Scintillators for high energy detection

Silicon-based sensors such as Charge Coupled Devices (CCDs) can be used for 'direct' detection of photons or particles with energies ranging from ~1.1 eV to ~15 keV. In order to 'see' these higher energy radiations, scintillators are typically used in conjunction with CCDs or scientific Complementary Metal-Oxide Semiconductor (sCMOS) – this mode of detection is typically referred to as 'indirect' detection. These devices convert higher energy radiations (e.g. x-ray photons, neutrons, electrons, gamma rays) into visible radiation that can be detected by the sensor. Typical applications include X-ray plasma imaging and spectroscopy, X-ray and neutron (µ-) tomography, radiography or Transmission Electron Microscopy (TEM).

The present document highlights the key considerations for selecting a suitable scintillator for indirect x-ray photons detection. Solutions for neutron or electron detection are not specifically covered here.

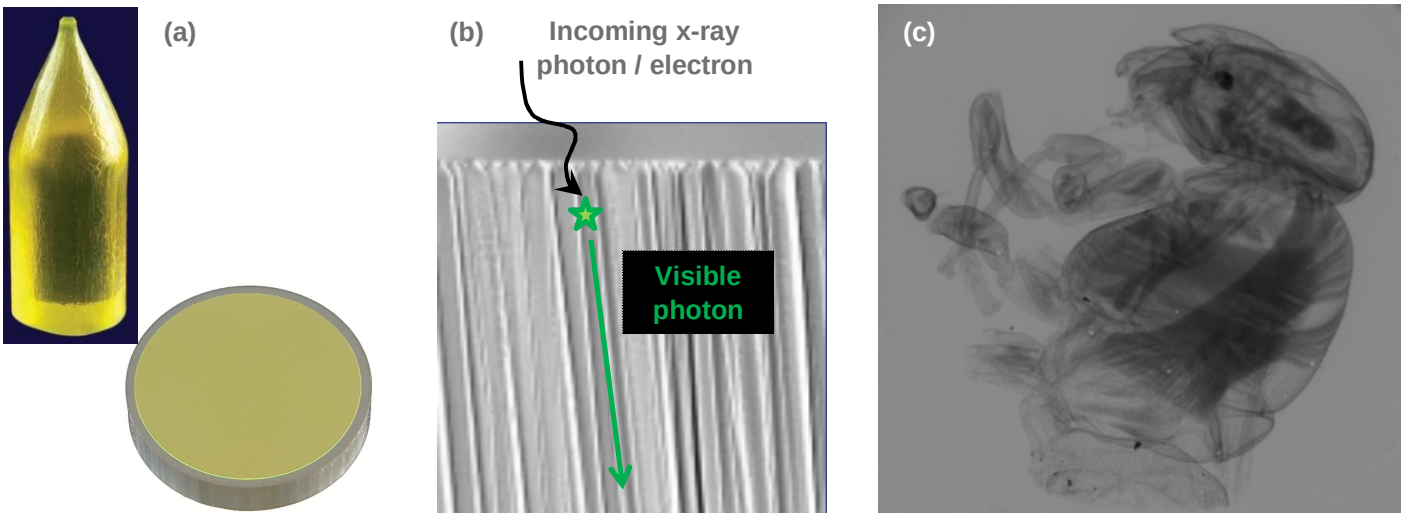


Figure 1 – Example of raw YAG:Ce single crystal and YAG:Ce scintillator attached to Fibre Optic Plate (FOP) [a, courtesy of Crytur], columnar structure details of a CsI:Tl scintillator [b, courtesy of Hamamatsu] and x-ray image of a wasp taken with Andor Zyla-HF fibre-coupled sCMOS and 20 µm thick YAG:Ce scintillator [courtesy of Crytur]

Key considerations for selecting a scintillator

Scintillation: the process by which ionization produced by charged particles excites a material and light is emitted by the de-excitation.

A number of parameters high energy photon can be absorbed by molecules or atoms present in the experiment environment, and ionise these species

- ✓ **Conversion efficiency** of the incident radiation energy into scintillation
- ✓ **Stopping power**
- ✓ **Luminescence decay time** and **afterglow**
- ✓ **Spectral match**
- ✓ **Linearity of light response**
- ✓ **Chemical stability**
- ✓ **Spatial resolution**
- ✓ **Optical coupling to detector**

Summary of selected parameters

Scintillator material	Peak emission wavelength (nm)	Cleavage/ Hygroscopic(*)	Photon Yield (ph/keV)	Decay time (ns)
YAG:Ce	550	No / No	35	70
LuAG:Ce	535	No / No	20	60
CsI:Tl	550/560 (Crytur / Hamamatsu)	No / Slightly	52 (Crytur) ? (Hamamatsu) 54 (St Gobain) 40-65 (other)	900 (Crytur) 1,000 (Hamamatsu) 1,000 (St Gobain)

