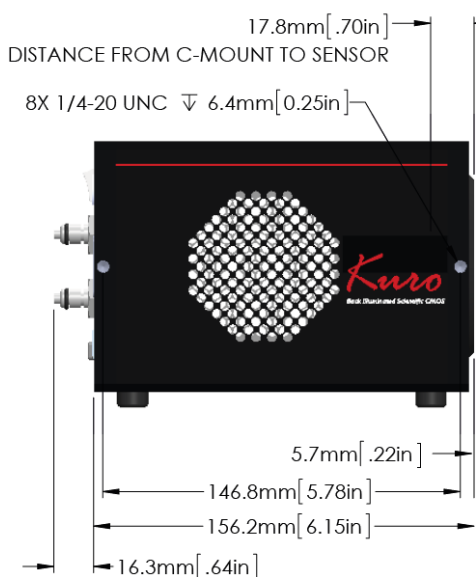
Feature	KURO 1200B	KURO 2048B
Sensor	1200 x 1200 back-illuminated scientific CMOS	2048 x 2048 back-illuminated scientific CMOS
Imaging Area	13.2 x 13.2 mm	22.53 x 22.53 mm
Bit depth	12 bit: 16 bit	
Frame rates @ full resolution	82 fps / 12 bit, 41 fps / 16 bit	47 fps / 12 bit, 23 fps / 16 bit
Exposure time	10 sec	30ms
Pixel size	11 x 11 μ m	
Pixel fill factor	100%	
Full wealth	80,000e ⁻	
Window	Single window in the optical path; UV-grade fused silica	
Readout noise	1.3 e ⁻ rms (median); 1.5 e ⁻ rms	
Binning	Yes (Software binning only)	
Data Interface	High-speed USB 3.0	
Trigger Modes	Start on single trigger; readout per trigger	
TTL output signals	EXPOSE (first row, any row, all rows); READOUT; READY; SHUTTER OUT	
Sensor cooling	-10° C (with air); -25° C (with liquid assist)	
Fan control	Software selectable fan speeds	
Dark current	1.9 e ⁻ /p/s @ -10° C; 0.7 e ⁻ /p/s @ 25° C	
Software Supported	Teledyne Princeton Instruments Lightfield (optional) LabVIEW (National Instruments) and MATLAB (Mathworks) supported via automation	
SDK	PICam (available for free)	
Operating system	Microsoft® Windows® 7/8/10 (64bit)	
Operating conditions	0° C to 30° C; 80% RH no-condensing	
Lens Mounts	C-mount (standard) C-to-spectrometer mount (optional); C-to-F-mount (optional)	F-mount (standard) C-to-spectrometer mount (optional); C-mount (optional)
Dimensions / weight	L x W x D: 6.15" (156.2mm) x 4.04" (102.6mm) x 4.04" (102.6mm); 3.8 lbs (1.7kg)	L x W x D: 7.30" (185.4mm) x 4.04" (102.6mm) x 4.04" (102.6mm); 3.8 lbs (1.7kg)

