A Novel Glass Ceramic for High-resolution Medical X-Ray Imaging

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Introduction

Storage-phosphor radiography is a digital technique that uses photostimulable phosphor screens to produce medical X-ray images [1]. Digital X-ray radiography using storage phosphors has several advantages over traditional X-ray films: larger dynamic range, higher sensitivity, environmental friendliness, and digital processing. In comparison with another digital X-ray detection system based on thin-film transistors, a storage-phosphor system has a separate readout mechanism from imaging screens, and therefore is more cost effective.

Commercially used storage-phosphor screens are based on polycrystalline $BaFBr:Eu^{2+}$ powder which is embedded in an organic binder [2]. A disadvantage of this system is an inferior spatial resolution (~ 3 line pairs/mm) compared to that of the scintillator-film system (~ 5 line pairs/mm). This inferiority is caused by light scattering from powder grains inside phosphor screens.

To improve image performance of storage phosphors, we have developed materials based on a modified fluorozirconate (ZBLAN) glass formulation. Imaging plates made from these materials are "grainless" and therefore can significantly reduce light scattering and improve image resolution. This paper discusses the X-ray imaging performance of these novel materials. The present study explores the possibility of using these ZBLAN-based glass ceramics for high-resolution X-ray storage phosphors.

Materials and Methods

Materials used for this study are EuF_2-doped ZBLAN glasses (a mixture of zirconium, barium, lanthanum, aluminum, and sodium halides). The Eu^{2+} dopant concentration is 2 mole percent added as EuF_2. Metal fluoride and chloride precursors are melted in a glassy carbon crucible, heated to 740 °C, and kept in an inert atmosphere of nitrogen. The melts are cast into a pre-heated brass mold (1cm × 1cm in dimension) to form ~ 1-mm thick glass plates. The glass plates are annealed in a nitrogen atmosphere at a temperature between 280 and 290 °C, and a time interval between 20 and 60 minutes. Then, the samples are cooled for characterization.

X-ray imaging tests on the ZBLAN-based plates were performed at the 2-BM beamline of the Advanced Photon Source. Figure 1 shows the experimental setup. A 4 mm (horizontal) × 2 mm (vertical) monochromatic X-ray beam is used as an imaging light source. A Huettner phantom is used as an imaging object for storage phosphor samples. This phantom has a series of parallel gold grids with spatial frequencies up to 20 line pair/mm (or 25 µm/grid). X-rays with photon energy of 21 keV are incident on the sample, and the X-ray exposure time (typically a few seconds) is controlled by an X-ray shutter. An X-ray image of the phantom is projected on the sample (imaging plate), which is mounted on a rotation stage with X, Y, and Z motion control. After exposure to X-rays, the sample is rotated 180° and is illuminated by a laser beam (wavelength = 660 nm, incident power density ≈1 mW/cm^2). The size of the laser beam is larger than that of the X-ray beam so that the whole X-ray illuminated region on the sample is exposed by the laser beam. A "latent image" in the storage phosphor sample is then "developed" by the laser illumination, and the formed image is taken by the CCD camera through a 2.5X objective lens. An optical filter is placed between the CCD camera and the objective lens to block scattered laser light but to let the stimulated luminescence light pass through. The laser beam is synchronized with the CCD camera so that the shutter of the camera is open while the laser is on.

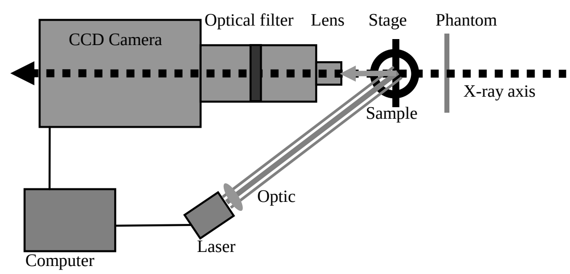

Figure 1: X-ray imaging setup for testing storage phosphor samples.

Results and Discussion

Figure 2 shows a photostimulated luminescence image recorded on a 2% Eu^{2+}-doped ZBLAN glass ceramic plate and on a commercial Agfa MD30 storage phosphor screen. The two sets of parallel grids shown in these images are from a part of the Huettner phantom. The numbers on the top of the grids indicates their spatial frequency, i.e., the right parallel grids have a spatial frequency of 20 line pairs (lp)/mm, and the left ones are 19 lp/mm. These two images were taken under the same experimental condition, and the horizontal strip-like features in the images come from static image background. As seen from Figure 2(a), the ZBLAN-based storage phosphor plate has an image resolution higher than 20 lp/mm. Further analysis shows that this imaging plate has a resolution of 28 lp/mm at the modulation transfer function (MTF) value equal to 0.2. In contrast, Figure 2(b) demonstrates that the commercial storage phosphor does not have high enough resolution to resolve 19 lp/mm parallel gold grids.