Scintillator recommendations for Andor indirect detection detector platforms

iKon-L HF CCD

Best Resolution			Best Throughput		
Scintillator characteristics	**Spatial resolution***	**Energy range**	**Scintillator characteristics**	**Spatial resolution***	**Energy Range**
YAG:Ce 40 µm thick on 3 mm FOP SCT-YAGCE-45-040-00	> 15 lp/mm	Best suited for broad 2 - 100 keV range	**CsI:Tl 150 µm thick on 3 mm FOP** SCT-CSITLT-50-150-00	~ 10 lp/mm	Best suited for broad 10 - 100 keV range
LuAG:Ce 40 µm thick on 3 mm FOP SCT-LUAGCE-45-040-00	> 15 lp/mm	Best suited for 10 -100 keV range			

*Spatial resolution is given at 10% MTF for the entire system iKon-L HF, 1:1 fibre-optic plate and scintillator at 40 keV. Please note that spatial resolution will decrease at lower energies.

Zyla HF sCMOS

Best resolution			Best resolution/throughput balance			Best throughput		
Scintillator characteristics	Spatial resolution *	Energy range	Scintillator	Spatial resolution *	Energy range	Scintillator characteristics	Spatial resolution *	Energy range
YAG:Ce 20 µm thick on 3 mm FOP **SCT-YAGCE -25-020-00**	>30 lp/mm	Best suited for broad 2-100 keV range	**YAG:Ce** 70 µm thick on 3 mm FOP **SCT-YAGCE -25-070-00**	~ 20 lp/mm	Best suited for broad 2-100 keV range	**CsI:Tl** 150 µm thick on 3 mm FOP **SCT-CSITLT -50-150-00**	~10 lp/mm	Best suited for 10-100 keV range
LuAG:Ce 20 µm thick on 3 mm FOP **SCT-LUAGCE -25-020-00**	>30 lp/mm	Best suited for 10-100 keV range	**LuAG:Ce** 70 µm thick on 3 mm FOP **SCT-LUAGCE -25-070-00**	~ 20 lp/mm	Best suited for 10-100 keV range			

*Spatial resolution is given at 10% MTF for the entire system Zyla HF, 1:1 fibre-optic plate and scintillator at 40 keV. Please note that spatial resolution will decrease at lower energies.

Absorption and Light yield characteristics of inorganic scintillators of interest

