PhD 2024-2027

Physics, Condensed Matter, Nanosciences a Nanotechnologies

Laboratory: Centre Interdisciplinaire de Nanoscience de Marseille, CINaM

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Title: Ferroelectricity and electrons-phonons dynamics in epitaxial chalcogenides
Keywords: ferroelectricity, photostrictive effects, GeTe, WTe_2, epitaxy, time-resolved X-ray diffraction, THz spectroscopy

Context: Using light pulses provide a powerful tool for controlling complex systems on ultra-short timescales and for probing the fundamental properties of solid state materials. This PhD aims at studying the light-induced mechanical stress of ferroelectric chalcogenides thin films with sub-nanosecond time resolution. To study these photostrictive effects and their temporal dynamics, time-resolved x-ray diffraction is a powerful tool. By analysing the dynamics of shear and longitudinal strain components measured by x-ray diffraction, the contribution of thermal and non-thermal processes resulting from the photoexcitation of charge carriers can be obtained. A close comparison with High Harmonic generation resulting from light pulses should provide a better understanding of charge carrier transport properties in this class of materials and open new routes in the field of THz generation.

Description: Due to their use as functional materials, **ferroelectric thin films are the subject of extensive research**. Complex ferroelectric structures have been evidenced, e.g. vortices [1,2], flux-closure polar domains [3-5] and even skyrmions [6]. **These structures result from the combined effects of mechanical stress** induced by the substrate and electrostatic boundary conditions at ferroelectric domain walls. The control of such structures may be achieved by light. Indeed ferroelectric materials is a subclass of piezoelectrics and when light hits a ferroelectric material, the energy carried by light may be converted in a mechanical stress that can modify the ferroelectric polarization state. This so-called **photostrictive** effect is therefore very appealing, as it provides a clue for studying ferroelectric fundamental properties, e.g. the ferroelectric-paraelectric phase transition.

Among ferroelectrics, ferroelectric Rashba semiconductors are a novel class of materials with strong potential for spintronic applications [7-10]. Seminal works have been obtained on GeTe thin films, however many questions remain concerning the possibility of switching the GeTe polarization state with an electric field due to its conductive character (small gap: 0.6 eV). In that perspective it is proposed to tune the ferroelectric polarization state with light. It has been shown by optical pump-probe experiments that the photoexcitation process may result in the supersonic diffusion of a photoexcited electron-hole plasma that transport energy much faster than lattice heat diffusion [11]. However even though these photoexcited carriers are suspected to modify the interatomic potentials in a non-thermal way, the light-induced strain field (longitudinal and shear) and change of ferroelectric polarization have been disregarded. To decipher the different contributions in the GeTe ferroelectric dynamics (strain field

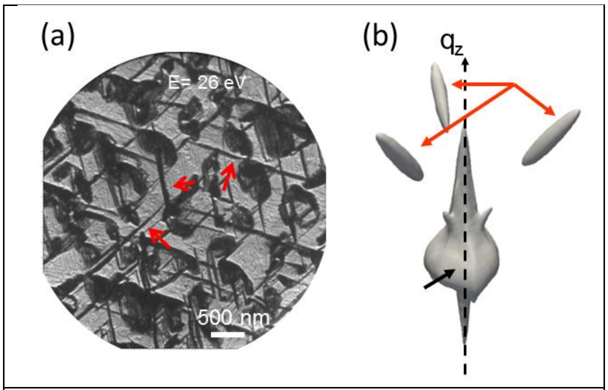

Fig. (a) Low Energy Electron Microscopy image of the surface of GeTe thin film grown on Si(111). (b) Corresponding 3D reciprocal space map around GeTe $(222)_c$ (iso-intensity surface) for a 60 nm-thick film).

components, polarization, Debye-Waller factor) the use of time-resolved x-ray diffraction on single crystalline thin film is crucial.

The aims of this PhD are therefore (i) to grow chalcogenide thin films by Molecular Beam Epitaxy on well-defined substrates; (ii) to investigate the ferroelectric state of the thin films by scanning electron microscopy, transmission electron microscopy and low energy electron microscopy and (iii) to address the strain field and the ferroelectric polarization state in the sub-nanosecond range by time-resolved x-ray diffraction. The PhD will focus first on the growth of GeTe thin films [12-14] and the characterization of ferroelectric polarization. The time-resolved x-ray diffraction experiments will be performed in close collaboration with LP3 lab (Laser Plasma et Procédés Photoniques) at the ASUR plateform on Luminy campus as well as at the ID9 beamline of the European Synchrotron Research Facility (ESRF, Grenoble). This study is part of the AMIDEX project "INDIGENA" and will be carried out in close collaboration with condensed matter theoreticians and with THz spectroscopy experimentalists.

Candidate profile: The candidate must hold, by July 2024, a Master degree in physics, nanoscience, or any equivalent diploma. **A Highly motivated candidate** in experimental physics with a solid background in condensed matter physics/nanophysics is forseen.

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