Investigation of the Impact of Moisture on the X-Ray Characteristics of Cesium Iodide Scintillators [†]

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Abstract

We found that when water vapor penetrates into the interior of Thallium Iodide (CsI:TlI) crystal pillars, the pillars would undergo deliquescence and change the morphology, which is going to enhance the probability of visible light scattering. On this basis, a new proposal of Parylene interlayer encapsulation, which enhances the ability of water vapor barrier and thus improved the MTF stability of CsI:TlI scintillators, by chemical vapor deposition (CVD) is presented.

Author Keywords

CsI:TlI scintillator; X-ray detection; MTF; Parylene interlayer.

1. Introduction

Digital X-ray detection systems have been widely used in medical imaging diagnose, industrial non-destructive testing (NDT), security and other fields. The X-ray detection technologies that have been maturity commercialized include indirect conversion type and direct conversion type. Generally, the indirect conversion type is the most cost-effective choice for X-ray detection scenarios that require large area imaging, as the conversion layer materials (known as scintillators) are easily prepared at low cost and high yield over a large area. As the core functional structure of indirect flat panel X-ray detectors, scintillator palys the role of converting X-ray to visible light, thus has a crucial impact on the detection performances.

For scintillators, the main correlative evaluation indexes are Sensitivity and Modulation Transfer Function (MTF). The Sensitivity mainly describes the degree of conversion per unit dose by X-ray irradiation and is used to characterize the scintillator absorption and luminescence efficiency, meanwhile the MTF is used to describe the spatial resolution of the system.

Due to the excellent X-ray absorption conversion efficiency and the unique fiber-crystal columnar structure, thermal evaporative CsI:TlI has occupied the mainstream position of current X-Ray scintillator materials. However, since Cesium Iodide, the main material of CsI:TlI, is a water-soluble material that is susceptible to deliquescence, the X-ray detectors with CsI:TlI scintillators are often sensitive to ambient moisture. After a long time storage in humid environment, the sharpness of X-ray images usually tends to deteriorate, which is reflected in MTF. In one of the research, the decay of MTF will be focused on.

Parylene, as a p-xylene polymer, is composed of transparent small molecules aggregated by an unique chemical vapor deposition process (CVD). It has excellent performance on water vapor barrier, corrosion resistance, temperature resistance and other properties, and is widely used in semiconductor devices, medical devices, aerospace and other high-tech fields. Therefore, the preparation of a protective interlayer against deliquescence by Parylene coating on CsI:TlI crystal pillars is expected to be able to reduce the degradation of aging properties of the scintillator.

2. Experiments

Preparation of CsI:TlI films:

We use indirect conversion TFT detector backplanes to construct the X-Ray detection systems. The a-Si TFT X-ray detection panels with silicon nitride passivation layers (panel size 14 inch ×17 inch, pixel size 140um) are surface-cleaned, and CsI films with thickness of 400um are deposited on the surface of pixel area by thermal evaporation, using TlI as the activating dopant. The background vacuum in the evaporation chamber is $<1\times10^{-3}$ Pa, and the CsI and TlI are co-evaporated by using dual-crucible independent sources. The quartz crystal oscillator is used to monitor the thickness of films.

Encapsulation of CsI:TlI films:

After natural cooling down, one TFT panel with CsI:TlI layer (Sample 1) is directly subjected to the encapsulation process using a vacuum lamination method. The sealing film is selected to be a composite film with a structure of PET/Al/reflective PET/adhesive on which the total thickness is up to 130 um. As the comparison sample, another TFT panel with CsI:TlI layer (Sample 2) is transferred to the Parylene CVD chamber first with the vacuum of <10 Pa. The evaporation temperature is 90-120℃, and the thickness is around 10 um. Then, sample 2 is subjected to the same encapsulation process. To overcome the weak bonding between the Parylene film and the surface of the silicon nitride passivation layer, we used another secondary sealing on Sample 2 at the edges with UV-cured seal glue to avoid the peeling problem. Figure 1 shows the schematic structures of the two samples after encapsulation.

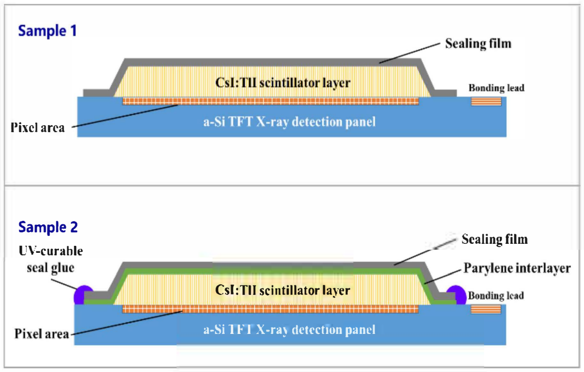


Figure 1. Schematic structures of the two samples after encapsulation.

