Nuclear Instruments and Methods in Physics Research A 359 (1995) 376–378

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NUCLEAR
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Section A

Micron spatial resolution X-ray image plates with non-erasing reading

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Abstract

New silverless radiophotoluminescence substances NaCl(Me) and LiF(Me) are proposed and tested as X-ray image detectors. Their spatial resolution is not worse than 2 μm and they allow one to register X-ray pictures with a dynamic range of about 5000. A stored X-ray image can be read out many times by photoluminescence measurements under UV excitation. The image can be erased completely by heating the substances up to a temperature of 400°C during 0.5 h.

1. Introduction

Special area detectors – imaging plates [1] – have been widely used lately. High detection efficiency (more than 80% for 8–20 keV photons), a wide dynamic range (about 10^5), high count rate capability and other excellent parameters of the imaging plates are very useful for the registration of X-ray images in X-ray diffraction studies, small angle scattering and so on. Unfortunately, the spatial resolution of the imaging plates, which is typically about 150 μm now and, in principle, may be up to several tens of microns, confines their use for the purposes of X-ray microscopy and holography.

During the past few years alkali halide crystals doped with heavy metal ions have been extensively studied as materials for image storing. These crystals have attracted the attention for optical information recording. A single memory cell in these crystals is a color or luminescence center, which has a very small size and allows one to record the information with a high spatial density. If ionization radiation creates, in the crystal lattice, a pair of centers – impurity hole center (Me^{++}) and F-center – the information can be read out measuring the recombination luminescence when the crystal is exposed to excitation radiation such as visible light. For this way of information recording, the stored data will be lost after the readout process or when the crystal is kept at room temperature in visible light.

In this work we report on new stable centers, which arise in crystals doped with ions of the IIIA group when they are exposed to X-rays. These centers can be used as single memory cells.

2. Experiment

The authors have proposed and examined, as an X-ray area detector, silverless radiophotoluminescence substances of modified LiF and NaCl [2]. A stored X-ray image is read out by measuring the photoluminescence intensity with a wavelength of ~ 530–560 nm under the excitation by ultraviolet light with a wavelength of about 365 nm. In contrast to the imaging plates, the stored image is not erased upon reading, and therefore reading out can be repeated many times. For completely erasing the image, the substances must be heated for 0.5 h at a 400°C.

When alkali halide crystals doped with ions of the IIIA group are exposed to X-rays, γ-rays, or ultraviolet radiation and then irradiated by light in the region of F-band absorption, a new band appears in their spectrum of luminescence. For example, in KCl–In crystals the maximum intensity in this band is observed at $\lambda = 524$ nm. The band of excitation of this luminescence in KCl–In has a maximum at $\lambda = 300$ nm. The intensity of this luminescence depends on the absorbed dose of X-rays. When this dose increases, the intensity of the luminescence band at $\lambda = 524$ nm increases too, but the intensity of the band at $\lambda = 424$ nm decreases. The band at $\lambda = 424$ nm is due to the luminescence of In^+ ions. The same effects can be seen in the other materials considered.

For examination of these area detectors, synchrotron radiation (SR) from the VEPP-3 storage ring of the Budker Institute of Nuclear Physics was used. For soft (1–5 keV) X-rays, the investigations were carried out at the X-ray

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SSDI 0168-9002(94)01634-8

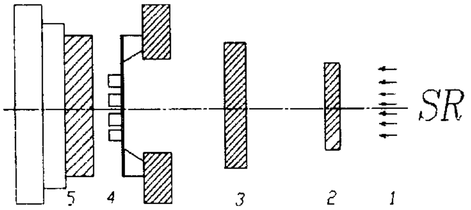

Fig. 1. The scheme for testing X-ray image registration: 1 – X-ray beam from the VEPP-3 storage ring; 2 – the 28-μm-thick beryllium filter; 3 – the 13-μm-thick kapton film; 4 – the X-ray mask (a 2-μm-thick silicon membrane with the pattern of a 0.9-μm-thick gold absorber); 5 – the radiophotoluminescence substance.

lithography station [3]. The scheme of the test image registration is shown in Fig. 1. There is the X-ray beam (1) from the VEPP-3 storage ring. A 28-μm-thick beryllium filter (2) separates the high vacuum of the storage ring from the SR beamline, and a 13-μm-thick kapton film (3) separates the beamline and the exposure chamber. An X-ray mask (4) contains the pattern of a 0.9-μm-thick gold absorber on a 2-μm-thick silicon membrane. The radiophotoluminescence substance (5) is 10 μm away from the X-ray mask.

The processes of recording the information are based on the creation of luminescence centers in the crystal lattice by ionizing radiation with the subsequent destruction of F-centers.

