Master – M2

PROPOSAL FOR AN INTERNSHIP: Academic Year 2020-2021

Laboratory: ***IM2NP*** UMR 7334 CNRS – AMU – Université de Toulon and ***LP3***, UMR 7341 CNRS-AMU
City, Country: ***Marseille, France***

Title of the Internship: Inducing and probing phase transition by laser in Ge:Te:Sb materials

Internship Supervision: M. Putero/P. Hans/O. Thomas – *IM2NP* and O. Utéza/M. Sentis – *LP3*
Email address (to contact us and apply): Olivier.thomas@im2np.fr, magali.putero@im2np.fr, philipp.hans@im2np.fr, sentis@lp3.univ-mrs.fr, uteza@lp3.univ-mrs.fr
Mail address:
- IM2NP, Faculté des Sciences de Saint Jérôme - Case 142, Avenue Escadrille Normandie Niemen, F-13397 Marseille Cedex 20
- LP3, Case 917, 163, Avenue de Luminy, 13288 Marseille cedex 09

Summary of the subject (maximum 1 page):

1. Scientific context:

Femtosecond lasers are extremely agile tools for inducing and reading movements of matter at the electron-phonon coupling time and atomic space scale uncovering vibrations and rotations in molecules, liquids or atomic motion in crystalline and amorphous solids [1,2]. In particular, they have been successfully applied to the triggering and thorough investigation of phase transitions of various solids even at the (sub)-picosecond (and above) time scale [2-5]. Importantly, knowledge and control of those abrupt laser-induced structural changes in materials would pave the way to fascinating applications including ultrafast (> THz) optical switching, data storage, and new laser-functionalized materials for opto-electronics, photonics or energy harvesting. Basically, those changes are induced by generating swiftly in the material with the help of an ultrashort pulse an extremely high electronic pressure related to the formation of a dense over-critical electron-hole plasma in the focal volume followed by electron recombination, transport and dissipative coupling to the lattice of the material. Such fast energy deposition (high transient electronic pressure) and fast energy cooling are both energetically favourable to implement exotic phase transitions in materials, some of them having been observed experimentally for the first-time using femtosecond lasers [6].

In this context, IM2NP and LP3 labs propose to combine their capabilities and efforts (see section 2) for exploring and studying phase transitions in a multi-compound phase change material (Ge:Te:Sb), fabricated by ST Microelectronics. This material is being heavily studied for the fabrication of Phase Change Memories (PCM) that are among the most mature non-volatile emerging memories to allow data storage at high programing speed with enhanced endurance compared to today Flash technology. PCM are based on the reversible transition of the so-called phase change material between a high resistance/low reflectivity amorphous state and a low resistance/high reflectivity crystalline state [7]. In the devices the transition is triggered by an electric current flowing in the small memory cell (50 nm). While the transition in the cells occurs at ns scale [8], structural studies (X-ray diffraction, Electron Microscopy …) are limited to much longer time scales [9]. The aim of this particular study is

to investigate the transition at timescales akin to the functioning of real devices using laser heating. This will certainly bring completely new results on the kinetics of the transition as well as on the resulting microstructure. In addition, fast laser heating may enable us to investigate the behavior of the material after a large number of transitions. The endurance of the material is also key to its implementation in future devices.

2. Description of works:

Samples are prepared at STMicroelectronics. The student will be in charge of characterization of the samples microstructure before and after crystallization/amorphization in IM2NP lab. SEM will be performed at CP2M platform.
The student will then operate (and if needed upgrade) a laser-matter interaction test-bench (available in LP3 lab) able to support ultrashort pulse duration (≤ 25 fs) in view of irradiating the material with well-controlled levels of fluence below and above the laser-induced damage threshold of the material. In particular, the motivation will be to determine the laser energy dose required to induce phase transition in the material which will be set in evidence and characterized using post-mortem diagnostics (IM2NP characterization platform).
The following step will consist in upgrading an optical setup to develop an in – situ optical pump – probe experiments in which imprint and initial optical characterization of the phase transition will be revealed using reflectivity measurements. Finally, depending on the progress of the experiment and of laser research in ASUR platform, the student will participate to preliminary pump-probe experiment using X-ray probe in the context of static and time-resolved X- for direct characterization of the details of the laser-induced phase transition in the sample at different time scales.

To carry out the research and development, the student will share his/her time in both IM2NP (preparation and characterization of samples) and LP3 lab (use of the ASUR laser platform for optical benchmarking of laser-induced phase transitions). Note that ASUR is a highly advanced ultrashort TW laser source (800 nm, 10/20 TW, 25 fs nominal, < 15 fs available, OPA fs: UV – IR) proposing secondary source generation (X-ray pulsed source @ 17.5 keV), laser-induced damage test bench, material structuration test-bench and time-resolved diagnostics of matter interaction. Advanced diagnostics tools for matter characterization are available in both IM2NP and LP3 labs: AFM, SEM, optical microscopy, confocal and Raman. Additional X-ray diffraction experiments may also be performed using a synchrotron source if time permits and if beam time is granted.

[1] M. Bargheer, N. Zhavoronkov, M. Woerner, and T. Elsaesser, Recent Progress in Ultrafast X-ray Diffraction, *ChemPhysChem* 7, 783 – 792, 2006.
[2] C. Rischel et al., Femtosecond time-resolved X-ray diffraction from laser-heated organic films, *Nature* 390, 490 – 492, 1997.
[3] W. Gawelda, J. Siegel, C.N. Afonso, V. Plausinaitiene, A. Abrutis, and C. Wiemer, Dynamics of laser-induced phase switching in GeTe films, *J. of Applied Physics* (109)12, p.123102, 2011.
[4] D. Boschetto et al., Small Atomic Displacements Recorded in Bismuth by the Optical Reflectivity of Femtosecond Laser-Pulse Excitations, *Phys. Rev. Lett.* 100, 027404, 2008.
[5] O.P. Utéza, E.G. Gamaly, A.V. Rode, M. Samoc, B. Luther-Davies, Gallium transformation under femtosecond laser excitation: Phase coexistence and incomplete melting, *Phys. Rev. B* 70, 054108, 2004.
[6] L. Rapp et al., Experimental evidence of new tetragonal polymorphs of silicon formed through ultrafast laser-induced confined microexplosion, *Nature Communications* 6, 7555, 2015.
[7] P. Noé, C. Vallée, F. Hippert, F. Fillot, and J.-Y. Raty, Semicond. Sci. Technol. 33, 13002 (2018)
[8] D. Loke, T.H. Lee, W.J. Wang, L.P. Shi, R. Zhao, Y.C. Yeo, T.C. Chong, and S.R. Elliott, Sci. Mag 336, 1566 (2012)
[9] M. Gallard, M.S. Amara, M. Putero, N. Burle, M. Richard, C. Mocuta, C. Guichet, O. Thomas, R.R. Chahine, M. Bernard, P. Kowalczyk, P. Noé, and O. Thomas, Acta Mater. 191, 60 (2020)

Keywords: phase change materials, femtosecond laser, damage, optics, physics of solids.

Additional information:
* *Required skills*: Optics and lasers, physics of solids, physics of plasmas, material sciences; and preferably, you are an experimentalist, enthusiast and happy to work in a collaborative framework with your time shared in two small lab groups focused on a stunning research objective.
* Miscellaneous: internship allowance (“gratification”) of approx. 590 €/month.

The research will take place in IM2NP (Campus of Saint-Jérôme, https://www.im2np.fr/fr/accueil) and LP3 (Campus of Luminy, www.lp3.univ-mrs.fr) in breathtaking locations of Marseille.