APPLICATIONS OF IMAGE PLATES IN VARIOUS NDE TECHNIQUES AT BARC

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ABSTRACT

Image plates based on photo stimulated luminescent phosphor are widely used in various fields like medicine, biology and physics for detection of neutrons, X-rays, α- and γ and other ionizing radiations distributed over large areas. The imaging plates have been found to be an excellent neutron and X-ray detector that has high spatial resolution (less than 200 µm), a wide dynamic range (more than 1:10^5) and high efficiency with no limitation on the size of the detection area. At BARC, X-ray and neutron image plates have been used for neutron radiography, hydrogen sensitive epithermal neutron radiography, neutron induced beta radiography, neutron diffraction, X-ray diffraction, small angle X-ray scattering etc. Efforts are being put to use neutron image plate as an alternative to 3He-filled neutron detectors for neutron spectrometers. The use of image plates for various NDE applications and the results obtained are described in this paper.

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INTRODUCTION

Imaging plate (IP) technology enables a direct means of recording the distribution of intensity of radiation and has replaced conventional film in routine X-ray crystallography, radiography and studies involving the use of synchrotron radiation sources [1]. The advantages of this technology include high spatial resolution, high sensitivity and a linear response to radiation dose over five orders of magnitude. Commercially available IP systems have a read-out spatial resolution ranging from 25 to 200 µm and the plates are available in sizes up to 100 x 240 mm to 350 mm x 1520 for X-rays and 200 mm x 250 mm to 200 mm x 400mm for neutrons. The success of IPs as large-area X-ray and charged-particle detectors has prompted a global effort to use the plates for neutron detection.

IP typically consists of a flexible plastic sheet coated with a thin (~100 µm) photostimulable phosphor, BaFBr doped with Eu^{2+} ions. When Eu^{2+} ions are struck by ionizing radiation, they lose an additional electron to become Eu^{3+} ions. These electrons enter the conduction band of the crystal and become trapped in the bromine ion vacancies of the crystal. This metastable state is higher in energy than the original condition, so a lower-frequency light source such as He-Ne laser that is insufficient in energy to create more Eu^{3+} ions can return the trapped electrons to the conduction band. As these mobilized electrons combine Eu^{3+} ions, they release a blue-violet 400 nm luminescence termed as photo stimulated luminescence (PSL) [2]. This light is produced in proportion to the number of trapped electrons, and thus in proportional to the original X-ray signal. It can be collected by a photomultiplier tube, enabling the resulting signal to be converted into a digital image. For the detection of neutrons, image plates are made up of a thin phosphor layer consisting of a mixture of storage phosphor BaFBr:Eu^{3+}, neutron converter mostly Gd_{2}O_{3} and organic binder that is coated on a polymer film. On exposure the neutrons are absorbed by the neutron converter and converted into ionizing secondary radiation. These radiations are detected as described above. The imaging plate is thus, a two-dimensional, integration-type detector of X-ray, neutron and electron beams. The image remaining after the reading can be completely erased by exposing to visible light so that the imaging plate can be repeatedly used. The sensitivity of an image plate is usually higher than that of photographic film, and it requires exposure times of a few seconds only. We used image plates FUJIFILM BAS-ND2025 and --SR2025 for detection of neutrons and X-rays and electrons respectively in conjunction with an off-line scanner, FUJIFILM BAS5000. The image plate can be read with resolution up to 25 µm and data can be stored in 8 or 16 bits gradation.

APPLICATIONS OF IMAGE PLATES AT BARC

Neutron Radiography

At BARC, neutron radiography was actively pursued by Solid State Physics Division for various R&D applications and NDE using the 400 kW Apsara and 40 MW CIRUS reactors as the
The facilities were extensively used for recording neutron radiographs of experimental fuel elements, water contamination in marker shell loaded with phosphorous, electric detonators, satellite cable cutters and pyrovalves, boron-aluminium composites, hydride blisters in irradiated zircaloy pressure tubes, variety of hydrogenous and non-hydrogenous materials. A neutron radiograph of INSAT cable cutter and a copper U-tube filled with wax recorded using Apsara reactor and the neutron image plate is shown in figure 1. The image quality of the radiographs recorded with neutron image plate is nearly same compared to that of Gd/X-ray film technique but the speed of recording the radiograph is 40 to 50 times faster with neutron image plate. The PSL intensity linearly increases with increase in exposure time and the range is much higher than for X-ray film. The image brightness and contrast can be controlled with the software provided to take care of under/over exposure of the image plate. Thus radiography with image plates is a fast and convenient process.

Neutron Radiography

The neutron induced beta radiography (NIBR) is a very useful technique for non-destructive evaluation of internal structures of thin samples with thickness up to few hundreds of µm. It has many industrial applications to test thickness, uniformity and defects in the manufacture of paper, metal and plastic films. It can be performed at any standard neutron radiography facility with available infrastructure. NIBR makes use of thermal neutron activated Dy or In foils as source of beta with energies 1.28 MeV and 1.0 MeV respectively [5,6]. The technique is similar to the transfer technique used in neutron radiography. Radiographs are obtained with an alumina and tin containing image plate (IP), a sample under inspection and the neutron irradiated Dy or In foil kept in tight contact with each other. The irradiation of the foil was performed at the CIRUS E-18 beam hole NR facility. An exposure of ~ 9 minutes for the Dy foil and ~ 5 minutes for In foil was enough to get the required activity in the foil for the radiography experiment. The radiographs were recorded for an exposure time of 1 to 1.5 minutes with a delay of ~15 minutes after neutron irradiation of the foil. To demonstrate some possible applications of the technique, variety of samples like Indian currency bill of ‘1000, postal stamps of Indian paintings and personalities, painting on cotton sheet are radiographed.

