Spatial beam shaping of high-power ultra-short laser pulses

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Abstract

This thesis presents both theoretical and experimental studies of a diffractive beam shaping system for ultra-short high-power laser pulses.

A theoretical model is developed to simulate the reshaped intensity profiles for a 100-fs pulse with various energy levels. Both temporal evolution and spatial intensity distribution of the pulse propagating to the target plane of the beam shaping system are calculated. Numerical simulation shows that after passing through the beam shaping system, the pulse front is significantly curved due to the propagation time delay, and the pulse duration time through the target plane is broadened because of the group velocity dispersion. However, for relatively low energy pulses (on the order of millijoules), and although the intensity distribution is changed considerably, the fluence top-hat profile is well maintained. This feature extends the application of this beam shaping system into the regime of ultra-short laser pulses. Theoretical calculation also shows the limit when the top-hat profile starts to degrade. For very high energy laser pulses (>50 mJ per pulse), the homogeneous fluence profile, as well as the intensity distribution, is destroyed due to the non-linear self phase modulation.

This thesis also presents an experimental study of the beam shaping system for ultra-short high-power laser pulses. A terawatt CPA laser amplification system was built in order to verify the theoretical simulation in experiment. The laser amplification system adopts a multi-pass configuration. The output of this CPA amplifier is operating at 30 Hz repetition rate with a pulse energy of 20 mJ/pulse. The compressed pulse duration is 70 fs, resulting in a pulse peak power of 0.3 TW. Experimental results of the beam shaping system with ultra-short laser pulse input agree with the numerical simulation of the reshaped fluence profiles at various energy levels from 6nJ to 20 mJ. The experimental results confirm the validity of this diffractive beam shaping system for ultra-short pulses with a pulse energy on the order of millijoulses. While millijoule pulses are commonly used in the micromachining technology, the adaptability of this diffractive beam shaping system is greatly improved. The influence of laser beam alignment and scaling errors on the reshaped beam profiles is also studied in experiment. Experimental data are in reasonable agreement with the theoretical calculation.