Quantum Efficiency Curve

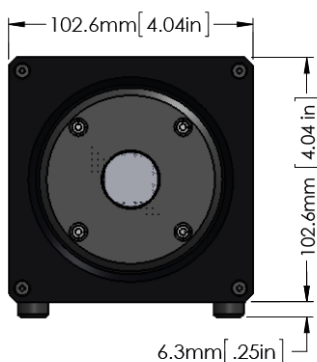


Mechanical Drawings

LEFT

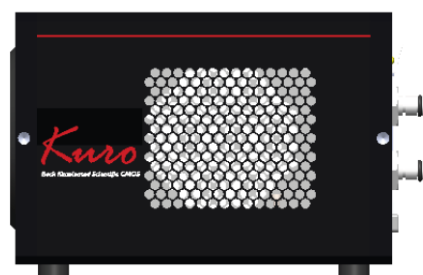


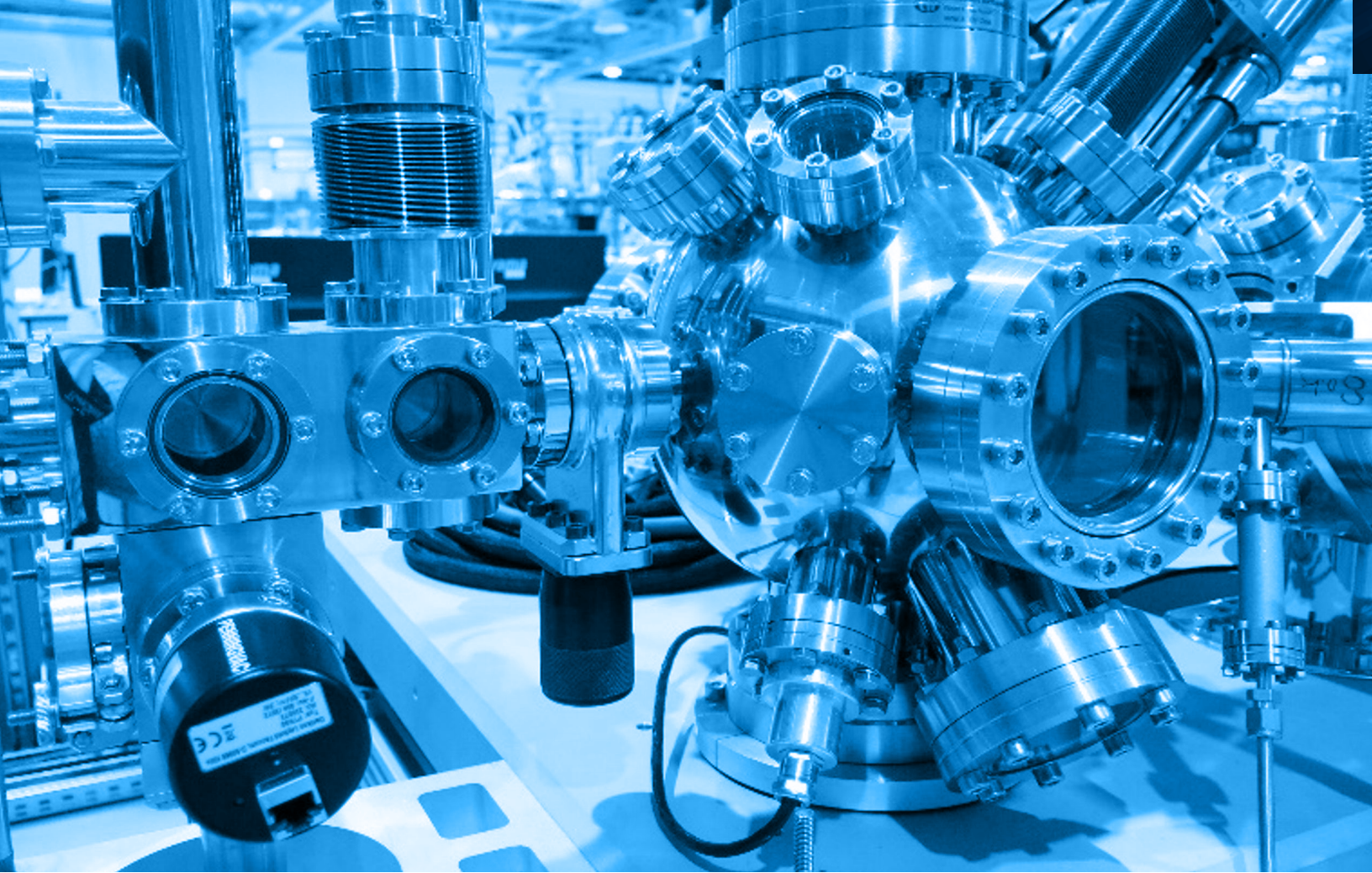
FRONT



BACK

RIGHT





Indirect Detection

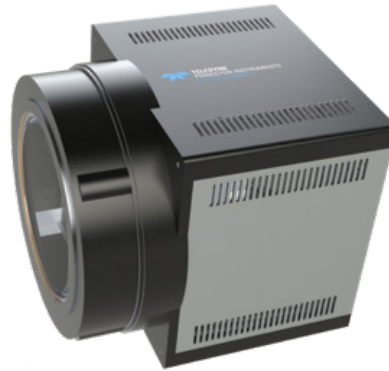
Under Development

COSMOS

HIGH PERFORMANCE, LARGE AREA CMOS CAMERAS

Through combining CCD like performance with CMOS technology, COSMOS is the optimal combination of resolution, pixel size, sensitivity, and speed. Combining low-noise electrons and novel sensor cooling and packaging, COSMOS delivers unprecedented performance.

Typical CMOS limitations, such as “glow”, limited dynamic range, and compromised global shutter, have also been improved to provide a turnkey product that answers the demands of many applications.



-
- Large sensor sizes, up to 8k x 8k, optimal for collecting scattering data
 - Range of readout modes for the ultimate flexible configuration
 - Low read noise and fast frame rates across the full sensor
-

Applications

With low read noise, high dynamic range, and fast frame rates COSMOS provides unbeatable sensitivity over large sensor sizes, making it ideal for multiple techniques such as:

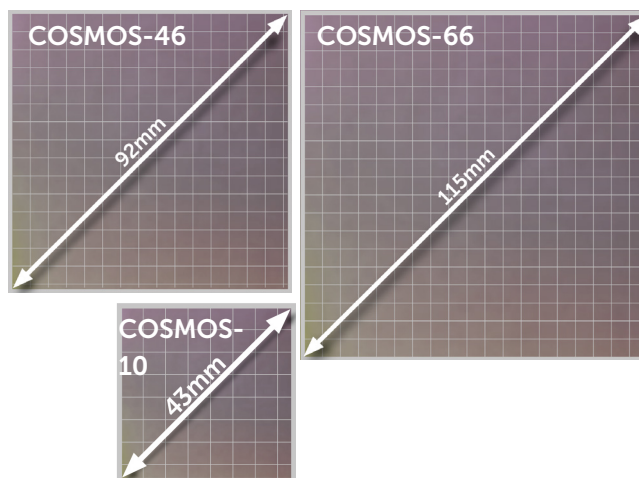
- X-ray scattering
- X-ray spectroscopy
- Phase contrast x-ray imaging
- Tomography
- X-ray microscopy
- Micro computational tomography

Key Features Explored

Large Format Sensor Options Without Compromise

The challenge of CMOS cameras has been maintaining performance when scaling to larger formats; in particular offering the combination of speed and low noise architecture.

COSMOS delivers deep-cooled, low-noise performance on a multi-megapixel scale, with 8120 x 8120 resolution, global shutter, 18-bit readout, and glow reduction technology



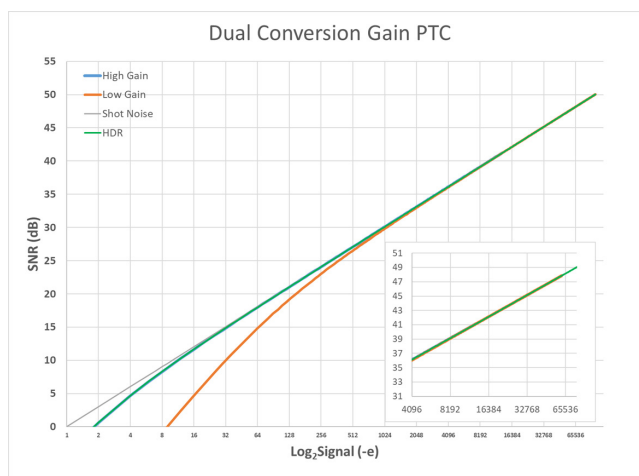
Unique Converter

Analog-to-Digital

With a unique, two-stage analog-to-digital converter (ADC), the COSMOS offers excellent linearity from faint signals to full well, covering a multitude of experimental techniques. By maintaining low read noise levels, photon shot noise is the only dominant noise contribution, allowing 14-bit or 16-bit digitization within a single read out.

Large, True Dynamic Range

High dynamic range allows for fine measurements of both very bright objects and very dim objects within the same image. Due to its low noise performance, of down to 0.7 e⁻ read noise, combined with 18-bit readout, COSMOS offers an incredibly wide true dynamic range of 94dB, providing reliable, quantitative measurements.



COSMOS

Full Specifications

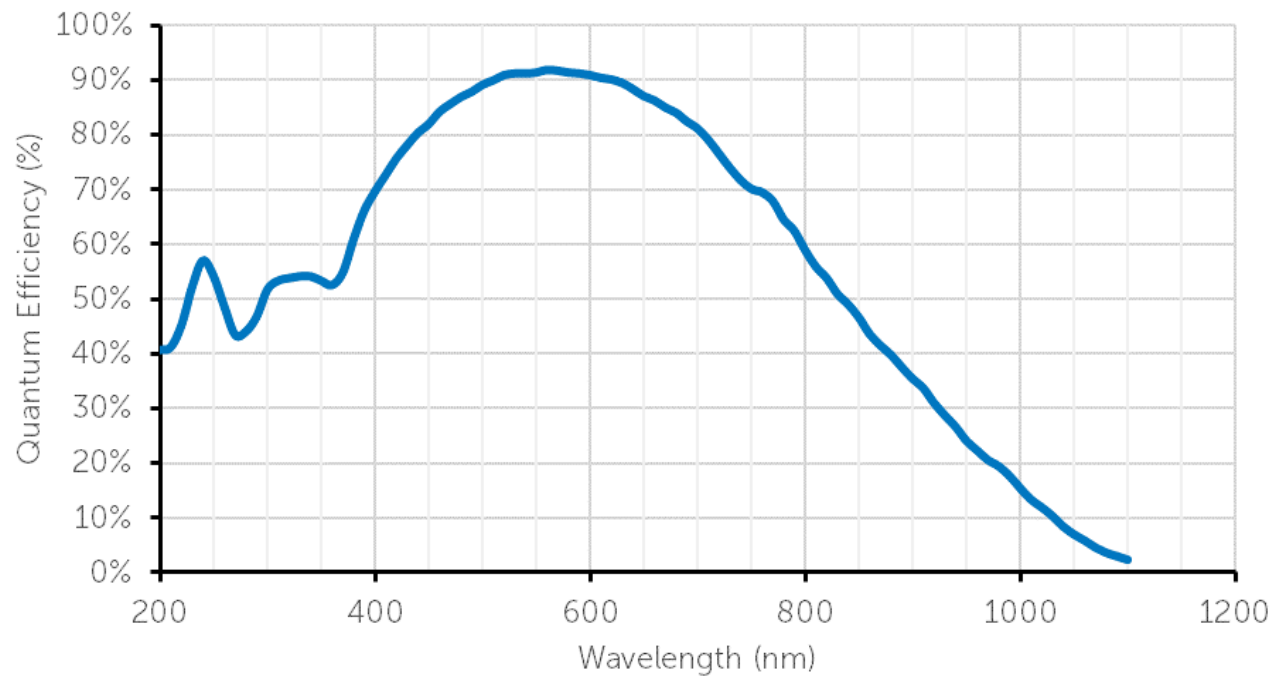
Feature	COSMOS-10	COSMOS-42	COSMOS-66
CMOS image sensor	Back illuminated; grade 1; 100% fill factor		
Dark current @ -25°C (with ambient air @ +20°C)	0.05 e-/p/s (typical)		
Quantum efficiency	> 90% Peak QE		
Pixel format		10 µm	
Imaging area	33 x 33 mm	65 x 65 mm	81 x 81 mm
Resolution	3260 x 3260	6500 x 6500	8120 x 8120
Sensor Cooling temperature	<-25°C (typical) with liquid chiller; <-20°C (typical) with air		
Cooling method	Thermoelectric air or liquid cooling (liquid chiller required)		
Full well	Single pixel: >80 ke- (typical)		
ADC settings	10, 14, 16, and 18 bit		
System read noise	< 1.8 e-rms ¹ , <1 e- rms ²		
Frame rate (fps) ³	61	31	25
Shutter	rolling and global		
Nonlinearity		<1%	
Binning ⁴		2 x 2; 4 x 4	
Data interface	USB 3.1 Gen 2	CoaXPress®	CoaXPress®
I/O signals	Three MCX connectors: (2) Software configurable outputs, (1) trigger input		
Operating environment	-30°C to +30°C non-condensing		
ROI	Multiple regions of interest		
Certification		CE	
Power supply		110/220 V	

