# YAP Imager, an Area Detector for High-Energy X-ray Photons

High-energy X-ray beams are outstanding scientific resources of third-generation synchrotron radiation facilities. They provide a powerful means of investigating the internal structures of thick or high-Z samples, local atomic structures of non-crystalline materials, and substances containing heavy elements. However, the detection of high-energy X-ray photons is not straightforward because they penetrate through and scatter in all detection media. High-density inorganic crystals with constituents of high-Z values are, therefore, widely used. With a single body CsI(Tl) scintillator attached to a diffractometer, the structure factor of a given sample can be measured by a slit scan method, which however, is highly time-consuming. To be more efficient, an advanced area detector is needed, which should be fast enough to resolve the individual high-energy X-ray photons arriving for background rejection.

In this respect, cerium-doped yttrium aluminum perovskite ($YAlO_3$:Ce, often abbreviated YAP(Ce)) is a promising scintillator, because its decay time (~ 28 nsec) is ten times faster than that of a NaI(Tl) scintillator, however, its light yield is 40% that of a NaI(Tl) scintillator. Its density (5.35 $g/cm^3$) is as high as that of germanium, and the wavelength of maximum emission (360 nm) is sufficiently blue to illuminate wavelength-shifting fibers as explained below [1].

By assembling 16384 elements of YAP(Ce) crystals, a 2D matrix of [128 × 128] has been fabricated at the SPring-8 facility as a detection media of an advanced high-energy X-ray area detector, called "YAP imager," (Fig. 1) [2,3]. Each crystal element is 1 mm×1 mm×6 mm. There are 128 wavelength-shifting fibers attached to the 128 columns (x-coordinate) on the top surface of the 2D array, and another 128 wavelength-shifting fibers attached to the 128 rows (y-coordinate) on the bottom surface. The 128 fibers of both coordinates are bundled into 8 groups, and are guided to their own photomultipliers. The photomultiplier has sixteen segmented anodes that position-sensitize its photocathode into 4 × 4 regions. The sixteen fibers in each group are attached to their own assigned regions.

When high-energy X-ray photons are absorbed in a YAP(Ce) crystal element, scintillation photons are induced (see Fig. 2). These scintillation photons emitted at an acceptance angle enter the corresponding wavelength-shifting fibers on both coordinates. By entering the fibers, the scintillation photons are absorbed and reemitted into the wavelength region from 390 nm to 450 nm. The red-shifted scintillation photons in each coordinate will travel through the fiber, and reach one of the segmented anodes. The arrival location of the incident X-ray photon on the 2D YAP crystal matrix can be uniquely identified by detecting the signals induced on segmented anodes on both coordinates. The scintillation pattern induced on the 2D crystal matrix is thus projected both coordinates. Due to the finite acceptance angle and wavelength-shift efficiency, only a few scintillation photons will reach the photomultipliers, so that the YAP imager does not give energy information of the

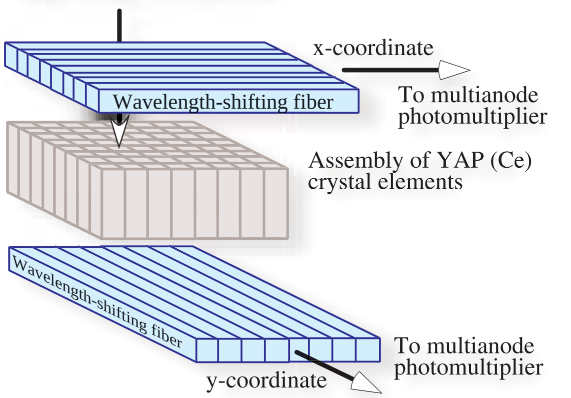


Fig. 1. Diagram explaining 2D YAP crystal assembly and wavelength-shifting fibers attached.

Fig. 2. Photograph of YAP Imager fabricated at the SPring-8 facility.

incoming X-ray photons. At the cost of losing the energy information, however, the YAP imager immediately digitizes the arrival locations of incoming X-ray photons on its 2D crystal matrix with a spatial resolution of 1mm × 1mm. This early digitization allows the YAP imager to be operated at a high counting rate with the dedicated readout system described below.

