A New Photostimulable Phosphor Detector for Digital Radiography

ディジタルラジオグラフィに用いられる新規な輝尽性蛍光体ディテクタ

Amitani,koji
Kano,Akiko
Tsuchino,Hisanori
Shimada,Fumio
Imaging Material Labolatories
R & D Center

Abstract:

We are developing a new digital radiography system, the "Konica Direct Digitizer (KDD)", which uses a new photostimulable phosphor, RbBr:Tl.

The phosphor has some excellent properties, particularly as follows:

1) The stimulation spectrum is suitable for the wavelength of a semiconductor laser emission.
2) The decay time of photostimulated luminescence is short.
3) The amount of light required to erase the remaining x-ray energy is small.

Such properties make it possible to miniaturize the equipment and shorten operating time.

網谷幸二
加野亜紀子
土野久憲
島田文生
技術研究所1部

1 INTRODUCTION

In the field of medical image diagnosis, digital image processing technology is becoming popular in the effort to realize greater diagnostic efficacy. It is an indispensable technology for the purpose of efficient managing and archiving of medical image information.

We are developing a new digital radiography system. We have presented the system as the "Konica Direct Digitizer (KDD)" at the 1986 RSNA[1] and 1987 PACS[2] and also presented a new type of photostimulable phosphor for the system at the 1986 SPSE[3]. This system has several advantages over other systems, and we expect it will replace a great deal of conventional screen-film radiography.

2 KONICA DIRECT DIDITIZER

The basic component of the KDD is a photostimulable phosphor detector. This detector can temporarily store a portion of irradiated x-ray energy, and then emit, upon stimulation by a semiconductor laser, a photostimulated luminescence (PSL) corresponding to the x-ray energy absorbed.

A schematic diagram of the KDD is shown in Fig.1. The photostimulable phosphor detector works as a highly sensitive, wide lattitude x-ray sensor as well as as a storage medium. When this detector is exposed to x-rays in the same way as conventional screen-film radiography, it temporarily stores the absorbed x-ray energy pattern. Then, by being scanned with a laser beam, it emits PSL whose intensity is in direct proportion to the absorbed x-ray energy. The PSL is detected by a photomultiplier tube and is converted to a time-series digital signal by an analog-to-digital converter.

The data are taken into the frame memory of a controller, then displayed as a visible image on a CRT. They are also stored on a magnetic disk to be transmitted to the host CPU. After scanning, the detector is exposed to a halogen lamp in order to erase the remaining x-ray energy. Repeating this procedure, the detector can be used again and again.

This paper concentrates on the properties of a new type of photostimulable phosphor detector used in the KDD.

3 REQUIRED PROPERTIES

Various photostimulable phosphors have been reported, for example BaFX:Eu[4] SrS:Ce,Sm, SrS:Eu,Sm[5-7], ZnS:Cu,Al[8], and Zn_2SiO_4:Mn[9] but most are not appropriate for practical use with regard to PSL intensity, PSL response, or other properties.

Among them BaFBr:Eu phosphor is the most widely known. BaFBr:Eu phosphor is efficiently stimulated with a He-Ne laser after x-ray irradiation. It is used in Computed Radiography (CR), but CR is not necessarily a satisfactory system, the major disadvantage being its large size.

This disadvantage originates chiefly from the properties of BaFBr:Eu phosphor.

Its trap level which can store part of irradiated x-ray energy is relatively deep,500-600nm, so that it is hardly stimulated by a semiconductor laser, and it is diffi-

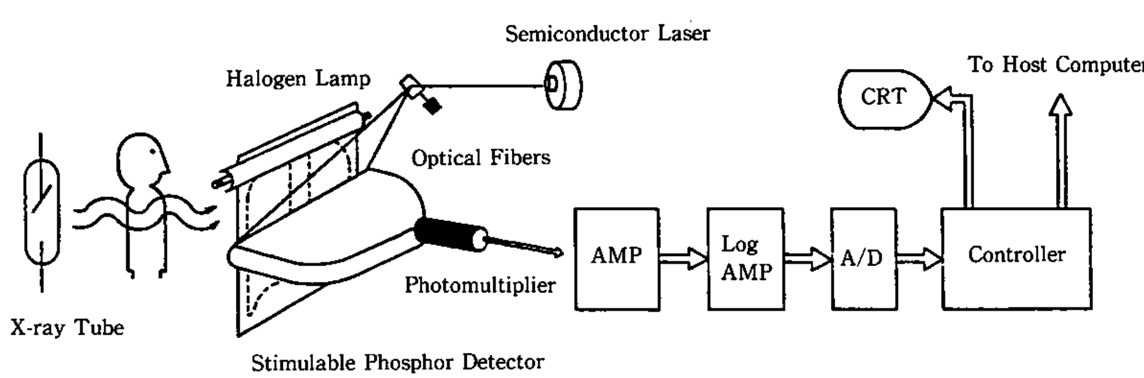

Fig.1 Schematic diagram of the Konica Direct Digitizer (KDD)

cult to erase remaining x-ray energy. As a result, a gas laser, for example a He-Ne laser, and plural erasing light sources are necessary, which is an obstacle to miniaturization of the equipment.