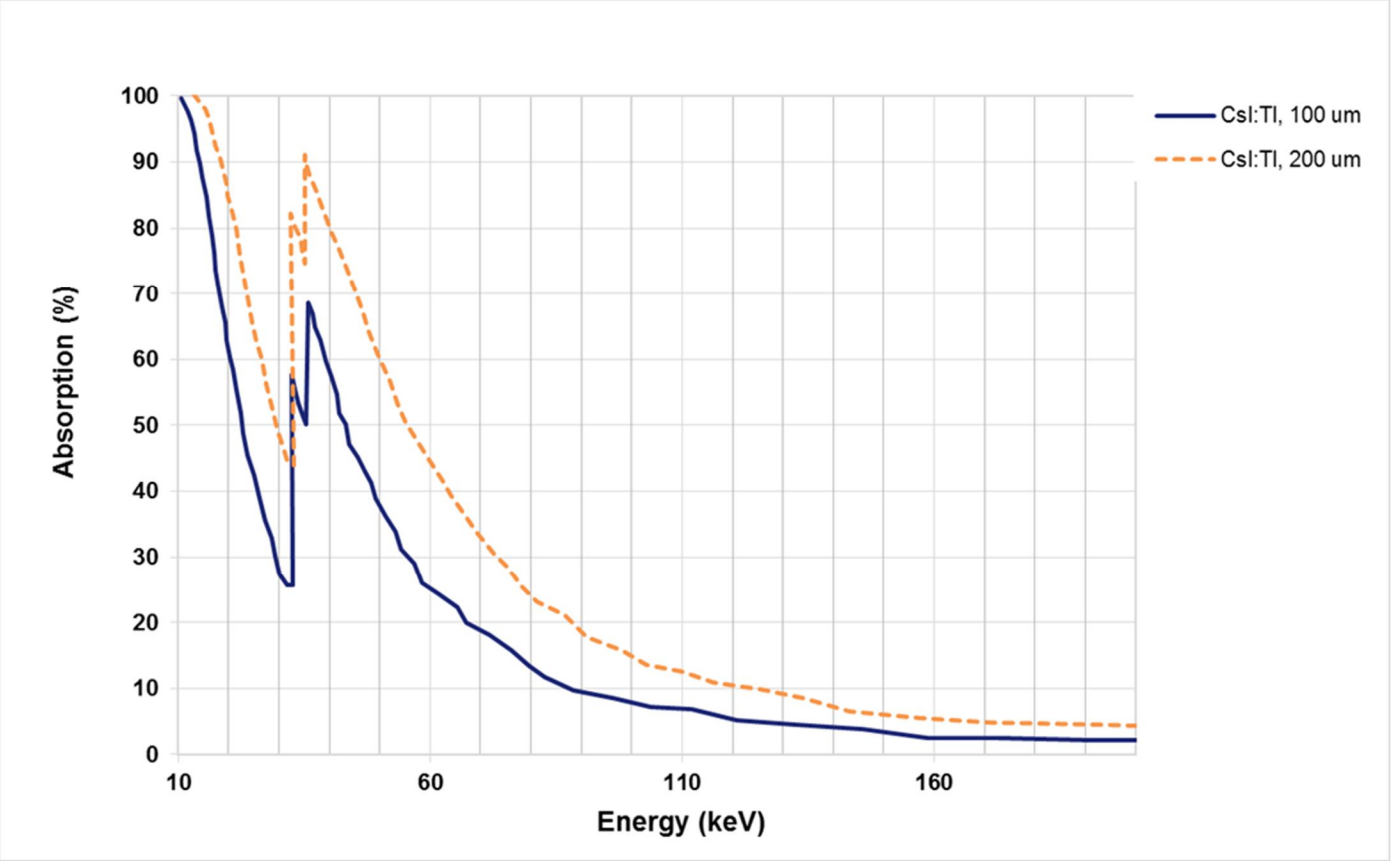
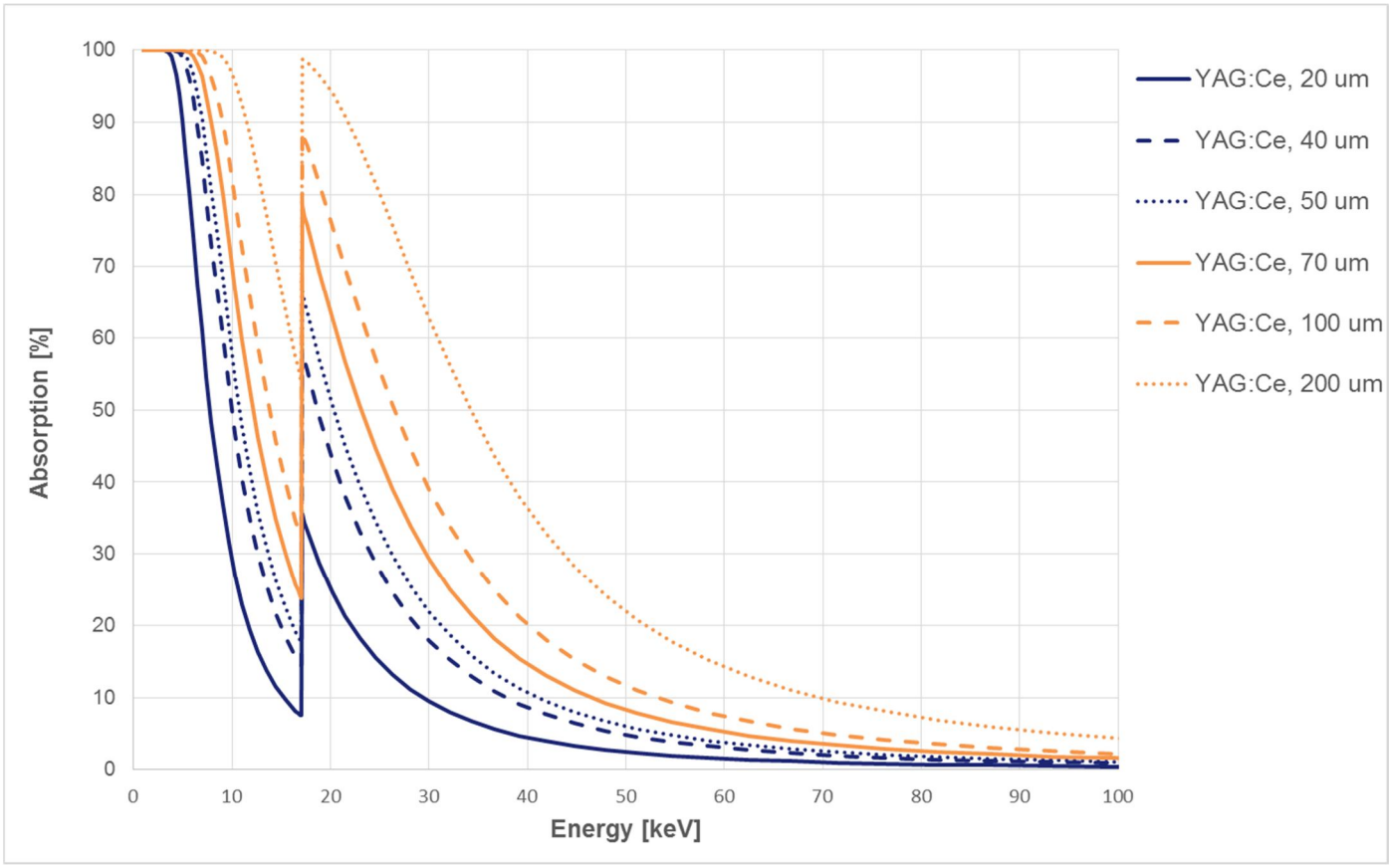


