Single Crystal Scintillator Plates Used in Micro-CT Application

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Abstract. In high resolution X-ray projection imaging, very thin scintillator layers of about 5-20 micrometers are used to achieve spatial resolution around one micrometer. This work deals with a high resolution CCD camera together with different single crystal scintillators in application for low energy X-ray NDT. Thin screens used were prepared by mechanical polishing from $Y_3Al_5O_{12}$ and $Lu_3Al_5O_{12}$ single crystals. The results show that the single crystal plates exhibit high spatial resolution and high sensitivity to low energy X-rays resulting in high image contrast. The use of the plates is highly suitable for low weight material objects X-ray radiography.
Several light-weight objects are imaged using the thin plates. 3D CT images prepared using such imaging system are presented.

1. Introduction

The X-ray micro-radiography is a non-destructive method that is of great interest in recent years. Basically, the X-ray radiation passes through an inspected sample and a high resolution detector based on a scintillator and an optical device is used to detect the X-ray passed. It is a contrast imaging technology using the difference in absorption of X-ray in different materials. Recently, three-dimensional CT imaging is of growing interest.

Very thin single crystal scintillator imaging plates are radiation detectors that are used in low energy X-ray micro-radiography. In high resolution X-ray projection imaging, very thin single crystal scintillator plates of about 5-20 micrometer are used to achieve spatial resolution of about one micrometer. Such thin plates are mainly used in micro-CT and nano-CT systems with either micro-focus X-ray tubes or with synchrotron sources. The light distribution on the plate is transferred by an optical system to a high-resolution CCD chip. For given parameters of the optical collection system, there exists an optimum thickness for the scintillator plate. A thicker plate absorbs high-energy photons more efficiently but the image on the CCD becomes blurred [1]. On the other hand an excessively thin scintillator does not provide enough absorption so that the integration time for an image is rather high.

1.1 Single Crystal Thin Plates

Single crystal thin plates are made of single crystal boles. The most used crystal is garnet composed of yttrium $Y_3Al_5O_{12}$ (YAG) or lutetium $Lu_3Al_5O_{12}$ (LuAG) both doped with cerium, see Fig. 1. High quality industrial YAG:Ce and LuAG:Ce single crystals are prepared by the Czochralski method [2] at Crytur.

These inorganic crystal scintillators are characterized by good mechanical and chemical stability, non-hygroscopicity, high scintillation efficiency and fast decays [3], [4]. The imaging scintillator screen made of this single crystal is optically transparent. The emission wavelength of YAG:Ce and LuAG:Ce is 550 nm and 535 nm, respectively. Imaging screens prepared from these crystals can be used in equipments for detection of different kinds of radiation and particles (UV, VUV, electrons or ions or their beams, X- or gamma-rays).

1.2 X-Ray CCD camera

The high-resolution X-ray camera consisting of high sensitivity digital CCD detector and thin YAG:Ce or LuAG:Ce scintillator imaging screen is used in the low-energy X-ray radiation radiography [5]. The camera includes a CCD optical sensor of the dimensions of 24x36 mm^2, and of about 11 Mpixels resolution. A Peltier thermoregulation system for cooling and temperature stabilization is used. The CCD pixel size is 9 micrometers, thus with optical system magnification of 1, the CCD limits the X-ray resolution to about 10 micrometers. The maximal resolution is limited by the screen thickness and numerical aperture of the objective. The maximum size of the scintillator plate is 50 mm in diameter. Different scintillator thicknesses are used to reach the highest resolution. The objective is focused into the plane inside the scintillator where the absorption image is of the best contrast. The camera is in side position to avoid the direct impact of the X-rays on the camera electronics.

2. Experiment

In the experimental setup the presented high sensitive CCD camera and YAG:Ce or LuAG:Ce single crystal thin plates was used for micro-radiography of light-weight objects.

The position of the object was very close to the scintillator plate, so almost no projection magnification was used. X-RayWorX microfocus X-ray tube equipped with Copper transmission target was used with X-rays intensity maximum at about 8 keV.

The imaging system was used to observe a light weight materials as the YAG:Ce and LuAG:Ce single crystals are high sensitive to low X-Ray energies (starting below 1 keV). Fig. 1 presents a 2-D radiography image of porous plastic foam.

