

Relation between group delay, stored energy and absorptance in dispersive dielectric mirrors

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In ultrafast (picosecond or femtosecond pulse) lasers, dielectric mirrors having a wavelength dependent group delay (GD) on reflection can be efficiently used for intra- or extra-cavity dispersion-compensation of chirped optical pulses. The desired dispersion properties can be achieved by precise control of the multilayer structure, which leads to different dispersive dielectric mirror designs. Basically, there are two main types of dispersive dielectric mirrors: the so called chirped mirrors [1] and the (single or multiple cavity) Gires-Tournois interferometer mirrors [2].

The fact that there is a relationship between the group delay and the electromagnetic energy stored in the volume of the multilayer structure is known from some earlier works [3,4], but only the lossless case was investigated in these articles. However, absorption and scattering loss of a laser mirror is an important issue in practice. Besides cavity loss, the absorbed power causes heating and subsequent wavefront distortion of the reflected laser beam in high power systems, which results in reduced focused intensities. Additionally, when relatively long (>50 ps) pulses are reflected, heating due to linear absorption is the main cause of mirror damage [5]. Therefore, investigation of the relationship between the absorptance and the group delay has a practical importance in such laser systems. Although there are some earlier results on specific mirror structures that indicate the proportionality of these two physical quantities [6,7], no systematic study of this issue has been provided.

In our presentation, based on the analytic results of Ref. [4], we deduce that the stored energy and, consequently, the absorptance of a dielectric mirror should be well proportional to the reflection group delay within the high-reflectance band, in the absence of such resonances that would cause high transmission group delay values. This result is supported by numerical simulations performed on four different dielectric mirror structures. The structures we investigated are a standard, low-dispersion quarter-wave (QW) stack, an ultrabroadband chirped mirror (UBCM) and two multi-cavity Gires-Tournois interferometer (MCGTI) mirrors of different structures. The calculations were performed for the lossless case and also for different (and wavelength independent) extinction coefficient values of the mirror layers, up to 10^{-3} , thereby extending our preliminary results [8]. We found that the reflection GD and the stored energy are very well proportional to each other for each mirror structure and extinction coefficient combinations of the layers. The absorptance is also well proportional to the GD in case of the dispersive mirrors (UBCM, MCGTI).

These results can be crucial regarding the use of ultrabroadband mirrors, which are inherently dispersive, in broadband or broadly tunable, high-power laser systems where the pulses are longer than ~ 50 ps. For shorter pulses, a more detailed study including nonlinear effects, such as avalanche ionization and multi-photon absorption, is required.

[1] R. Szipőcs et al., *Opt. Lett.* **19** (1994) 201

[2] R. Szipőcs et al., *Appl. Phys. B* **70** (2000) S51

[3] M. Gerken et al., *Appl. Opt.* **42** (2003) 1330

[4] H. G. Winful, *New. J. Phys.* **8** (2006) 101

[5] B. C. Stuart et al., *Phys. Rev. B* **53** (1996) 1749

[6] D. I. Babic et al., *IEEE J. Quant. Electron.* **28** (1992) 514

[7] K. Ferencz et al., *Opt. Eng.* **32** (1993) 2525

[8] R. Szipőcs et al., in *Optical Interference Coatings*, OSA Technical Digest (2010) paper FB3