Scintillation Arrays

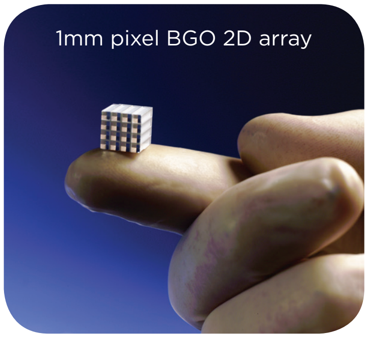
Linear arrays are used in CT scanning (medical/security/industrial), line scanning (security/industrial) and many research applications.

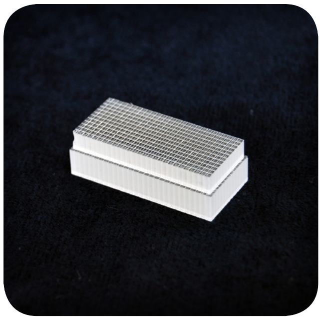
Two-dimensional arrays provide imaging capability in CT scanning, nuclear medical applications (e.g. SPECT/PET), portal imaging, X-ray flash radiography, non-destructive testing and various research applications.

There are other imaging applications in nuclear medicine, industrial imaging (non-destructive testing), portal imaging, flash radiography and research and space applications.

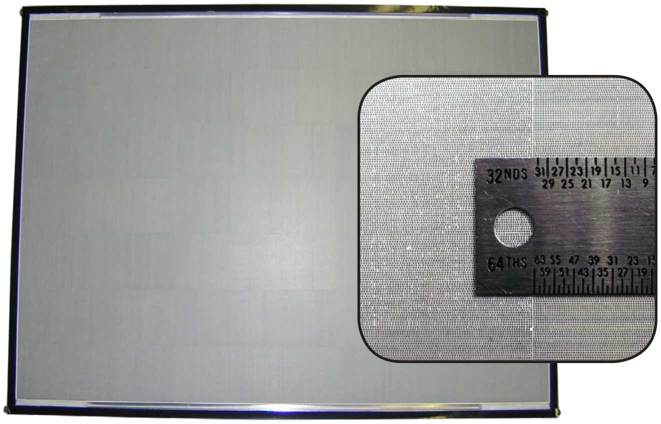
Chart of Applications Well-Suited for Saint-Gobain Crystals' Array Materials

Material	CsI(Tl)	CdWO4	BGO	LYSO
Gamma Cameras	X			
CT Imaging	X	X		X
Postitron Emission Tomography	X		X	X
Line Scanning	X	X		
Industrial Imaging	X	X	X	
Flash Radiography			X	X
Digital Radiography	X		X	





12x27 element coupled to a 13x28 element LYSO array having pixels that measure 1.12mm with a 1.17mm pitch. "X"-Ray thicknesses are 4mm for the smaller array, and 6mm for the larger array



CsI(Tl) Scintillator panel measuring 30cm x 40cm with 0.3mm pixels X-ray thickness 10mm

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General Description
Materials for Array Applications

The optimal material choice involves a combination of factors including the application, the photo readout device to be used, etc. For example, if the application calls for rapid detection of radiation pulses, then the decay time and afterglow drive the choice (BGO, LYSO, $CdWO_4$). If high efficiency and low cost are paramount, then NaI(Tl) with a PMT readout or CsI(Tl) with a photodiode readout are the first detectors to consider. The physical properties of each material must be considered as well. For example, the natural cleavage plane in $CdWO_4$ restricts the minimum size of 2D pixels. Saint-Gobain's technical experts can help guide your decision.

$CdWO_4$ high light output and low afterglow makes it ideal for use with silicon photodiodes in detectors for medical and industrial CT scanners. $CdWO_4$ has very good radiation resistance, and its temperature dependence is small in the 0 to 60°C range. Its high density makes it a good choice for 300+ keV imaging for container and vehicle scanning.

