Observation and optimization of laser-induced structural transitions in band-gap materials

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Ultrafast laser technology has emerged as a feasible method to perform advanced processing of band-gap materials. The additional possibility of programmable temporal tailoring of laser pulse intensity envelopes creates the premises to upgrade the degree of process control. The concept of optimizing laser interactions is based on the possibility to regulate in a synergetic manner the energy delivery rate so that control of laser-induced processes can be achieved. We will discuss several cases of materials excited by temporally tailored ultrafast laser radiation including semiconductors and wide band-gap dielectrics.

The procedure allows, for example, to select thermodynamic paths in excited semiconductors leading to flexible material removal or modification. As consequence we indicate the possibility to manipulate the kinetic properties of ions emitted from ultrafast laser-irradiated semiconducting samples, using excitation sequences synchronized with the phase-transformation characteristic times. Versatile sub-keV ion beams are obtained exploiting transitions to supercritical fluid states with minimal energetic expenses.

A potential implementation of ultrafast lasers lies in the possibility to design photonic functions by structuring materials of optical interest. The strong nonlinear localization of energy induces refractive index changes that may add specific functions (light guiding, coupling, diffraction, or amplification) to compact, integrated optical devices. Nevertheless, the result of the laser action depends essentially on the nature of the material and may result in specific electronic and structural changes associated with either increasing or decreasing the refractive index under light exposure. Employing real-time phase contrast microscopy we study the formation dynamics and the resultant transient and permanent morphology of laser-induced modifications in bulk dielectric materials in different conditions of irradiation. Several interaction regimes with respect to the input energy dose can be established based on these observations, emphasizing the role of nonlinear pulse propagation and of the intrinsic material properties. The balance of the laser-induced sequence of electronic and structural transformations under modulated excitation defines the end result of the laser action. Temporal pulse shaping has the potential to achieve a high degree of process control and to design the nature of the refractive index so that guiding structures can be induced in materials that does not allow it under normal excitation conditions.

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