The scheme for reading out a stored X-ray image using luminescence registration under ultraviolet excitation is shown in Fig. 2. A radiophotoluminescence substance (1) is illuminated by a mercury lamp (2) through a filter (4). The luminescent picture is observed by a microscope (3) through a filter (5) which cuts off the excitation light. The picture formed by luminescent light can be registered either by a photofilm or by a scanning system with a photomultiplier (6).

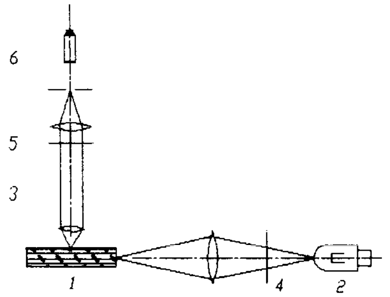

Fig. 2. The scheme for reading out a stored X-ray image by luminescence measurements under ultraviolet excitation: 1 – the radiophotoluminescence substance; 2 – the mercury lamp; 3 – the microscope; 4 – the filter for excitation light; 5 – the filter for luminescence light; 6 – the photofilm or scanning system with a photomultiplier.

Preliminary results indicate that the spatial resolution of the substances is not worse than 2 μm. Examples of luminescent pictures produced by registered X-ray images in radiophotoluminescence substances of modified NaCl are presented in Fig. 3. The width of the narrow black lines on the pictures corresponds to 2 μm of the X-ray mask pattern. The dynamic range of these area detectors is illustrated in Fig. 4, where the luminescent intensity versus the X-ray irradiation dose is presented. For low doses (lower than 3×10^5 keV/μm^3), this curve is not quite correct because the excitation light scattered by optical defects in the substances was not completely stopped by the filter used for the extraction of luminescent light. Nevertheless, as can be seen from Fig. 4, the dynamic range is not less than three orders of magnitude. A similar study of these substances with 6–30 keV photons at the X-ray microscopy station of VEPP-3 [4] also showed that the dynamic range is about 5000.

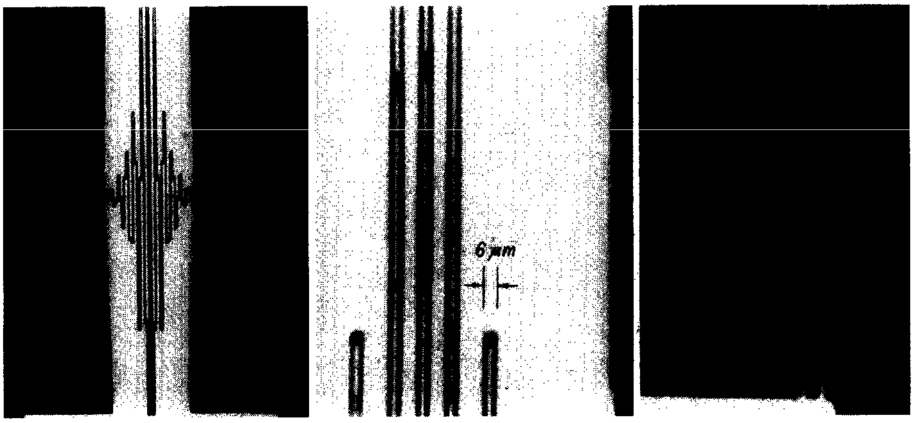

Fig. 3. Examples of patterns of X-ray images that were read out by luminescence registration from radiophotoluminescence substances of modified NaCl.

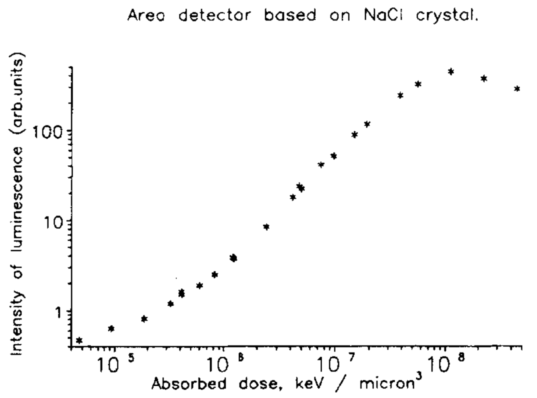

Fig. 4. The dependence of the luminescence intensity versus the absorbed dose of X-ray irradiation.

No degradation of the image luminescence intensity of the substance is observed after storing it for one year.

3. Discussion

The obtained results show that these substances may be promising for the registration of X-ray pictures in different experiments [5]. The dynamic range for these substances may be really wider than found now, and this problem will be investigated with defectless substances and with sharper bandpass filters for luminescence detection in order to determine the lower limit of the detected intensity. A stored image is not erased upon reading, therefore the readout process can be repeated many times for detecting low light intensities. These area detectors can be used many times because the stored images can be erased completely by heating the substances.

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