Specifications are preliminary and subject to change. Certification CE

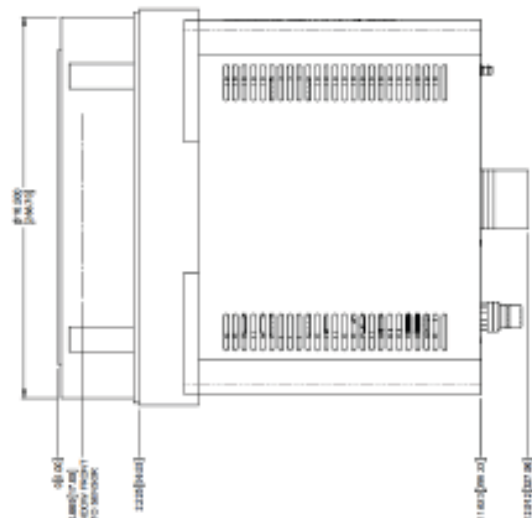
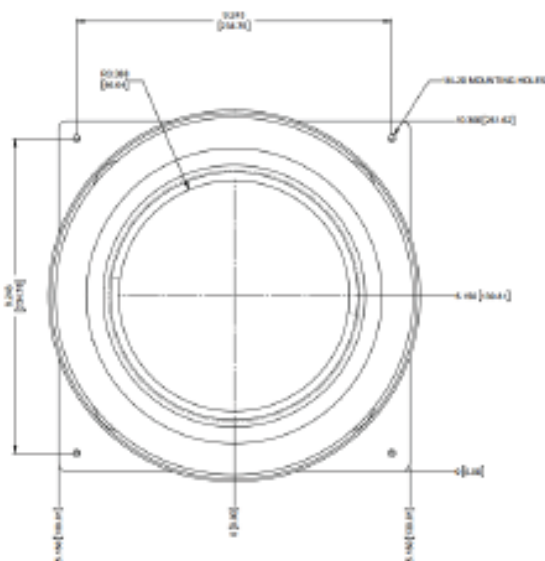
1. Rolling shutter and high gain. Global shutter and high gain < 3 e- rms
2. With Correlated Multiple sampling and high gain
3. Frame rates stated with rolling shutter, non-HDR, and 14 bit digitization
4. FPGA binning

Feature	COSMOS-10	COSMOS-42	COSMOS-66
Physical Size (H x W x L)	tbc	tbc	26.2 x 26.2 x 32.8 cm (W x H x L)
Weight	tbc	tbc	18 kg
Mounting	Multiple Mechanical Options Available		
Cooling	Heat Exchanger Liquid		
Min sensor temperature	-25 °C		
Thermostating precision	+/-1.0 °C		
Ports/Cabling	USB 3.1 Gen 2		CXP12 4-Lane
Camera I/O	OUT-A, OUT-B, Trigger, Sync External Shutter Control - TTL logic Power		
Window	Fused SiO ₂ (Grade 0A), NO AR		
Cover Set	Black anodized Al		
External Lights	(1) LED indicator		
Power supply	110/220 V		
Operation environment	Temperature:-30°C ~30°C Relative humidity:≤ 90% Altitude:0~3900 meter		
Storing environment	Temperature:-30°C ~ 50°C Relative humidity:≤ 90% Altitude:0~3900 meter		

Quantum Efficiency Curve



Mechanical Drawings





Other Capabilites

Lacera Technology

Large Area CMOS

Only From Teledyne Imaging

LACera™ represents the dawning of a new era in CMOS technology, exclusively developed and owned by Teledyne Imaging. LACera is a monumental step forward in CMOS capabilities for advanced imaging, enabling the next generation of discovery. The challenge of CMOS sensors has been maintaining performance when scaling to larger formats.



LACera combines high speed and low noise architecture, while delivering deep-cooled, low-noise performance on a multi-megapixel scale with global shutter, 18-bit readout, and glow reduction technology.

LACera represents a critical element of advanced imaging solutions and is only possible with the nature and scale of Teledyne. From pixel, sensor, and ROIC design, through low noise electronics, to deep cooling, and system interface, Teledyne is the only company capable of delivering this one hundred percent organic solution in large-format CMOS.

Future Direction

With over 50 years of innovation, and decades of x-ray camera development, Teledyne Princeton Instruments has developed and optimized innovative camera systems designed to facilitate the most advanced x-ray imaging and x-ray spectroscopy applications. Thousands of these reliable systems continue to prove their outstanding utility and value on a daily basis in a diverse range of scientific and industrial settings worldwide.

By combining the advanced imaging technology associated with LACera, and the years' worth of x-ray expertise, Teledyne Princeton Instruments will be developing x-ray compatible, next generation, large area CMOS technology for both in-vacuum and flange attachment experiments.

