

Image Quality Assessment of a CMOS/Gd₂O₂S:Pr,Ce,F X-ray Sensor

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Abstract. The aim of the present study was to examine the image quality performance of a CMOS digital imaging optical sensor coupled to custom made gadolinium oxysulfide powder scintillators, doped with praseodymium, cerium and fluorine (Gd₂O₂S:Pr,Ce,F) screens. The screens, with coating thicknesses 35.7 and 71.2 mg/cm², were prepared in our laboratory from Gd₂O₂S:Pr,Ce,F powder (Phosphor Technology, Ltd) by sedimentation on silica substrates and were placed in direct contact with the optical sensor. Image quality was determined through a single index image quality parameter (information capacity). The CMOS sensor/Gd₂O₂S:Pr,Ce,F screens combinations were irradiated under the RQA-5 (IEC 62220-1) beam quality. The detector response function was linear for the exposure range under investigation. Under the general radiography conditions, both Gd₂O₂S:Pr,Ce,F screen/CMOS combinations exhibited comparable overall imaging properties, in terms of the information capacity, to previously published scintillators, such as Gd₂O₂S:Eu.

Keywords: Information Capacity; CMOS; Inorganic Scintillators; Gd₂O₂S:Pr,Ce,F

1. Introduction

Indirect medical imaging detectors incorporate a scintillator detector coupled to an optical sensor (CCD, CMOS, etc.). In this case, the scintillator is used in the form of a powder phosphor screen [1]. Optical ceramic scintillators have been also developed in order to replace single crystals in some applications [1-4]. Ceramic gadolinium oxysulfide doped with praseodymium, cerium and fluorine (Gd₂O₂S:Pr,Ce,F) (ultra-fast ceramics-UFC), has been proposed to be used in Computed Tomography (CT) scanners [4]. Gd₂O₂S:Pr,Ce,F is an efficient and fast scintillator (decay time of the order of 3-4 ~ s) based on the well-known traditional Gd₂O₂S host material [5].

A semiconductor technology that has been used widely recently is complementary metal oxide (CMOS) semiconductors [6-8]. Active pixel sensor (APS) CMOS provide high resolution even at high framing rates and, in association with scintillating screens, have been increasingly investigated for medical imaging applications [9]. In the present study, image quality of a CMOS digital imaging sensor, coupled to Gd₂O₂S:Pr,Ce,F powder phosphor screens, was investigated by assessing the information content through the information capacity (IC) [10].

2. Materials and Methods

2.1. Phosphor screens

Gd₂O₂S:Pr,Ce,F was purchased in powder form (Phosphor Technology Ltd, England, code: UKL59CF/N-R1) with a mean grain size (estimated by ultrasonic dispersion with a coulter counter



having 100 μm aperture) of approximately 16.0 μm at the 95% of the volume and quartile deviation of 0.25 (Phosphor Technology Ltd., datasheet) [5]. $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ has effective atomic number $Z_{\text{eff}} = 61.1$, density of 7.34 g/cm^3 and a decay time of the order of a 3×10^{-6} s [3]. The phosphor was used in the form of thin layers to simulate the intensifying screens employed in X-ray imaging [11]. Two screens with coating thicknesses 35.7 and 71.2 mg/cm^2 were prepared by sedimentation of $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ powder on fused silica substrates (spectrosil B). Sodium orthosilicate (Na_2SiO_3) was used as binding material between the powder grains [12].

2.2. CMOS sensor

The $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ scintillating screens were manually coupled to an optical readout device including a CMOS Remote RadEye HR photodiode pixel array [13]. The CMOS photodiode array consists of 1200x1600 pixels with 22.5 μm pixel spacing. The $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ screens were directly overlaid onto the active area of the CMOS photodiode array, consisting of an N-well diffusion on p-type epitaxial Silicon. A 70 kV (RQA-5) X-ray beam was used, following the IEC standards [14]. IEC standard X-ray spectrum was achieved by adding 21 mm Al filtration in the beam to simulate beam quality alteration by a human body [15]. A General Medical Merate tube with rotating Tungsten anode and inherent filtration equivalent to 2 mm Al, was used for the RQA-5 beam quality. According to IEC standard, the source-to-detector distance (SDD) between the X-ray focal spot and the surface of the detector should be no less than 150cm. In this study was set to 176 cm. The added filtration was placed as close as possible to the source.

2.3. Image quality

2.3.1. Signal Transfer Property (STP)

The Signal Transfer Property (STP) provides the relationship between mean pixel value (MPV) and incident air Kerma (ESAK) at the detector surface. This relationship was obtained by plotting pixel values versus ESAK at the detector, as described in the IEC method [14]. A sequence of uniform images was acquired at different exposure levels. MPV was evaluated in a 1×1 cm^2 region of interest (ROI). The system's response curve was fitted using a linear equation of the form $MPV = r + b \times K_r$, where r and b are fit parameters and K_r the ESAK in units of μGy . From the slope of the system's response curve, the value of the gain factor (G) was obtained [16]. The magnitude of the pixel offset at zero air-Kerma was also estimated [17].

