# Progress on dynamic structural lattice modulation of single crystals for CLS applications

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The development of Crystal-based Light Sources (CLS) for the generation of brilliant γ-ray sources by exposing properly prepared crystal lattices to ultra-relativistic charged particle beams is a promising emergent field that is expected to open up radically new possibilities in various technological and scientific fields [1]-[2][3]. Crystalline Undulators (CUs) have attracted interest due to their technological feasibility and wide range of diverse implementations [1]-[5]. Currently, charged particle undulation is achieved by using strong periodic magnetic fields, which are commonly produced by expensive and large magnets in setups called Free Electron Lasers (FELs), commonly housed in large laboratories [6].

CUs are novel devices that take advantage of the remarkably high electric fields present in crystal lattices to induce undulation in ultra-relativistic $e^-/e^+$ or charged hadron beams. These electric fields can attain strengths of up to $10^{10}\mathrm{V/cm}$, an equivalent of 3000 T, that are significantly larger than the maximum of 10 T magnetic fields found in typical magnet undulators [2]. In CUs, undulation is induced by sinusoidal-like modulation of the lattice geometry, which can be done either statically, via structural deformation methods such as periodic mechanical stress, grooving, epitaxially-grown superlattices [1]-[2][7]-[8], or dynamically, through e.g. the launch of acoustic waves inside the crystal [9]. In the latter case, the enforced sinusoidal-like modulation of the lattice planes can cause the charged particles to follow sinusoidal-like trajectories, resulting in the emission of γ-ray photons with energies of up to several tens of MeV [2].

In this work, we present the ongoing progress on the development of acoustic wave (AW) CUs. AW CUs are among the least studied γ-ray CLS due to the challenging technicalities in their design, which are mainly related to the difficulty in the accurate control and characterisation of proper acoustic waves inside crystalline materials. Nevertheless, AW CUs are very promising as they can lead to tunable devices regarding both the period and amplitude of the lattice modulation, which is crucial for the technology development, i.e. for experimental optimization, but also in the intended applications. Moreover, compared to static lattice modulation techniques, e.g. mechanical bending, AW CUs allow for a large number of undulation periods to be induced inside the crystal, which is expected to lead to an important increase in the intensity of the emitted undulation γ-ray spectral peaks, for the case of charged particle channeling. The mentioned difficulties and potential benefits of the successful development of AW CUs render the presented project a high-risk high-gain scientific venture.

More specifically, in this work novel AW CU schemes will be presented for the generation of longitudinal waves inside Silicon [9] and Germanium monocrystals based on a typical Acousto-Optic Modulator (AOM) design. AOMs are implemented in either standing or travelling wave designs. Here, it will be argued that under real experimental conditions for the generation of semi-coherent brilliant narrowband γ-rays, travelling wave designs exhibit significant advantages over standing wave implementations. For this purpose, two different excitation methods will be investigated, particularly the well-established piezoelectric acoustic wave excitation and the recently proposed [10] laser-based excitation with the use of thin metallic film photoacoustic transducers. Results from Finite Element Method (FEM) simulations for the evaluation of the dynamic lattice deformations induced in the different proposed schemes for the undulation of ultra-relativistic beams will also be presented and discussed.

Accurate diagnostic schemes based on imaging laser interferometry and laser Bragg diffraction for the precise characterisation of the acoustic waves and crystal lattice modulation will also be discussed. Finally, future work and a roadmap for the construction, characterisation and actual evaluation of the AW CUs in particle accelerator facilities will be outlined.

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