ConFlat Support

The PIXIS-XO has an open nose, rotatable ConFlat flange providing an ultra-high vacuum (UHV) compatible interface that can achieve vacuum levels below 10^{-6} Torr. Teledyne Princeton Instruments offers 3 different flange sizes for the PIXIS-XO:

- 6 inch flange (ISO 150, DN 100)
- 4.5 inch flange (ISO 100, DN 63)
- 4.5 inch removable beryllium window (0.010"/250 μ m)

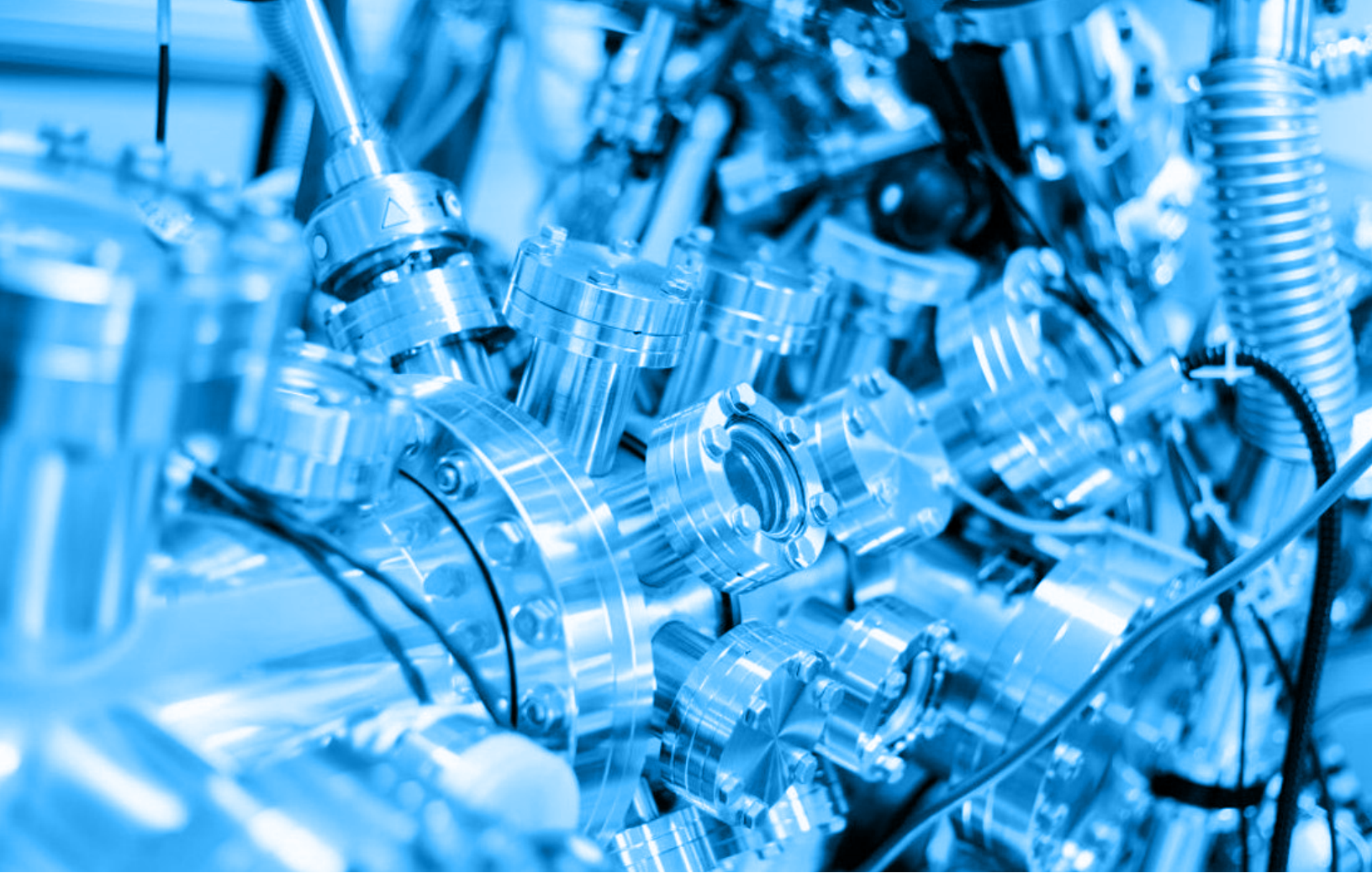
Each flange has an English thread, metric thread, or through hole option (6" flange only). The SOPHIA-XO also has the latest UHV technology, with industry-standard ConFlat flange vacuum interfaces, with options of either a 6 inch or an 8 inch flange.



Accessories

Teledyne Princeton Instrument's provides two cooling accessories for use with their x-ray cameras. The first is the CoolCUBE II, a compact liquid circulator designed for use with PIXIS-XO, -XB, and -XF cameras. Setup is easy using the circulator's no-spill, quick-disconnect fittings. The second is the ThermoCUBE, a compact liquid chiller designed for use with the PI-MTE3 camera. Both units are self-contained, providing liquid circulator for deep, efficient cooling. These units are ideal for applications that require vibration-free and/or thermally stable environments free of air currents.





Interfaces

Hardware and Software Compatibility

Hardware Interfaces

Direct and Indirect Detection Cameras

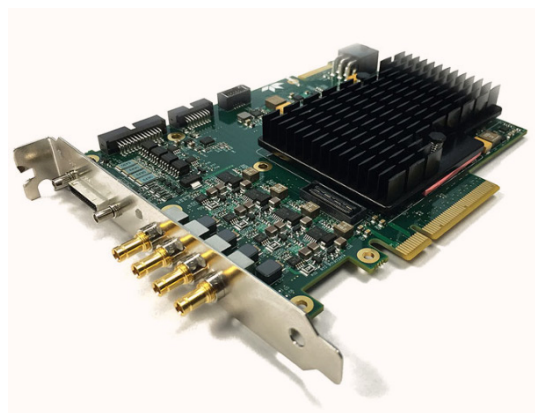
The SOPHIA-XO, PI-MTE 3, and KURO cameras utilize USB 3.0 interfaces, taking advantage of the 5 Gbit/s transfer rate. The Kinetix camera, with its faster readout, utilizes a USB 3.2 interface with transfer speeds of up to 10 Gbit/s.



The PIXIS-XO, -XB, and -XF cameras all utilize USB 2.0 interfaces for data transfer. Teledyne Princeton Instruments offers two USB 2.0 kits dependent on your needs. The USB 2.0 to fiber optic remote-operation kit allows these cameras to be separated by up to 500 meters from a host computer without any loss of data. The second kit is a USB 2.0 to Ethernet package, providing a 100-meter separation between these cameras and a host computer without any loss of data. Both kits are easy to install and are ideal for use in hazardous and high-EMI environments.

Indirect Detection Cameras Under Development

Our under development indirect detection camera, COSMOS, utilizes CoaXPress for high-speed image transfer, with up to 50 Gbps of data bandwidth. COSMOS is designed to work with Teledyne Imaging's high-performance Xtium™-CXP PX8 to provide maximum throughput and ready-to-use image data. COSMOS is specifically designed to work with Xtium only with drivers and interfacing provided through PICam. It is not compatible with all CoaXPress frame grabbers as GENICAM is not supported.



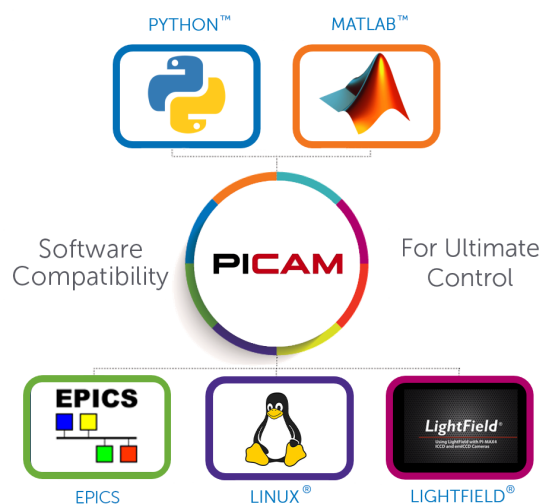
Software Compatibility

PICam API and SDK, from Teledyne Princeton Instruments, offers complete control over all cameras. Available for all 64-bit Windows and Linux systems, it allows for the ultimate flexibility, providing developers, scientists and integrators the ability to build their own control and user interface directly on top of the driver. PICam configures the identified hardware by adjusting parameters within its interface.