The problem can be solved by utilizing a semiconductor laser instead of a gas laser as a stimulating light source. Moreover, recent rapid progress in the output power and stability of semiconductor lasers has led to a shortening of their reading time and an improvement of their signal-to-noise ratio over He-Ne lasers.

It has been reported that an evaporated CsI:Na film is efficiently stimulated by a semiconductor laser after x-ray irradiation[10], but the film is impractical because it has to be kept at a low temperature (below 100K).

Our goal has been to develop a new photostimulable phosphor which can be efficiently stimulated by a semiconductor laser after x-ray irradiation. The properties required for such a photostimulable phosphor material are summarized as follows:

(1) The stimulation band after x-ray irradiation must be suitable for the wavelength of a semiconductor laser emission (780-830nm).

(2) The PSL should be in the range of 300-500nm, where photomultiplier tubes have high quantum efficiency. This would also mean there would be a wide wavelength separation between the emission band of the semiconductor laser and the PSL band so that the PSL could easily be isolated by using filters.

(3) The decay time of the PSL must be less than a few μ seconds to realize a scanning speed high enough for practical use.

(4) The x-ray absorption coefficient must be high. This generally means the phosphor is composed of atoms of high atomic number and its density is high.

(5) Fading of the PSL in the dark should be slight.

(6) The remaining x-ray energy must easily be erased by exposure to light.

After researching many photostimulable phosphors, we discovered that RbBr:Tl phosphor satisfies all the requisites listed above. We also found that strong PSL can be obtained by controlling the composition and manufacturing process of the phosphor.

4 PROPERTIES of RbBr:Tl

Fig.2 illustrates the stimulation spectra and luminescence spectra of RbBr:Tl and BaFBr:Eu. It shows first that RbBr:Tl phosphor can be efficiently stimulated by a semiconductor laser, for example one whose emission wavelength is 780nm. Secondly, the PSL spectrum of RbBr:Tl phosphor is in the range where photomultiplier tubes have high quantum efficiency. The range is far enough from the wavelength of the semiconductor laser that the PSL is easily separated from semiconductor laser emission by glass filters.

Fig.3 shows the PSL responses of RbBr:Tl and BaFBr:Eu. The PSL decay time($\tau_{1/e}$)of RbBr:Tl is about 0.3 μ seconds and is shorter than that of Ba FBr : Eu.

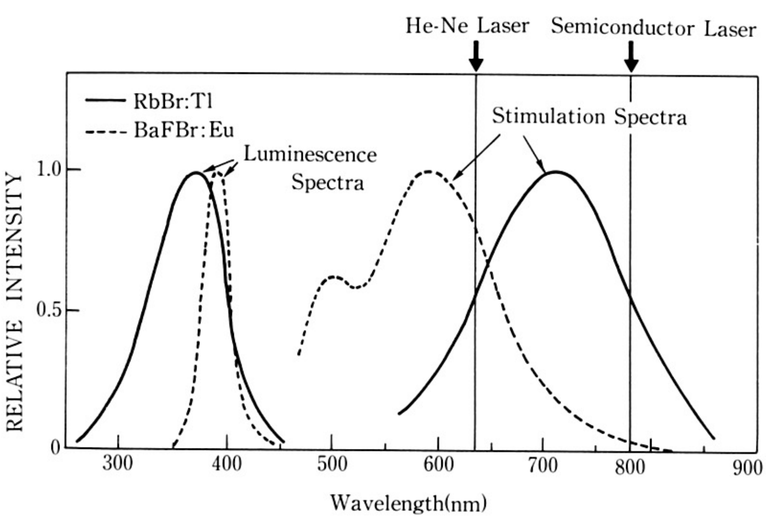

Fig.2 Photostimulated luminescence spectra and stimulation spectra of RbBr:Tl and BaFBr:Eu

