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Seminar über Ultrafast Science and Technology

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Titel: From Theory To Application: Role of Numerical Simulations in Laser-Material Interaction and Laser Amplifier

This presentation contributes mainly to the theoretical investigation of spot size effect during the laser ablation on metals with picosecond and femtosecond laser pulses. In addition, the simulation of optimized design of laser amplifier in high power laser system is taken as an example, demonstrating extended functionality of simulation in practical application. With the help of beam expanders, short and ultrashort pulsed lasers with different spot sizes, ranging from several to tens of micrometers in radius, are applied to the laser ablation experiments on metals. Two kinds of femtosecond laser systems working at wavelength of 1026nm and 1030nm with pulse duration of 260fs and 350fs, respectively are used. Specific removal rates are derived from measuring the depth of the machined squares on the surface of copper and iron, and the ablation thresholds and energy penetration depths of both metals are deduced by measuring the depth of machined craters. Similar experiments are carried out by using a picosecond laser system working at wavelength of 1064nm with pulse duration of 10ps on copper. The beam spot size effect on ablation threshold and specific removal rate during the laser ablation process on noble metal were fund.

A set of axisymmetric 2-dimensional model are developed for both picosecond and femtosecond laser ablation on copper with lower and higher laser fluences, respectively. Some of the important thermal properties of electron and lattice for copper, such as thermal conductivity, heat capacity, and electron-phonon coupling coefficient, are deduced by employed the first-principles electron structure calculations of electron density of states and Debye model, respectively. Although the nonlinearity of the equations increases, these descriptions of thermal properties of subsystems are especially crucial for the thermal response of material to the ultrashort pulsed laser irradiation. The critical point model is applied to describe the dynamic response of optical properties, optical penetration depth and reflectivity, of material to the irradiation. The models are further developed on the basis of the principles of Two Temperature Model (TTM). For the laser fluence closed to the measured ablation threshold, the models are coupled with thermoplastic theory. As the laser fluence approaches to the melting threshold, thermal viscoplasticity is taken into consideration. For the cases where phase transition occurs hydrodynamics coupled with TTM becomes the corresponding model. The characterized features, which distinguish the models for femtosecond laser ablation and picosecond laser ablation are that, on one hand, the former one is derived from Boltzmann transport equations considering the dynamics of electrons under the ultrafast processes, and on the other hand the ballistic motion of the excited electrons during the ultrafast irradiation process.

The results from the simulations of picosecond laser ablation on copper with various spot sizes indicate that the deviations of thermomechanical responses to different spot sizes lead to the change of ablation threshold and in a certain range of laser fluence the specific removal rate predicted by the model has a good agreement with the experimental ones for all the tested beam radii. For the ones from simulation of femtosecond laser ablation on copper, however, it indicates that the ballistic movement of excited electrons plays a crucial role in the beam spot size effect.

The last part of the presentation presents the role of the simulation that plays in the practical application by showing the study of optimized design of Yb: YAG amplifier in high power solid state laser system. The validation of the model is confirmed by comparing the simulated and experimental results. For the study of optimization, the optimal ratio of the radii of pump beam to seed beam and the optical focal position of pump beam for the crystal in certain geometric scale and dopant concentration are obtained. By simulating the thermomechanical responses in different gluing conditions, the risk of the generation of cracks are analyzed.

Zeit: Donnerstag, 30.11.2017, 11:15 Uhr

Ort: **Hörsaal B116**, Gebäude exakte Wissenschaften, Sidlerstrasse 5, Bern, Schweiz