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AN07: Scintillator Options for Shad-o-Box Cameras

Introduction

Digital imaging detectors can use a variety of detection materials to convert x-ray radiation either to light or directly to electronic charge. Many detectors such as amorphous silicon flat panels, CCDs and CMOS photodiode arrays incorporate a scintillator screen to convert x-rays to light. The light emitted via fluorescence in the scintillator is then absorbed by the detector and converted to an electronic image. Some detectors can be equipped with different scintillators in order to optimize their sensitivity and resolution for a given application. In particular, the Shad-o-Box digital x-ray camera can be equipped with different scintillator options at the factory to match a specific energy range or resolution requirement.

This study compares three different scintillator screens that are available for the Shad-o-Box cameras. Both the standard model Shad-o-Box camera and the EV (extended voltage range) model are used in the comparison. A range of x-ray energies from 30 to 120 kVp is examined, and the detectors are tested in terms of sensitivity, resolution and signal-to-noise performance. The resulting graphs and tables will hopefully provide useful information to the prospective user in determining which camera and scintillator gives the best performance for their application.

Overview of Scintillators

Gadolinium Oxysulfide doped with Terbium (Gd_2O_2S:Tb, or simply Gadox) is one of the most efficient scintillators available in terms of light output per incident x-ray energy. In addition, its high atomic number and density make it an effective absorber of x-rays. Its main disadvantage is that it is manufactured in a homogeneous layer of small crystalline particles. This means that any light generated by x-rays is rapidly scattered and diffuses before it is intercepted by the detector. Thick Gadox screens, which are better at absorbing high-energy x-rays, exhibit strong blurring and can't be used for high-resolution imaging. Thinner screens, on the other hand, fail to absorb a large fraction of the incoming x-rays – especially at the higher energies – which leads to lower sensitivity and poor signal-to-noise ratio. This concept is illustrated in Figure 1.

One possible solution to the sensitivity vs. resolution tradeoff is the structured scintillator. In a structured scintillator the light emitted by an absorbed x-ray is confined to a narrow vertical channel, which prevents it from scattering or spreading sideways even in a thick scintillator (see Figure 2). Fiberoptic scintillating faceplates and columnar-grown cesium iodide (CsI) are two examples of such a scintillator. However, even though these structures appear to be an ideal solution, in practice they are difficult and expensive to manufacture and they often have internal absorption and scattering mechanisms that can outweigh their advantages. Fiberoptic scintillators are typically useful only at very high energies where the advantages of thickness and high resolution overcome their low sensitivity. CsI is difficult to grow in sufficient thickness to provide good sensitivity and yet maintain its high resolution.

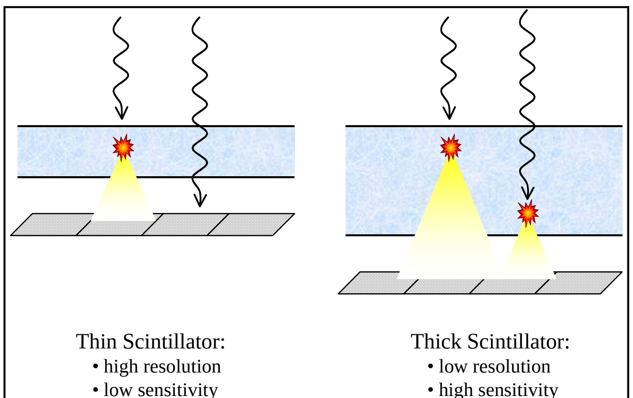


Figure 1: Sensitivity vs. Resolution Tradeoff.

Figure 3 shows a plot of the linear absorption coefficients of Gadox and CsI, along with several typical x-ray spectra. For a given thickness, Gadox is by far a more efficient scintillator than CsI except for a narrow window between the k-edges of cesium and gadolinium (approximately between 35 and 50 kV). It is possible to grow CsI to several hundred micron thickness, at which point it achieves both better sensitivity and higher resolution than the thickest Gadox screens. However, most commercially available CsI screens are less than 150 µm thick, which is usually not enough to outperform a good Gadox screen.

