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Photostimulated Luminescence and Imaging Properties in $SrCl_2:Eu^{2+},Na^+$ Imaging Plate

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Photostimulated luminescence (PSL) properties of imaging plates, made with $SrCl_2:Eu^{2+},Na^+$ photostimulable phosphor, have been tested for digital radiography. The PSL spectrum of the imaging plate showed a broad band peaking at 407 nm with a half-width of 16.6 nm. The imaging plate exhibited linear dependence on dose in the range of 0.25 ~ 200 mGy. The PSL intensity of the imaging plate faded by approximately 40 % after 120 minutes at room temperature. The spatial resolution of the imaging plate was about 2.1 lp/mm. We obtained clear X-ray radiograph of an annual ring of pine tree from our imaging plate.

KEYWORDS: strontium chloride, photostimulable phosphor, imaging plate

I. Introduction

Photostimulable phosphor, which can temporarily store a X-ray image, is used in imaging plates to acquire images in a digital format and to produce images that may be electronically displayed on a screen or printed. Imaging plates have some advantages over conventional X-ray films, in terms of higher sensitivity, wider dynamical range, the direct digitization of the image during the photostimulated readout and reusability[1)].

Various photostimulable phosphor materials for imaging plates have different PSL properties, such as PSL intensity, fading characteristics, excitation and PSL emission spectra, light scattering, and PSL sensitivity relative to various kinds of radiation. Therefore a single phosphor material cannot be used ideally for all applications. Therefore various kinds of new photostimulable phosphors for radiographic imaging have been reported[2-4)].

The photoluminescence (PL) properties of $SrCl_2:Eu^{2+}$ were reported by Kobayasi et al.[5)], and Caldino et al.[6)], and the formation of defect centers in $SrCl_2$ doped with alkali metal ions was studied by Rzepka et al[7)].

We reported the PSL properties of $SrCl^2:Eu^{2+}$ and the influence of alkali-metal-ion doping on the photoluminescence (PL) and PSL of $SrCl_2:Eu^{2+},Na^+$ [8)]. In order to characterize the optical storage properties of this material, we also investigated thermoluminescence (TL), PL and PSL of $SrCl_2:Eu^{2+},Na^+$.[9)]

In this paper, imaging plates were fabricated with $SrCl_2:Eu^{2+},Na^+$ photostimulable phosphor. The PSL spectrum, fading characteristics, and dose dependence of the fabricated imaging plates were examined. In addition, the spatial resolution and the contrast of the imaging plate were measured to evaluate its radiographic quality.

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II. Experimental methods

$SrCl_2:Eu^{2+},Na^+$ phosphor powders were prepared by firing intimate mixtures of the starting material $SrCl_2 \cdot 6H_2O$, EuF_3 and NaF at temperature 850 °C for 45 minutes in a reducing atmosphere. The optimum concentrations of EuF_3 and NaF were 0.5 and 0.1 mol%, respectively[8)].

In the fabrication of $SrCl_2:Eu^{2+},Na^+$ imaging plate, $SrCl_2:Eu^{2+},Na^+$ powder and polytetrafluoroethylene (PTFE) was mixed in a ratio of 8 to 2. The mixture was coated onto a 200-μm-thick transparent sheet of polyethylene terephthalate. The plate coated with the mixture was covered by a sturdy transparent film to protect the photostimuable layer from damage during handling, and then pressed at 400 kg/cm^2. The thickness of the photostimulable layer was about 600 μm, and the imaging plates fabricated were about 10×10 cm^2 in size.

The structure of the $SrCl_2:Eu^{2+},Na^+$ was checked via X-ray powder analysis. The $SrCl_2$ lattices have a cubic structure with space group $F_{m\bar{3}m}$ is isotopic with CaF_2[10)].

The PSL intensity of $SrCl_2:Eu^{2+},Na^+$ was about 1.8 times stronger then that of $SrCl_2:Eu^{2+}$, and the PSL emission spectra of $SrCl_2:Eu^{2+},Na^+$ was identical to that of $SrCl_2:Eu^{2+}$. The increase in PSL by doping monovalent Na^+ ions is due to the creation of equivalent number of anionic vacancies in order to maintain the charge neutrality in the $SrCl_2:Eu^{2+},Na^+$, and this result in an increase of F-centers.