CsI(Tl) has the highest light output of these scintillators, and its emission matches well with silicon photodiodes. However, its long afterglow limits its use to applications for which intervals between sampling are long or some residual signal can be tolerated. CsI(Tl) is a rugged, malleable material that can be easily fabricated into a variety of geometries. It is slightly hygroscopic but is packaged in a manner to minimize exposure to moisture. CsI(Tl) is regularly fabricated into both linear and 2-dimensional (2D) arrays with pixel sizes as small as 500 microns square.

LYSO ($Lu_{1.8}Y_{.2}SiO_5$:Ce) is a Cerium doped lutetium based scintillation crystal that offers high density and a short decay time. It has an improved light output and energy resolution compared to BGO ($Bi_4Ge_3O_{12}$), which has a similar density. Applications that require higher throughput, better timing and better energy resolution will benefit from using LYSO material.

Saint-Gobain Crystals fabricates arrays from a variety of other scintillation materials including BGO and ceramics.

PSPMT Readout –

Pixellated crystals direct photons onto the readout device with less light spread. The use of a Position Sensitive Photomultiplier Tube (PSPMT) will improve spatial resolution and reduce image distortion. Each sensitive area of the PSPMT provides spatial X and Y coordinates for the exposed pixel. Spatial resolution depends on the crystal and septa size. Energy resolution is improved by the more efficient PSPMT and more effective collecting of the crystal's scintillation light.

BGO materials lend themselves well to the use of a PSPMT due to the emission wavelength of less than 480nm.

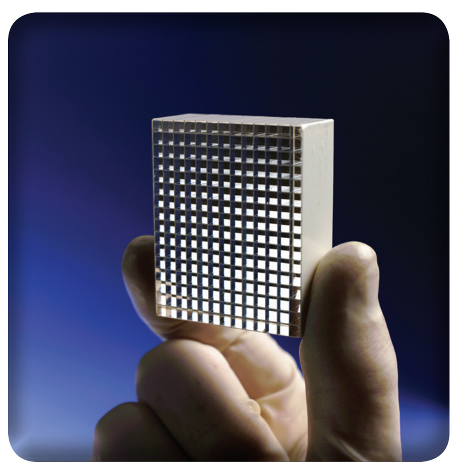
Photodiode Readout –

Photodiodes offer some advantages over Photomultiplier Tubes for certain applications. Because CsI(Tl) has most of its emission above 500nm , the material is well suited for a photodiode readout. For certain crystals, the shape of the emission spectrum is a function of the temperature. Therefore, the response for crystals with photodiode readout can be different.

Photodiodes are available in a variety of sizes. When choosing a photodiode, the size of the diode should be such that a maximum amount of the scintillation light can be detected by the diode.

Properties of the Materials

General Properties	CsI(Tl)	$CdWO_4$	BGO	LYSO
Density, g/cm³	4.51	8.0	7.13	7.10
Solubility in H_2O, g/100g@25°C	85.5	0.5	–	–
Hygroscopic	slightly	no	no	no
Relative Light Output [photons/keV]	54	13	9	32
Relative Rad Hardness	Medium	High	High	High
Wavelength of Maximum Emission	565	475	480	420
Primary Decay Time	1µs	14µs	300ns	41ns
Afterglow	0.5-5% @6ms	0.1% @3ms	0.005% @3ms	<0.1% @6ms



General Description
Materials for Array Applications

There are choices of scintillator materials and separator/reflectors to optimize performance to a specific application. The listing of parameters addresses the elements that must be considered in the design of a linear or 2D array.

The table below shows the materials and the associated pixel sizes that are regularly producible today. The pixel sizes are controlled primarily by mechanical properties of the crystals, e.g. hardness, cleavage, ease of machining. For example, $CdWO_4$ has a cleavage plane in one crystallographic direction. For that reason, it is not possible, with current techniques, to achieve 0.3 x 0.3 mm^2 pixels because of fractures along the cleavage planes that occur during cutting and grinding in manufacture. However, 0.3 x 1.0 mm^2 pixels can be produced.

Array Design Parameters –

Material: Type of scintillation crystal or material desired.

Pixel or Element Size: The "X" and "Y" dimensions of each scintillator pixel.

