Design of dielectric high reflectors for dispersion control in femtosecond lasers

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ABSTRACT

Chirped dielectric rugate mirrors were constructed for broadband dispersion control in femtosecond laser oscillators by Fourier transform. Dispersive properties of the mirrors are tailored and explained on the basis of the time shifting theorem of Fourier analysis. Depending on their construction parameters, these chirped gradient-index structures exhibit high reflectivity and nearly constant negative, i.e. anomalous, group delay dispersion over frequency ranges well beyond the currently available fluorescence bandwidths of broadband laser-active materials. As a consequence, practical implementation of these novel dispersive devices would permit the full utilisation of the bandwidth offered by these broadband gain media, and allow the construction of small, compact femtosecond solid state laser oscillators generating optical pulses shorter than those achieved so far, directly from the laser oscillator.

1. INTRODUCTION

One of the main trends of laser physics today is the research and development of femtosecond laser sources[1]. The appearance of transition-metal-doped crystals having extremely broad fluorescence bands has brought great advances in this field allowing the construction of laser oscillators generating optical pulses of 10-100 fs directly at the laser output[1,2]. In the nineties, application of these femtosecond solid state lasers in the fields of physics, chemistry, biology, medicine and technology has made it possible to investigate temporal processes that could not be observed before due to the lack of measuring apparatus with high enough temporal resolution. There are two additional positive features of these systems originating from the short pulse durations: the low energy content and the high spectral bandwidth of every laser pulse. The former property significantly reduces the risk of damaging the samples, e.g. a semiconductor device being investigated by optical pulses, while the latter property allows us to apply them as broadband, high intensity, easy to handle light sources with very short emission times. Some of the most important applications of these ultrashort-pulse laser oscillators include the following: spectroscopic investigation of biological and chemical reactions, of semiconductors or other solid state materials with high temporal resolution[3], investigation of strongly nonlinear optical processes, and high speed opto-electronic data transmission and processing systems. By utilising laser amplifier systems, the intensity of a single laser pulse can be boosted to the terawatt power range, which is widely used in plasma physics. In the long term, coherent X-ray sources (X-ray lasers) and new particle accelerators, that are smaller and cheaper than those used today, are planned to be built using these laser amplifier systems.

Femtosecond solid-state laser oscillators rely on a net negative, i.e. anomalous, intracavity group-delay dispersion (GDD) due to their soliton-like pulse shaping mechanism[1,2]. Until recently, prism pairs built in the laser cavity were the only low loss sources of broadband negative GDD. As a new physical concept, we have developed chirped multilayer high reflectors consisting of alternate discrete layers of high and low index dielectrics by using a standard computer optimisation technique[4]. The mirrors exhibited high reflectivity and nearly constant negative GDD of -45 fs^2 over a frequency range of 80 THz centred at 800 nm, and could be manufactured by means of a standard electron-beam evaporation technique[5]. To test these novel dispersive devices, a Kerr lens mode-locked Ti:sapphire laser was built, which consisted merely of cavity mirrors, a 2 mm-thick gain medium and an intracavity aperture. By taking advantage of several bounces on the dispersive mirrors in the cavity, the laser was able to generate optical pulses as short as 9 fs, which represents the best result reported to date[6]. Our experiments indicate that the

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