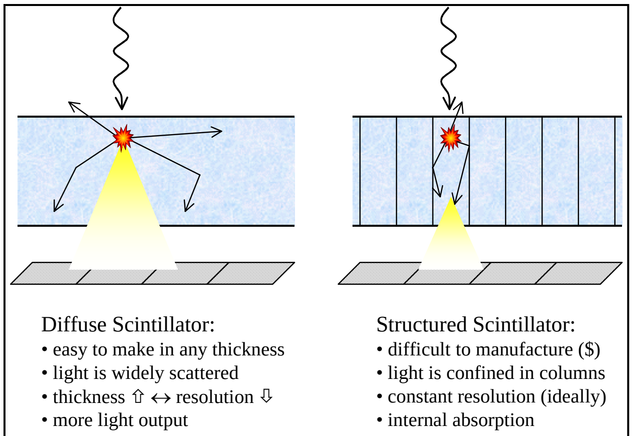


Figure 2: Diffuse vs. Structured Scintillator.

Performance Study

This study examines three Gadox screens that are commercially available as flexible sheets with a plastic backing: Lanex Fine, Min-R Medium and Lanex Fast (all three are manufactured by Kodak). The RadEye2 CMOS photodiode detector inside a Shad-o-Box 1024 digital x-ray camera is used to capture the light output of the phosphor screens. The standard model of the Shad-o-Box camera is used to test the screens at kVp settings of 30, 50 and 80 kVp, whereas the EV model is used at settings of 80 and 120 kVp. The 80 kVp setting is outside the recommended operating range for the standard Shad-o-Box camera, but we want to provide a direct comparison between the two camera models at this energy setting. A standard tungsten-target x-ray source with minimal filtering is used for these tests.

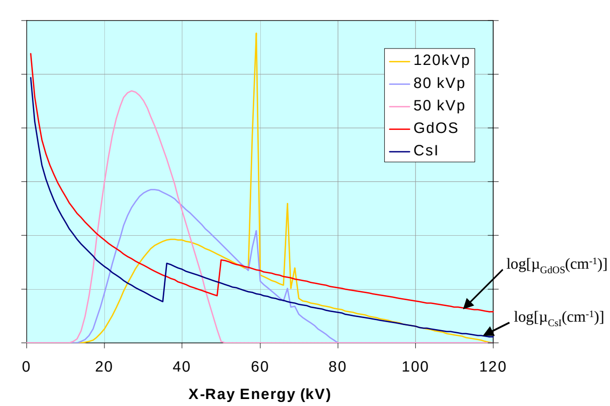


Figure 3: Energy Spectrum and Absorption Coefficients.

Sensitivity

The sensitivity of a digital x-ray camera is a function of (1) what percentage of x-ray photons are absorbed by the scintillator, (2) how much light is generated by the screen for each absorbed photon, and (3) how efficient the detector is at collecting and converting the light into electric charge or voltage. The input signal is the exposure per frame (in mR) or simply the dose rate times the camera integration time. The exposure is changed by adjusting the mA setting of the x-ray source and calibrated with an ion chamber. The output signal in this case is the digital count value per pixel (in ADU, or analog-digital units) from the camera's A/D converter, averaged over several region-of-interest areas in the image. This metric also lumps in the detector gain and the camera's electronic gain with the sensitivity measurement, which is OK since we are interested in a comparison of the different scintillators rather than an absolute measurement.

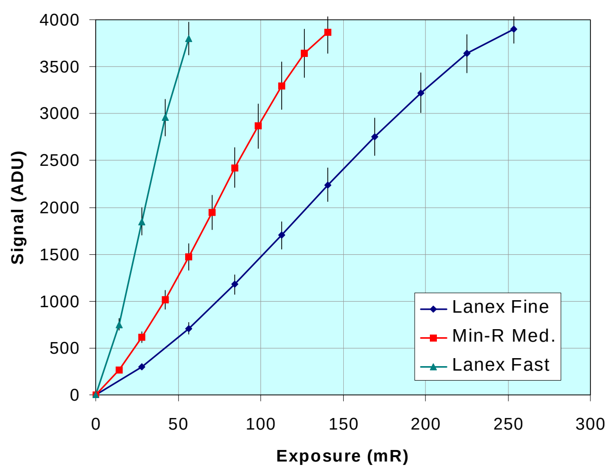


Figure 4: Signal Response at 50 kVp.

Figure 4 shows a typical response curve for the three scintillators using a 50 kVp spectrum. The Lanex Fast scintillator, because it absorbs a higher percentage of x-rays, is roughly twice as sensitive as the Min-R Medium, which in turn is about twice as sensitive as the Lanex Fine screen. The curves have a slight "S" shape, which is characteristic of the detector's intrinsic response curve. The saturation point of the detector is slightly above the maximum camera signal of 4095 ADU (the Shad-o-Box cameras have 12 bit A/D converters). Table 1 shows the measured average sensitivity for all tested combinations.