The X-ray attenuation length of a YAP crystal becomes equal to the thickness of the present 2D YAP crystal matrix at approximately 120 keV, where the matrix absorbs 63% of incoming X-ray photons. Although absorption efficiency increases as the X-ray photon energy decreases, the number of scintillation photons generated in the crystal elements decreases at the same time, making the overall detection efficiency from 60 keV up to 120 keV to be nearly constant at approximately 60%. The position dependence of overall detection efficiency was observed over the detection area, presumably due to the structural irregularities remaining in the crystal matrix, the wavelength-shifting fibers, and the multianode photomultipliers. Flood field images obtained by detecting tungsten X-ray fluorescence are analyzed together with experimental data to eliminate this non-uniformity.

In the present data acquisition system, the 128 segmented anode signals on both coordinates are degenerated into 16 unified signals by combining all the *n*-th segmented anode signals into an *n*-th single signal. Also eight dynode signals of the photomultipliers for both coordinates are sent to the data acquisition system. The dynode signals identify which photomultiplier is fired, and the degenerated anode signals which segmented anode is fired, thus providing sufficient information to determine the arrival location of X-ray photons. In this wiring scheme, the total number of signals to be processed is drastically reduced to forty eight, which is less than 0.3% of the total number of crystal elements assembled. To efficiently encode degenerated anode signals and dynode signals into position information, a high-speed logic processing module, called the “position encoder,” has been developed as the central module in the data acquisition system for the YAP imager [4].

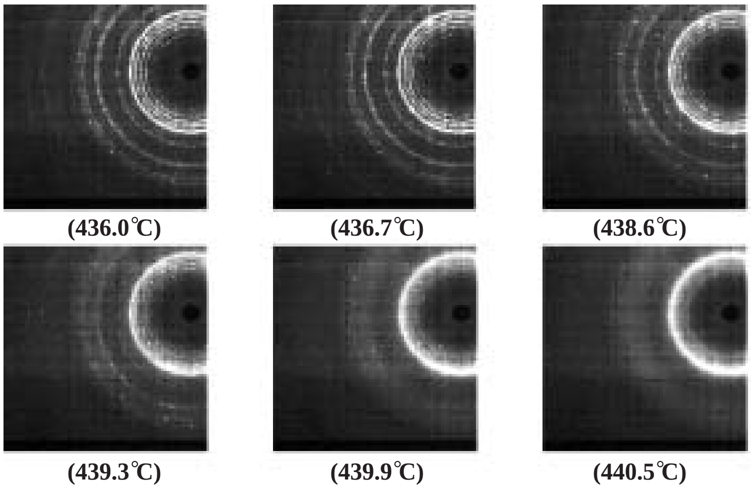

Fig. 3. A series of Zn diffraction patterns visualized with the YAP imager while Zn was undergoing the phase transition at approximately 438.6℃.

One of the important applications of the YAP imager is the *in situ* observation of two-dimensional diffraction patterns formed by a sample undergoing phase transition. A Zn powder sample in a glassy carbon cell was placed in an electric furnace, and was positioned on the diffractometer of the high-energy X-ray diffraction beamline **BL04B1**. By using the 113.4 keV monochromatic X-ray beam, a series of Zn diffraction patterns were observed while Zn was changing its phase from crystal to liquid or from liquid to crystal at approximately 438.6°C (Fig. 3). Because of the excellent detection efficiency of the YAP imager system, only 60 sec of the exposure time was sufficient for the present case. The YAP imager is now ready for performing various types of time-resolved imaging at a high-energy X-ray region beyond 100 keV.

Katsuya Hirota, Hidenori Toyokawa and Masayo Suzuki

SPring-8 / JASRI

E-mail: toyokawa@spring8.or.jp

## References

[1] S. Baccaro *et al.*: Nucl. Instrum. Meth. A **361** (1995) 209.
[2] A. Gorin *et al.*: Nucl. Instrum. Meth. A **510** (2003) 76.
[3] K. Hirota, H. Toyokawa, M. Suzuki, T. Kudo, M. Nomachi, Y. Sugaya, M. Yosoi, A. Gorin, I. Manuilov, A. Riazantsev, and K. Kuroda: Nucl. Instrum. Meth. A **510** (2003) 83.
[4] K. Hirota *et al.*: Nucl. Instrum. Meth. A **513** (2003) 187.