Fourth-Order Dispersion Compensation for Femtosecond PW-Class Lasers

Z Li, Y Leng, and R Li

1State Key Laboratory of High Field Laser Physics, Shanghai Institute of Optics and Fine Mechanics, 201800, Shanghai, China. Contact Phone: +862169918528
Contact Email: zzyylee@siom.ac.cn

Recently, femtosecond petawatt (PW) laser is a research hotspot, and several PW-class lasers have been demonstrated worldwide. At present, there are two feasible techniques for femtosecond PW-class lasers: the chirped-pulse amplification (CPA) and the optical parameter chirped-pulse amplification (OPCPA). In a high power femtosecond CPA or OPCPA laser, a key task is dispersion management, especially higher-order dispersion management, which determines the temporal characteristic as well as the peak intensity of the final pulse. Generally, in order to achieve a short compression pulse in a wide-broadband femtosecond CPA or OPCPA laser system, the third-order dispersion (TOD) must be compensated, which can be obtained easily. And if the duration as well as the peak intensity needs to be further improved, the fourth-order dispersion (FOD) must be compensated too, which is very important for recent femtosecond PW lasers and especially future femtosecond 10PW lasers. In future 10PW femtosecond lasers, the amount of pulse stretching and compression needs to be increased to reduce nonlinearity effects and the number of transmission materials will rapidly increase due to a higher amplification ratio. In this condition, the pulse temporal distortion caused by FOD will be even more serious. However, there are very few works focusing on the compensation of FOD in ultra-high power femtosecond lasers. In 1997, O. E. Martinez had proposed a method for dispersion compensation of as much as fourth-order by changing the two dimensional incident angles on compressor gratings. But this method cannot completely compensate both TOD and FOD. Besides, the complex adjustment process and the high driven accuracy of the method challenge its actual applications. In 2014, N. Forget had proposed a method by tilting the prism with respect to the grating within a grism pair compressor to compensate the FOD of a bulk-material stretcher, but this dispersion system can only introduce a small amount of pulse stretching and is only suitable for a small-scale low power CPA or OPCPA laser. Apart from above passive methods, lots of active elements are used for higher-order dispersion compensation, for example liquid-crystal modulators, mechanically deformable mirrors and acousto-optic modulators. In an ultra-high power femtosecond laser, especially a PW-class femtosecond laser facility, the amount of dispersion distortion generally is too large for active compensation methods or elements. But even more important, a laser facility for engineering application should operate as stable as possible. Thereby, a static dispersion compensation method is required by the static dispersion distortion introduced by the stretcher, the materials and the compressor. In addition to technical considerations, passive dispersion compensation elements generally are much cheaper than active ones. In this situation, we propose a passive FOD compensation method for ultra-high power femtosecond CPA or OPCPA lasers. Simulations based on our PW-class Ti:Sapphire laser are carried out, and the result shows that the residual GVD, TOD and FOD of the system can be completely compensated simultaneously and an exactly near Fourier-transform-limit pulse could be achieved. The verification experiment is demonstrated, the pulse duration has been reduced from 35 to 28 fs that is around 1.12 times Fourier-transform-limit, the normalized peak intensity of the compression pulse is improved by about 1.25 times, and the spectral phase distortion over the pulse spectrum is optimized from 12rad to 4rad. We believe that the proposed hybrid dispersion management configuration and the optimization process supply multi-petawatt femtosecond laser systems with a stable and low-cost solution for achieving near Fourier-transform-limit pulses.