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The LAUE project: latest developments

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Abstract. We present the status of the LAUE project devoted to develop a technology for building long focal length Laue lenses for hard X-/soft gamma-ray astronomy (80-600 keV). The Laue lens will be composed of bent crystals of Gallium Arsenide (GaAs, 220) and Germanium (Ge, 111), and, for the first time, the focusing property of bent crystals will be exploited for this field of applications. At the present the goal of the project is the building of a 20 m focal length Laue lens petal capable of focusing X-ray in the energy range 90-300 keV.

1. Introduction

The LAUE project, supported by the Italian Space Agency (ASI), is a follow-up of the HAXTEL project [1] and is devoted to create a technology to build a Laue lens with long focal length (20-100 m) able to focus photons in the 80-600 keV energy range, unreachable with multilayer telescopes. The experience acquired from the HAXTEL project has shown that, for focal length longer than 10 m a new assembling technique is needed. Furthermore, a new generation of crystals must be developed for Laue lenses, given that the Point Spread Function (PSF) of a flat crystal is related to the size of the crystal itself [2]. Simulations have shown that a Laue lenses made of Ge (111) bent crystals can overcome by far the sensitivity of the current X-ray astrophysics missions [3].

On the basis of these requirements, the LAUE project was conceived to face the following challenging goals:

- to realize a technology to produce a large number of diffractive crystals with high efficiency;
- to find a method for assembling the crystals and fixing them in place with high accuracy in a relatively short time.

Regarding the first item, the development of bent crystals was considered of key importance, in order to increase the reflection efficiency and to obtain a better focusing of the photons. As of the last two items in the LAUE project, an industrial accommodation study of a modular lens was included.

Concerning the second goal, in order to decrease the cumulative error budget, we decided to develop an apparatus to correctly orient and fix each crystal to the lens frame under the control of a gamma-ray beam. For the same reason, we also decided to keep the lens petal fixed and to move the gamma-ray beam parallel to the lens axis [4].

2. The project apparatus

The entire apparatus for both assembling and testing the lens was designed to be installed in the LArge Italian X-ray laboratory (LARIX) located at the Physics and Earth Sciences Department of the University of Ferrara. The laboratory includes an experimental room (LARIX A) with a 12 m long facility and an assembling facility consisting of a 100 m long tunnel. The length of the tunnel (Fig. 1) will allow to obtain a small divergence of the beam impinging on each crystal and to build Laue lenses with long focal length [4].

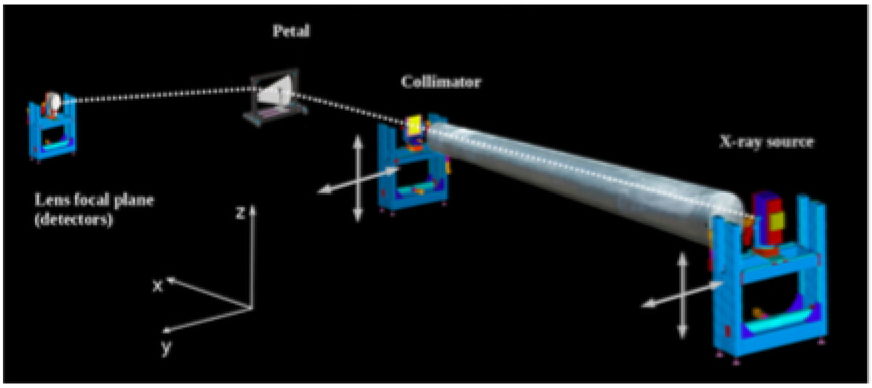

Figure 1. Layout of the LAUE apparatus at the University of Ferrara.

In the LAUE project a flat frame is used as a support for the crystal tiles composing the single petal. During the entire building phase the petal frame is kept fixed while a pencil beam of radiation is moved in front of the petal frame to mimic the presence of an astronomical gamma-ray source. The source of radiation is also directly used to control the correct positioning of the crystals. The total number of crystals that composes the designed petal is 275 and the tiles are distributed in 18 concentric ring sections [5]. Positioning each crystal with the correct diffraction angle and keeping this orientation unchanged is the most challenging phase.
The layout of the developed apparatus is shown in Figure 1, with details reported in another paper [4]. The main components of the facility are:

- A gamma-ray source produced by an X-ray tube with maximum voltage of 320 kV and a very small spot size (0.4 mm diameter) from which the photons are emitted. The source photons are mechanically collimated to get an output beam of about 20 arcmin. The source can be translated in a plane (y, z) perpendicular to the beam axis (called x axis) and tilted around axes z (vertical axis) and y (Fig. 2);
- A 21 m beam-line (60 cm inner diameter) within which the gamma-ray beam travels under vacuum to avoid absorption and scattering interactions;
- At the exit of the beam-line, a final shield of the gamma-ray beam with a square hole in the center, where a slit with the aperture defined by 4 independently movable Tungsten Carbide blades is set up (Fig. 2);
- Lens-petal frame, which is held by a pedestal that can be manually rotated and translated. It has the shape of a circular sector, 18 degree wide as seen from the lens axis;.
- A fine six-axes motorized robot (hexapod) that allows the correct positioning of each crystal tile on the lens frame under the control of the gamma-ray pencil beam. Once the diffracted photons are focused on the lens focus, the crystal tile is fixed to the lens frame (Fig. 3);
- Two focal plane detectors (a gamma-ray imager and a spectrometer), one above the other, held by a pedestal. The pedestal can be moved along the x axis using a rail oriented along

this axis. For a fixed value of x, the detectors can be translated in the (y, z) plane and rotated around each of the three axes x, y, and z (Fig. 3);