Figure 1 – CsI:Tl absorption characteristics versus incoming x-ray photon energy and material thickness (source Hamamatsu)

Note: most of the x-ray photons below 8 keV will be absorbed by the protection layer before reaching CsI layer.



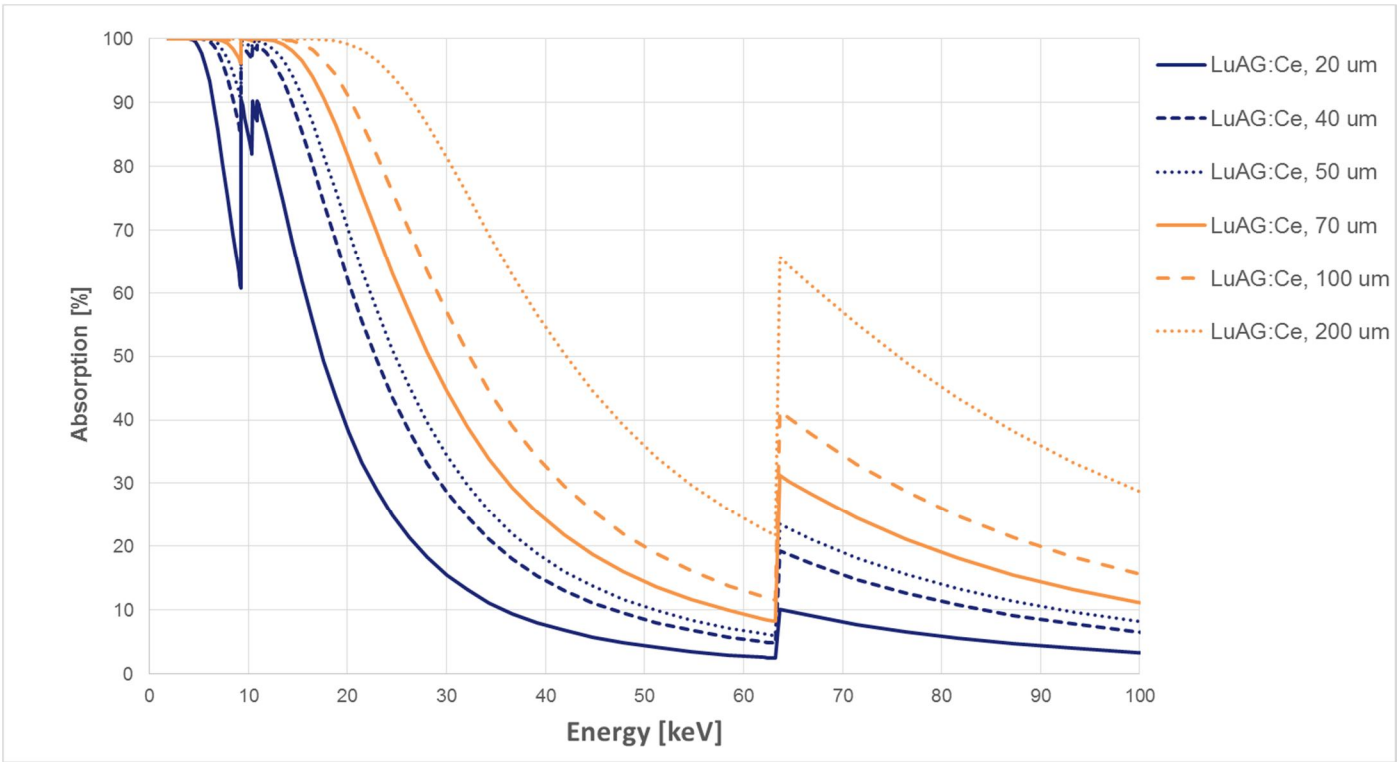


Figure 2 – Absorption characteristics of YAG:Ce (top) and LuAG:Ce (bottom) vs incoming x-ray photon energy and material thickness (courtesy of Crytur)