For those who require a “plug-and-go” system, LightField® Software allows for complete control of all cameras on an ease of use platform. LightField software also includes simple, image post-processing software and a built-in, smart math engine to obtain the most from acquired data.

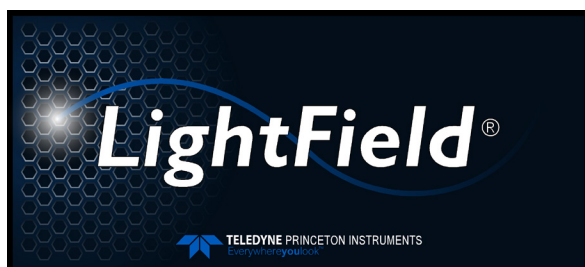
PICam

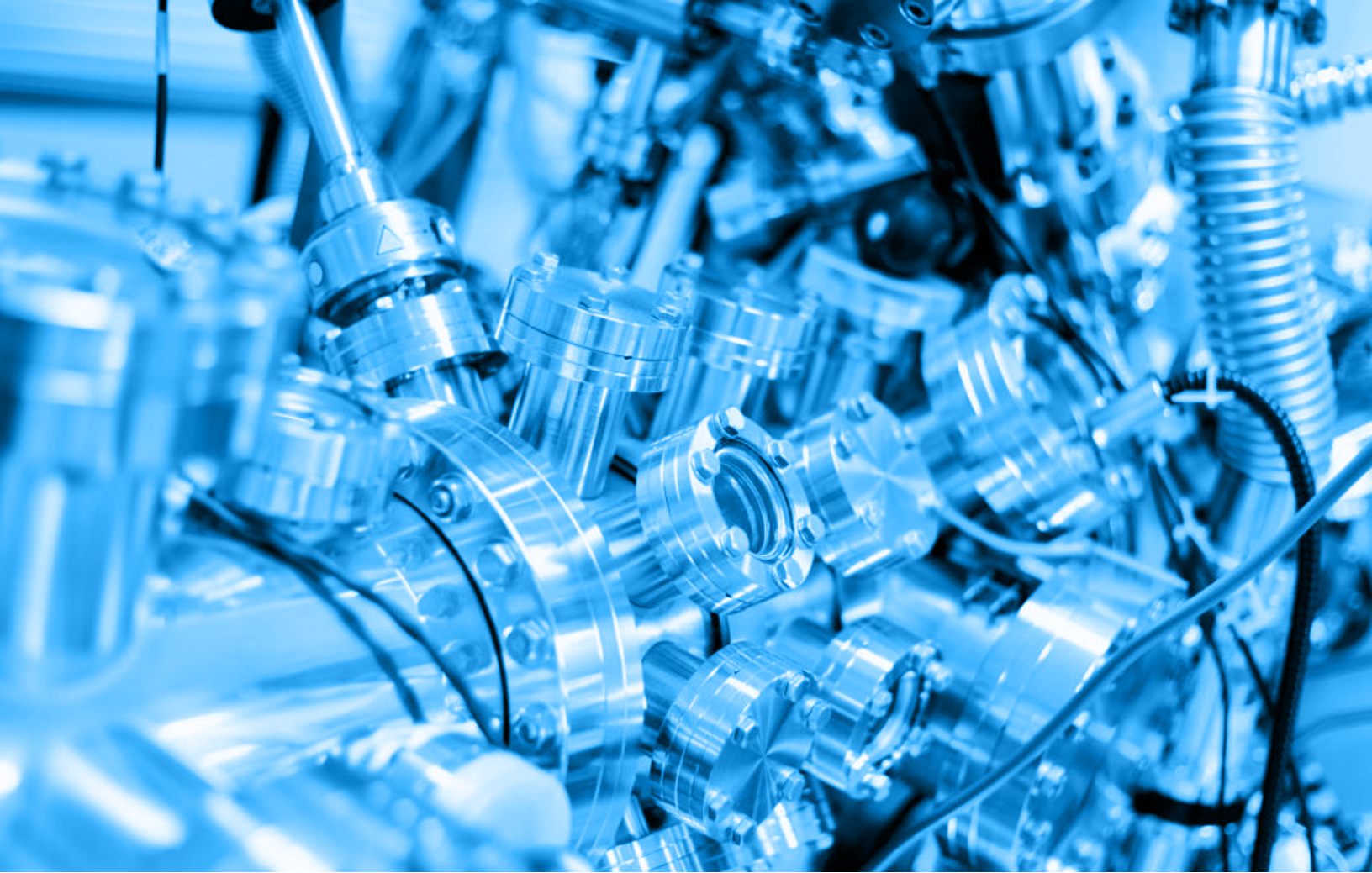
Teledyne Princeton Instruments PICam (64 bits) universal programming interface is a custom, ANSI C library that is used to create the camera control and data acquisition interface. It contains a suite of functions that allow configuration of the data acquisition process in a number of different ways as well as control of standard camera functions. It can be used with a wide variety of programming environments, including support for Linux and Windows, C, C++, and LabVIEW amongst many more.



LightField Software

Teledyne Princeton Instruments LightField® software is a 64-bit data acquisition software platform that runs under Microsoft® Windows® 10 and has been designed for use in x-ray imaging and spectroscopy applications. It provides comprehensive control of all Teledyne Princeton Instruments cameras via easy-to-use tools that help streamline experimental setup, data acquisition, and post processing.





Technical Notes

Technical Notes

FLEXIBLE ELECTRONIC ARCHITECTURE EXTENDS UTILITY OF SCIENTIFIC CAMERAS

The true worth of a scientific camera is determined by its ability to flexibly meet the performance requirements deemed most useful by a given researcher. As research evolves, the list of critical requirements expands, meaning versatile, high-performance cameras are essential.

Teledyne Princeton Instruments scientific CCD cameras offer flexible electronic architecture, with unique output amplifiers, software-selectable speed and gain settings, enabling researchers to tailor performance to suit various x-ray applications.

Dual-Amplifier Design

The exclusive dual-amplifier configuration has two independent amplifiers whose electronics are optimized for high-capacity readout and high-sensitivity readout, respectively (Fig.1) The high-capacity amplifier increases full well capacity, allowing each pixel to collect a greater number of photons resulting in wider dynamic range, ideal for applications involving medium-energy x-rays or high levels of incident light. The high-sensitivity amplifier delivers the lowest possible read noise at a given readout frequency, optimal for low-energy x-rays or low levels of incident light.