Separator Type and Thickness: The type of reflector between the crystal pixels and its overall thickness, "Gap X(A)" or "Gap Y(B)". Note: this may be a composite or laminate of white reflector and metal materials.

Pitch: This is the distance between the center of one element to the center of an adjacent element, "X" + "Gap X(A)" or "Y" + "Gap Y(B)" Note: In 2D arrays with rectangular pixels, the pitches in the "X" and "Y" directions will be different.

Radiation Thickness: This is the "Z" dimension and specifies the thickness of the array in the direction of the incoming radiation.

Back Reflector Thickness: Usually a white reflector is applied to the radiation entrance side of the array to reflect the light back into the pixel so it can be directed to the light sensor.

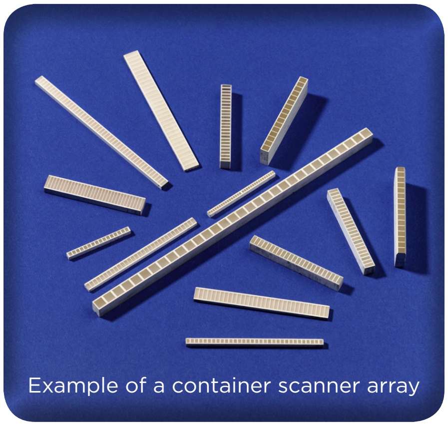
Material adjacent to the end pixels or elements: The end crystals may need a special reflector thickness or other treatment, e.g., to keep a constant pitch from array to array if they will be joined together in use.

Minimum Discrete Pixel Sizes Available in Crystal Scintillators

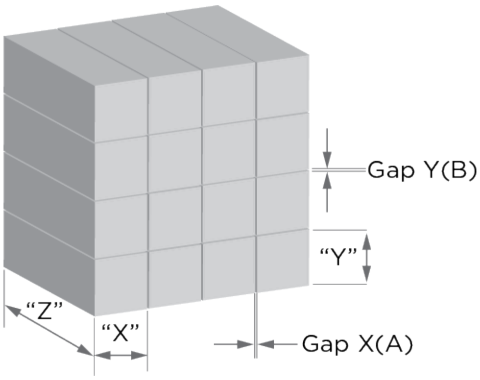
Material	Minimum Pixel Sizes *		Comments
	Linear (mm)	2D (mm)	
CsI(Tl)	0.3	0.5	
$CdWO_4$	0.3	1.0	Cleavage Plane
BGO	0.3	0.3	
LYSO	0.8	0.8	Min. Untested

*Guidelines not hard numbers

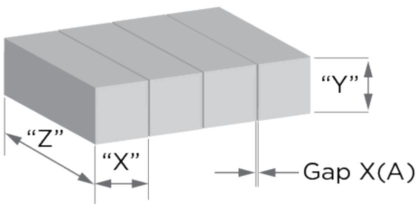
All dimensions, including array length and width and pixel size and length, may be defined by the application.



Example of a container scanner array



Dimensions to consider in the design of a 2D array



Dimensions to consider in the design of a linear array

Designing an Array Specific Parameters

Proprietary processes developed by Saint-Gobain Crystals ensure superior light output and improved pixel-to-pixel uniformity. The reflector material we use between the pixels provides outstanding reflection as well as excellent protection against optical crosstalk.

Separator/Reflector Type and Thickness –

The geometry of the pixel, the thickness of the reflector, the scintillator material used and other factors influence the reflectivity obtained in each array design. Array reflector materials are listed in the order of decreasing reflectivity. The reflectivity numbers are presented as a guide only. The first two separator materials listed (white powder and Teflon sheet) are not practical for most of the small pixel arrays discussed here – they cannot provide the bonding properties required. However, they are useful in some encapsulated units. Once mixed with epoxy, the white powder provides the diffuse reflectivity required to channel the scintillation light to the exit surface and the adhesive properties for a mechanically stable array.

