Thin and Flexible Germanium Plate-like Crystals for Negative Particles Channeling

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INTRODUCTION

Charged particle beams can be efficiently steered by using silicon and germanium bent crystals [1,2] and only very recently sub-GeV electron beams have been observed to be deflected by planar channeling and volume reflection within curved crystal planes of <211> silicon [3]. Bending of a plate-like crystal with this crystallographic orientation generates the quasimosaic effect, resulting in a secondary bending of the planes (111) lying in the crystal thickness. Those planes can be exploited to channel and steer energetic negative particles, provided that crystal thickness is lower or comparable with dechanneling length.

The MAinz MItrotron (MAMI) facility at the Institut für Kernphysik of Mainz University can provide an electron beam (size 200×400 µm) with 855 MeV in energy and it has been used to perform the very first tests on channeling of sub-GeV negative particles through bent silicon plates. In this condition, the dechanneling length has been calculated to be about 16.5 µm for the case of {111} flat crystal planes [3]. On the other hand, negative particles in the sub-GeV range have been demonstrated to undergo rechanneling phenomena thus leading to longer dechanneling lengths than those calculated neglecting this contribution [3], as recently proved by the excellent results in deflection efficiency collected using a bent silicon crystal 30.5 ± 0.5 µm thick. The case of germanium is even more critical to deal with: the dechanneling length is much shorter, owing to the almost double atomic number with respect to silicon, and numerical calculation leads to the value 11.5 µm [4], without considering rechanneling. Still another challenging aspect is the bending of such a thin plate-like crystal avoiding breakage and generation of unwanted torsions, which cause unpredictable changes in local curvature.

In this report we describe the more recent developments adopted to produce a thin germanium plate with thickness around 13 µm, mounted on a mechanical holder and bent without torsions down to a curvature radius of 15 mm.

EXPERIMENTAL

Germanium crystals with very low thickness have been produced recently [4,5,6] by all-chemical fabrication methods. Starting from a Ge <211> wafer 64 ± 5 µm thick (Umicore, Belgium), several small rectangular slabs 13×15 mm in size have been obtained without using mechanical dicing methods. Thinning procedures using etching bath called HP20 composed of H2O2 (27%), HF (50%) and H2O (bidistilled) (20:20:60, volume ratio) have been applied firstly to reach the ultimate thickness of 15 µm. The crystal was fixed to the mechanical holder and thinned down to the desired thickness “on-board”, in order to avoid handling of too thin material. The etch rate with above composition was 3.6 ± 0.1 µm/min and it allowed to perform the treatment using manual stirring in a reasonable time. Unfortunately, the manual movement is not constant and the obtained plate-like crystal displayed severe lack in thickness homogeneity, with thickness variations higher than 20% over few mm.

Hence, a different approach was attempted: as a first step the plate was thinned inside a rotating bottle, with 400 ml of HP3 solution H2O2 : HF : H2O 3:3:94 volume ratio, with etch rate of 0.75 ± 0.01 µm/min. In figure 1 there is a scheme of the used set-up.

![Fig. 1. The “rotating bottle” set-up for first etch step (left) and the thinned Ge pad fixed on the steel pins, ready for the final etch step (right).](image)

The Ge crystal is removed carefully from the bottle, rinsed gently and set on the steel pins (figure 1, right), where a double sided Kapton tape strips will hold it firmly in place. In the final etch step, which lasts about 7 min, the same HP3 solution is used, but the sample is moved during etching by a software controlled motorized system (Micos).

The crystal thickness has been measured by high resolution X-ray diffraction (HR-XRD, Xpert model PANalytica) exploiting the attenuation of X-rays passing through germanium, as described by the Beer-Lambert law:

\[ I = I_0 e^{-\mu x} \]

where \( \mu \) is the attenuation coefficient of Ge at the selected
X-ray wavelength, which must be known with great accuracy, and \( x \) is the sample thickness. Therefore, precise measurement of X-ray beam intensity after passing through germanium allows to determine the sample thickness.

**RESULTS AND DISCUSSION**

The application of the “rotating-bottle” system proved to be highly reproducible, as for both removal rate and surface smoothness. In figure 2 is reported a photo of the sample after the final thinning and the X-ray map of the thickness distribution across a wide plate area.

![Figure 2](image1.png)

Fig. 2. Photo of thinned Ge plate-like crystal (left) and X-ray map of crystal thickness as evaluated on a wide central area 5×12 mm in size (right).

The sample is about 13 µm thick and thickness variation on the scanned 5×12 mm central area can be easily appreciated by color changes: very small variations, around 0.2 µm are observed for wide regions, much larger in area than the spot size of MAMI electron beam.

The plate-like crystal so fabricated was then transferred to the final sample holder, equipped with manual micrometric translator to introduce the desired curvature.

![Figure 3](image2.png)

Fig. 3. 3D sketch of the used holder to allocate Ge plate (top). Photo of the holder, with indication of the most peculiar parts (bottom).

In figure 3 a sketch of the sample holder is reported, showing the micrometer translator system, the four differential screws, the sample located flat on the steel pins. A more detailed description of the system and working principle will be reported in a forthcoming paper [7]. The pins are free to rotate around their own axis, hence the micrometer driven worm pushes the pins one towards the other, thereby causing the crystal to bend, as a consequence of pins rotation. This movement can easily introduce unwanted torsions of the crystal plate, therefore four differential screws have been foreseen in order to manually act after bending to remove torsion and fully restore the pins parallelism. This process is of paramount importance to avoid severe failure in channeling phenomena as a result of crystal planes unpredictable distortions. Torsions elimination and accurate bending radius measurements have been performed by fixing the whole system on the diffractometer motorized stage and using XRD in transmission mode. A detailed description of the full apparatus and of the adopted method to deeply characterize the bent Ge crystal will be reported in ref. [7].

The plate-like germanium crystal was bent up to a curvature radius of 15 mm, much lower than that applied to silicon crystal for the recent experiments at MAMI accelerator (30 mm). The plate was able to withstand this great flexural stress without breaking, thus demonstrating enormous flexibility and elasticity, as can be appreciated by observing the photo in figure 4. This result can be pursued only by chemical methods, where the material is removed by dissolution, with no induced stress or crystal defects which can indeed act as cracks starting points or lines.

![Figure 4](image3.png)

Fig. 4. Photo of the plate-like Ge crystal fixed and bent on the holder (curvature radius is 15 mm).

**REFERENCES AND ACKNOWLEDGMENTS**

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