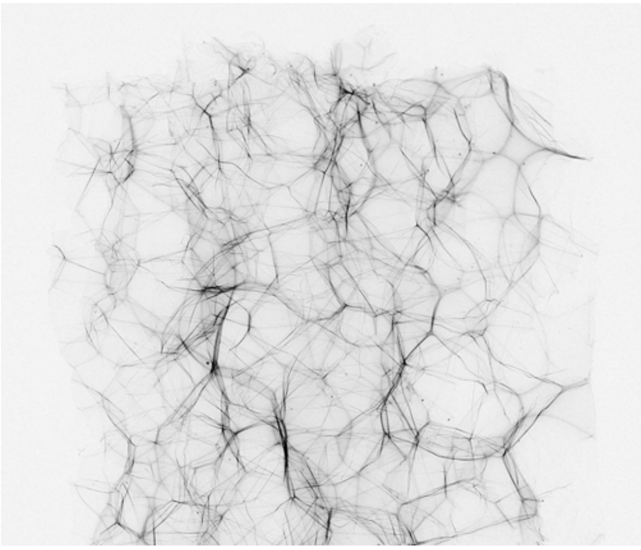

Fig. 1. X-Ray Projection of Plastic Foam

The plastic foam with drop of plastic glue was used for X-ray 3-D tomography reconstruction. Fig. 2 presents one of the reconstructed slices. Another object was cotton on plastic stick, see Fig. 3. Examples of the reconstructed slices are shown in Fig. 4.

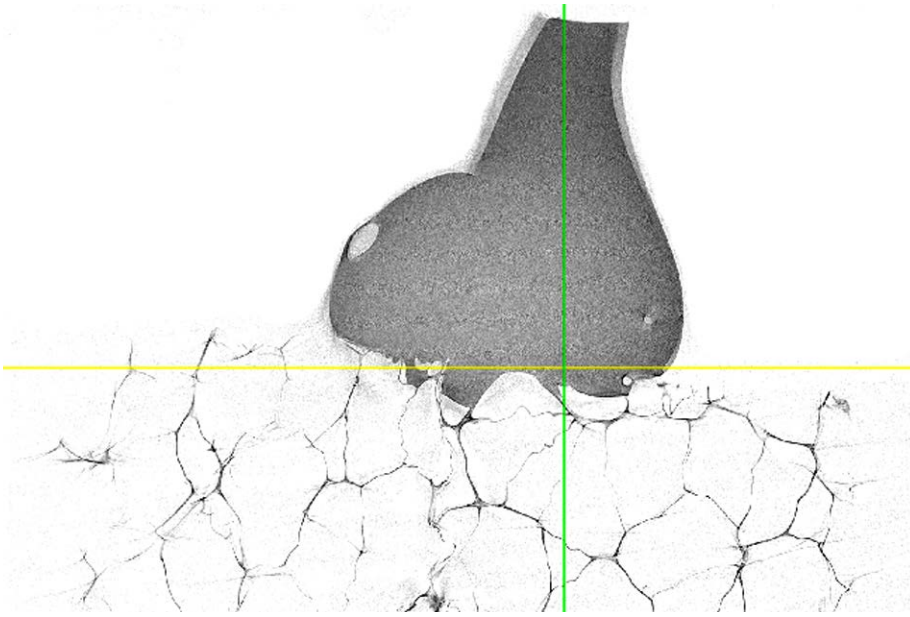

Fig. 2. One Slice of 3-D Reconstruction of the Plastic Foam

Fig. 3. Cotton on Stick

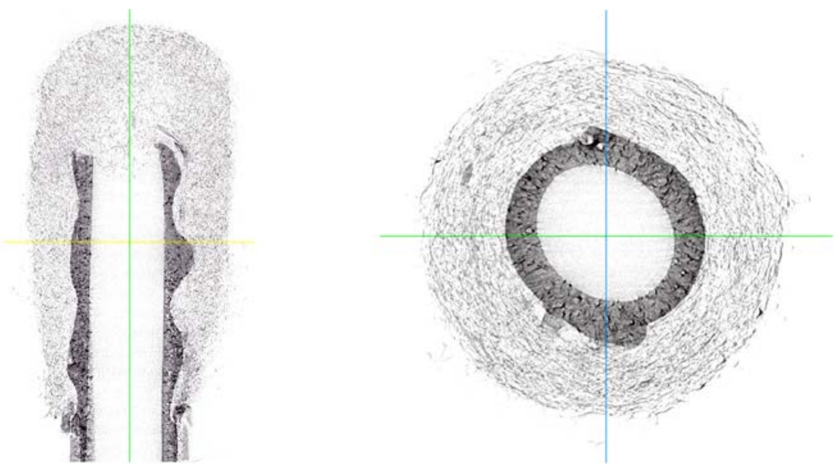

Fig. 4. Reconstructed Slices of the Cotton on Stick

Carbon fibres have very low absorption for X-rays. Using the YAG:Ce thin plate some 7 -10 micrometer carbon fibres were imaged. The result is in Fig. 5.