Metal or metallized separators prevent optical crosstalk between the pixels while maintaining minimum gap "G" thicknesses. However, the metal surfaces, even polished, do not provide the best reflection of the scintillation light to the exit surface. This is where composites are useful. They combine the reflective properties of the white materials with the "zero" optical crosstalk of solid metals or films. Metal separators can serve another function: to absorb the radiation that is incident on the separator area before it strikes the light sensor and produces noise. Nuclear dense materials like Lead, Tungsten, and Tantalum are used. Also available are white epoxies where the reflector particle fillers are more nuclear dense than TiO_2 or Al_2O_3. However, in practice, their effectiveness is limited to low energies, up to 60keV.

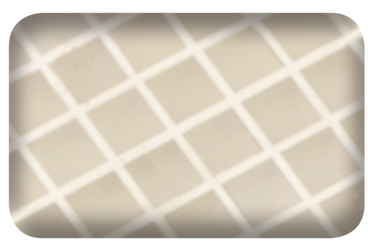
Separator Types and Thicknesses in Order of Decreasing Reflectivity

Material	Thickness Range	Approximate Relative Reflectivity *
White Powder (e.g. TiO_2, MgO) **	0.25 mm and up	100%
Teflon Sheet **	0.15 mm - 0.50 mm	98%
White Reflector Paint	0.04 mm - 0.10 mm	96%
White Plastic	0.05 mm and up	95%
White Epoxy	0.10 mm - 0.75 mm	94%
Composites ***	0.10 mm and up	94%
Aluminum/Epoxy	0.05 mm - 0-.1 mm	75%
Metals (Pb, Ta) / Epoxy	0.05 mm and up	65%

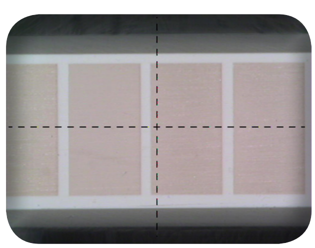
* These are guidelines only and are based on optimum, not minimum, thickness. Values will vary with pixel geometry, surface finish and other specific design parameters.

** These are used as reflector materials in large scintillation crystal packaging.

*** Composite separators are clear epoxy-paint-clear epoxy, white epoxy- metal-white epoxy.



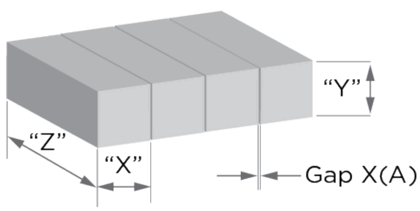
Close-up of a $CdWO_4$ 2D array with white reflector technology



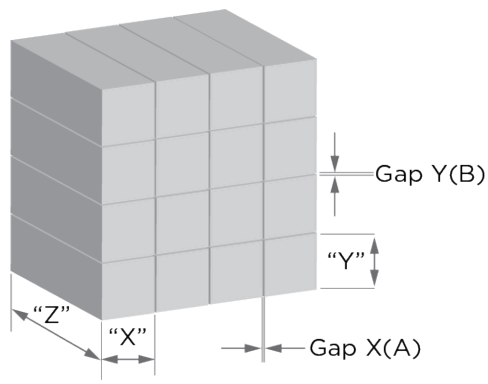
50X magnification of a linear array

Understanding Array Model Numbers

		1D Array	2D Array
	Example of a Model Number	**82.58X4.2A30/16/5.2CsI(Tl)**	**82.58X4.2A30/16x4/5.2x4CsI(Tl)**
1	Active area length	82.58	82.58
2	Active area height	4.175	4.175
3	X-ray crystal depth (Z)	30	30
4	Number of pixels If the array is 2D, this is in the format [Pixels X]x[Pixels Y].	16	16x4
5	Pitch [X + Gap X(A)] If the array is 2D AND the pitch is different in X and Y, this is in the format [X+GapX(A)]x[Y+GapY(B)].	5.2	5.2x4
6	Scintillator	CsI(Tl)	CsI(Tl)
Note: All dimensions in mm			



Dimensions to consider in the design of a linear array



Dimensions to consider in the design of a 2D array

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