The third harmonic (355 nm) of a pulsed Nd:YAG (yttrium aluminum garnet) laser was used for the excitation of the PSL. The light source for stimulation was used a 10-mW He-Ne laser (632.8 nm), and the PSL of the samples was detected with a Hamamatsu R928 photomultiplier tube placed at the exit slit of a 25-cm monochromater. The X-ray generation system used in these experiments was a model DXG-325R produced by DongA Co. The X-ray radiographs were obtained using the reading system BAS-1000 produced by Fuji Photofilm Co.

III. Results and Discussion

1. PSL spectrum

Figure 1 shows the PSL spectrum of the $SrCl_2$:Eu^{2+},Na^+ imaging plate. The PSL emission spectrum of the imaging plate is located in the range of 380～440 nm, peaking at 407 nm. The PSL in $SrCl_2$:Eu^{2+},Na^+ is due to the $4f^65d \rightarrow 4f^7$ transition of Eu^{2+}.

The peak of this PSL emission spectrum well matches the peak spectral sensitivity of the photomultiplier tube. Futhermore, the image reading light source, such as a He-Ne laser and a red semiconductor laser, can easily be separated from the PSL. This imaging plate can also be used in commercial Computed Radiography (CR) system without any modifications.

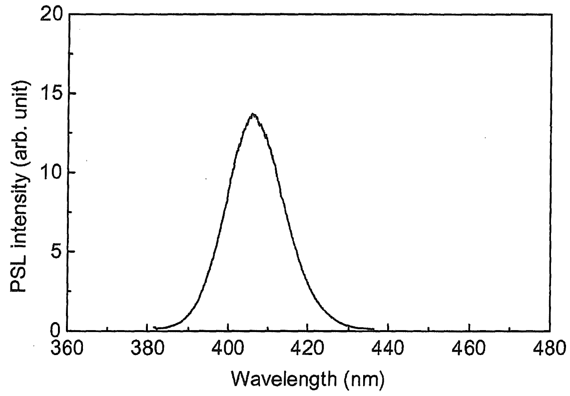


Fig. 1 PSL emission spectrum of $SrCl_2$:Eu^{2+},Na^+ imaging plate.

2. Fading of the PSL signal

Figure 2 shows the effect of storage temperature of the irradiated imaging plate on the PSL intensity. The vertical axis is the ratio between the PSL intensity of the imaging plate measured immediately after irradiation and measured after storing for various periods. The imaging plates were stored at 30, 40 and 50 °C in a dark place for different periods. As shown in **Figure 2**, when the imaging plate was stored at 30 °C for about 120 minutes, the PSL intensity was reduced to about 60 % of the initial value. The imaging plates were exposed to x-rays (80 kVp, 200 mA) for 0.1 s.

3. Relationship between the dose and PSL intensity

The linearity of the PSL intensity of the imaging plate to radiation dose is one of the important properties for a X-ray radiography. **Figure 3** shows the relationship between the dose and the PSL intensity of the imaging plate. The x-irradiation was performed at 80 kVp. As shown in **Figure 3**, the linearity of the PSL intensity holds over a wide range from about 0.25 to 200 mGy. Its linearity allows accurate quantification of the radiation dose.

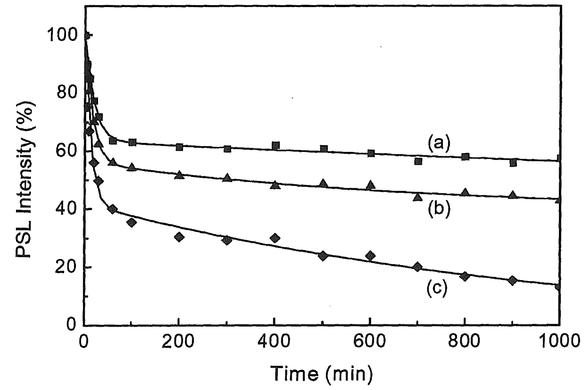


Fig. 2 Fading curves of the $SrCl_2$:Eu^{2+},Na^+ imaging plate at **(a)** 30 °C, **(b)** 40 °C and **(c)** 50 °C after X-ray irradiation. The ordinate is normalized at the time of zero.