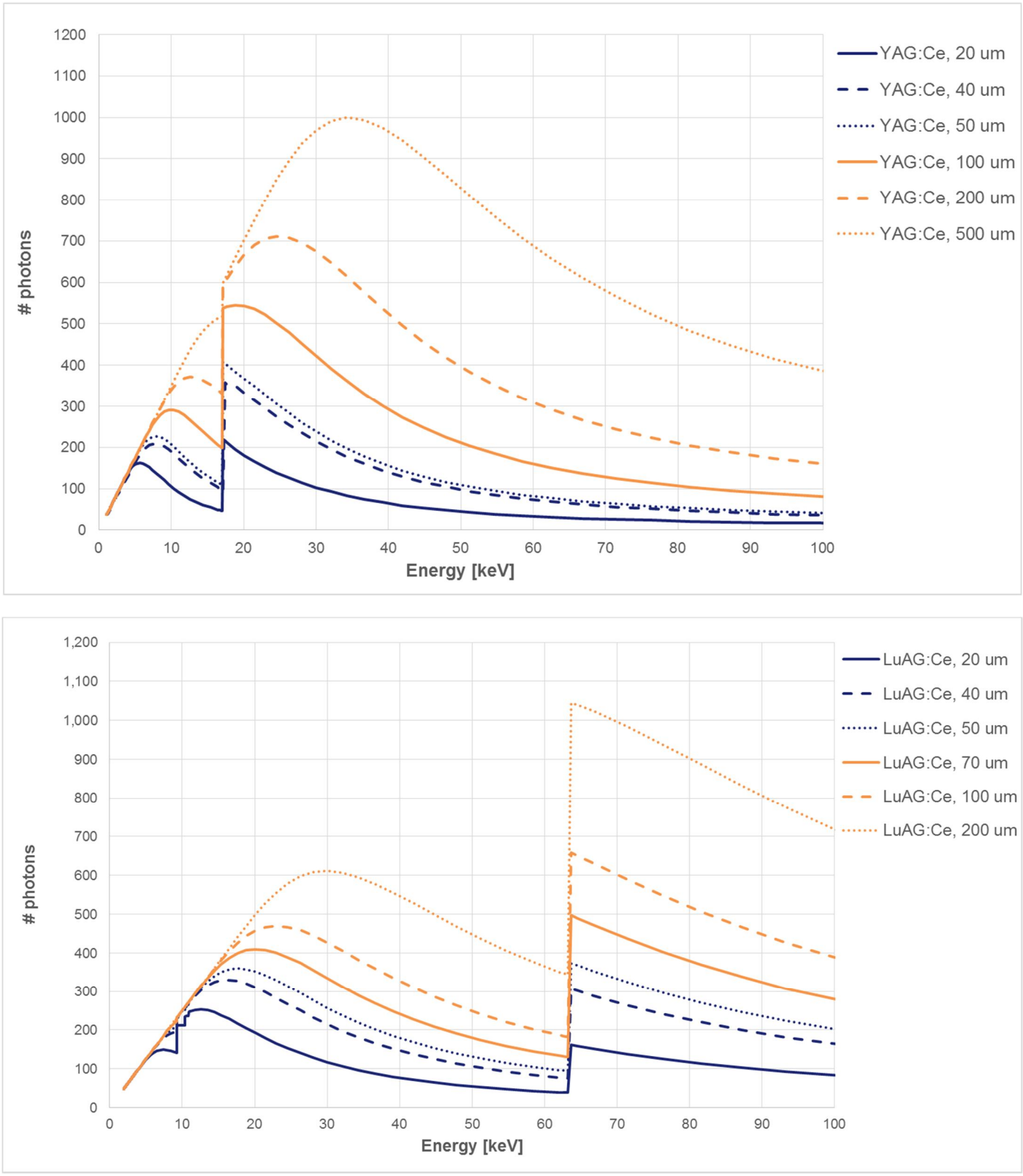


Figure 3 – Photon yield characteristics of YAG:Ce (top) and LuAG:Ce (bottom) vs incoming x-ray photon energy and material thickness (courtesy of Crytur)

Spectral matching

The scintillator emission wavelength should be matched to the sensitivity of the detector. Quantum efficiency of typical CCD and sCMOS sensors are shown on Fig. 4 alongside the peak emission wavelength of scintillators of interest.

