High-resolution/high-speed 2D photon counting X-ray detector

HyPix-3000

1. Introduction

Rigaku's HyPix-3000 is a next-generation two-dimensional semiconductor detector designed specifically to meet the needs of the home lab diffractionist. One of the HyPix-3000's unique features is its large active area of approximately 3000 mm^2 with a small pixel size of 100 μm square, resulting in a detector with high spatial resolution. In addition, the HyPix-3000 is a single photon counting X-ray detector with a high count rate of greater than 10^6 cps/pixel, a fast readout speed and essentially no noise.

HyPix-3000 has the following features:

- Ultra-high dynamic range and high sensitivity
- Seamless switching from 2D-TDI (Time Delay and Integration) mode to 2D snapshot mode to 1D-TDI mode to 0D mode with a single detector
- XRF suppression by high and low energy discrimination
- High spatial resolution, direct-detection pixel array detector

2. State of the art detector technology

Featuring a double-threshold (window) discriminator, the HyPix-3000 has three readout modes that can be selected based on the purpose of a measurement. "Differential" mode can be used to suppress fluorescence from elements in a sample or background derived from cosmic rays. "31-bit" mode is used for experiments in which a very wide dynamic range is needed. "Zero dead time" mode makes it possible to perform extremely fast data collection.

The HyPix-3000 was designed for optimal flexibility and minimal maintenance. For example, the compact angular enclosure was designed to allow excellent high angle accessibility. Compared to the design of other types of detectors, the HyPix-3000 is essentially maintenance free. Unlike other types of detectors, it does not require an external cooling device as required on CCD detectors, or gas exchange and anode wire washing as required on multi-wire detectors.

3. How do you most effectively suppress background noise?

Each pixel on the HyPix-3000 detector has dual energy discriminators, which makes it possible to adjust the energy window width by setting the energy threshold to "high" and "low", respectively. The low-energy

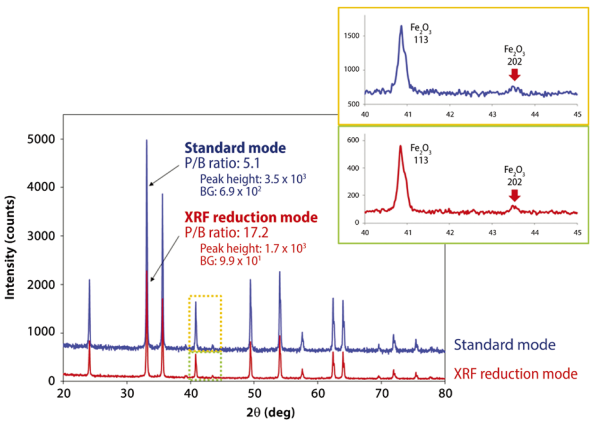

Fig. 1. X-ray diffraction patterns of iron oxide powder, measured in standard mode and XRF reduction mode.

discriminator can eliminate electrical noise and reduce fluorescence background, and the high-energy discriminator can eliminate cosmic rays and white radiation. As a result, you can measure data with an optimized signal-to-noise ratio. Figure 1 shows the X-ray diffraction pattern of a powder sample containing iron measured in standard mode (upper) and XRF reduction mode (lower). By using differential XRF reduction, it is possible to obtain an X-ray diffraction pattern with low background, and thereby improve the ability to detect trace components, even when measuring Fe-based compounds with a Cu source.

4. What is the best way to measure very strong reflections?

A big advantage of a hybrid pixel array detector is that each pixel is independent and the overall dynamic range of a detector is a sum of the dynamic range of each individual pixel. Each pixel of the HyPix-3000 has two 16-bit counters, and these can be combined to work as a single 31-bit counter achieving very wide dynamic range. This means that, wide dynamic range measurements can be performed without an attenuator, thus removing the error associated with the attenuator factor, as well as optimizing data measurement time. Figure 2 shows the high-resolution rocking curve profiles of InGaN/GaN multiple quantum wells (MQW) with the HyPix-3000 (wide dynamic range 31-bit mode) and scintillation counter. The profile obtained in 31-bit mode clearly indicates separated peaks without saturation.

5. How do you obtain data with excellent spatial resolution?

The HyPix-3000 detector's small pixel size provides outstanding spatial resolution. Figure 3 shows a typical qualitative analysis, which, in this example, was done in 2 minutes. In this case, the detector was run in a one dimensional Time Delay and Integration mode (1D-TDI mode), which allows continuous movement of the detector during measurement. If you want resolution less than 0.03 degrees at full width at half maximum (FWHM), as shown in Fig. 4, you can run the detector in 0D mode which requires placing a mechanical slit on the face of the detector.

6. How can you effectively investigate phenomena that are constantly changing over time?

The HyPix-3000 detector is equipped with high-speed readout circuit. This means that dead time during readout is actually zero. Due to true shutterless operation, *in situ* and time resolved measurement can be easily performed. As shown in Fig. 5, the phase transition process in the synthesis of gehlenite from the mixture of corundum, quarts, and calcite under conditions of continuous temperature rise was visually recorded at each stage by utilizing the detector features

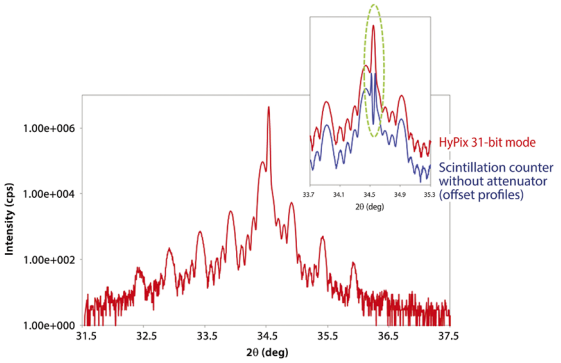

Fig. 2. High resolution rocking curve profiles of InGaN/GaN MQW.