- Both the final slit and the petal frame are located in the already mentioned clean room to guarantee the crystal positioning and fixing to the lens frame under constant cleanliness and environment conditions.

Figure 2. The X-ray tube (*left*) and the Tungsten collimator (*Right*).

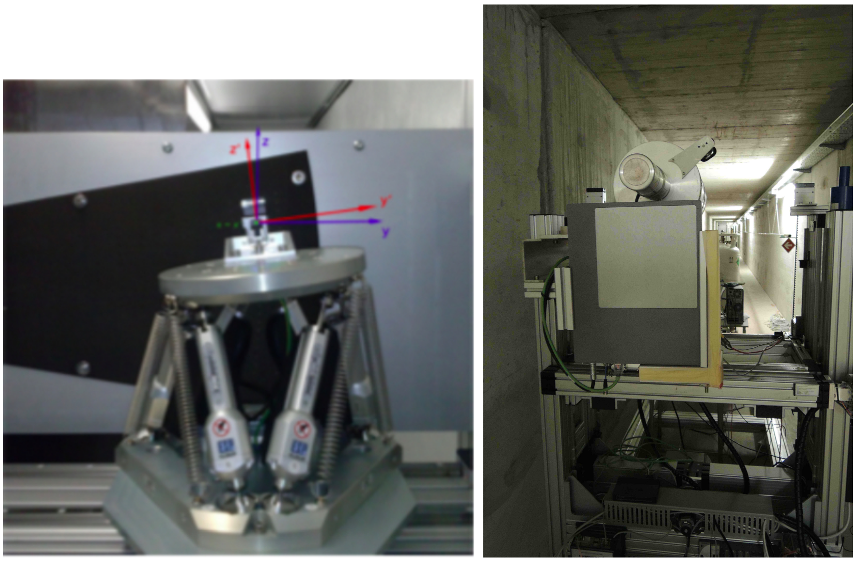

Figure 3. The hexapod system with the petal lens frame (*left*) and the X-ray detectors (*Right*).

3. Petal features and crystals selection

The lens petal is designed in such a way as to diffract photons in the 90-300 keV energy band. The upper threshold is due to the maximum energy of the photons available with the X-ray tube adopted. The lens petal passband is defined by the inner and outer radius of the lens petal.

The crystals will be positioned and glued on the frame so that to focus the diffracted beam at a distance of 20 m. The width of the designed lens petal subtends an angle of 18°. It is being covered with bent crystal tiles of Ge (111) and GaAs (220) as shown in Figure 4.

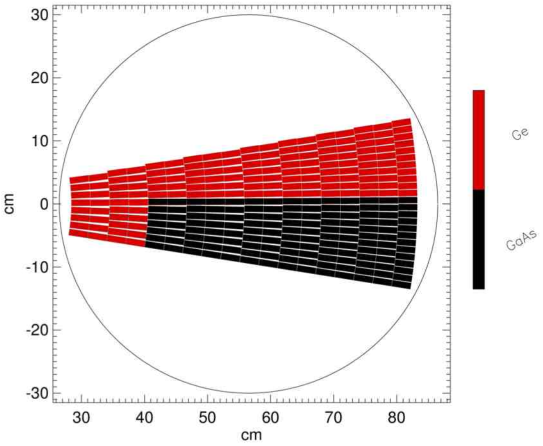

Figure 4. The upper part of the petal (*red*) will be filled with Ge (111) tiles while the bottom part (*black*) will be filled with GaAs (220) tiles.

The crystal tile size of both crystal types as required for the Laue project is 30 x 10 mm^2, with a thickness of 2 mm (Fig. 5). For the lens petal prototype, which is being assembled, all the bent Ge (111) crystal tiles (about 150) have been provided by LSS (Sensor and Semiconductor Laboratory of Ferrara) with a nominal angular spread of 4 arcsec. A self-standing uniform spherical curvature of perfect crystals has been achieved by making indentation on the main external surface of the crystal. The produced grooves yield an external curvature (primary curvature) which for some crystallographic orientations, induces a quasi-mosaic (QM) deformation of the internal diffracting planes [6]. The curvature is preliminary measured by the LSS staff by means of a profilometer, obtaining a curvature radius of about 40m.
IMEM (Istituto dei Materiali per l' Elettronica ed il Magnetismo) has supplied bent crystal tiles of GaAs (220). The bending technique adopted in this case relies instead on a controlled surface damaging, obtained by means of a mechanical lapping process on one side of the sample [7].

