	Experiment title: Study and development of crystals for a gamma-ray Laue lens application	**Experiment number:** MA-476
Beamline: ID 15A	**Date of experiment:** from: 5/03/08 to 08/03/08 (first part, interrupted by a technical problem on the beamline) from 17/05/08 to 20/05/08 (beamtime recovery)	**Date of report:** 17/08/08
Shifts: 18	**Local contact(s):** John Daniels and Veijo Honkimaki	*Received at ESRF:*

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Report:

This experiment was the third performed in the framework of the development of a Laue lens for a space borne gamma-ray telescope (after ME-1203 and MA-173).

A Laue lens focuses gamma rays using Bragg diffraction in the volume of crystals (Laue geometry). Crystal tiles are positioned in concentric rings such that they diffract incident radiation onto a common focal spot [1]. In a given ring, all crystals are identical and diffract a given energy. To cover a large energy bandpass, each ring must diffract an energy band large enough to overlap partially the energy band diffracted by the neighbouring rings. For us, this constraint implies a mosaic spread between 15 arcsec and 1 arcmin.

Our last space borne satellite project is called the Gamma-Ray Imager (GRI) [2] and is based on a Laue lens made of about 28000 crystal slabs (15mm x 15mm) in germanium, silicon-germanium, and copper. This mission has been proposed recently as a medium class mission to the European Space Agency (ESA), as a response to the first Announcement of Opportunity of the Cosmic Vision 2015-2025 program. The GRI lens is designed to focus radiation from 250 keV up to 950 keV (for the first diffraction order), aiming to address astrophysical topics such as the Type Ia supernovae explosion mechanism, the origin of the soft gamma ray background radiation, the physics of the disk and jets in black holes and neutrons stars, and particle acceleration in the strongest magnetic fields in the universe.

During this experiment, we measured several pieces of mosaic copper crystals produced by the ILL monochromator group, as well as several pieces of a silicon alloy containing a gradient of concentration of germanium produced at the Institute for Crystal Growth (IKZ, Berlin), and a sample of gold mosaic crystal from the Mateck company. These measurements were performed at energies between 300 keV and 600 keV, selected thanks to two Ge 711 crystals bent at the Rowland curvature. Samples were hold by a sucking plate designed on purpose to hold up to 4 pieces of 15 x 15 mm^2 without inducing strains and allowing fast changes. Sample holder was set on the first tower (the closest from the optical hutch).

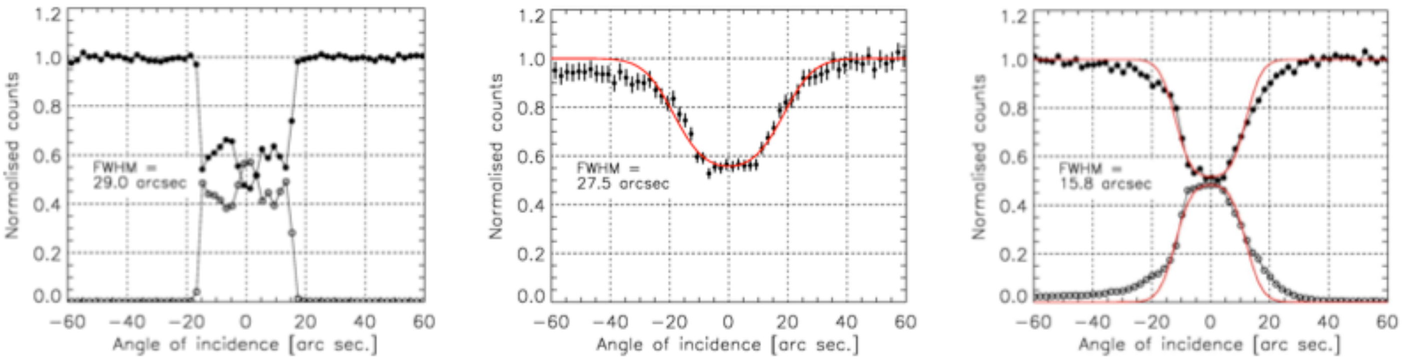

Figure 1 : Left: RC of a 23 mm thick SiGe gradient crystal measured at 300 keV (reflection 111). Center: RC of a 8.6 mm thick Cu crystal (220 reflection) realized at 489 keV. Right: RC of a 2 mm thick Au crystal (reflection 111) realized at 588 keV. Applying the transmission coefficient due to the absorption through the crystal, the achieved reflectivities are respectively: 0.26, 0.24 and 0.31. Results published in [3].

With copper crystals, the aim was to check the homogeneity and the mosaicity at high energy of many samples that had already been studied at lower energy using the Hard X-ray diffractometer of the ILL monochromator group. The best samples have shown very high diffraction efficiency at 589 keV with very low mosaicity down to 13 arcsec (figure 1). This has permitted us to select crystals that will be put on a technological prototype of Laue lens, which should be ready by the end of 2008 (Financed by the French Space agency CNES, and in collaboration with Tales Alenia Space).

Development of SiGe crystals has been running since 2005 (see experimental reports of previous experiments ME 1203 and MA 173). These crystals are mainly composed of Si with an increase of Ge ratio along the growth axis ([111] in our case) that induces a continuous deformation of the lattice spacing, resulting in a curvature of the (111) planes. SiGe gradient crystals are interesting for a Laue lens because they combine high theoretical diffraction efficiency (up to 100%, disregarding the absorption through the sample) and a square-shaped rocking curve, which is good for the focusing. Planes curvature is directly related to the gradient of Ge concentration. For the Laue lens, a constant bandpass over the cross section of crystals is required, which implies to have constant gradient crystals.

The aim of the experiment was to characterise 14 pieces of 15 x 15 x 23 mm^3 designed to produce a bandpass of 30 arcsec and optimal diffraction efficiency at 300 keV, which were extracted from 3 ingots. It was the first time that ingots, large enough to extract more than 1 piece, was grown, and it has been very successful. Despite the fact that ingots were not featuring a constant gradient over their full length, the bandpass desired has been obtained in the first pieces of each ingot with a satisfying homogeneity at the scale of one piece, showing that the curvature of planes (and hence the crystal bandpass) can be controlled very precisely. The next step in this iterative development process will be to grow larger crystals with constant gradient, which seems on a good way seeing our last measurements.

Finally we characterised a 2 mm thick gold mosaic crystal at 400, 500 and 600 keV, which revealed to be excellent with a good homogeneity, a mosaicity around 15 arcsec, and a very good reflectivity (figure 1). The aim was to establish a first diagnostic of the mosaicity of gold crystals as produced by a company. This high Z material presents a very high diffraction power (structure factor divided by elementary cell volume, [3]) much more interesting in term of performance and mass, than copper crystals for energies above 600 keV. These first measures have been very encouraging, and have prodded our collaboration to purchase other high Z crystals like silver and platinum.

This experiment allowed us to realize systematic tests on many Cu crystals at energies adapted to the thickness of each sample, between 300 keV and 600 keV. We are now confident that Cu crystals are ready to be used on a Laue lens. First attempt of growing large ingots of SiGe with a constant gradient of Ge concentration revealed to be a half-success with very good quality samples despite a varying gradient. Finally, the path towards high diffraction power crystals for high energies is now open with the excellent results we got with gold crystal.

References

[1] Barrière et al., *proc. SPIE* **6688**, pp.66880O (2007)
[2] Knödlseder et al., *proc SPIE* **6688**, pp. 668806 (2007),
[3] Barrière et al., Nuclear Instruments and Methods in Physics Research A (2008), in press