Environmental Reliability Test:

We conduct a reliability storage test up to 240 hours on the samples at 60 ℃ and 90% relative humidity (6090 RA) next. Calculated by

ISSN 0097-996X/25/5603-1929-$1.00 © 2025

the Arrhenius acceleration model, this condition is equivalent to the effect of one year of storage at room temperature and humidity. Before and after the 6090 storage, the samples are tested for X-ray image quality and characterization. The X-ray test conditions are chosen to be RQA5 irradiation quality, with X-ray tube voltage of 70kV, and aluminum filtering of 21mm. The Sensitivity is calculated using the slope of a linear fit between image grey level - irradiation dose, and the MTF was calculated using edge-device images according to the IEC 62220-1-3:2008 standard. Meanwhile, in order to analyze the relationship between characteristic change and crystal morphology, we use a HITACHI Regulus 8100 scanning electron microscope (SEM) to observe the microscopic morphology of the CsI:TlI film layers.

3. Results and Discussion

Trends in MTF characteristics:

Figure 2 shows the MTF trends of Sample 1 and Sample 2 before and after the 6090 RA test. The initial MTF characteristic of sample 1 is slightly higher than that of sample 2, which is generally believed to be due to the Parylene interlayer increasing the optical range of visible light propagation, thus enhancing the overall light scattering. After the 6090 240h, the MTF of sample 1 decayed more (~15%), while that of sample 2 showed almost no decay, as shown in Table 1.

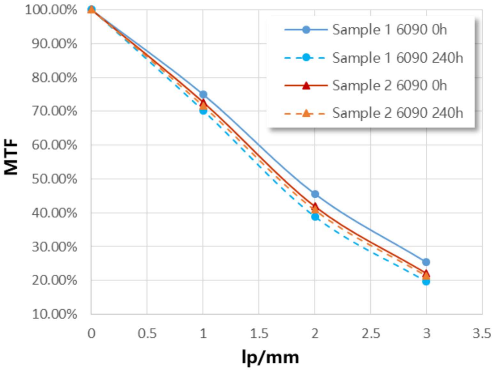
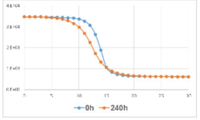
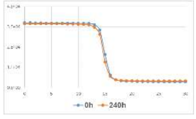


Figure 2. Trends of MTF characteristics before and after 6090 RA for different encapsulation samples.

Table 1. MTF decay with 6090 RA for different encapsulation samples

	Sample 1 (without Parylene interlayer)		Sample 2 (with Parylene interlayer)	
6090 RA Duration	0h	240h	0h	240h
MTF @2lp/mm	45.6%	38.9%	41.9%	40.90%
Relative MTF Decay @2lp/mm	-14.6%		-2.3%	
Profiles of edge-device				

X-ray image quality:

Table 2 shows the the Sensitivity and Grey Level values of the samples before and after the RA test. It is found that there is no obvious change for Sample 2 encapsulation scheme, while for sample 1, Sensitivity shows a certain degree of upward trend, which we believe is related to the occurrence of deliquescence and re-fusion of the CsI crystal columns, leading to the enhancement of the scintillator transparency

Table 2. Sensitivity and Grey level changes with 6090 RA

	Sample 1 (without Parylene interlayer)		Sample 2 (with Parylene interlayer)	
6090 RA Duration	0h	240h	0h	240h
Sensitivity (LSB/uGy)	467.6	476.4	463.6	465.9
Grey Level	33541	33788	33163	33274

Figure 3 shows the comparison of X-ray images before and after the RA test, and no obvious differences appear, especially in the edge and corner regions which are susceptible to moisture intrusion. It's worth noting that, for Sample 1, a certain degree of resolution degradation could be judged by the change in the clarity of the defect contours as shown in Figure 4, which indicates a degradation in the detail sharpness of the imaging system.