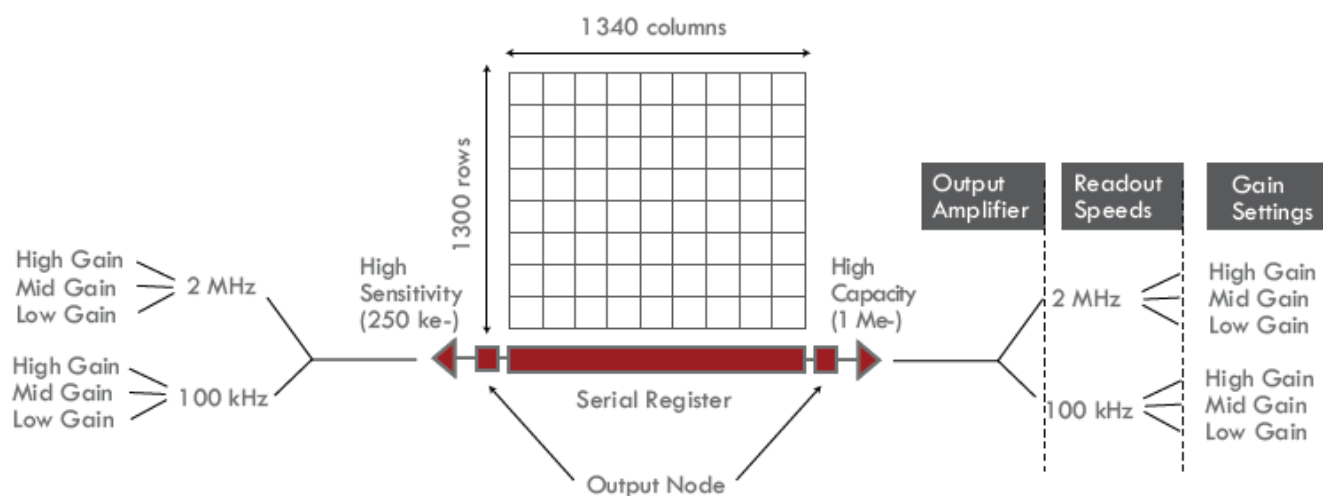


Fig.1: Two independent amplifiers optimized for high-capacity readout and high-sensitivity readout extend CCD camera utility

Technical Notes

Software Selectable Gain

Researchers can fine tune camera performance via the software-selectable speed and gain settings. Faster readout speeds can be used to acquire images quickly with a sufficient incident beam without compromising results. Slower readout speeds deliver high sensitivity by preserving dynamic range and boosting signal-to-noise ratio (SNR).

Selectable gain settings also provide researchers with another way to tailor camera performance. Gain defines the number of electrons that correspond to a single analog-to-digital unit (e-/ADU). Prior to the application of gain, each photon detected by the CCD generates a given number of electrons based on the photon's energy.

Soft X-ray Applications

Soft x-rays are advantageous as they provide quantitative sample analysis, including elemental, without any sample preparation typical of electron microscopy. At these low energy wavelengths only a few electrons are generated, therefore the high-sensitivity amplifier should be utilized.

Slower speed settings can also be incorporated to improve sensitivity. The high-sensitivity amplifier's gain settings should be used to optimize dynamic range and SNR to achieve the image contrast required, alongside tubing of the x-ray energy.

Hard X-ray Applications

There are multiple hard x-ray applications which utilize both imaging and spectroscopy. Even at the lower boundary of the medium-energy x-ray range, only a few hundred electrons are generated for each photon detected by the CCD.

Since additional sensitivity is not required to boost SNR, the high-capacity amplifier should be used when working with hard x-rays. Slower readout speeds and higher gain settings are typically less beneficial in this energy range due to the already sufficient sensitivity and ample signal.

[Read the Full Article Here](#)

DIRECT DETECTION OF X-RAYS (30eV - 20keV) USING CCD TECHNOLOGY

Direct-detection cameras are directly exposed to the incoming x-ray photons, which enables direct absorption of the photons. Standard thickness CCDs can absorb x-rays over the ~30 – 20,000 eV range (Fig.1), however other aspects of the CCD determine how suitable they are for detecting low- and medium-energy x-rays.

One of these aspects is back-illumination and any anti-reflective coatings. The electrode structure and the insulating layer of traditional front-illuminated CCDs absorbs x-ray photons below energies of 700 eV, meaning that back-illuminated CCDs are essential. AR coatings absorb low energy x-rays between ~30-500 eV, meaning they are not used with direct detection x-ray CCDs. For medium energy x-rays, deep depletion technology is required which ensures the direct detection of these higher energy x-rays.

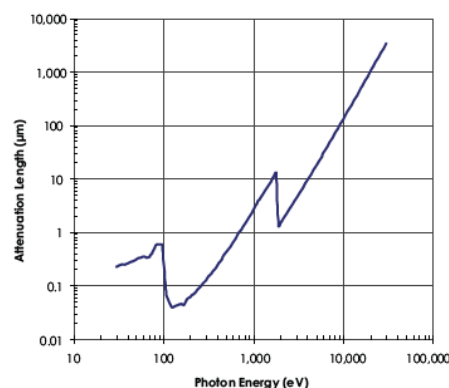


Fig.1: X-ray attenuation length at various energy levels.

Charge-Generation Mechanism

X-ray photons travelling through the layers of a CCD can lose energy through Compton scattering, fluorescence, or the photoelectric effect. For energies <150 keV, the photoelectric effect is dominant. This means when an x-ray photon below 150 keV is absorbed in the silicon, an electron-hole pair is generated based on the primary x-ray photon energy. The energy required to generate an electron-pair in silicon is 3.65 eV, meaning that any x-ray photon above this energy will create multiple electron-pairs.

Charge-Collection Mechanism

Quantitative measurements rely on the charge generated by an x-ray photon being collected within one pixel and transported to the output amplifier without suffering losses from imperfect charge-transfer efficiency (CTE). However, there is some probability that the photoelectron charge cloud will be split between two or more pixels. This uncertainty must be accounted for in order to ensure the most accurate data.

If the charge is generated in a field-free layer, it moves by diffusion and either recombines or reaches the edge of the depletion layer field. Any charge within the depletion layer is quickly drifted to the surface collection site with minimal radial spread. Charge generated close to the edge of a pixel, or deep in the substrate, can split between pixels.

In a back-illuminated device, in which the field-free layer is etched out, the electrons are generated directly in the epitaxial layer. Therefore, in this case, migration of generated electrons can also occur in lower-energy x-rays, as they are generated near the surface.

Technical Notes

Radiation Damage

The better the sensitivity and the higher the quantum efficiency of a direct x-ray detection CCD comes with an inherent trade off. If a significant quantity of x-ray radiation bombards the CCD, permanent damage occurs. This radiation changes parameters of the CCD including an increase in dark current, a flat-band voltage shift, and a reduction in CTE. Different types of radiation, such as protons, neutrons, and heavy ions, influence the CCD parameters in various ways and at differing degrees.

Annealing Damage

There are multiple treatments that have been reported to reverse the effects of irradiation on a CCD. One treatment involves treating the CCD in forming gas at high temperatures for a few hours to reverse the effect of high dark current from x-ray radiation. Another relies on exposure to UV to reduce a shift in various voltages. These treatments however may render the CCD more susceptible to future x-ray damage.

One treatment involves annealing the CCD in both air and forming gas to countermand damage effects. None of these treatments have been performed in the Teledyne Princeton Instrument's lab, therefore we strongly recommend that caution is exercised when attempting these procedures.

