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Photostimulated luminescence properties of neutron image plates

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ABSTRACT

The luminescence properties of two commercial neutron-sensitive image-plates based on Gd_2O_3-doped BaFBr:Eu^{2+} storage phosphors are examined. These are white Fuji plates and blue Fuji plates (BAS-ND) with Gd_2O_3 content by weight of 34% and 50%, respectively. Both plates show two maxima in the photostimulation spectrum near 500 nm and 600 nm, with the ratio of the peak responses ($I_{600\ nm}/I_{500\ nm}$) 1.39 and 0.53 for the white and blue plates respectively. The optimum wavelengths for photostimulation for the two phosphors are therefore different. The response of the blue plate is only 25% that of the white plate, if each is stimulated at its optimum wavelength.

1. Introduction

A great deal of research has been performed during the last two decades on photostimulated luminescence and photostimulable storage phosphors [1–15]. Such materials can find attractive application in many different fields of radiation imaging.

When a storage phosphor (e.g. BaFBr:Eu) is mixed with a neutron converter (e.g. Gd_2O_3 or LiF), it becomes sensitive to thermal neutrons [16–20]. Neutron-sensitive image plates (NIP's), made of such storage phosphors, have great potential as two-dimensional integrating thermal-neutron detectors [16–20]. Before 2007, there were two neutron image-plate diffractometers at the Institute Laue-Langevin (ILL): LADI (Laue diffractometer) [18], located on a cold-neutron beam, and VIVALDI (Very Intense Vertical Axis Laue Diffractometer) [21], located on a thermal-neutron beam, both of which have been proven to give quantitative structural information in various biological, chemical and magnetic studies [18,21,22]. In 2007 LADI has been replaced by LADI-III image plate diffractometer [22].

On LADI, four Gd_2O_3-doped BaF(Br,I):Eu^{2+} Fuji image plates of dimensions 400 mm × 200 mm are bonded onto the outer surface of the cylindrical detector drum. These plates have a Gd_2O_3 content of 34% by weight, a detective quantum efficiency of ~20% and a point-spread function of ~100 μm [23]. Their active surface is white, so we will hereinafter refer to them as White NIP's.

On VIVALDI, commercial NIP's (Fuji BAS-ND), also dimensions 400 mm × 200 mm in area, were installed and used during the first 2.5 years of operation (2001–2004). Their active surface is blue, so we will hereinafter refer to them as Blue NIP's. Some properties of the commercial Blue NIP's have been reported by [24]. In these plates the BaFBr:Eu^{2+} phosphor/Gd_2O_3 converter ratio is 50/50 by weight. The thickness of the phosphor layer is 135 μm, and is covered by a 6 μm thick polyethylene-terephthalate (PET) protective layer. The support is a (black) 190 μm thick PET film. A ferrite layer is also attached to the rear of the IP for ease of mounting and manipulation in cameras and readers by using the magnetic properties of ferrite. The structure of the Blue NIP is shown in Fig. 1. The blue-colored[1] IP's were developed for transmission electron microscopy with the aim to improve the spatial resolution, and subsequently applied to synchrotron protein crystallography [25,26]; it has been reported that blue X-ray IP's provide a twice better spatial resolution than that provided by conventional white X-ray IP's, possibly via suppression of laser light scattering within the IP without loss of sensitivity [26]. While the improved resolution can be very advantageous for X-ray crystallography and radiography with either X-rays or neutrons, it is less so for neutron crystallography where the reflection size is dominated by the crystal size, which is rarely less than 0.1 mm.

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[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