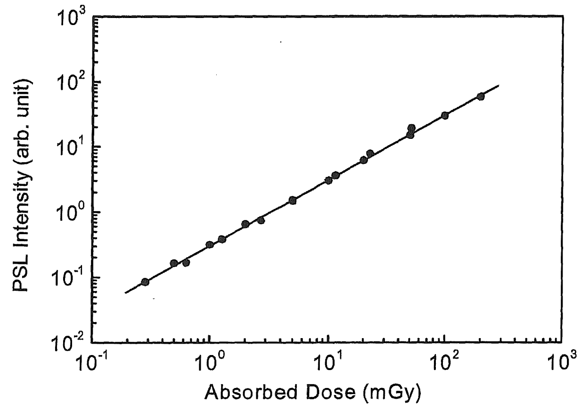


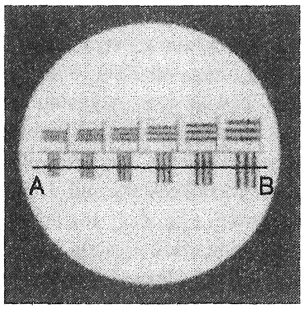
Fig. 3 Dose dependence of PSL intensity of $SrCl_2$:Eu^{2+},Na^+ imaging plate irradiated with X-rays.

4. Radiographic quality

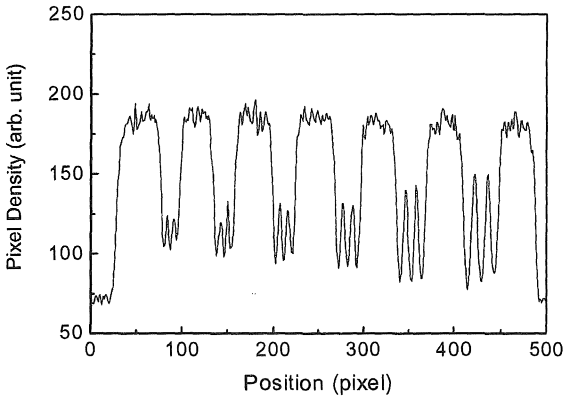
In order to determine the spatial resolution of the fabricated imaging plate, modulation transfer function (MTF) of the imaging plate was measured. The MTF was obtained using the spatial resolution test slit. The test slit used in these experiments was a model Nr 45663 produced by Nuclear Associate Co.

Figure 4 (a) shows the X-ray radiograph of the spatial resolution test slit obtained from $SrCl_2$:Eu^{2+},Na^+ plate. The spatial frequency of this test slit is from 1.0 to 2.0 lp/mm. Exposure setting were 42 kVp, 3 mAs. **Figure 4 (b)** shows the line profile of the pixel density along the line A-B in **Figure 4 (a)**.

Figure 5 shows the MTF of the imaging plate obtained from **Figure 4 (b)**. The maximum spatial resolution is determined by the spatial frequency at MTF equal to 0.1. As shown in **Figure 5**, the spatial resolution of the $SrCl_2$:Eu^{2+},Na^+ imaging plate is found to be about 2.1 lp/mm.



(a)



(b)

Fig. 4 (a) X-ray radiograph of the spatial resolution test slit obtained using $SrCl_2:Eu^{2+},Na^+$ imaging plate and **(b)** line profile of the pixel density along the line A-B in **(a)**.