![Fig. 1](image1.png)

![Fig. 2](image2.png)

![Fig. 3](image3.png)
Hydrogen Sensitive Epithermal Neutron radiography

The technique, Hydrogen Sensitive Epithermal Neutron (HYSEN) radiography was first developed [7] for imaging small amounts of hydrogenous materials encapsulated within high thermal neutron absorbers and found to be useful in study of hydride-induced embrittlement of metals. The HYSEN imaging system [8] consists of a converter screen (In) and a neutron beam filter (In + Cd) with the object placed between the screen and filter. For neutrons, In has a resonance peak at 1.49 eV. Combination of Cd foil with In foil almost completely cuts off neutrons with energy lower than 1.49 eV. Incident neutrons with energy higher than 1.49 eV, which pass through, are scattered elastically by hydrogen atoms present in the object. The neutrons that are slowed down to the vicinity of 1.49 eV by this scattering are absorbed by the second In foil placed behind the sample. The image induced by the scattered neutrons, represents signature of hydrogen present in the sample and the grey intensity its concentration. Hydrogen concentrations as low as 50 ppm (0.020 mg H/cm\(^2\)) in 0.62 mm zircaloy coupons have been reported[7]. The detection limit of standard NR techniques is about 0.66 mg H/cm\(^2\).

Neutron radiograph of 1-, 2-, 3-, 4- layers of cellophane adhesive tape as hydrogenous object was recorded. The gradation of hydrogen concentration in successive layers of adhesive tapes was clearly seen in the radiograph (Fig.6.7).

Neutron Diffraction

In neutron scattering experiments \(^3\)He gas filled position sensitive detectors are used for recording angular distribution of scattered neutrons from the sample. Recent international crisis on availability of \(^3\)He gas and its escalating cost has become a matter of concern to the neutron scattering community. In order to overcome this concern alternative technologies are being tried. We have attempted to utilize the neutron image plate for recording powder diffraction pattern on High-Q neutron spectrometer at Dhruva reactor, BARC [9]. The diffraction pattern from a polycrystalline Fe rod, mounted on the high Q diffractometer at Dhruva reactor was recorded on a FUJIFILM neutron image plate BAS ND2025 using neutron beam of \(\lambda = 0.783\ \text{Å}\) and \(\Phi = 3 \times 10^7 \text{n/cm}^2\text{/sec}\).

The image plate enclosed in an aluminium cassette was mounted at a distance of 280 mm from the sample covering \(10^\circ\) - \(70^\circ\) of the 2\(\theta\) range. The image plates were scanned and the image of the diffraction pattern and digitized diffraction profile of the sample were obtained. The PSL intensity versus mm data set was corrected for the base line background intensity and then converted to PSL versus 2\(\theta\) using the
The diffraction pattern of the sample collected simultaneously with $^3$He filled position sensitive detectors placed behind the image plate. The diffraction pattern is shown in figure 7(a). The diffracted beam profile was found to be sharp at the central region of the image plate while it broadens towards the edges of the plate. Only central region portion shown in figure 7(b) was taken for digitizing and further analysis. The diffraction profile obtained thus is shown in figure 2. The peak widths $\Delta 2\theta$ were calculated by fitting the individual peaks to Gaussian distribution. Figure 3 shows the plot of $\Delta 2\theta/2\theta$ versus $2\theta$. The present spectrometer is a medium resolution spectrometer and the individual reflection broadening in peak width is due to various contributions such as detector position resolution, size of the collimated beam, beam divergence, sample size, sample to detector distance, and mosaic spread of the monochromator crystal. Therefore, position resolution of the IP cannot be directly represented by the peak width. The overall resolution is expected to be minimum at $2\theta = 2\theta_m$, where $2\theta_m$ is a monochromator angle and was found be $\sim 0.025$. Further work on improving the performance is being done by optimizing sample size, sample to detector distance, exposure time and mounting the image plates in curvilinear fashion to overcome parallax errors. The use of neutron image plate for recording small angle neutron scattering (SANS) is also being tried.

X-ray Diffraction

X-ray diffraction work on organic and inorganic materials has been routinely carried out using the BAS SR-2025 image plates, Figure 10 shows X-ray diffraction pattern of palmatic acid. Presently data is being used to check the crystallinity and initial identification of the sample.

Small Angle X-ray Scattering

Small angle X-ray scattering, or SAXS, is a nondestructive technique where the elastic scattering of X-rays (wavelength 0.1 to 0.2 nm) by a sample which has inhomogeneities in the nm-range, is recorded at very low angles (typically 0.1 - 10°). This angular range contains information about the shape and size of molecules, characteristic distances of partially ordered materials, pore sizes, and other data. In the SAXS instrument (figure 10 (a)), a point collimated monochromatic beam of X-rays is incident on a sample from which some of the X-rays scatter, while most simply go through the sample without interacting with it. The scattered X-rays form a scattering pattern which is detected using typically a 2-dimensional flat X-ray detector situated behind the sample perpendicular to the direction of the incident beam. The scattering pattern contains the information on the structure of the sample. The
transmitted beam that passes through the sample is blocked, without blocking the closely adjacent scattered radiation. The scattered intensity is small and therefore the measurement time is in the order of hours or days in case of very weak scattering samples. Figures 10(b) and (c) show SAXS Pattern from a porous carbon sample irradiated with CuK$\alpha$ radiation and that of direct beam without sample. Both the patterns were recorded using FUJIFILM image plate BAS SR-2025.

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