Thin YAG:Ce and LuAG:Ce Single Crystal Imaging Plates Used for High Spatial Resolution In X-ray Imaging Systems

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Abstract

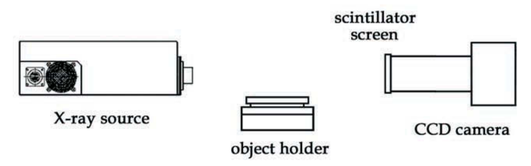
A high-resolution imaging X-ray CCD camera based on YAG:Ce or LuAG:Ce scintillating screens is presented. The obtained spatial resolution of X-ray images is in order of micrometers. The high resolution is proved on several objects as grids and small animals with parts of several microns in dimensions.

Introduction

The high resolution imaging system is a combination of a high sensitive digital CCD camera and an optical system with a thin scintillator imaging screen. The screen is the YAG:Ce ($Y_3Al_5O_{12}$) or the LuAG:Ce ($Lu_3Al_5O_{12}$) inorganic scintillator. These materials have the advantages in the mechanical and chemical stability, non-hygroscopicity, and a high radiation hardness.

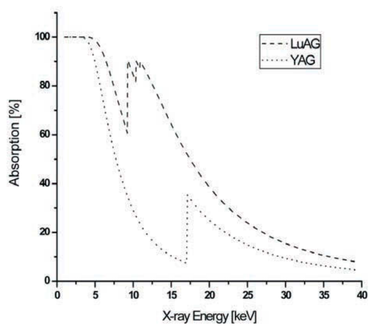
Experiment

The experimental setup consists of an X-ray micro-focus source and a high resolution CCD camera with an optical system (Fig.1). Objects are in a very close position to the scintillation screen. It is then possible to take X-ray images with the resolution better than 1 micrometer by a combination of the thin screen and the high resolution CCD detector.



Experimental setup

The optical properties of YAG:Ce and LuAG:Ce materials allow to achieve the very high spatial resolution of 1 micrometer. The spatial resolution of the screen depends on screen thickness, photon energy and the depth of absorption of the photon. An optical system using a magnifying lens was used to transfer the scintillator screen image to the CCD image area surface.



Absorption of X-ray radiation in 20 microns thick layer of YAG and LuAG

The high resolution imaging screen is the basic part of the high-resolution imaging system. The very thin imaging screens are based on the YAG:Ce or the LuAG:Ce single crystal scintillation material (Fig.2).
The intensity of the light generated by LuAG:Ce is about 1,51 times the value of YAG:Ce. The LuAG:Ce single crystal is more dense compared to YAG:Ce and the X-rays are absorbed stronger by LuAG:Ce.

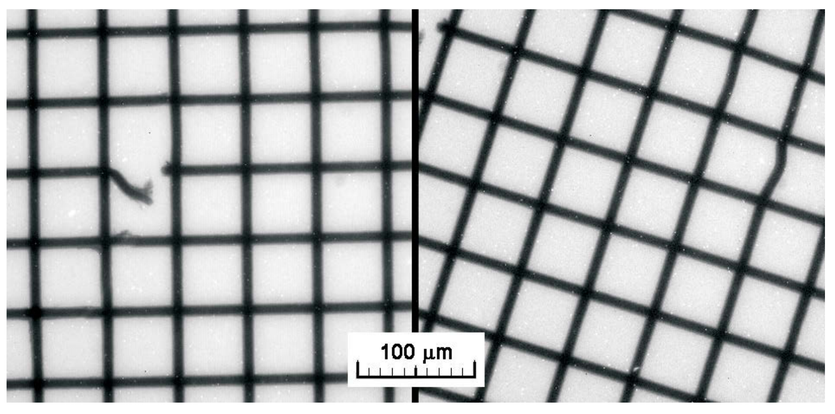
Thin YAG:Ce screen

Experiment results

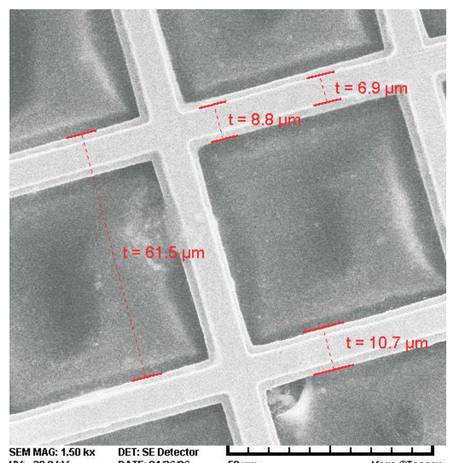
An optimal thickness of the screen is a compromise between the detection efficiency and the high resolution. The very thin screen on a precise optical substrate is imaged by an optical system with the Peltier cooled CCD detector.

