High-resolution imaging of biological and other objects with an X-ray digital camera

J. Touša, K. Blažek, L. Pina, B. Sopko

Crytur spol. s r.o., Palackého 175, Turnov CZ-511 01, Czech Republic
Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, V Holešovičkách 2, Praha 8 CZ-18000, Czech Republic
Faculty of Mechanical Engineering, Czech Technical University, Technická 4, Praha 6 CZ-16607, Czech Republic

ARTICLE INFO

Keywords:
High resolution imaging
YAG:Ce
LuAG:Ce
Single-crystal imaging screen
Micro-radiography
Synchrotron beam inspection

ABSTRACT

A high-resolution CCD X-ray camera based on YAG:Ce or LuAG:Ce thin scintillators is presented. The high resolution in low energy X-ray radiation is quantified with several test objects. The achieved spatial resolution of the images is < 1 μm. The objects used for imaging are grids and small animals with parts of several microns in extent. The high-resolution imaging system can be used with different types of ionizing radiation (X-ray, electron, UV, and VUV) and for non-destructive micro-radiography and synchrotron beam inspection.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

The spatial resolution of an X-ray and ionizing radiation imaging system is one of its most important parameters when used for X-ray non-destructive micro-radiography and radiation beam inspection. The imaging systems are generally based on two-dimensional position-sensitive detectors (PSD). There are many different types of PSD detectors with each having its advantages and disadvantages Eijk and Carel, 2002. X-ray micro-radiography is an X-ray imaging method well known from a number of medical and biological applications related to the imaging of very small objects. The sample is irradiated with X-rays with energies sufficient for penetrating the object of study and being detected with a fine resolution X-ray position-sensitive detector. Different parts of the sample usually have different integral attenuation lengths for X-rays of given energy and therefore the intensity of detected X-rays depends on the properties of the sample materials (different integral absorption lengths can be caused by different materials or different thicknesses).

The high-resolution imaging system in the present work is a combination of a highly sensitive digital CCD camera and an optical system with a thin scintillator imaging screen. The screen is the YAG:Ce (Y₃Al₅O₁₂) or LuAG:Ce (Lu₃Al₅O₁₂) inorganic scintillator. High quality industrial YAG:Ce and LuAG:Ce single crystals were prepared by the Czochralski method Brandle, 2004 at Crytur. These materials have the advantages in the mechanical and chemical stability and the non-hygrosopicity. The imaging scintillator screen is optically transparent. The emission wavelength of YAG:Ce and LuAG:Ce is 550 and 535 nm, respectively.

2. Experiments

The scheme of the experimental setup is shown in Fig. 1. The scintillator was placed in the focused object plane of the optics. In the experiments, the scintillators have the shape of a round plate with diameter of 19 mm and thickness of 20 μm. Several objects were placed in proximity to the imaging screen in order to keep the smearing effect caused by the X-ray focal spot size as low as possible. To achieve high resolution, a micro-focus X-ray tube with copper anode was used. The temperature of the camera was stabilized by a recirculating water cooling chiller. The resulting images were processed via dark background subtraction and flat field correction.

3. Results and discussion

Fig. 2 presents an image of a golden grid made of wires which have a size of about 10 μm. The image was taken using the LuAG:Ce 20 μm screen. The effective pixel size of the CCD camera was 0.74 μm. The X-ray microfocus source was operated at 40 kV/2 mA. The image acquisition time was 5 s and the averaging was performed with samples of 25 images.

The resultant image 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. 3. 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 the image of the grid taken in scanning electron microscope SEM).

The optical properties of YAG:Ce and LuAG:Ce allow the acquisition of images with spatial resolution of 1 μm, which is about 10 times better than standard X-ray imaging CCD cameras (standard X-ray imaging CCD cameras have pixel size from 10 to 24 μm, also due to charge capacity and use mainly non-transparent phosphors). 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.

Several biological samples were studied in the next experiments. Here only Drosophila is presented. The image is shown in Fig. 4 with the grayscales indicating the transparency of the sample.

The images were taken by the CCD camera in the same setup as the images of the grid, using a YAG:Ce 20 μm screen and a magnifying lenses. The acquisition time was set to 20 s.

The zoom image showing selected details of the fly’s leg in Fig. 5 demonstrates that a resolution of several μm is achievable with this imaging system. The effective pixel size of the system is about 0.65 μm.
The used microfocus X-ray source with Cu anode generates photons at characteristic Kα ~8 keV lines with background of continuous energies up to 40 keV. The measured intensity of the light generated by LuAG:Ce is about 1.51 times the value of YAG:Ce after conversion of the photons flux from the source. The light was detected by the CCD and averaged in a squared ROI of 200 × 200 pixels. The LuAG:Ce single crystal is more dense compared to YAG:Ce (density: 6.73–4.57 g/cm³) and the X-rays are absorbed more strongly by LuAG (an average of 1.7 times more of X-ray radiation is absorbed in the range between 1 and 40 keV), as can be seen in Fig. 6. Attenuation coefficients are taken from X-ray Form Factor.

4. Conclusion

In the experimental setup presented, a high-resolution imaging system based on a CCD camera with lenses and precisely manufactured YAG:Ce and LuAG:Ce single-crystal X-ray convertor screens was used for X-ray micro-radiography. The mean absorption depth of X-ray radiation in the scintillator depends on incident 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, the better the resolution achieved in the image. On the other hand, the detection efficiency decreases with scintillator thickness.

The experiments proved that the YAG:Ce and LuAG:Ce screens are suitable for imaging with high spatial resolution. The submicrometer spatial resolution using synchrotron radiation has been already achieved Koch, 1998. The resolution of the presented imaging system is about 1 μm.

The LuAG:Ce screen was found to have higher conversion efficiency than the YAG:Ce screen, so that the signal to noise ratio of the corresponding images is better.

Acknowledgment

This work was supported by the grant of the Ministry of industry and trade of the Czech Republic no. FT-TA/100.

References

X-ray Form Factor, Attenuation, And Scattering Tables, (http://physics.nist.gov/).