I. Physikalisches Institut (IA)
Phasenwechselmaterialien
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Topic for a Bachelor or Master Thesis

Understanding Ultrafast Carrier and Phonon Dynamics in Plasmonic PCMs

Phase change materials (PCMs) are solid materials which occur in two different stable phases, namely the disordered amorphous phase and the ordered crystalline phase. A tremendous contrast in the electrical and optical properties of the two phases can be observed. For most of these PCMs this property change can be explained by a transformation of the chemical bonding upon crystallization: while the amorphous phase is covalently bonded, the crystalline phase employs an unconventional bonding mechanism, which differs from covalent, ionic and metallic bonding, denoted as metavalent bonding. However, there are also PCMs that exhibit metallic behavior in their crystalline phase. This allows switching back and forth between a metal and a semiconductor. An application of these unique properties is a programmable nanophotonics material platform, where resonant metallic nanostructures can be directly written, modified and erased on and below the meta-atom level in a thin film sample [1].

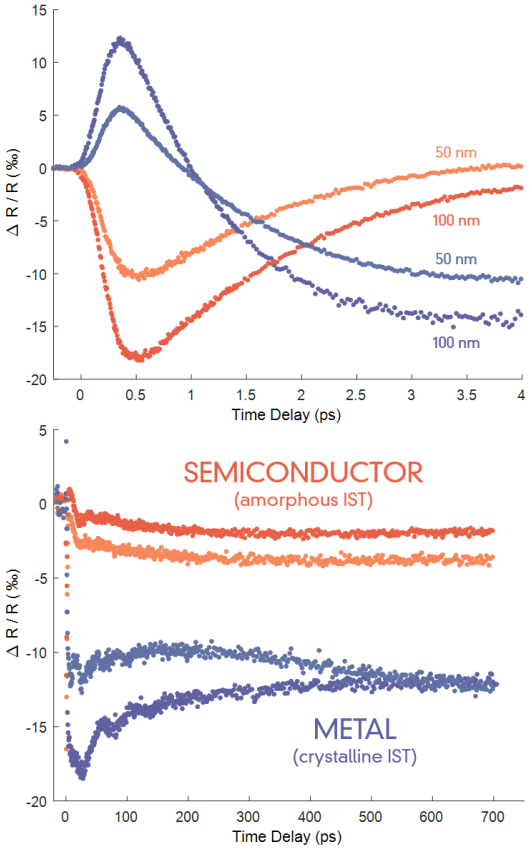

Figure 1. Time-resolved reflectivity of amorphous (red) and crystalline (blue) thin-film samples of the PCM In_3SbTe_2 (IST) on timescales of a few picoseconds (top) and on the order of a nanosecond (bottom).

To better understand the change in the bonding mechanism, the lattice dynamics of the two phases are studied on an fs time scale. For this purpose, transient reflectivity measurements are performed. An intense 800 nm pump-pulse irradiates the sample, while a weaker tunable probe-pulse is delayed relative to the pump-pulse to characterize the samples time dependent reflectivity. The preceding processes are well understood for standard semiconductors on different time scales [2]. After photoexcitation, there is an initial electronic response on a 10^{-14} s time scale. As time evolves the hot carriers lose their excess kinetic energy while attempting to reach thermal equilibrium with the lattice through optical phonon scattering on a 10^{-12} s time scale. The optical phonons subsequently couple to acoustic phonons and overlap with Auger recombination processes on a 10^{-11} - 10^{-10} s time scale. Ultimately, the bulk lattice heats up on a 10^{-9} - 10^{-8} s time scale [2].

In this work, these processes will be investigated on the mentioned time scales on amorphous and crystalline PCMs of different bonding mechanisms. How do the processes change during the transition from semiconductor to metal? Do amorphous PCMs behave differently than standard semiconductors such as GaAs, with respect to these processes? Does the metavalent bond type show unique properties here as well? For this purpose, pump probe reflectivity measurements at the fs-Laser-Setup are combined with Multiphysics Simulations. Measurement data of the distinct phases on different time scales are shown as an example in Figure 1.

Thus, a wide range of tasks awaits you, including characterization of the samples by X-ray diffraction, measurement of the samples by optical ultrashort pulse pump probe technique, evaluation of the measured data, as well as performing and comparing with Multiphysics Simulations.

[1] Heßler, Andreas, et al. "In3SbTe2 as a programmable nanophotonics material platform for the infrared." Nature communications 12.1 (2021): 1-10.
[2] Othonos, Andreas. "Probing ultrafast carrier and phonon dynamics in semiconductors." Journal of applied physics 83.4 (1998): 1789-1830.

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