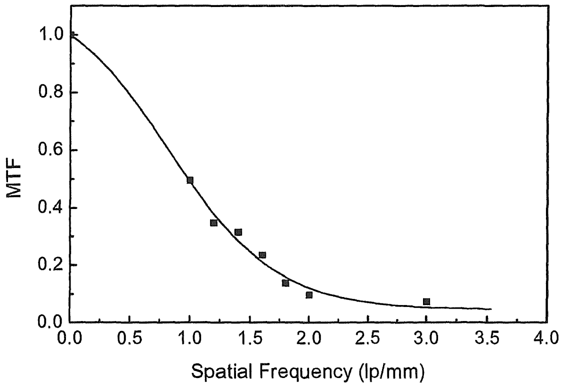
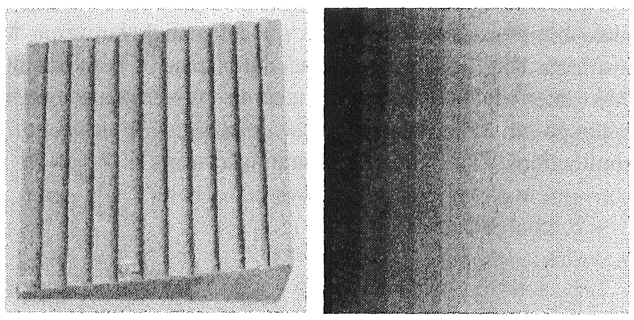


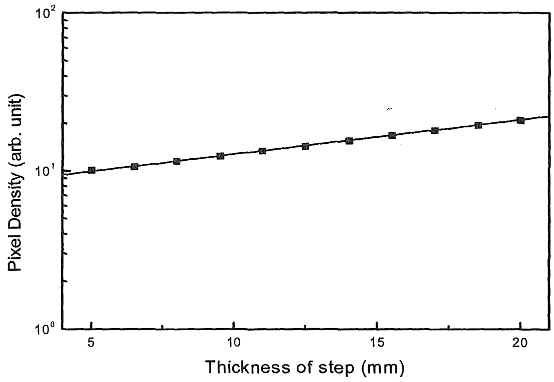
Fig. 5 MTF of $SrCl_2:Eu^{2+},Na^+$ imaging plate.

For the quantitative determination of radiographic quality of the imaging plate, the aluminum step wedge is used. **Figure 6 (a)** shows the photograph of aluminum step wedge which have 11 steps in the range of 5.0 to 20.0 mm. **Figure 6 (b)** shows the X-ray radiograph of the step wedge obtained from $SrCl_2:Eu^{2+},Na^+$ imaging plate. The X-rradiation was performed at 42 kVp, 10 mAs. We can clearly distinguish the contrast of all 11 steps of different thickness. **Figure 6 (c)** shows the relationship between log pixel density obtained from **Figure 6 (b)** and the thickness of the step wedge. The log pixel density linearly increases as aluminum thickness increases.

This result strongly suggests that our imaging plates are able to distinguish a small difference of absorption properties of objects, caused by the differences in density, atomic number, electron density and thickness of the objects.



(a) (b)



(c)

Fig. 6 (a) The aluminum step wedge and **(b)** its X-ray radiograph obtained using $SrCl_2:Eu^{2+},Na^+$ imaging plate. **(c)** The relations of the log pixel density and the step thickness of the aluminum step wedge.

Figure 7 shows X-ray radiograph of an annual ring of pine tree obtained from our imaging plate. The tree was exposed to X-rays (42 kVp, 100 mA) for 0.1 s. As shown in **Figure 7**, the X-ray radiograph of an annual ring of pine tree is clear. This result indicates that our imaging plate can be used for X-ray radiography such as X-ray diagnostics, X-ray diffraction, etc.

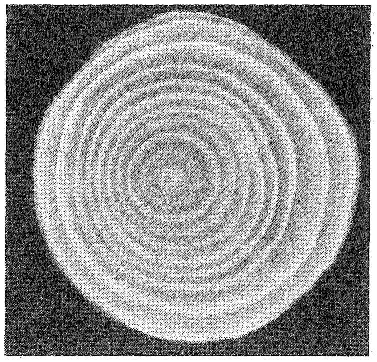


Fig. 7 X-ray Radiograph of an annual ring of pine tree. Exposure setting were 42 kVp, 10 mAs.

IV. Conclusion

It was found that the fabricated $SrCl_2:Eu^{2+},Na^+$ imaging plate exhibits a high sensitivity, a good spatial resolution, an available PSL spectrum and a good linearity between the PSL intensity and X-ray irradiation dose. These results make possible the imaging plate for use in various scientific applications. The imaging plate also can be used in a conventional Computed Radiography system.

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