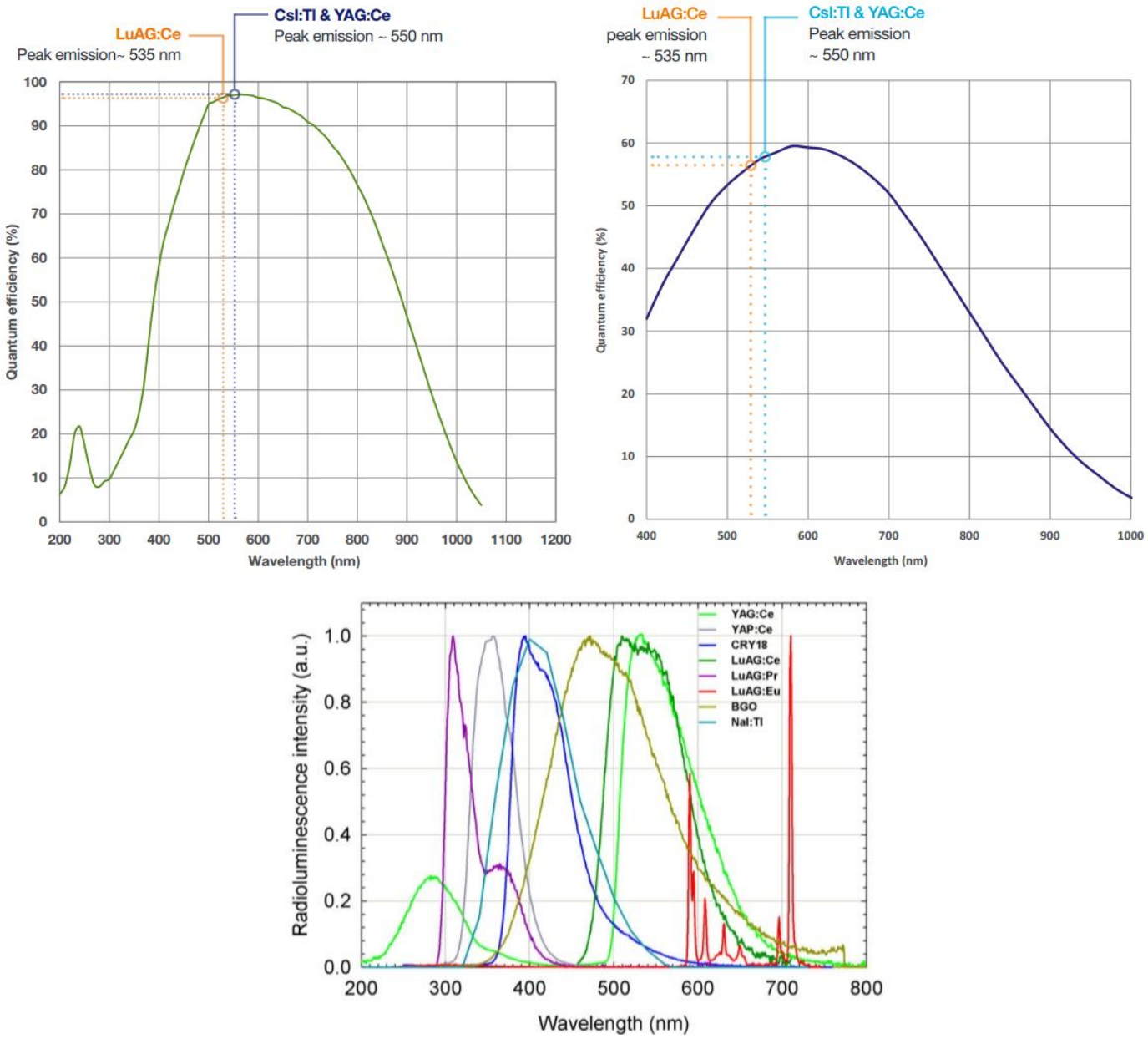


Figure 4 – Back-illuminated CCD (top left) and front-illuminated sCMOS (top right) typical Quantum Efficiency curves overlapped with peak emission wavelength of relevant x-ray scintillators. Bottom figure shows full spectral response of various scintillators including YAG:Ce & YAG:Ce types (courtesy of Crytur)

Spatial resolution and throughput

A single scintillator does not typically simultaneously achieve high spatial resolution and high light throughput. Compromise on the scintillators properties (e.g. thickness) have to be made to favour one aspect over the other or achieve the best balance between the two. The figure below shows an example of a high spatial resolution image obtained with a Zyla-HF sCMOS coupled to a high resolution 20 µm YAG:Ce scintillator and a high throughput 150 µm CsI:Tl scintillator. To achieve similar intensity with the two configurations, the exposure time for the high resolution scintillator had to be 100 times higher than for the high throughput option.