Commercially used readout systems for storage phosphors is based on a laser point-scan method, i.e. a focused laser beam scan through a sample point by point, and the stimulated luminescence light at each point is collected so that a whole image can be mapped out. In our case, we use an expanded laser beam to stimulate the X-ray irradiated area on the sample, and then directly collect the image through a CCD camera and a objective lens. Note that Agfa material was not measured under optimum condition (point by point laser scanning) and was used only for comparison.

Reference data on Agfa MD30 storage phosphor screens show that it has spatial resolution of 2.5 lp/mm at square wave response (SWR) = 0.2 [3]. In other words, the resolution of the 2% Eu^{2+}-doped ZBLAN glass ceramic plate could be one order of magnitude better than that of an Agfa MD30 storage phosphor screen. Our study thus demonstrates that it is possible to use our novel storage phosphors for high resolution digital radiography. In addition, the use of a "grainless" glass based plate potentially enables instantaneous readout of the image rather than the slower point-by-point technique required for polycrystalline materials.

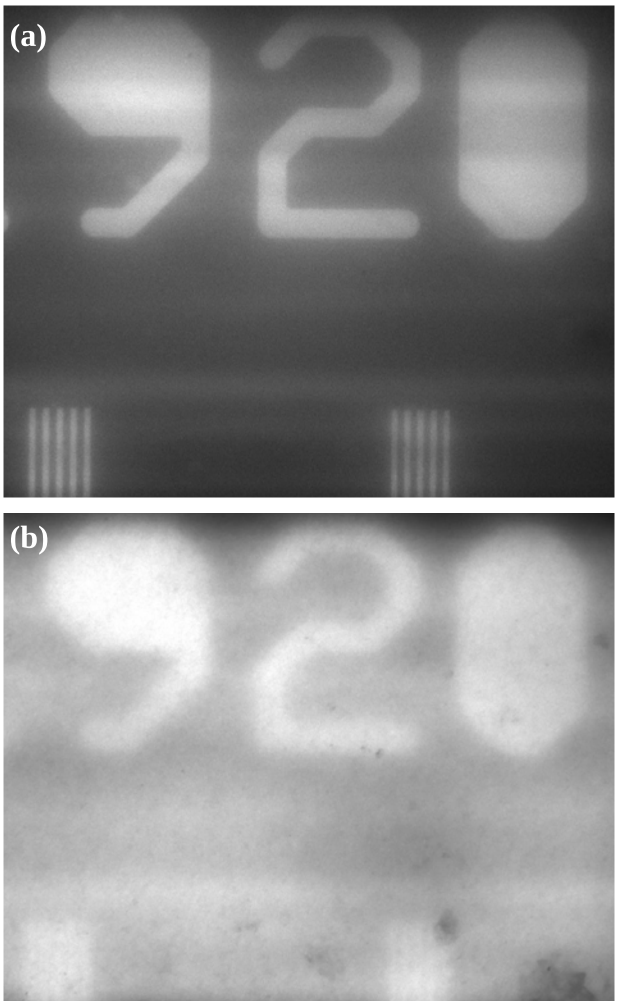

Figure 4: (a) Photostimulated luminescence (PSL) image of a Huettner phantom recorded on a 2% Eu^{2+}-doped ZBLAN glass ceramic plate (1 mm in thickness). The image resolution is estimated to be 28 line pairs/mm at MTF = 0.2. (b) PSL image of the same Huettner phantom recorded on a commercial storage phosphor screen (Agfa MD30).

Conclusion

In conclusion, we have partially optimized a ZBLAN-based glass ceramic suitable for high-resolution digital radiography for medical purposes. The X-ray imaging study shows that a 2% Eu^{2+}-doped ZBLAN storage phosphor has an image resolution of 28 lp/mm at MTF = 0.2, which is one order higher than that of a commercially used storage phosphor screen.

Work is continuing to optimize the properties of the materails, to scale the plates, and to achieve the large light output required to minimize patient X-ray dose.

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References

[1]. W. R. Hendee and E. R. Ritenour, *Medical Imaging Physics*, p. 231, Willey-Liss, New York, 2002.

[2]. M. Sonoda, M. Takano, J. Miyahara, and H. Kato, "Computed radiography utilizing scanning laser stimulated luminescence", Radiology **148**, pp. 833-838, 1983.

[3]. See www.agfa.com for the details of MD30 storage phosphor.