The imaging system was tested on several objects. The first object is a gold grid with the wires about 10 microns wide. The images were taken by using the 20 micrometers thick YAG:Ce or 20 microns thick LuAG:Ce imaging screen on quartz glass.

In the Fig.3, the image on the left hand side was taken with the LuAG:Ce 20 μm screen and the picture on the right was taken using the YAG:Ce 20 μm screen. The effective pixel size of the CCD camera used was 0.74 μm. The X-ray microfocus source was operated at 40 kV/2mA. The image acquisition time was 5 s and the averaging was performed with samples of 25 images.

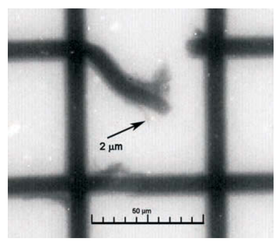


Radiographies of a gold-grid taken by using LuAG:Ce (left) and YAG:Ce (right) screen

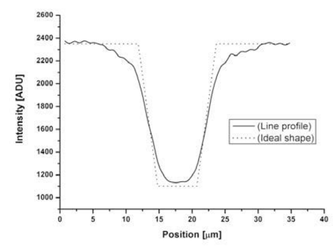


SEM image of the mesh

A zoom-in on a detail of the grid is shown in Fig 4. It shows that the resolution of the imaging system is in the order of micrometers.
The line profile of one grid wire is shown in Fig 5. The profile is compared with the geometric profile of the grid wire, which has trapezoidal shape with a base of 10.7 μm and top 6.8 μm wide (measured in an SEM image of the grid, see Fig. 6).

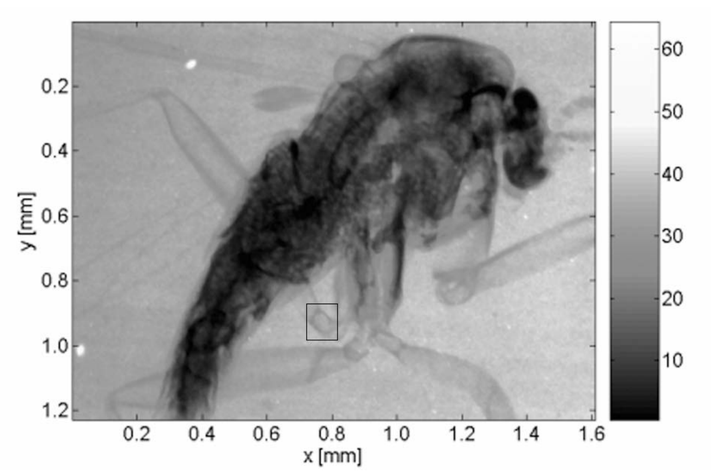


Detail of broken wire

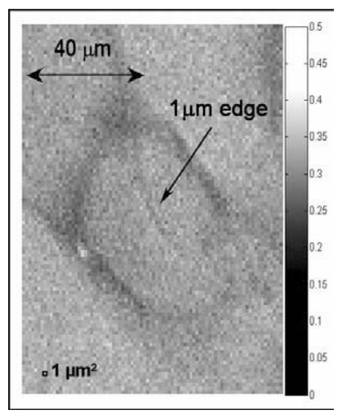


Line profile of the grid wire

The high resolution microradiography images of biological objects - a drosophila, a termite and a tick are imaged by using the high resolution system. The mean absorption depth of X-ray radiation in the scintillators depends on photon energy and the material. The YAG:Ce and LuAG:Ce screens are optically transparent so the image of interaction points is easily transferred to the CCD. However, the advantage of the material transparency decreases with the thickness of the imaging plate. If the scintillator is thinner, the mean absorption depth is lower and the created image is sharper due to less blurring of the image due to less lateral spread of the scintillation photons. Hence, the thinner the imaging plate is, the better is the resolution achieved in the image. On the other hand, the detection efficiency decreases with scintillator thickness.



Microradiography of the body of Drosophila melanogaster



Drosophila melanogaster - a detail of the leg

A termite

The zoom image showing selected details of the fly's leg in Figure 8 demonstrates that a resolution of about several μm is achievable by the used imaging system. The effective pixel size of the used system was about 0,65 μm.

A tick

A detail of the tick

Conclusions

The results

- **the resolution of order of micrometers can be obtained by means of the thin YAG:Ce or LuAG:Ce single crystal imaging screen.**

High resolution depends on

- **minimal thickness of the plate**
- **excellent parallelism of faces**
- **high optical quality**
- **space homogeneity of luminescence**
- **optical coating**

Advantages

- **long life operation**
- **high resolution better than 1 micron**
- **X-ray, electron and UV detection**

Application

- **industry and science**
- **defects inspection**
- **biological imaging**
- **technical imaging**
- **X-rays, electrons and UV**

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