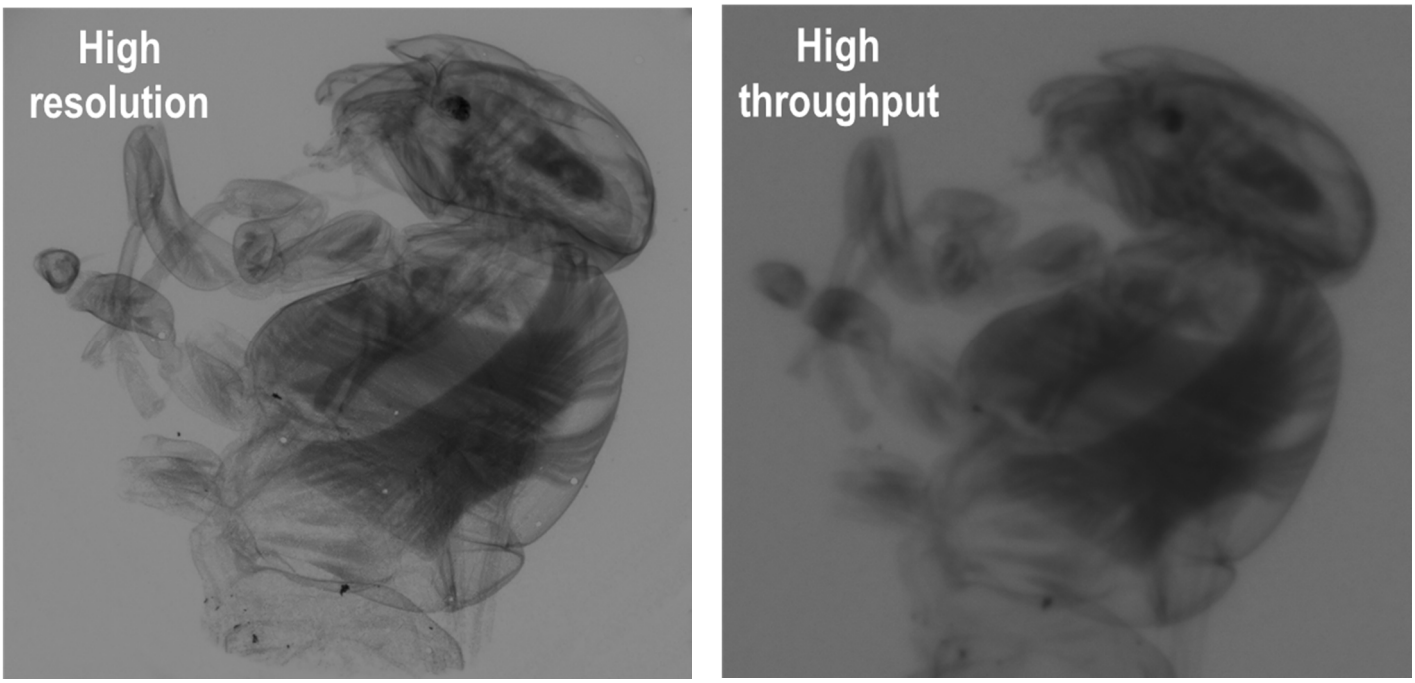


Figure 5 – X-Ray image of a wasp taken with a 40 kV X-ray source, courtesy of Crytur.
Left: Zyla-HF fibre-coupled to a 20 µm YAG:Ce scintillator, 10s exposure time.
Right: Zyla-HF fibre-coupled to a 150 µm CsI:Tl scintillator, 0.1s exposure time.

Andor 'Fibre-optic' 'HF' camera platforms

iKon-L HF CCD platform

Zyla HF sCMOS platform

Detectors for imaging	iKon-L DF936N-FB	Zyla-HF	
		ZYLA5.5X-FO	ZYLA5.5B-FO
Sensor technology	CCD	Scientific sCMOS (sCMOS)	
Sensor format	2048 x 2048 matrix 13.5 µm pixels e2v CCD 42-40	2560 x 2160 matrix 6.5 µm pixels	
Sensor size	27.6 x 27.6 mm	16.6 x 14.0 mm	
Sensor options	Back-illuminated, front-illuminated	Front-illuminated	
Minimum TE-cooling temperature	-35 °C	0 °C	
Maximum full frame rate	0.95 fps	100 fps	40 fps
Pixel well depth	100,000 e^-	30,000 e-	
Output node capacity well depth	1,000,000 e^-	n/a	
Readout noise	4.9 e^- @ 50 kHz	2.4 e^- [Global shutter]	
Data range	16-bit	12 and 16-bit	
PC interface	USB 2.0	Camera-Link 10-tap	USB 3.0