2.3.2. Information Capacity (IC)

The concept of image information capacity (IC) has been introduced within the context of Shannon's information theory, in order to assess image information content [18-23]. In digital imaging, the continuous spatial distribution of an optically generated image is sampled by the discrete sensitive pixels on a photodiode array, whose outputs are converted into digitized signals and stored in an image processing system for numerical evaluation. In this study information capacity was calculated according to Equation (1) [24]:

$$IC = 1/2 \int_0^u \log_2(1 + SPS(u) / NPS(u)) df u du \quad (1)$$

where SPS is the signal power spectrum, defined as: $SPS = (MTF \times G)^2$ [24].

3. Results and Discussion

Figure 1 shows the detector response curves (STP) of the CMOS sensor combined with the 35.7 and 71.2 mg/cm^2 $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ screens, respectively under the RQA-5 (70kVp) beam quality. The detector was found to have a linear response, covering the whole exposure range, with a pixel value offset of -9.046 and 16.63 for the 35.7 and 71.2 mg/cm^2 $\text{Gd}_2\text{O}_2\text{S}:\text{Pr,Ce,F}$ screens. The linear no threshold fits gave correlation coefficients (R^2) greater than 0.9987 and 0.9989 for the 35.7 and 71.2

mg/cm² Gd₂O₂S:Pr,Ce,F screens. Using flat-field images the gain factors were determined by linear regression to be G=2.610 and 4.379 digital units per ~Gy for the 35.7 and 71.2 mg/cm² Gd₂O₂S:Pr,Ce,F screens.

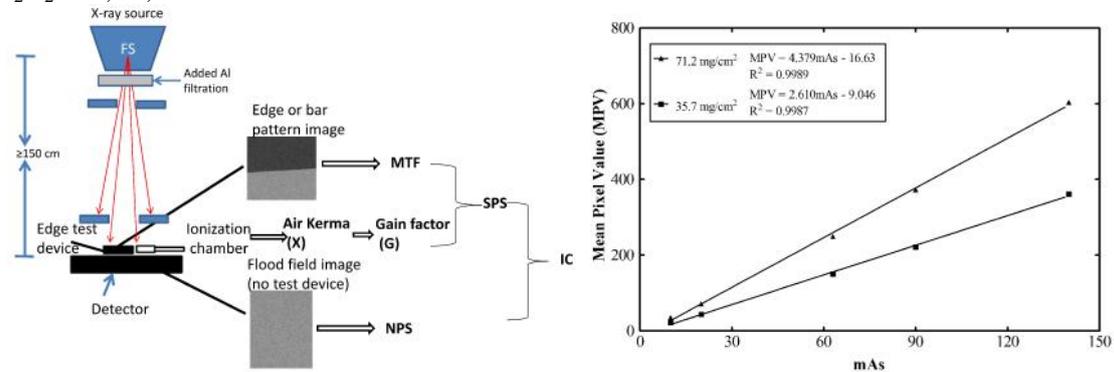


Figure 1. Experimental setup (left) and detector response curves (STP) of the CMOS sensor combined with the 35.7 and 71.2 mg/cm² Gd₂O₂S:Pr,Ce,F screens, respectively under the RQA-5 (70kVp) beam quality (right).

Table 1 shows information capacity values for the combination of the CMOS sensor with the 35.7 and 71.2 mg/cm² Gd₂O₂S:Pr,Ce,F screens under investigation, and previously published IC values for a CMOS sensor coupled to Gd₂O₂S powder scintillators, activated either with Terbium (Tb) or Europium (Eu). The investigation was carried out under the RQA-5 X-ray spectrum, as a function of air-Kerma. The thinner Gd₂O₂S:Tb screen (33.91 mg/cm²) showed the highest IC values due to the screen thickness and the higher MTF values of this screen, compared to the 35.7 mg/cm² Gd₂O₂S:Pr,Ce,F coupled to the CMOS sensor. The IC values of the thicker 71.2 mg/cm² Gd₂O₂S:Pr,Ce,F were lower than all the other screens, even from the IC value of the 65.1 mg/cm² Gd₂O₂S:Eu screen due to the fact of the higher thickness and screen uniformity, leading to lower MTF values and higher noise. The comparison was obtained at the same exposure level for all screen/sensor combinations. These data show that, for a given level of incident X-ray fluence, information capacity is mainly determined by the intrinsic phosphor material properties and by the screen thickness of the imaging system. In thick screens the lateral light trajectories are very long causing a large fraction of the laterally directed photons to be absorbed before reaching the screen output.

Table 1. Information Capacity values.

		Information capacity (bits/mm ²)			
Beam quality	Coating weight (mg/cm ²)	CMOS-Scintillator combinations			
		Gd ₂ O ₂ S:Tb	Gd ₂ O ₂ S:Eu	Gd ₂ O ₂ S:Pr,Ce,F	MTF @10% (lp/mm)
RQA-5	33.91	2806±34	-	-	9.1
	65.1	-	1826±18	-	5.0
	35.7	-	-	1813±23	6.7
	71.2	-	-	1722±35	4.8

4. Conclusions

In the present study image quality of two custom made Gd₂O₂S:Pr,Ce,F powder scintillator screens, coupled to a CMOS digital imaging sensor, was investigated under X-ray radiography imaging conditions. Image quality was investigated in terms of the information capacity, in the general radiography energy range. The detector response function was linear for the exposure range under investigation. The overall imaging properties, in terms of IC, of both Gd₂O₂S:Pr,Ce,F screen/CMOS

combinations, can be considered for medical imaging applications since it was found comparable with previously published scintillators, such as the $Gd_2O_2S:Eu$.

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5. References

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