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Invited paper

Theory and design of chirped dielectric laser mirrors

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Abstract. Chirped dielectric laser mirrors offer a general solution for broadband feedback and dispersion control in femtosecond laser systems. Chirped mirrors developed for mode-locked solid-state lasers, femtosecond parametric oscillators, chirped pulse amplification systems and pulse compressors are introduced. Basic theoretical and design considerations are also presented.

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One of the main trends of laser physics today is ultrafast laser technology. Recent research on high-power semiconductor laser diodes and solid-state laser materials with a broad fluorescence emission band has paved the way for compact, reliable, broadly tunable all-solid-state continuous wave (cw), picosecond (ps) and femtosecond (fs) pulse laser sources. One approach is based on Ti:sapphire (Ti:S) [1], which can be efficiently pumped by the frequency-doubled output of AlGaAs diode-pumped neodymium lasers. Alternatively, the direct diode pumping of colquiriite laser-active materials such as $LiCaAlF_6$:Cr^{3+} (Cr:LiCAF) [2], $LiSrAlF_6$:Cr^{3+} (Cr:LiSAF) [3], and $LiSrGaF_6$:Cr^{3+} (Cr:LiSGAF) [4] became feasible by the use of enhanced mode-matching schemes [5] or AlGaInP semiconductor lasers with "improved" beam quality operating near 670 nm [6]. The latter approach might offer greater simplicity, efficiency, compactness, and cost effectiveness. The importance of these features for wide-ranging applications needs no explanation. These advances in laser technology offered the possibility of constructing laser oscillators generating optical pulses in the sub-20-fs regime by using different mode-locking techniques such as self-mode-locking of the laser [7].

Because of the dominant role of soliton-like pulse shaping in ultrashort-pulse solid-state lasers [8], femtosecond-pulse generation relies on net negative, i.e. anomalous, intracavity group-delay dispersion (GDD). Solid-state gain media always introduce a certain amount of frequency-dependent positive (normal) dispersion in the cavity, which must be balanced as well. Until recently, Brewster-angled prism pairs [9] built into the laser cavity were the only low-loss sources of broadband negative GDD. In prism-pair-controlled broadband lasers, a major limitation to ultrashort-pulse generation originates from the variation of the intracavity GDD with wavelength. The principal source of this higher-order dispersion, however, was found to be the prism pair [10, 11]. If the lasers are operated in the vicinity of zero GDD, the spectra of sub-20-fs pulses from prism-pair-controlled oscillators are asymmetric with a broad shoulder [10] or are double peaked [8, 11] depending on whether the soliton-like pulses are, respectively, third- or fourth-order dispersion limited. This deviation from the ideal sech pulse spectrum causes a weak but significant pedestal in the time domain, the length of which may substantially exceed the pulse duration defined as the full width at half maximum (FWHM) intensity. This degradation in pulse quality may be unacceptable in a number of spectroscopic applications requiring high temporal resolution. An additional problem in the time domain is the increased sensitivity of the pulse width to the cavity and prism alignment. Cavity mirror alignment changes the position of the resonator axis and thus the glass path through the prisms. Hence any small cavity realignment calls for subsequent readjustment of the prism positions and orientation to restore the original pulse width and the corresponding spectrum. This makes "turn-key" operation and thus the integration of these devices in complex systems [e.g. chirped pulse amplification (CPA) systems, opto-electronic data processing systems] extremely difficult. Furthermore, the minimum prism separation sets a constraint on the resonator length and, in turn, the size and repetition rate of femtosecond-pulse solid-state laser oscillators.

Continuous wave, ps, and fs lasers contain optical coatings as important functional elements, e.g., high reflectors (HR), output couplers (OC), and antireflection (AR) coatings. These optical elements are based on the interference phenomenon of light. Their theoretical analysis generally relies on the well-known scattering matrix formalism [12, 13] derived from the Maxwell equations. Laser performance strongly depends on the quality of optical coatings: the high reflec-