INTRODUCTION

Curved crystals, thanks to the electrostatic potential generated by the coherent atomic structure, may deflect ultra-relativistic charged particles by means of channelling and volume reflection effects [1,2], and are widely investigated as potential tools for beam conditioning and radiation emission applications [3,4]. Most of the experimental knowledge about these phenomena was gathered with Si crystals, though new materials has been recently proposed: Ge can improve the Si performance thanks to its higher atomic number that guarantee an higher confinement potential [5,6], while compositionally graded SiGe alloy has been investigated since of its self-bending properties [7].

In this paper we investigate an alternative material that is LiNbO3; it is a quite investigated crystal for its piezoelectric and non-linear optic properties. The potential advantages for its use in channeling applications could be twofold: i) it has a quite high z element (Nb) in its lattice that can provide strong confinement potentials. ii) its remarkable piezoelectric properties could open the way to the realization of piezo-actuated bending devices, alternatives to mechanical bending systems.

A crucial aspect for a channeling material is the crystalline perfection. As a matter of fact, while Si and Ge can be produced in a quasi-ideal perfection and reach the deflection efficiency predicted by perfect crystal theories [3,4,8], SiGe alloy of Ref. [7] has a non-ideal behavior with a channeling efficiency reduction from the predicted 76.5 % of the perfect crystal case to the measured 62.5 %. This was ascribed to the presence of few dislocations 10^2 cm^-2 dislocations, in the lattice.

In this paper we investigate commercial available LiNbO3 materials prepared in the form of mechanically bent strips to deflect 400 GeV protons provided by SPS-H8 CERN beam line. As many other single crystal materials with the exception of Si and Ge, LiNbO3 has more than 10^1 cm^-2 dislocations, this will allow us to test in more detail the effect of dislocations on channeling performances and at the same time, to check the applicability of LiNbO3 to this field.

EXPERIMENTAL

LiNbO3 is a trigonal crystal where 3 conventional orthogonal direction (X, Y, Z) identify 3 different kind of planes. Channeling tests performed at low energy (2 MeV proton beam provided by AN2000 accelerators of LNL) allowed to asses that the lattice plane orthogonal to the Y direction give the maximum channeling efficiency and minimum dechannelling with respect to the others. In order to produce a Y bent plane for relativistic beam deflection experiment we proceed as follows. Commercially 1 mm thick LiNbO3 wafers with Z plane on the main surfaces was purchased by Crystal. Tech. Inch. and diced in 0.5 mm strips along the X direction (other strips with analogous results was produced by Roditi wafers). The strips were bent by standard mechanical bender that gives a primary curvature around the Z axis. In this way the Y plane undergoes an anticlastic curvature that is exploited in the channeling experiments. This manufacturing procedure allows to use the original surfaces of the wafer as beam incoming and out-coming faces. The lateral faces are damaged by the dicing procedure. X-ray diffraction analysis allows to establish that there is a about 50 micron deep damaged region below those surfaces. Those crystal portions will not be considered by the analysis of the channeling data.

In order to evaluate the dislocation density, etch pits density measurement was performed by etching the surface in HF:HNO3 1:2 solution and by counting the hillocks on optical microscope images.

Channeling experiment was performed at SPS – H8 CERN beam line with the same experimental apparatus described in references [5-7]. A goniometric apparatus allows to precisely adjust the crystal with respect to the beam with 1 μrad precision and a telescope system allows to trace the trajectory of each particles before and after its interaction with the crystal.
RESULTS AND DISCUSSION

In Fig. 1 an optical image on the Z surface etched for 40 minutes is shown. Triangular structures due to the presence of dislocation are clearly visible. Counting the features on several photos allows to estimate a dislocation density of about $10^4 \, \text{cm}^{-2}$.

In Fig. 2 the 400 GeV channeling data are reported. The x-axis is the angle between the beam and the plane direction at the entrance of the crystal strip, y-axis reports the deflection angle of the particle after the interaction with the crystal. All the typical feature of beam interaction with bent crystals are visible: i) at negative incident angle particles are symmetrically scattered since no coherent interaction occurs. ii) at positive angle most of the particles are slightly deflected due to volume reflection interaction that occurs when the beam trajectory becomes tangent to the bent crystalline plane. iii) around the zero angle (beam aligned to the Y-planes inside the critical angle) a spot at about 180 $\mu$rad deflection appears; this is due the particles that are trapped into channeling and follow the lattice curvature all along their trajectory into the crystal; part of these particles lose their confinement along the path due to dechanneling and populate the histogram tail between the channeling spot and the 0° deflection zone.

From these data it is possible to extract fundamental physical quantities describing the particle-crystal interaction. Channeling deflection peak is at 183 $\mu$rad and involves 2.5 % of the particles. The deflection is in agreement with the 5.4 m anticlastic bending radius and 1mm thickness of the strip. The efficiency is quite low if compared with the efficiency that would have Si (66%) [8] and Ge (72 %) [6] with the same curvature. By exponential fit of the dechanneling tail it is possible to determine the dechanneling length that results 0.35 mm, about 4 time shorter than the nuclear dechanneling length measured in Silicon [9]. This strongly suggest that the dechanneling in LiNbO₃ is largely dominated by interaction with defects.

The parameters regarding volume reflection are better. Volume deflection angle is 9.7 $\mu$rad with an efficiency of 86.5 %. For comparison a Si crystal with a similar curvature would have a deflection of 11.7 $\mu$rad and a deflection efficiency of 97.5 % [2].

In conclusion the detrimental effect of dislocations on channeling efficiency is largely demonstrated. Very interestingly, the effect is much weaker on Volume Reflection (VR), this is probably due to the fact that the VR deflection acts on a more local scale of the trajectory i.e. around the tangent point, and therefore the probability of particles interaction with the defects is reduced. In general LiNbO₃ can not be used for application in high energy beam deflection without a strong improvement on the starting crystal quality in term of defect density. We can also conclude that the same hold true also for other available single crystal i.e. III-V semiconductors or LiTaO₃ that have in general more than $10^3 \, \text{cm}^{-2}$ dislocation density.