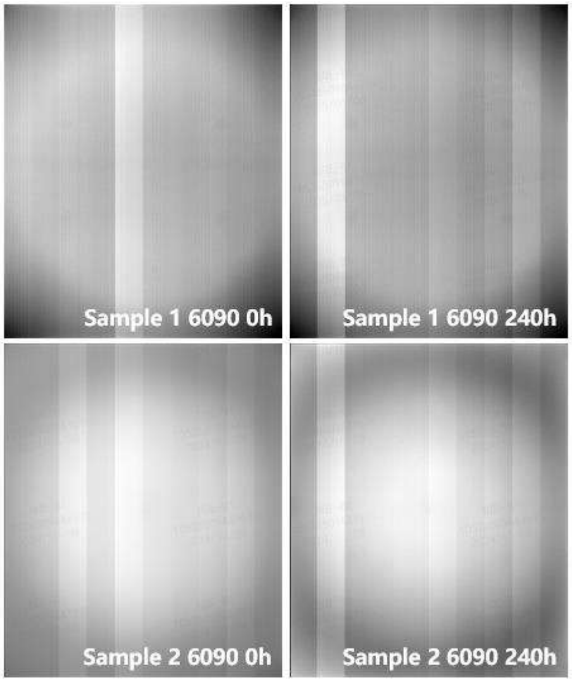


Figure 3. X-ray images before and after 6090 RA for different encapsulation samples

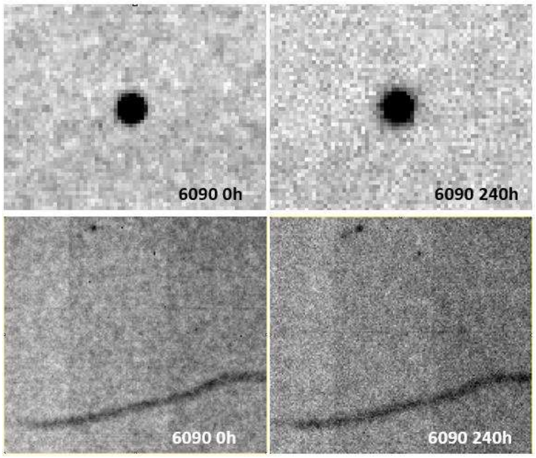


Figure 4. Blurring of localized defects contours in X-ray images of Sample 1 after 6090 RA test

SEM micro-morphology analysis：

Figure 5 shows the SEM images of CsI:TlI films before and after the RA test for samples with and without Parylene interlayers. Figs. a, c, e, and g show the morphology of the top and bottom of CsI:TlI crystal pillars before RA, and the prisms of the pillars are distinct and the boundaries are clear. Figs. b and d give the morphology of the crystal pillars after RA of Sample 1, and the results show that the corners of the pillars at the top become rounded and large-scale adhesion occurred. The original inter-crystal boundaries are fused and a large number of fusion bubbles appear, which means the overall cesium iodide has deliquescent adhesion. In comparison, Figs. f and h show the morphology of Sample 2 after RA, and the results give the crystal pillars are basically the same as the initial morphology. We believe that this has something to do with the fact that Parylene interlayer penetrate into the inside of the crystal pillars during the CVD deposition and wrap the CsI:TlI layer, which further strengthen the protective effect from water vapor.

Combined with the results of the previous X-Ray images, we believe that the microscopic changes could not be effectively recognized from the macro images because the size of the pillars is much smaller than the pixel size of the a-Si TFT panels.

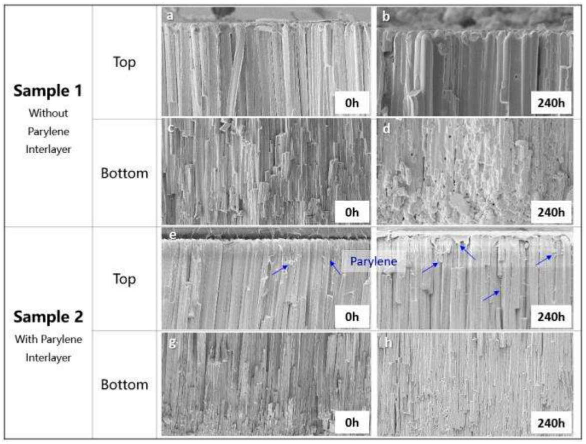


Figure 5. SEM images of CsI:TlI films before and after 6090 RA for different encapsulation samples

4. Conclusion

This work mainly investigates the effects of high temperature and high humidity reliability test (6090 RA) on CsI:TlI scintillator samples. After the water vapor penetration, certain degree of microscopic deliquescence of the CsI:TlI layer occurs with the attenuation of the MTF characteristics, while no significant degradation could be seen in X-Ray image quality or Sensitivity characteristics. Boundary fusion between the crystal pillars and the neighboring pillars resulted in the formation of polycrystalline pillars adhered together and the enhancement of the light scattering. In response to this phenomenon, we propose an improved encapsulation scheme. By introducing a Parylene interlayer, the independent wrapping of the crystal pillars can be realized, and the ability of water vapor barrier can be enhanced, thus we improving the stability of MTF characteristics of CsI:TlI scinttilators.