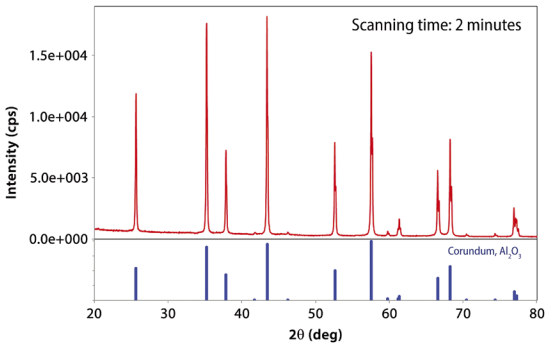

Fig. 3. X-ray diffraction pattern of Al_2O_3 powder.

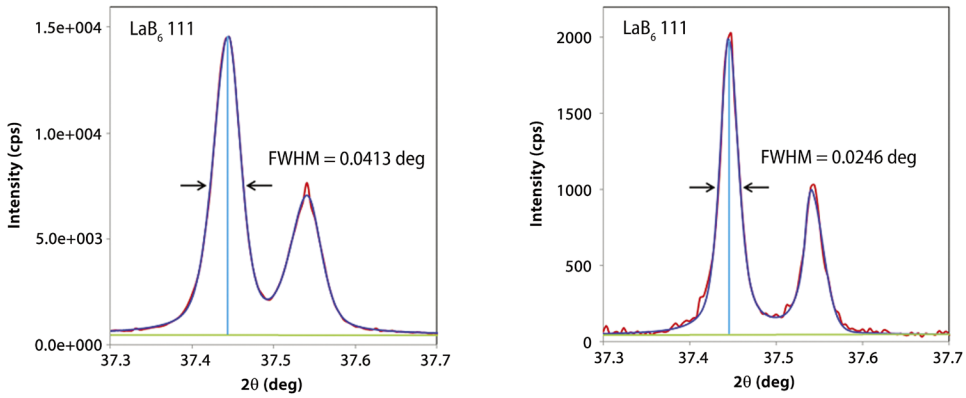

Fig. 4. X-ray diffraction patterns of LaB_6 powder.

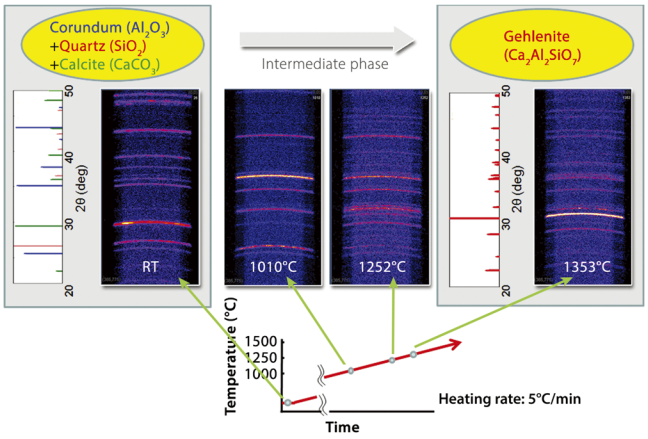

Fig. 5. 2D *in situ* exposure measurement of ceramic.

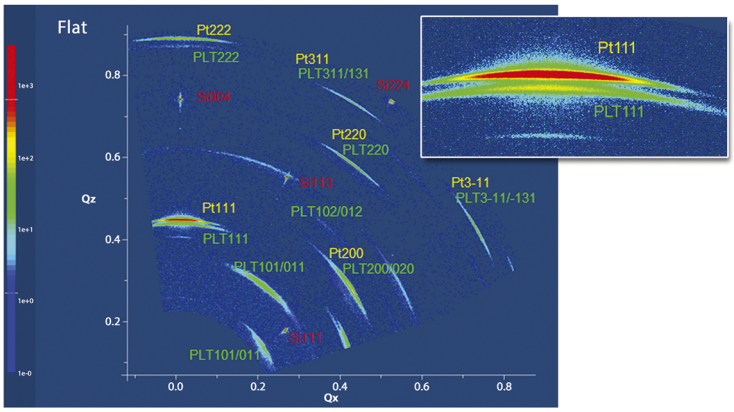

Fig. 6. Reciprocal space map of PLT/Pt/Si.

of fast readout and large active area.

7. How can you measure a wide angle range rapidly?

The HyPix-3000 supports two-dimensional Time Delay and Integration mode measurement, so a 2D detector can be used for simultaneous scanning like a 0D or 1D detector is used.

The ability to operate a fast 2D detector in TDI mode is best illustrated for the measurement of a reciprocal space map. Figure 6 shows a wide range reciprocal space map of a (Pb, La)TiO_3 (PLT) orientated film on a Pt base layer and a Si substrate. Data collection for the calculation of this reciprocal space map was completed within 10 minutes. This fast data measurement speed was accomplished due to the size of the detector, the TDI data measurement mode and the high readout speed, which allows shutterless data collection.

Table 1. Specifications.

Sensors	Semiconductor pixel sensor
Active area	2,984 mm^2 (77.5×38.5 mm)
Pixel size	100×100 μm
Number of pixels	775×385=298,375 pixels
Counter mode	Differential/31-bit/zero dead time
Count rate	Global: >2.9×10^{11} cps Local: >1×10^6 cps/pixel
Efficiencies	Cr, Fe, Co, Cu: 99% Mo: 38%
Readout time	3.7 ms (0 ms for zero dead time mode)
Energy resolution	Better than 25% at Cu $K\alpha$
Dimensions	147(W)×93(H)×180(D) mm
Weight	Approximately 2 kg