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Negative dispersion mirrors for dispersion control in femtosecond lasers: chirped dielectric mirrors and multi-cavity Gires–Tournois interferometers

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Abstract. Chirped dielectric laser mirrors have been known for years as useful devices for broadband feedback and dispersion control in femtosecond pulse lasers. First we present a novel design technique referred to as frequency domain synthesis of chirped mirrors. These mirrors exhibit high reflectivity and nearly constant group delay over 150 THz supporting generation of sub-5-fs pulses in the visible. Afterwards, multi-cavity thin-film Gires–Tournois interferometers are introduced for the first time as an alternative approach to realize "negative dispersion mirrors". These novel dielectric high reflectors exhibit reflectivities $R > 99.97\%$ and a negative group delay dispersion of $-50 \pm 1\ \mathrm{fs}^2$ over a bandwidth of 56 THz. Dispersive properties originate from coupled resonances in multiple $\lambda/2$ cavities embedded in the layer structure. The general structure and performance of multi-cavity Gires–Tournois interferometers are compared to that of chirped dielectic mirrors and their distinct applications are discussed.

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Recent development of ultrabroadband chirped dielectric laser mirrors (UBCMs) [1, 2] with prescribed phase properties brought revolutionary progress to the generation of femtosecond pulses both in the near infrared [3] and in the visible [4] spectral regimes. This resulted in optical pulses as short as 4.5 fs and 4.7 fs, respectively. With the combination of chirped mirror (CM) technology with air-silica microstructure optical fibers [5], further revolutionary progress in the generation and application of optical pulses of few cycles can be predicted: using standard sub-100-fs laser oscillators (for example, Ti:sapphire) with 1–2 nJ pulse energies, microstructure optical fibers for efficient continuum generation and ultrabroadband chirped mirrors [1, 2] for dispersion management, sub-5-fs pulses could become an everyday tool in ultrafast laser laboratories.

In this paper we present our recent advances in fs laser technology that might help the ultrafast optics community to establish such ideal conditions. First we present a novel technique, *spatial frequency domain optimization* for designing discrete layer ultrabroadband chirped dielectric mirrors with prescribed second-, third-, and fourth-order dispersion. Since we perform our optimization process for few parameters (6–8) for full description of the chirped layer structure instead of using the individual layer thicknesses (40–60 parameters), we obtain an optimum solution within 1–2 min on a 266 MHz Pentium computer. The mirrors exhibit high reflectivity and nearly constant group delay dispersion over 210 THz and 140 THz, respectively, supporting sub-5-fs pulse generation in the visible spectrum [4, 6]. Second, an alternative approach for realizing "negative dispersion mirrors" with pure quadratic phase shift on reflection is introduced. We refer to them as *multi-cavity thin-film Gires–Tournois interferometers* (MCGTI): their dispersive properties originate from coupled resonances in multiple $\lambda/2$ cavities embedded in the layer structure. These novel devices exhibit extremely low reflection losses – when they are manufactured by our state-of-the-art ion-beam sputtering technique – ($R > 99.95\%$) and high-order dispersion-free group delay vs. frequency functions (for example, $-50 \pm 1\ \mathrm{fs}^2$) over a bandwidth of 56 THz. Accordingly, they support clear, pedestal free sub-15-fs pulses, or sub-100-fs pulses tunable over a 100..120 nm around 800 nm in mirror-dispersion-controlled solid-state laser oscillators. Finally, we report on our recent *experimental results with the low loss, ion-beam-sputtered MCGTI-s* developed for mode-locked Ti:sapphire lasers [8].

1 Phase properties of dielectric mirrors

Optical thin-film devices play an important role in the final performance of fs laser systems: high reflectors (HR), output couplers (OC), antireflection (AR) coatings, or thin-film

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