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ENERGY RESOLUTION IN DIRECT-DETECTION CCDS

Many parameters must be considered to ensure that the theoretical energy resolution of a direct-detection CCD camera is realized. A few of the most important factors for achieving the highest energy resolution are the right type of CCD, the best charge transfer efficiency (CTE), the lowest thermal noise, and linear response throughout the entire dynamic range. Teledyne Princeton Instruments x-ray cameras use scientific-grade CCDs and world-renowned low-noise electronics to optimize these parameters. Assuming the best performance from the camera, the average energy required to create 1 e-h pair in the CCD is ~3.65 eV/e-. Only considering single-pixel events (i.e., ignoring any split-pixel events and electron loss in the field-free substrate), the energy resolution in eV can be calculated as:

$$R(E) = 3.65 \times 2.355 \sqrt{F(N + RN^2)}$$

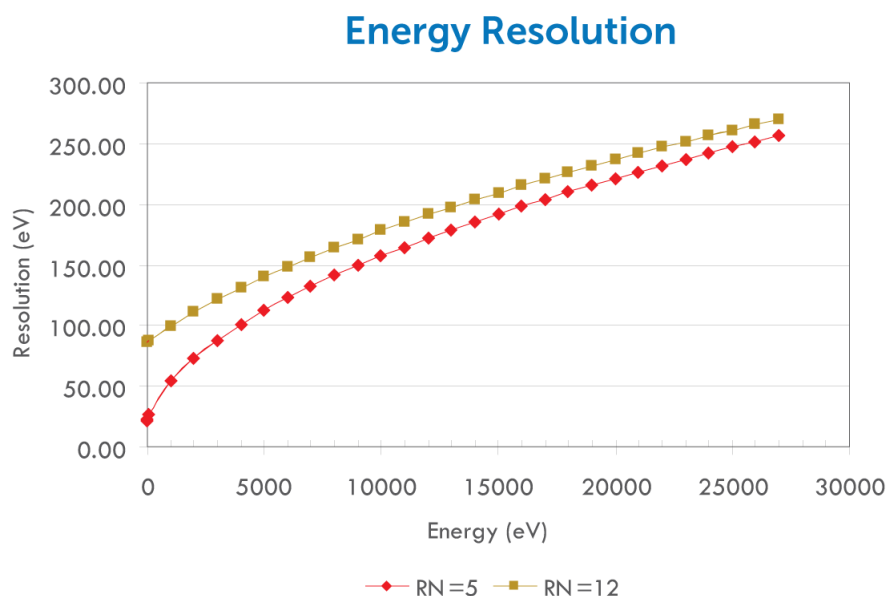
Where:

R(E) is the energy resolution in eV

N is the number of electrons generated in the CCD for a given x-ray energy

RN is the CCD RMS read noise

F is the Fano factor, an empirically derived factor why which the variance of the generated e- (from the primary x-ray photon) is reduced from the expected random distribution, for silicon F is 0.12.



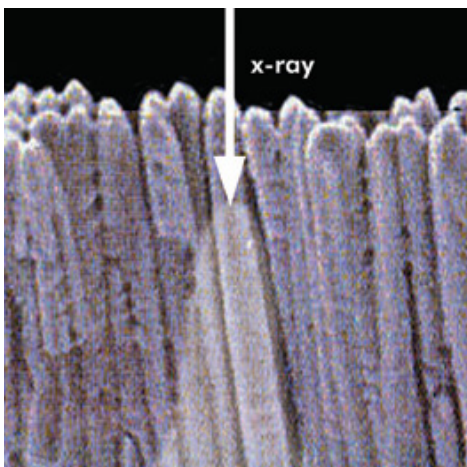
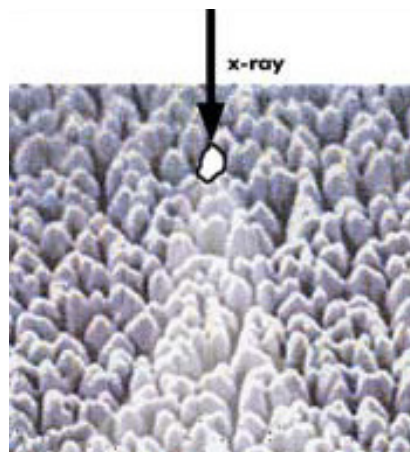
Technical Notes

UTILIZING PHOSPHORS FOR INDIRECT DETECTION OF X-RAYS

Teledyne Princeton Instruments has developed two types of phosphors for x-ray imaging applications in the energy range between 5 keV and 50 keV. The $\text{Gd}_2\text{O}_2\text{S:Tb}$ is recommended for x-ray energies <33 keV due to its higher absorption efficiency, while the CsI:Tl is recommended where higher resolution is required.

Polycrystalline Gadolinium Oxysulphide with Terbium

Teledyne Princeton Instruments has developed three distinct phosphors for 8, 12, and 17 keV x-ray energies based on $\text{Gd}_2\text{O}_2\text{S:Tb}$ polycrystalline powder. To provide the best possible resolution and sensitivity, small-grain powder is used on special Mylar®. These phosphors are recommended when large image area, high efficiency, and lower cost are primary considerations.



Crystalline (Needle Structure) Cesium Iodide with Thallium

Teledyne Princeton Instruments has developed phosphors based on crystalline (needle structure) CsI:Tl for 8 and 24 keV x-ray energies, recommended when high resolution is the primary consideration. Although it has lower absorption at x-ray energies < 33 keV, CsI:Tl holds a number of advantages over GdOS:Tb powder phosphors, providing higher resolution, needles acting as a light guide, and more uniform light output due to special coatings

UTILIZING FIBEROPTICS FOR INDIRECT DETECTION OF X-RAYS

Quite often, users of indirect-detection systems assume that the camera manufacturer has carefully selected the ideal combination of sensor, fiberoptic (faceplate/taper) and phosphor to preserve image quality. Unfortunately, each application requires different parameters, and it is difficult for a manufacturer to know every requirement. Therefore, it is imperative that each customer understands the component options available to obtain optimal performance. Although there are many requirements to consider, the main specifications to consider when selecting a fiberoptic are the size of the fibers, the type of extramural absorber (EMA), and blemishes/distortions.

Size of Fibers in a Fiberoptic

When coupling a fiberoptic to a sensor, matching the pixel size to the fiber is ideal. Unfortunately, precisely matching pixel pattern to a fiber pattern is practically impossible to manufacture (Fig.1). However, if the fiber size is selected to match the pixel size, a mismatch will occur (Fig.2) and there will be a huge variation in pixel-to-pixel sensitivity, which is mostly undesirable.

To avoid this, it is very important to choose a fiber size that is significantly smaller than the sensor pixel size, so there are many fibers per pixel. For this reason, our camera systems utilize a fiber size that is 304 times smaller than the pixel size, so there are at least 9 pixels per pixel (Fig.3) to preserve the best image quality.

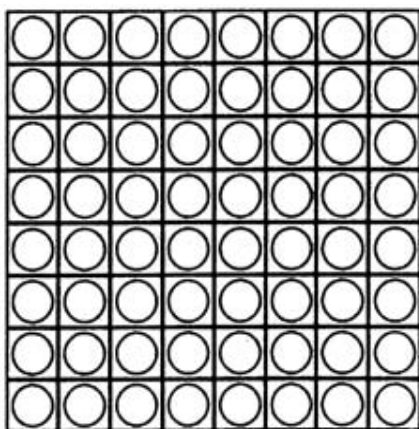


Fig.1: Ideal fiber-to-pixel arrangement

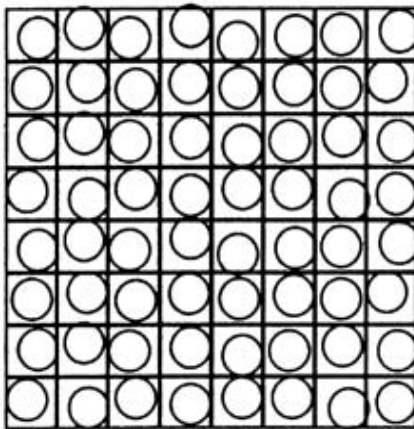


Fig.2: Realistic fiber-to-pixel coupling

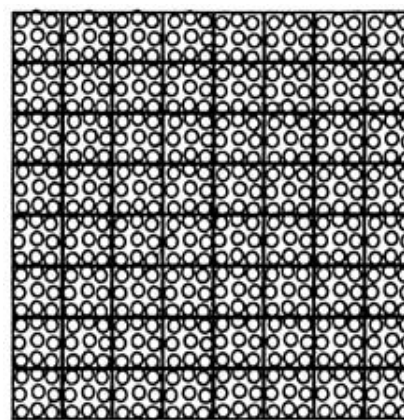


Fig.3: Our fiber-to-pixel coupling

Type of Extramural Absorber (EMA)

Once to fiber size is selected, it is important to choose the right type of EMA. There are several types of EMAs available, each with its own advantages and disadvantages, with options to add variations to enhance performance.