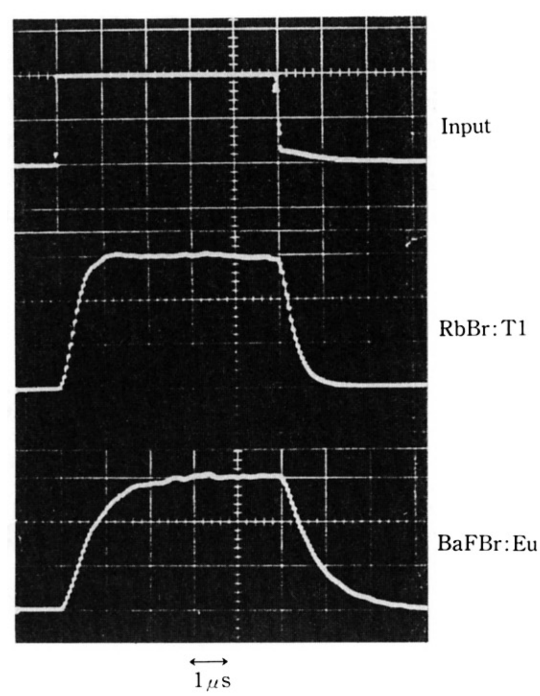

Fig.3 PSL responses of RbBr:T1 and BaFBr:Eu

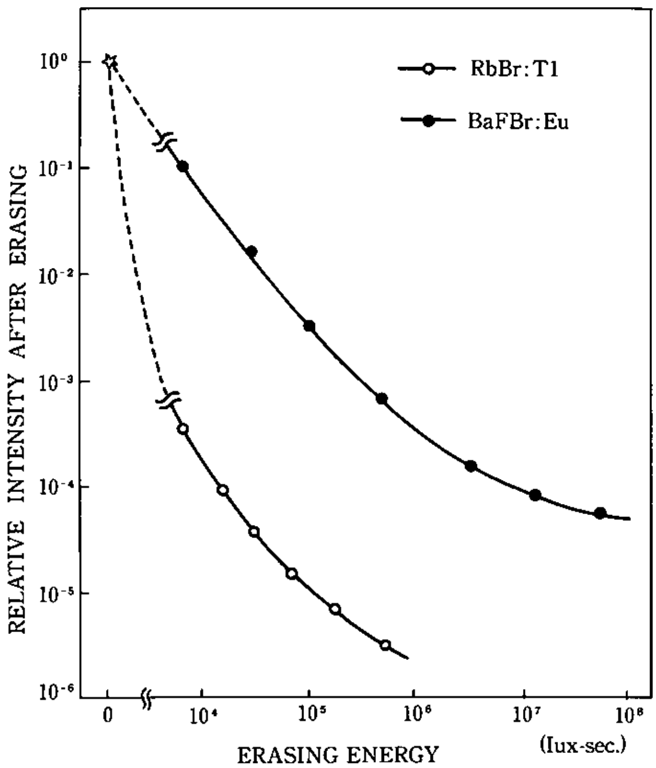

Fig.4 Erasing characteristics of RbBr:Tl and BaFBr:Eu

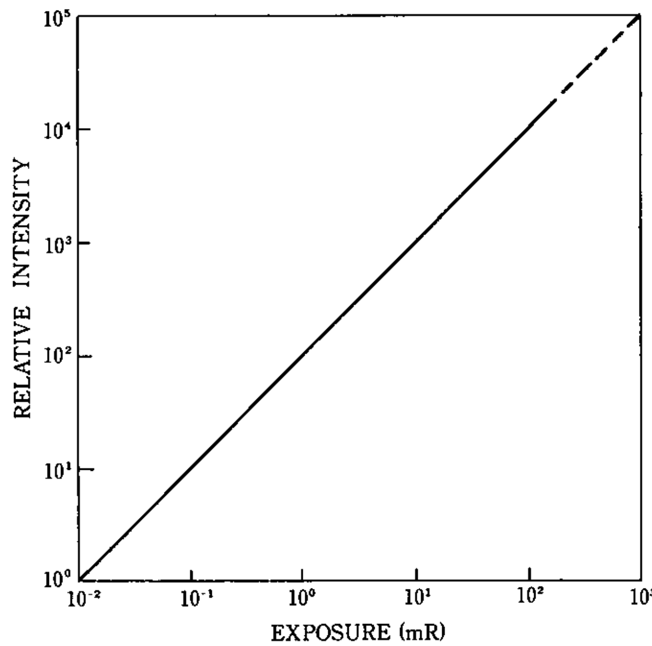

Fig.5 Dynamic range of RbBr:Tl

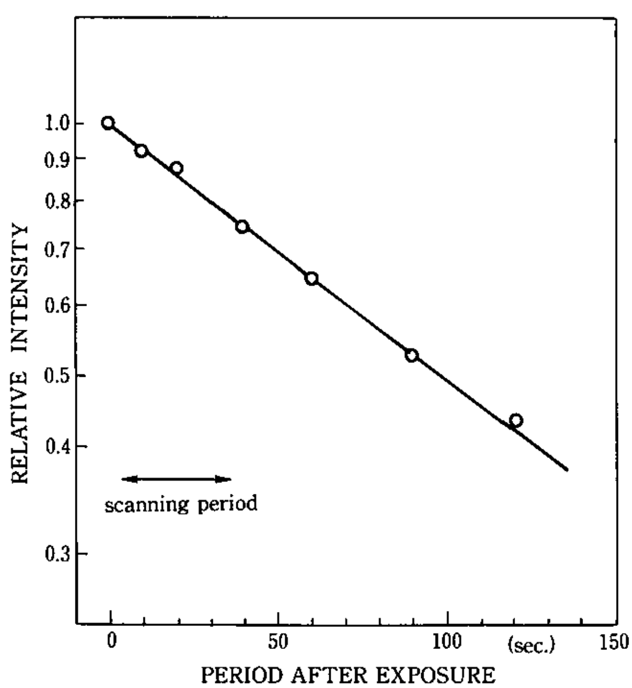

Fig.6 Fading characteristic of RbBr:Tl

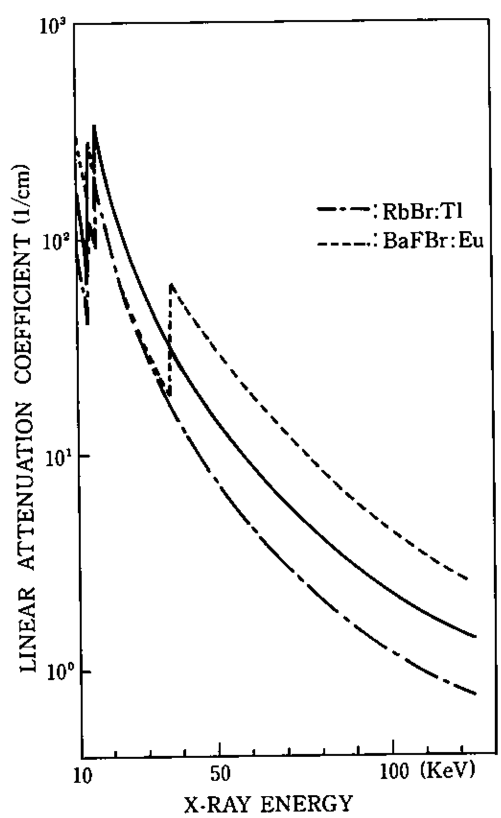

Fig.7 X-ray absorption characteristics of RbBr:Tl and BaFBr:Eu (powder-coated with binder)

We found by simulation for RbBr:Tl phosphor that the scanning speed can be increased to up to 150m/sec without degrading the modulation transfer function, which means the scanning period of 2000×2000 pixels can be shortened up to about 10 seconds. The scanning period of our present system is about 30 seconds because of other factors such as its electronic circuitry.

The erasing characteristics of remaining x-ray energy are shown in Fig.4. The light source is a halogen lamp. The amount of light required to erase the remaining x-ray energy of RbBr:Tl is very small compared to that needed for BaFBr:Eu, which makes it possible to shorten the erasing period and to miniaturize the equipment.

The dynamic range is extremely wide, as shown in Fig.5. Since the PSL intensity increases in proportion to the exposed x-ray energy, image processing is very simple.

Fig.6 shows the fading characteristic of RbBr:Tl. The fading of PSL in the dark is slight within the scanning period of about 30 seconds. Even if, under unsuitable conditions, fading is significant, the fading effect can be easily corrected because the intensity decreases exponentially, as the figure shows.

Fig.7 shows the x-ray absorption characteristics of RbBr:Tl and BaFBr:Eu. The intrinsic disadvantage of RbBr:Tl is that the x-ray attenuation coefficient is lower than that of other phosphor materials for screens. There are, however, ways in which this disadvantage can be overcome.

It is easy to produce a RbBr:Tl phosphor film by evaporation, so that the x-ray absorption would be improved to the level of the solid line because its packing density would be about twice as high as that of powder-coated film. Moreover, we expect that an evaporated RbBr:Tl film could be thicker than a powder-coated film without degrading the spatial resolution because the evaporated film is made up of crystal pillar shaped block structures where the scattering of a laser beam would be suppressed (see cover illustration). Therefore the x-ray absorption of a RbBr:Tl detector would be expected to be almost as high as that of a powder-coated BaFBr:Eu plate.

