Application example: High pressure measurements in Diamond Anvil Cells

The LAMBDA pixel detector is designed for high-end X-ray experiments, particularly at synchrotron sources. It achieves an extremely high image quality by combining effectively noise-free photon-counting operation with a small pixel size of 55 µm. For fast and time-resolved experiments, LAMBDA can be read out at up to 2000 frames per second with no time gap between images. But speed and resolution are not the only thing LAMBDA excels at, you can find a more information at www.x-spectrum.de . Or contact us anytime at info@x-spectrum.de

Key features:

- **Effectively zero noise (photon counting)**
- **55 µm pixel size**
- **Up to 2000 frames per second**
- **Deadtime-free readout**
- **up to 1536 by 1536 pixels (85 x 85 mm^2)**
- **Energy binning capability**

Every version of the LAMBDA pixel detector is available with different sensor layers for different X-ray energy ranges. For hard X-ray detection, the GaAs and CdTe LAMBDA systems replace the standard silicon sensor layer in LAMBDA with a "high-Z" (high atomic number) sensor. This provides high quantum efficiency at high X-ray energies (75% at 40 keV for GaAs, and 75% at 80keV for CdTe), while retaining single-photon-counting performance and our high frame rate of up to 2 kHz. Upon request we also provide LAMBDA versions that can be operated in vacuum.

Comparison of different LAMBDA sizes; a 750K single module of 1528 x 512 pixels and a 2M system with three-module system and 1528 x 1536 pixels.

Ever since the first prototypes of the LAMBDA camera have been developed it has been used in different applications. The following example has been chosen to demonstrate the capabilities of the system. LAMBDA has already found its way into routine operation at a few light sources, so the following example highlight only a fraction of the many possible ways LAMBDA cameras can be used.

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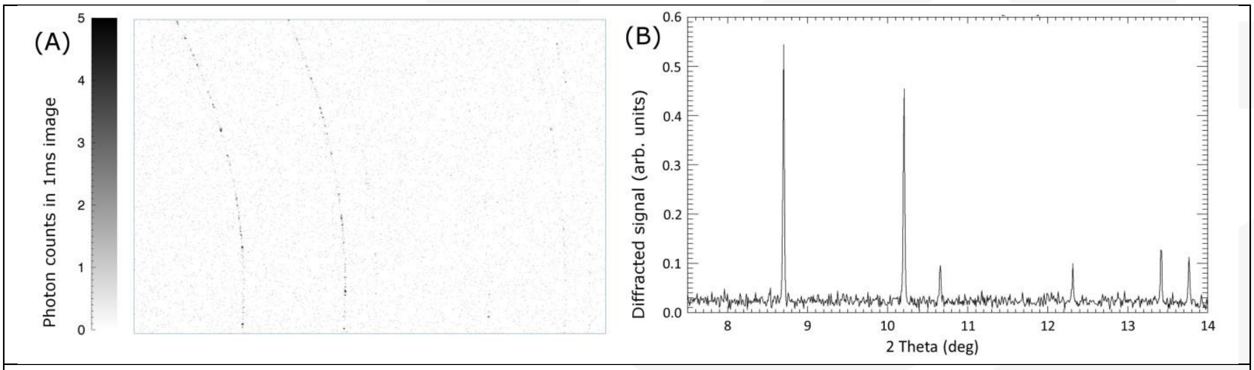
High pressure measurements in Diamond Anvil Cells

A high proportion of experiments at synchrotrons use X-ray diffraction to study a sample's structure on an atomic scale. Using hard X-rays for these experiments makes it possible to gain higher spatial resolution, to study large samples or samples made of heavier elements, and to probe samples while they are contained in sample environments. Extreme conditions experiments are a good example of the latter. By compressing a sample inside a diamond anvil cell while heating it with a laser, it is possible to recreate the extremely high pressures and temperatures found inside of planets or in the outer layers of stars. If a highly-focused X-ray beam is fired through the sample, the X-rays will be diffracted, and from the diffraction pattern it is possible to infer the atomic-level structure. High-speed photon counting detectors like LAMDBA can then allow scientists to study the rapid changes that occur in a sample when the pressure and temperature change.

To investigate this possibility, the GaAs LAMBDA detector was tested at PETRA-III beamline P02.2, which is used for extreme conditions experiments [1, 2]. A sample of a common test standard, CeO_2, was placed inside a diamond anvil cell in the X-ray beam. The X-ray beam had a photon energy of 42 keV; at this energy, the photoelectric absorption efficiency of 500 µm-thick GaAs is 74%, compared to 4.6% for the same thickness of silicon. The LAMBDA GaAs detector was placed at a distance of 35 cm, with a horizontal offset of 4 cm between the X-ray beam and the edge of the sensitive area. A series of images were then taken with different shutter times [3].

Figure A shows an image taken with an acquisition time of 1 ms. Because the sample is a coarse powder, the diffraction pattern consists of rings of diffraction spots, with each spot produced by scattering from a single grain of the material. The angle and intensity of these rings convey information about the crystalline structure of the material. Due to the short shutter time, the rings are faint, with most pixels only detecting a few photons. Nevertheless, due to the effectively noise-free behaviour of the detector, when the photon hits in the 1 ms image are integrated as a function of scattering angle a clear diffraction signal is obtained, with the rings clearly distinguished from the background level, as shown in Figure B. This demonstrates that the detector could be used to measure structural changes in a sample on a timescale of milliseconds.



(A) Diffraction pattern obtained in 1ms with the GaAs LAMBDA detector. The sample was CeO_2 powder in a diamond anvil cell, illuminated by a 42 keV synchrotron X-ray beam at PETRA-III P02.2. (B) The diffracted X-ray intensity integrated as a function of scattering angle, using the single 1ms image shown in A. (Reproduced from [3].)

More recently, two 3-module (2 megapixel) GaAs systems have been constructed and are now in routine use for diamond anvil cell experiments at 2 kHz frame rates.

[1] http://photon-science.desy.de/facilities/petra_iii/beamlines/p02_hard_x_ray_diffraction_beamline/ecb/index_eng.html

[2] Liermann, H.-P. et al., "The Extreme Conditions Beamline P02.2 and the Extreme Conditions Science Infrastructure at PETRA III", *Journal of synchrotron radiation* 22 (2015), p908-924.

[3] Pennicard, D. et al., "The LAMBDA photon-counting pixel detector and high-Z sensor development", *JINST* 9.12 (2014): C12026.