Table **1** – Andor 'fibre-optic coupled' cameras key specifications

Andor ‘Fibre-optic’ ‘HF’ cameras accessories

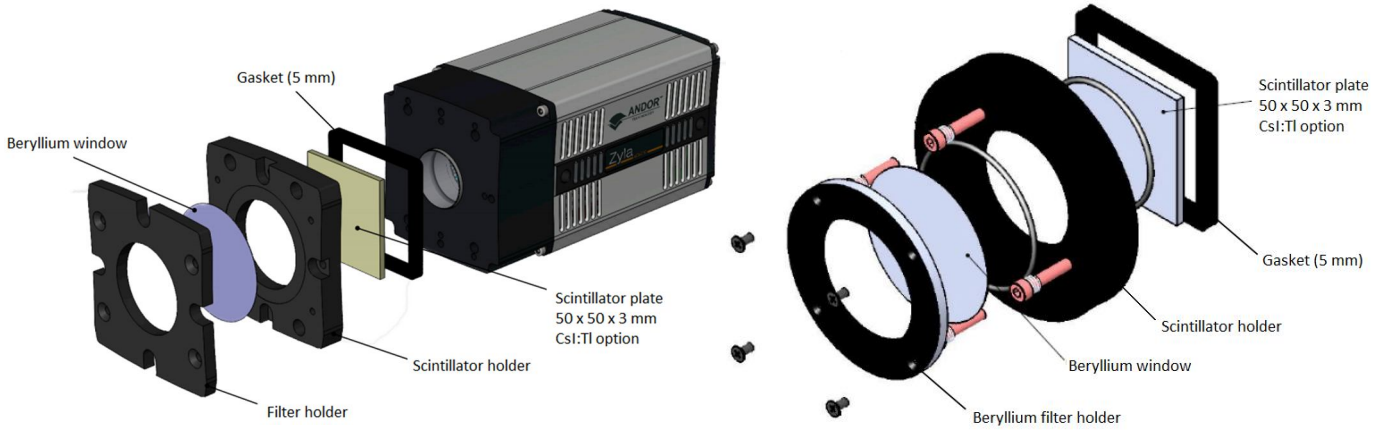


Figure 6 – Zyla-HF (left) and iKon-L HF (right) filter and scintillator holders configuration with a 50 x 50 x 3 mm CsI:Tl scintillator; configuration is slightly different to accommodate the circular YAG:Ce and LuAG:Ce scintillators

Camera platform	Scintillator and filter holder	Standard scintillators compatibility	Standard filter compatibility
Zyla-HF	**SCT-FLT_HLD-C025ZYL** *Ø25.4 x 3 mm scintillator* *Ø45.5 mm filter*	**SCT-LUAGCE-25-0xx-00** **SCT-LUAGCE-25-0xx-AL** **SCT-YAGCE-25-0xx-00** **SCT-YAGCE-25-0xx-AL**	**ACC-OPT-02839** Ø45.5 mm Be filter, 250 µm thick [minimum recommended thickness: 200 µm]*
	SCT-FLT_HLD-H050ZYL *50 x 50 x 3 mm scintillator* *Ø45.5 mm filter*	**SCT-CSITLT-50-150-00** **SCT-CSITLR-50-150-00**	
iKon-L	**SCT-FLT_HLD-C045IKL** *Ø45 x 3 mm scintillator* *Ø60 mm filter*	**SCT-LUAGCE-45-0xx-00** **SCT-LUAGCE-45-0xx-AL** **SCT-YAGCE-45-0xx-00** **SCT-YAGCE-45-0xx-AL**	**ACC-OPT-03838** Ø60 mm Be filter, 250 µm thick [minimum recommended thickness: 200 µm]*
	SCT-FLT_HLD-H050IKL *50 x 50 x 3 mm scintillator* *Ø60 mm filter*	**SCT-CSITLT-50-150-00** **SCT-CSITLR-50-150-00**	

Table 2 – Standard scintillator and filter holders for Andor fibre-optic ‘HF’ platforms
(*xxx* denotes the scintillator thickness)

* available through CSR – thinner windows carry increased risks of breakage, long-term stress

Q&A

What information should be provided for custom scintillator?

Parameter	Value	Notes
Camera platform		e.g. Zyla-HF, iKon-L HF
Radiation type		e.g. x-ray photons, electrons, neutrons
Energy range of interest	*keV - keV*	e.g. 0.1 keV to 50 keV
Importance of detector spatial resolution		e.g. high, medium or low importance, or ideally provide target resolution in lp/mm or µm
Importance of photon yield (from scintillator)		e.g. high, medium or low importance
Grounding		Should be considered when electric charges could build up on the scintillator, e.g. electron signal detection in TEMs
Low energy radiation filtering		Yes/No, cut-off energy (keV), fixed/removable filter – certain types of scintillators can be manufactured with a filter (e.g. Al) directly bonded to the device surface