Signal-to-Noise Ratio

The signal-to-noise ratio is measured by dividing the average signal over a region-of-interest in the image by the standard deviation over the same area. The dominant noise source in most x-ray imaging applications is the quantum mottle of the x-ray beam itself. The noise contributed by the RadEye detector and the Shad-o-Box camera electronics is insignificant – typically on the order of 0.5 ADU. Thick scintillators tend to average out more of the high-frequency quantum mottle than thinner screens because of their strong blurring. Table 2 clearly shows that the resulting signal-to-noise ratio of the images is highest for Lanex Fast. It also shows that the EV camera, even though its sensitivity is 40% lower than the standard camera, has significantly higher signal-to-noise ratios. This is because direct absorption of x-rays in the CMOS photodiodes, a source of noise in the standard camera, is significantly reduced in the EV models.

Resolution

The MTF is measured using the slanted-edge technique. In this measurement a thin block of tungsten (or other highly absorbing material) with a long, straight edge is placed directly on the detector. The edge is aligned to within 10° of, for example, the column direction. A row profile from an image taken of the tungsten block shows the edge response of the detector and screen. The edge response can be differentiated to give the line spread function, which in turn is Fourier transformed to yield the MTF of the detector.

The measurement accuracy of a single row transformed this way is poor. However, the exact position of the edge can be estimated to sub-pixel accuracy using a simple least-squares fit. By using the edge position information and averaging across all available rows a smooth, oversampled line spread

Table 1 – Average Sensitivity (ADU/mR).

kVp	Camera	Lanex Fine	Min-R Medium	Lanex Fast B
30	Std.	11	23	41
50	Std.	18	32	73
80	Std.	31	60	266
80	EV	18	33	161
120	EV	27	45	189

Table 2 – Signal-to-Noise Ratio at 1000 ADU.

kVp	Camera	Lanex Fine	Min-R Medium	Lanex Fast B
30	Std.	48	63	263
50	Std.	43	53	169
80	Std.	34	46	120
80	EV	114	136	305
120	EV	98	115	255

Table 3 – Resolution (in lp/mm) at 10% MTF.

Camera	Lanex Fine	Min-R Medium	Lanex Fast F	Lanex Fast B
Std.	10.3	8.5	n/a	n/a
EV	9.6	7.5	4.9	2.4

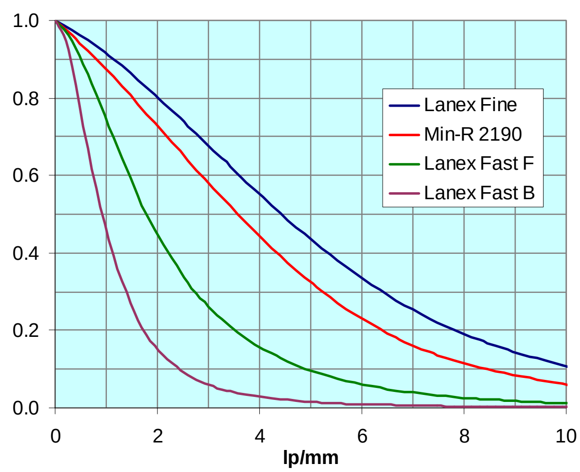


Figure 5: Typical MTF for each scintillator.

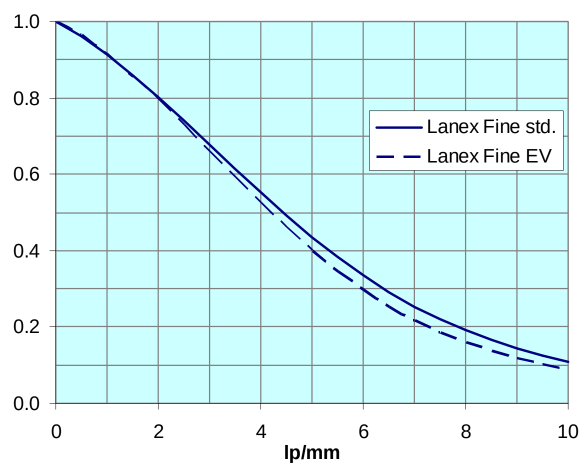


Figure 6: Std. vs. EV MTF for Lanex Fine.

function can be obtained. The Fourier transform of this oversampled line spread function is called the pre-sampled MTF because it effectively eliminates the artifacts caused by the sampling process in a pixellated detector (such as aliasing). Because the response is averaged over many rows the resulting curves tend to be smooth and noise-free.