To summarize the properties of RbBr:Tl phosphor:

(1) The stimulation spectrum is suitable for semiconductor laser stimulation.

(2) The PSL spectrum is in the range where photomultiplier tubes have high quantum efficiency.

(3) The PSL decay time is short enough for practical use.

(4) Erasing remaining x-ray energy is very easy.

(5) PSL intensity increases linearly with absorbed x-ray energy, and its dynamic range is very wide.

(6) Fading is slight within an acceptable scanning period.

(7) X-ray absorption is relatively low, but it is improved by evaporation.

5 MECHANISM of PSL

Experimental results have provided some information for discussing the PSL mechanism of RbBr:Tl. RbBr:Tl phosphor is slightly colored after being heavily x-ray irradiated. Fig.8 shows the reflectivity of x-ray irradiated RbBr:Tl, where reflectivity is normalized to 100% for non-irradiated RbBr:Tl. It is thought the reduction of reflectivity results from the absorption of F-centers[11].

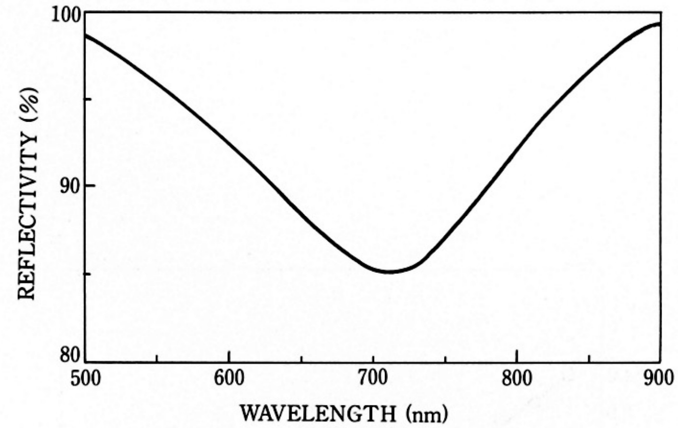

Fig.8 Reflection spectrum of x-ray irradiated RbBr:Tl

The reflection spectrum or absorption spectrum of F-centers corresponds to the stimulation spectrum. We suspect that F-centers are PSL centers. In fact, the color of RbBr:Tl fades away quickly upon exposure to visible light, while the intensity of the PSL decreases to the same degree.

The results shown above suggest that x-ray irradiation induces free electrons which are immediately trapped in F^+-centers, and creates F-centers. By light stimulation, trapped electrons are again liberated and recombine with holes, part of the recombination energy is transfered to Tl, and thus the luminescence of excited

Tl is produced (Fig.9).

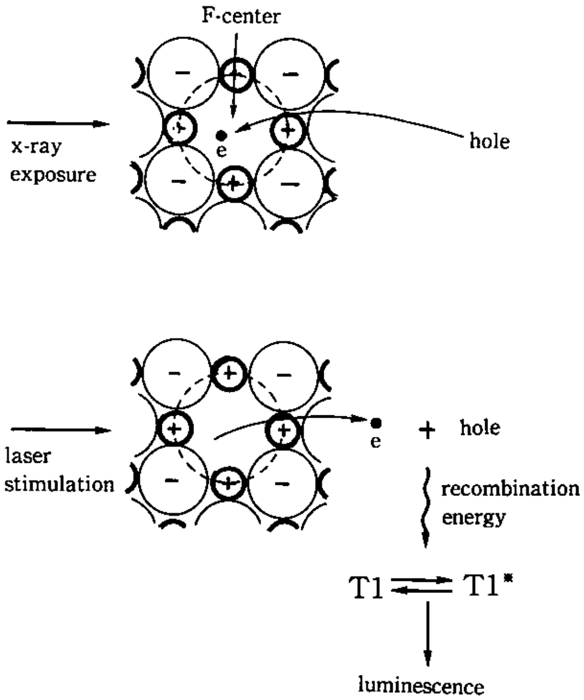

Fig.9 PSL mechanism of RbBr:Tl

6 CONCLUSION

We are developing a new type of photostimulable phosphor, RbBr:Tl, whose stimulation spectrum after x-ray irradiation is suitable for semiconductor laser excitation.

The material has some excellent properties, particularly a short PSL decay time and easy erasure of remaining x-ray energy.

We believe the new photostimulable phosphor, RbBr:Tl, is a highly promising material which will greatly improve digital radiography.

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