Short Pulse Laser Induced Phase Transitions and Ablation in Solid Materials

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Lasers represent an important technological tool for materials processing. Examples from the wide range of applications include simple cutting, drilling and welding, but also microstructuring of materials and thin film growth by pulsed laser deposition. During the last few years ultrafast laser technology has attracted increasing interest and pico- and femtosecond lasers began to move into a field dominated by long-pulse CO_2-, Nd:YAG and Excimer lasers. Further development of their technological potential requires a thorough understanding of the ultrafast laser-matter interaction which is still incomplete. The talk will give an overview of the work carried out over the last few years in our institute to clarify the fundamental physical processes typically involved in materials processing. The following examples will be discussed:

1. Thermal and non thermal melting of covalent semiconductors:

Seince the first experiments by Shank et al. in 1983 fs-laser-induced, non-thermal melting of semiconductors has been extensivley studied and attributed to an instabilty of the lattice structure in the presence of a very high density electron-hole plasma. We will discuss recent experimental results aimed not only to investigate in detail the dynamics of the phase transition, but also to obtain quantitative information on the properties of the optically excited solid prior to the melting transition. For rather strong excitation e-h-densities in excess of $10^{22}cm^{3}$ have been determined, and electronic melting within a few hundred fs is observed above a distinct threshold fluence[1]. Below that threshold melting occurs on a 100ps time scale and is of thermal nature. We describe this type of the phase transition as heterogeneous melting under strongly overheated conditions.

2. Ultrafast Phase Changes in amorphous GeSb:

Up to now ultrafast melting of the group IV and III-V-semiconductors is the only experimentally verified example for an electronically driven, non-thermal phase transformation. In GeSb, a material discussed for rewritable, short pulse driven optical memories, we found first experimental evidence for the occurance of a sub-ps, non thermal solid to solid phase transformation.[2]

3. Short pulse laser ablation:

Most of the applications of lasers in materials processing involve material removal, *ablation*. In the particular case of ablation by sub-ps pulses a complete understanding is still lacking. The ablation process depends on the properties of the material, but is also influenced by laser parameters as wavelength, intensity and number of pulses. In transparent materials the required non-linear absorption mechanisms favour high intensities and therefore the use of very short pulses. Ablation is initiated by dielectric breakdown and plasma formation at the surface. In linearally absorbing semiconductors and metals ablation is also possible at lower intensities. In a narrow range of excitation below the threshold for plasma formation the laser pulse acts as fast heat supply. Ablation is brought about by hydrodynamic expansion of the hot, pressurized matter followed by rapid, homogeneous decomposition into a two-phase, liquid-gas mixture (*phase explosion*). The experimental data, characterized by a distinct transient interference phenomenon observed on a 100ps to ns time-scale, reveal a material independed ablation behavior. It can be interpreted by the unique and *universal* properties of materials in the liquid gas coexistence regime.[3] On some materials (two-component systems, e.g. GaAs) and a longer time scale the observation of μm-sized, bubble-like structures seems to indicate also the occurance of heterogeneous boiling.

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[3] K. Sokolowski-Tinten, J. Bialkowski, A. Cavalleri, D. von der Linde, A. Oparin, J. Meyer-ter-Vehn, and S.I. Anisimov, Phys. Rev. Lett. **81**, 224 (1998).