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High-efficiency Fast X-Ray Imaging Detector Development at SSRF

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In fast X-ray micro-imaging application, usually an indirect X-ray imaging detector which consists of scintillator screen, microscope optics and scientific high-speed CMOS camera is used to increase the spatial resolution. However, the efficiency of the indirect X-ray imaging detector based on the microscope optics is very low because the coupling efficiency of the microscope optics with limited numerical aperture (NA) is about only 5%. Moreover, X-ray photon flux on each pixel is very limited due to the very short exposure time and very small pixel size. In order to get higher quality image, a large NA optical complex lens is designed to gather more photons from the scintillator screen which converts the X-ray into visible light to the CMOS detector. The complex lens has 8× magnification and NA of 0.5. The NA is twice of Commercial lens and the coupling efficiency is 4 times of Commercial lens. The effective pixel size of the detector is 2.5μm. The optical path of the complex lens is shown in Figure 1: X-ray photons transmit through the object and the glassy carbon and then reach the scintillator. The scintillator converts the X-ray photons into visible light. Then visible light is reflected by the mirror and then pass through the lead glass and microscope optics to the CMOS camera. The scintillator is 50μm-thick LuAG matching with the NA of the microscope optics. It is mounted on a spring base which can be easily replaced. By moving the camera up and down with high accuracy, position errors and thickness errors of the scintillator can be compensated to get clearer image. Glassy carbon is used to isolate the effects of ambient visible light and help to improve the imaging contrast.

The total working distance from lead glass to scintillator is 30 mm. It belongs to large NA and long working distance microscopic imaging lens. In order to improve the transmission efficiency of the lens, high transmittance optical glass is used and anti-reflective coating is plated on the surface. The pixel size of the high-speed sCMOS detector is 20μm. Since the magnification, the effective pixel size is 2.5μm and the ultimate resolution is 200lp/mm. According to the MTF curve of the lens designed is shown in Figure 2, the contrast ratio of the lens in the whole field is > 65%@200lp/mm. Due to the dual measures of mirror turning and 4.5mm lead glass, the lens can work for a long time in the high dose X-ray irradiation environment. A gas cooling structure is designed between the scintillation crystal and the reflector to further enhance the environmental adaptability of the device.

A test experiment is performed with this developed high efficiency fast X-ray imaging detector. We got the image of the resolution chart at frame frequency of 100000fps at test beamline at Shanghai Synchrotron Radiation Facility. Figure 4 shows 5μm line pairs clearly. The test result shows the developed high-resolution high-speed X-ray imaging detector can realize clear X-ray imaging with 5μm spatial resolution at frame frequency of 100000fps. The detector will help SSRF users to observe directly and research high-speed processes which include deformations and invalidations of materials under strong dynamic load and the high pressure/speed spray process of fuel in automobile engines [3].

References:
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[2] Y. Zhang *et al*, Nuclear Techniques **37** (2014), p. 70102.

[3] Authors acknowledge funding: National key research and development program 2017YFA0403801

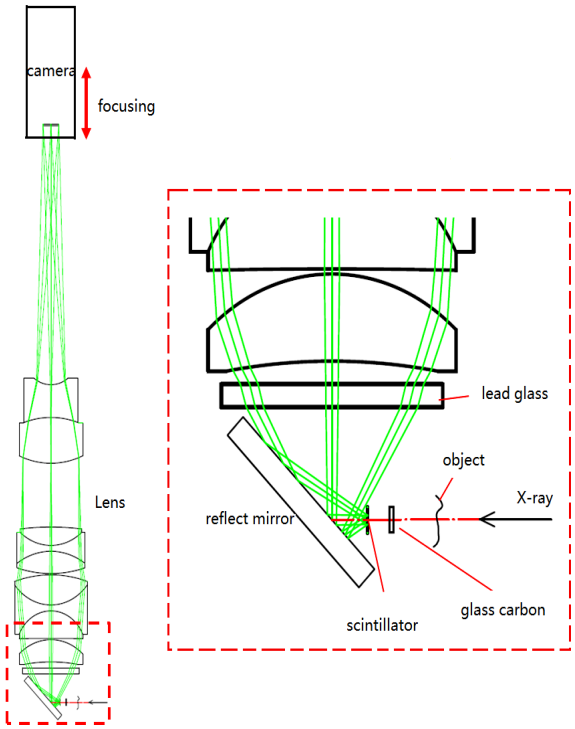

Figure 1. Structure of the complex lens

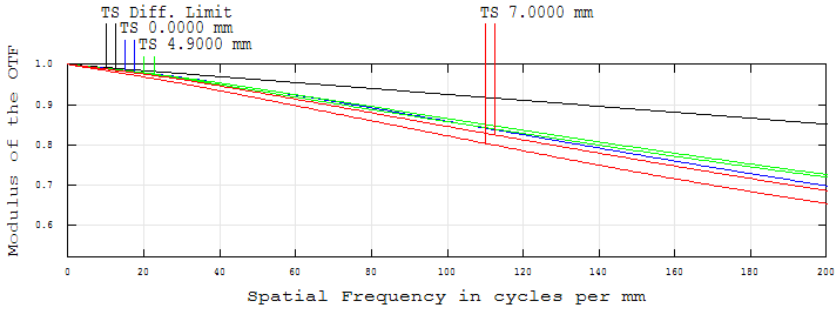

Figure 2. MTF of the complex lens

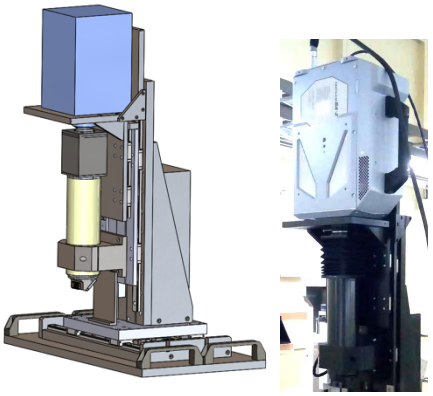

Figure 3. structure and photo of X-ray detector

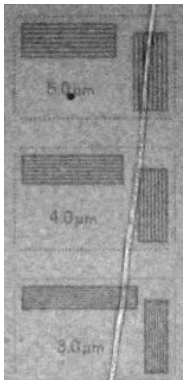

Figure 4. image of resolution chart at 100000fps

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