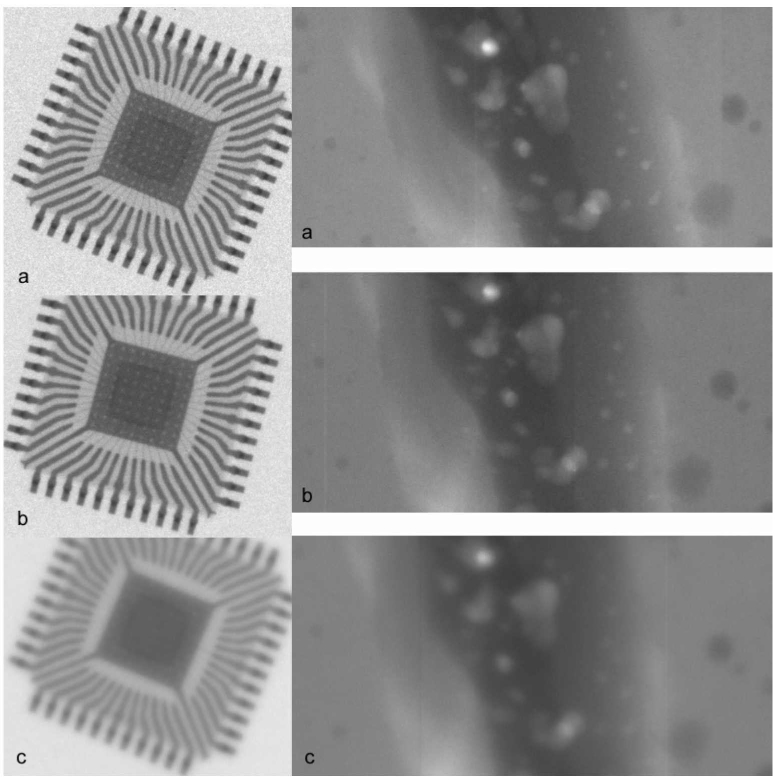
A typical MTF curve for each of the three scintillators is shown in Figure 5 (for comparison, both front and back elements of the standard Lanex Fast pair are shown). As expected, the thinner phosphors have better resolution than the thick Lanex Fast screen. Table 3 shows the resolution (in lp/mm) at which the MTF drops below 10% for each camera type and scintillator. The EV camera has slightly lower resolution than the standard version (see Figure 6). There is very little variation in the MTF with respect to x-ray energy, although for Lanex Fast there is a very small increase in resolution with increasing energy. This is caused by the fact that, at 30 kVp, most of the x-rays are absorbed near the top of the scintillator, and the light that is generated is both scattered and absorbed by the screen itself before it reaches the detector. At higher energies more x-rays are absorbed near the bottom of the screen, contributing to an overall increase in resolution.

Conclusion

Using a thick scintillator such as Lanex Fast can be advantageous for applications that do not require high spatial resolution. However, the capabilities of a high-resolution detector such as the Shad-o-Box camera are underutilized with this type of phosphor. On the other hand, a very thin scintillator like Lanex Fine only achieves a small improvement in resolution at a high cost in sensitivity and signal-to-noise ratio.

Figure 7 illustrates the performance of the three scintillators in two typical imaging applications. Clearly, the Lanex Fast phosphor can't resolve some of finer image details such as the wirebonds in the IC or some of the smaller voids in the weld sample. The visual differences between the images taken with Lanex Fine and Min-R Medium, on the other hand, are very small even though the Lanex Fine weld image required twice the exposure time of the Min-R Medium case.

Figure 7 – Application images of an IC (left) taken at 80kV and a ¼" steel weld (right) at 120kV for (a) Lanex Fine, (b) Min-R Medium and (c) Lanex Fast scintillators.



Since the scintillator is the first element that an x-ray photon encounters on its way to becoming a digital image, optimizing the scintillator performance typically has the greatest effect on image quality. Some scintillators such as structured CsI can be grown in a way that preserves resolution even for thicker layers. However, these materials also lead to additional complexity and expense in the detector. A future study comparing CsI with Min-R Medium may provide further insights.

Of course the final choice of scintillator depends on many factors including the detector characteristics and the nature of the application it will be used in. For this particular detector, Min-R Medium appears to provide the optimum combination of sensitivity, signal-to-noise ratio and resolution.

Note: Since this study was performed, the Kodak Min-R Medium scintillator has been discontinued and replaced by Min-R 2190, which offers a slight improvement in contrast and sensitivity over the original material.