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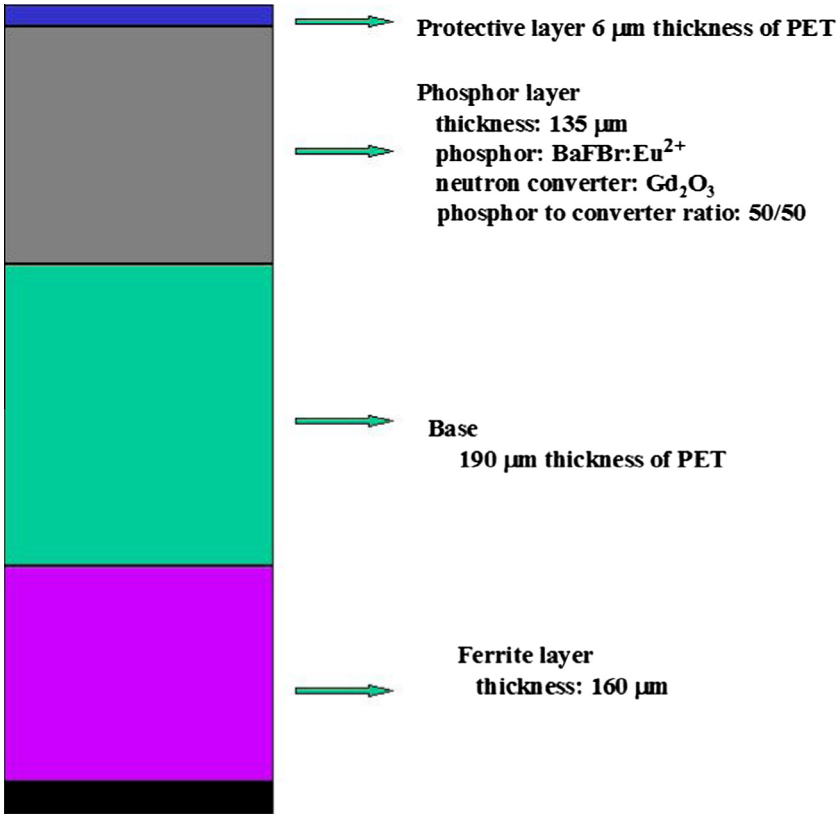

Fig. 1. Structure of the Fuji BAS-ND image plate.

The aim of this work was to evaluate the luminescence characteristics of Blue and White NIP's, and thus to find for them the optimal conditions for both stimulation and detection of photostimulated luminescence (abbreviated to PSL stimulation and PSL detection).

2. Experimental

X-ray irradiation was performed by a medical X-ray tube with a tungsten anode (Polymobil, Siemens AG) utilizing an acceleration voltage of 90 kV, a 1.4 mm Al filter and a beam current of 16 mA. PSL-stimulation spectra were measured on samples exposed to an X-ray dose of 370 mGy. For PSL excitation of storage centers, light from a 75 W Xenon lamp (Hamamatsu L2174) was dispersed through a monochromator (Jobin-Yvon model DH10UV), chopped and focussed onto the sample. The PSL was collected by means of a photomultiplier (Hamamatsu Model R4220), and the signal was recorded by a lock-in amplifier. The intensity of excitation light was calibrated by means of a Si photodiode. A combination of blue glass filters (Schott) between the sample and the photomultiplier was used to separate the excitation light from the emitted light. X-ray excited luminescence spectra were detected by an optical multichannel analyzer (Spectroscopy Instruments). Photoluminescence excitation and emission spectra have been measured utilizing a Cary Eclipse Spectrometer (Varian).

3. Results and discussion

Upon X-ray irradiation electron–hole pairs are generated in a storage phosphor. These then recombine either by emission of spontaneous luminescence, or by generation of a latent image which consists of pairs of electron/hole color centers. As shown in Fig. 2, the spontaneous luminescence emission consists of a single band at 3.10 eV (400 nm) with a half-width of 0.25 eV, which corresponds to the $4f^6 5d^1 \rightarrow 4f^7(^8S_{7/2})$ transition of Eu^{2+} ions, which substitute for Ba ions [1]. Subsequent optical excitation of the color centers leads to the release of trapped electrons and their further recombination with trapped holes giving luminescence. The resulting stimulation spectra give unique information on the electron centers responsible for PSL in a particular storage phosphor. It is generally accepted that the stimulation spectrum is determined by the optical absorption spectrum of the *F*-type centers in BaFX (X = Cl, Br, I) storage phosphors [1,2,4,5,8,10], by both *F*-type centers and/or impurities with trapped electrons in alkali

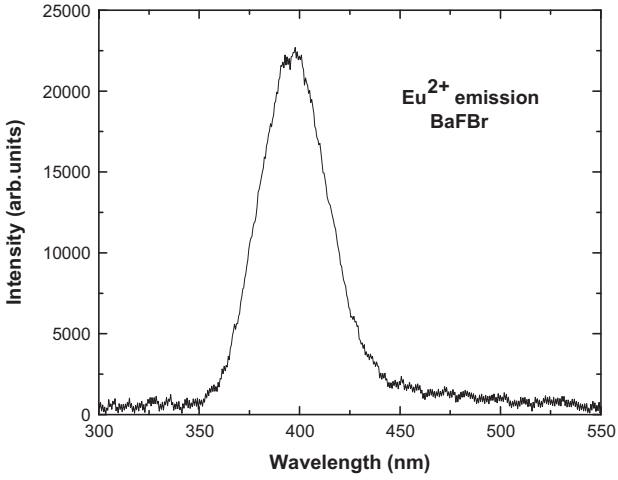

Fig. 2. Spontaneous luminescence spectrum of the White NIP under X-ray excitation.