All dispersive mirrors compressor for femtosecond lasers

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Abstract. We report on the development of highly dispersive mirrors for chirped-pulse amplifiers (CPA). The designed mirrors are potentially capable of replacing the prisms in the existing CPA compressors making them more compact and stable.

Introduction

High-energy femtosecond laser systems deal with dispersion of the materials in pulse compressors, in spectral broadening stages, either inside the laser oscillator cavity or outside. In all cases, the amount of the (absolute) dispersion to be compensated usually grows with the pulse energy. In the case of negative-dispersion oscillators, or chirped-pulse Ti:Sa oscillator CPO, such a monotonic dependence had already been proven theoretically and experimentally [1-5] providing in such a way a stable soliton-like intracavity pulse. In kHz systems the compressor size and its intrinsic dispersion grows with energy because of both the size of the dispersive components and the propagation distance through the components to be used. In high-energy femtosecond Ti.Sa oscillator-amplifier systems, usually prism or grating compressors are in use because they allow compensating large material dispersion of the order of (2-5)x10^4 fs^2 in a wavelength bandwidth of interests (~40 nm), resulting in sub-60 fs pulses. For a broader spectral range, uncompensated third-order dispersion (TOD) becomes so large that the pulse can not be compressed down to the targeted duration (usually 20-30 fs) and additional high-dispersive (hereafter: chirped) mirrors must be added. An alternative to this approach can be an all-chirped-mirror (CM) compressor. "Standard" CMs with the group delay dispersion (GDD) of the order of -50-100 fs^2 cannot be used in compressors of such type or/and in high-energy (of μJ-level) oscillators due to a large number of bounces required. To make the problem clear, let us make a rough estimate of the throughput of the compressor equipped with "standard" CMs. For the dispersion to be compensated of the order of 2x10^4 fs^2, the number of necessary bounces must be as high as 200. For a typical CM reflectance of 0.995, it leads to a throughput of only $0.995^{200} = 0.37$. After 500 bounces which one needs to compensate a material dispersion of 5x10^4 fs^2 with 100 fs^2-CMs, the throughput of less than 10% becomes completely unacceptable. A second, even more important obstacle, is that the initial pulse will be completely destroyed after such amount of bounces due to accumulated deviations of the realized GDD curve from the targeted one. Meantime, based on the progress in the CM development [6-13], one can expect CMs with dispersion values of ~10^3 fs^2 and reflectivity of some 0.995 for a spectral range of at least 50 nm around a central wavelength of 800 nm. Such mirrors, being realized, could replace prisms and gratings in the compressors giving thus a compact cheap device with a stable output beam free of residual TOD. The absolute value of the CM dispersion can be even higher as the spectrum becomes narrower, as it happens in a case of Yb:YAG disk oscillator [14], where mirrors with the dispersion around 10^3 fs^2 per bounce were successfully demonstrated for the spectral width of several nm. Due to the fact that CMs have higher losses and lower damage threshold in comparison to Bragg (= high) reflectors, CMs with GDD of the order of up to 10^4 fs^2 are desirable for that spectral range in order to decrease the total amount of chirped mirrors in the oscillator cavity.

High dispersive chirped mirrors

As a first step in direction of highly dispersive mirrors (HDCM) for CPA, we demonstrate the usability of highly dispersive mirrors for high-energy femtosecond oscillators, namely for i) CPO [3] and ii) an Yb:YAG disk oscillator. In both these oscillators GDD to be compensated is around $2x10^4$ fs^2, of the order of the nominal dispersion present in the CPA compressor. By definition, HDCM is characterized by a high group delay of different spectral components. Because the delay is proportional to the optical thickness of the layers involved, HDCM has thick layers and a big total multilayer structure thickness. From that we can formulate the conditions of manufacturing HDCMs: we need a very stable deposition process allowing us to deposit a thick multilayer structure with high accuracy. The total amount of GDD of a HDCM compressor needed for obtaining chirp-free high-energy pulses out of a Ti.Sa CPO is of the order of $2.5x10^4$ fs^2 at 800 nm and this value is achievable with only 20 bounces of the HDCM shown in Figure 1 (a).

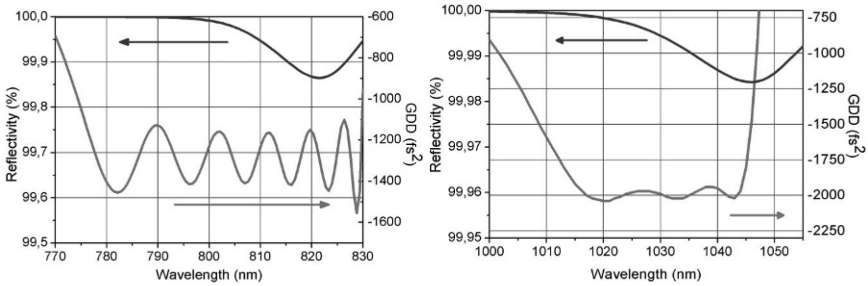

Fig. 1 (a,b). The calculated GDD and reflectivity of HDCMs. Left: HDCM for Ti:sapphire CPO, right: for Yb:YAG oscillator.

We have now to prove that such amount of bounces will not deteriorate the incident test chirp-free pulse in terms of its duration and energy. In the analysis, the main part of the dispersion was taken away and only residual GDD ripples were included. For virtual compression experiment, we used an incident 60-fs pulse realized in Ti:Sa CPO [3]. The reflected pulse does not become longer when the ripples are absent or small. Calculations show that after 20 bounces i) the exiting pulse preserves its incident duration and ii) the main pulse contains >95% of the energy from the initial value. Based on the analysis above, we hope for efficient compression of highly-chirped pulses exiting the CPO. In a Yb:YAG oscillator, HDCM will provide enough negative dispersion for keeping high-energy soliton pulse inside the oscillator cavity, Figure 1 (b). A HDCM compressor was successfully applied for compressing 2 ps chirped pulse out of Ti:Sa CPO down to 65 fs pulse at 5.3 MHz repetition rate. The group delay dispersion of the HDCM is -1300 fs^2 per reflection @800 nm that represents the highest negative dispersion value in the 40 nm wavelength bandwidth, realized so far. The HDCM at 1030nm has a nominal dispersion of ~ -2000 fs^2.Three HDCMs inside the Yb:YAG disk oscillator allowed us to generate stable 6 μJ 800 fs pulses. The low amount of HDCMs allowed us to minimize the losses in the optical part of the oscillator.

Conclusions

We demonstrate that the required CPA dispersion of the order of 10^4 - 10^5 fs^2 can possibly be introduced by a set of high-dispersive chirped multilayer dielectric mirrors offering several advantages including simplicity, alignment-insensitivy, and the potential for increased efficiency. As a first step toward an all-HDCM CPA compressor, we have shown 2 sets of HDCMs with both bandwidth and the main value of the dispersion comparable to what one expect in CPA lasers. The mirrors were manufactured and successfully tested in μJ-level laser oscillators.

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