1. **Interstitial EMA (Fig.4):** small black fibres are placed between the fiberoptic stitching boundaries to absorb most of the stray light.
2. **Statistical EMA (Fig.5):** Black EMA fibers of the same diameter as the optical fibers allowing the manufacturer to control the percentage of EMA used to deliver the highest possible transmission efficiency. Due to positioning however, the MTF and resolution performance is inferior to interstitial EMA.
3. **Annular EMA (Fig.6):** thin black cladding surrounds each monofiber, ensuring the most uniform EMA distribution, producing very high MTF and resolution. These fibers have the lowest transmission efficiency and therefore are used in very special applications only.
4. **Enhanced EMA (Fig.7):** an improved statistical EMA design is utilized with higher light absorbing dark fibers than those in standard statistical EMA design, delivering a better-contrast image.

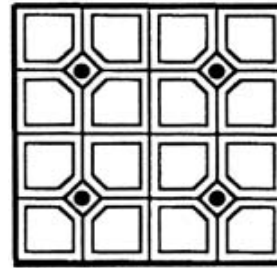


Fig.4: Interstitial EMA example

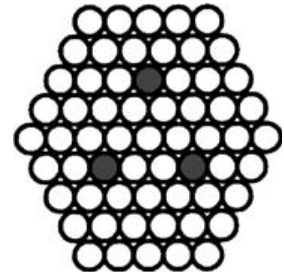


Fig.5: Statistical EMA

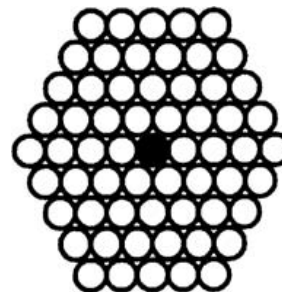


Fig.6: Annular EMA

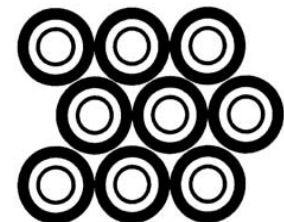


Fig.7: Enhanced EMA

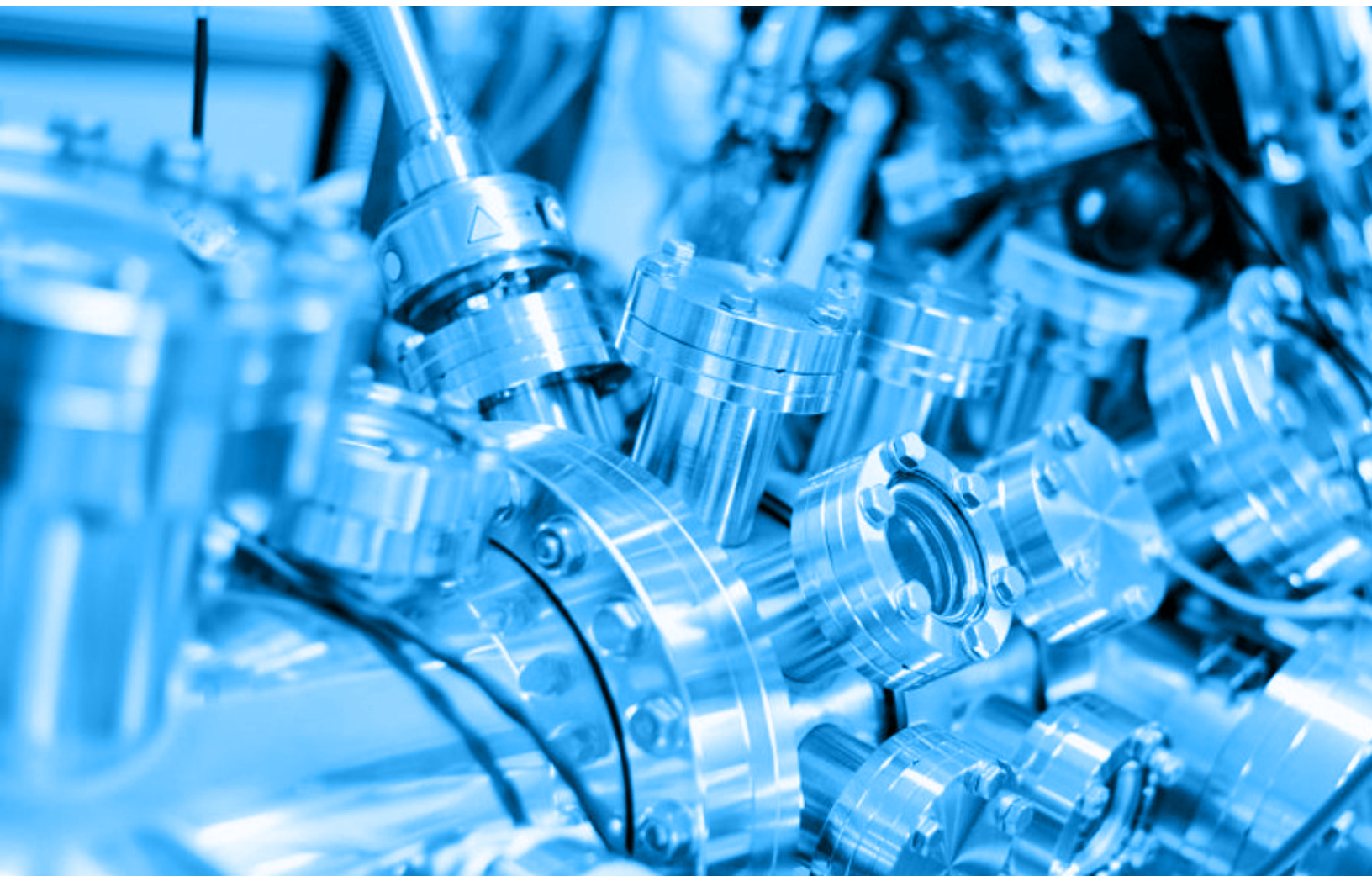
Blemishes and distortions

There are two major types of defects that occur during manufacture: : blemishes and distortions.

Blemishes: There are two types of blemishes, spot blemishes and line blemishes. Spot blemishes are caused by trapped contaminants that are left behind after fibers are cleaned and fused, resulting in non-transmitting fibers. Line blemishes are chicken-wire patterns caused by damage to the outside edge fibers when improperly cleaned.

Distortions: There are two types of distortions, sheer and gross distortions. Shear distortions are caused by the lateral misalignment of multi-multi fibers along the length of a fusion. Gross distortions are caused by material flow in the fusing operation, causing a straight line to be imaged as a continuous curve.

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