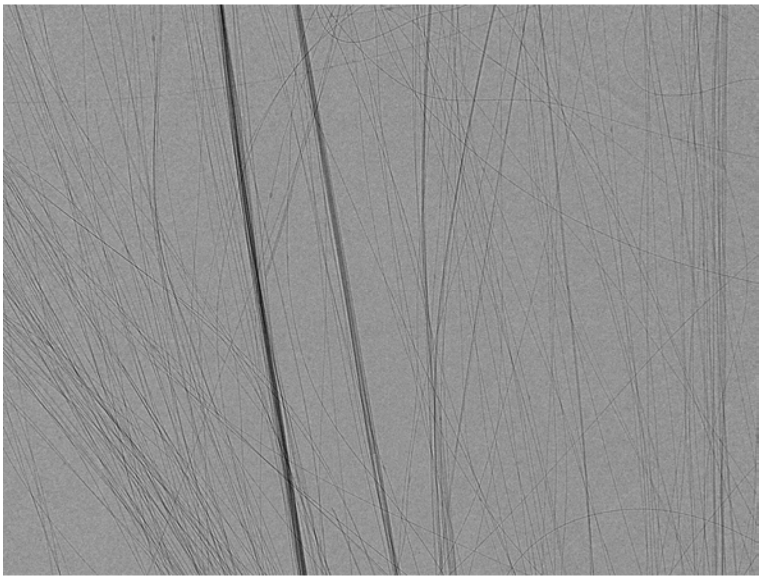

Fig. 5. X-Ray Radiograph of Carbon Fibers

4. Discussion

The resolution of a scintillator based system depends on several factors, mainly on X-ray absorption process, screen geometry (mainly thickness), and the optical system. The resolution is limited practically only by geometry and diffraction limit of the optical system [1]. Thus with the typical scintillator emission wavelength of 550 nm the highest submicron resolution has probably already been reached in synchrotron laboratory [6].

Low Z (light-weight) materials are composed mostly of carbon, hydrogen, oxygen, nitrogen, with atomic numbers smaller than 10, and up to 18. These low Z elements are characterized by the absence of an absorption edge (atomic shell energy) higher than 5 keV. Real X-ray tube spectrum has almost no energy below 5 keV, thus low Z elements have extremely low contrast due to, almost entirely, their density.

The highest 2D-spatial resolution achieved in the radiography images using the presented system was about 1 micron [5].

5. Conclusions

In the experimental setup presented, a high resolution imaging system based on CCD camera with lenses and precisely manufactured YAG:Ce and LuAG:Ce single crystal screens was used for X-ray micro-radiography and 3-D tomography.

The experiments proved that the YAG:Ce and LuAG:Ce screens are suitable for imaging with high spatial resolution. The highest resolution achievable by the presented imaging system is about one micrometer. The LuAG:Ce screen has higher conversion efficiency than the YAG:Ce screen, so that the signal to noise ratio of the image is better.

The sensitivity of the YAG:Ce and LuAG:Ce single crystals screens to low energies predicts their use to low weight (low Z) materials radiography. The experiments show that the light weight materials like plastic and carbon fibres are resolved.

6. Acknowledgements

The support of Czech GA AV project KAN300100802 is gratefully acknowledged.

References

[1] Koch, A., Raven, C., Spanne, P., and Snigirev, A., *X-ray imaging with submicrometer resolution employing transparent luminescent screens,* J. Opt. Soc. Am. A 15, 1940-1951 (1998).

[2] Brandle, C.D., Czochralski growth of oxides, J. Crystal Growth 264 (2004) 593-604.

[3] Nikl, M., *Scintillation detectors for X-rays*. Meas. Sci. Technol. 17, R37-R54 (2006).

[4] J.A. Mares, A. Beitlerova, M. Nikl, N. Solovieva, C. D'Ambrosio, K. Blazek, P. Maly, K. Nejezchleb and F. De Notaristefani, Rad. Meas. 38, 353-356 (2004).

[5] Tous, J., Horvath, M., Pina, L., Blazek, K. and Sopko, B., *High-resolution application of YAG:Ce and LuAG:Ce imaging detectors with a CCD X-ray camera*. Nucl. Instr. Meth. Phys. Research A, 591 264-267 (2008).

[6] T. Martin et al., *Recent developments in X-ray imaging with micrometer spatial resolution*, J. Synchrotron Rad. **13**, 180-194 (2006)