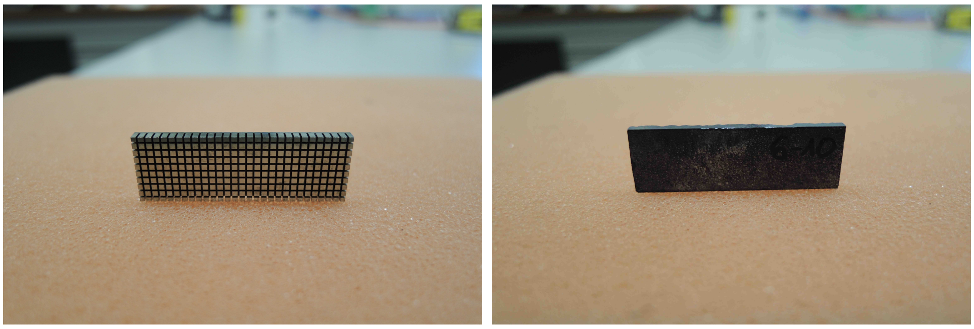

Figure 5. Ge (111) crystal tile (*Left*) and GaAs (220) crystal tile (*Right*).

4. Last results of the project

Various different methods to set the crystals at the correct diffraction angle have been considered. All the procedures were based on setting the crystals over a frame and the match between crystal and substrate was made with a structural adhesive. The most critical effect while positioning a crystal is the rotation around the z axis. Once the crystal is positioned, the curing process induces a differential adhesive shrinkage that results in a non negligible tilt around that axis. The petal frame is a 2 mm thick carbon fiber with an hole for each crystal. The procedure foresees the coupling between the tile and the support by injecting the adhesive through the hole, with the crystal set at the correct position. The crystal tile is positioned in such a way to have the diffracted image barycentre in the center of the detector. After 60 minutes from the glue injection and at regular time intervals thereafter, the focused point is monitored with an optical camera (Fig. 6).

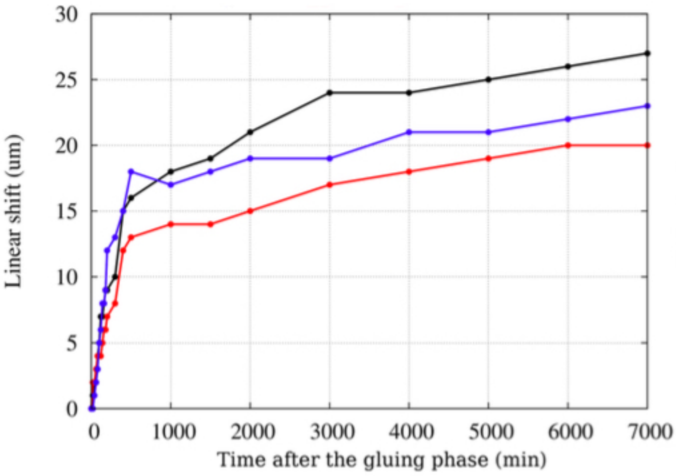

Figure 6. Linear shift, as a function of time, of a glued crystal obtained with the optical camera.

As shown in Figure 6 the total shift (20-25 μm) corresponds to a combination of rotation and translation of the crystal caused by the glue shrinkage. For the first 60 minutes the sample was set into the clamp and no motion was observed. After the release of the clamp, a common trend was observed which corresponded to a decrease of the Bragg angle. Even though the trend is monotonically decreasing for all curves, the effect is not systematic. The procedure adopted turned out to be limited for our goals due to errors introduced by the glue shrinkage which are not negligible.

A new method has been developed in order to reduce the error budget and to have a more control over the total assembling procedure (gluing + paste polymerization). It relies on the employment of a new adhesive (DYMAX OP-61-LS) which is low-shrink and allow us to control the curing by using an UV light. A new transparent support made of polymethyl methacrylate has been also adopted in order to better exploit the new curing paste. The main advantage of the UV adhesive is that the crystal tile position can be fine adjusted even if the glue has been already applied, since the polymerization is controlled by the application of the UV light.

The new technique has shown good improvements and the results obtained can be found elsewhere [8].

5. Conclusions

The latest LAUE project results are very promising for the prospects of the hard X-ray astronomical observations (up to 600 keV). The accuracy with the new adopted crystal assembling method has turned out to be what we expected, allowing the building of a Laue lens petal with a precision in the crystal positioning of 15-20 arcsec. The new generation of bent crystals Ge (111) and GaAS (220) have shown good results in terms of curvature, efficiency and focusing capability, and represent good candidates for an astrophysics mission based on a Laue lens. After a preliminary study of adhesives, the new UV curing paste showed be satisfactory and is a perfect candidate to fulfill the requirement of a short polymerization time and a good positioning accuracy (15-20 arcsec). Improvements in the mounting process chain are still possible.

5.1. Acknowledgments

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