Pump-probe Reflectivity Studies of Ultrashort Laser-induced Acoustic Strains in Layered Materials

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In the present work the implementation of an experimental optical pump-probe set-up, based on ultrasonic acoustic wave generation and detection by laser pulses is demonstrated. The generated acoustic strains are of several tens of femtoseconds duration and are applied to the characterization of nanostructured layered targets and processes of high scientific and technological interest. For the proposed pump-probe experiments the output pulses of a Ti: Sapphire amplifier system at 800 nm, with duration ~30 fs, energy per pulse ~1 mJ and repetition rate of 1 kHz are used.

Due to the interaction with the target material, the pump beam generates a longitudinal acoustic wave that propagates perpendicular to the target surface. The probe beam focuses on the target after a variable delay relative to the pump beam, which is introduced through a controlled change in the optical path of the probe beam. Part of the probe beam is reflected by the propagating mechanical distortion and therefore changes in the reflectivity signal are observed. These changes in reflectivity are related to the dynamic behavior of the elastic wave propagation, and consequently to the dynamics of the material as it returns to its equilibrium state after experiencing the mechanical deformation. More specifically, with the present method the Brillouin scattering of the probe photons by the acoustic phonons can be detected and conclusions about the physical properties of the materials under study can be drawn.

The materials studied are in the form of thin films of thicknesses of a few tens to hundreds of nanometers. The films are covered with thin metal coatings such as gold (Au) or titanium (Ti) of tens of nanometers thickness (10-30 nm). The metal coatings play the role of the optoacoustic transducer, that is, in the coating the conversion of the optical energy absorbed by the metal, into an acoustic wave takes place. Results are presented for materials of high technological interest for industrial applications, such as solar cells, nanoelectronics, converters and sound absorbers, touch screens, sensors, etc. Such materials like silicon Si, but also complex semiconductors like ZnO, constitute the building blocks of semiconductor systems. With the method presented, properties of the materials such as: acoustic impedance, velocity of sound, elasticity, etc. can be determined with very high accuracy. The future goal of the project is the development of a standard workstation in IPPL for the rapid and reliable investigation of materials with high technological impact.

The experimental results are validated by numerical results of thermomechanical analysis, using the finite element method. The method simulates the mechanism of acoustic wave generation after absorption of optical energy from the material, taking into account the transfer of energy from non-thermal electrons to thermal electrons and then from the thermal electron cloud to the crystal lattice. Thus, characteristics such as space-time distribution, intensity and speed of propagation of the acoustic wave, as well as displacement and temperature of the crystal lattice can be calculated with extremely high accuracy and can be compared with the experimental findings.

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