Group-delay measurement on laser mirrors by spectrally resolved white-light interferometry

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The frequency-dependent group delay of dielectric mirrors was measured by spectrally resolved white-light interferometry. Chirped mirrors and thin-film Gires–Tournois interferometers designed for dispersion control in a femtosecond Ti:sapphire laser oscillator–amplifier system were tested with a group-delay resolution of ±0.2 fs and a spectral resolution of ~1 nm over the spectral range of 670–870 nm.

The pulse duration of femtosecond laser oscillator–amplifier systems strongly depends on the frequency-dependent group delay of the optical components utilized.[1] Because all these systems contain dielectric mirrors, precise knowledge of their dispersion is essential. Furthermore, it has been demonstrated that dielectric mirrors with nearly constant second-order[2] and third-order[3,4] dispersion can be designed and manufactured. Recently, a number of studies have been devoted to the problem of group-delay measurement in optical components, e.g., optical glasses, prism pairs, dielectric mirrors, Gires–Tournois interferometers, Ti:sapphire crystals, and birefringent filters.[5–8]

In this Letter we report on a fully automated inexpensive alternative method for fast, accurate determination of the frequency-dependent group delay over a broad spectral range, which is introduced by reflection of light from laser mirrors. The method—previously used for refractive-index measurements of dye solutions[9]—is based on spectrally resolved white-light interferometry.

Figure 1 shows the experimental setup, which is basically a Michelson interferometer illuminated by a white-light source (tungsten halogen lamp). The spatial coherence of the light source in the vertical direction is increased by the horizontal slit S_1. The incoming collimated beam is divided by a beam splitter cube (Spindler & Hoyer No. 33520). We placed a low-dispersion plane gold mirror (M_R) in the reference arm and the plane dielectric mirror (M_S) to be measured in the sample arm (the substrates of the mirrors had a flatness of $\lambda/10$). When one of the mirrors is tilted around a horizontal axis and the other mirror is vertical, horizontal interference fringes (fringes of equal thickness) are generated by each spectral component of the white-light source at the plane of slit S_2. A transmission grating (200 grooves/mm) and an achromatic lens ($f = 50$ mm) are used to create the spectrally dispersed image of a vertical cut (slit S_2) of the superimposed (white-light) interference fringes on the CCD camera (Electrim Corporation EDC-1000, 165 × 196 pixels). The interference patterns corresponding to different wavelengths are linearly dispersed in the horizontal direction depending on the angular dispersion of the transmission grating. To provide a one-to-one correspondence between the horizontal pixel positions and wavelength values, we determined the pixel positions of some spectral lines (697, 852, and 894 nm) of a cesium spectral lamp. Note that pixel position y' is proportional to y, depending on the magnification of the imaging system. The inset of Fig. 1 illustrates a typical spectrally resolved interference pattern when the phase shift on reflection of the sample mirror is a second-order function of the frequency.

In the following, we show how the frequency-dependent group delay of the sample mirror [$\tau_S(\lambda)$] can be obtained by computer processing of the spectrally resolved interference pattern detected on the CCD camera. Let us consider monochromatic, plane-wave, homogeneous illumination of the interferometer and suppose that the sample mirror is

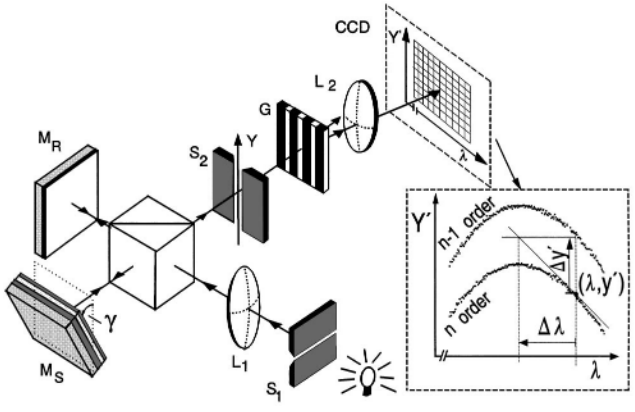

Fig. 1. Spectrally resolved white-light interferometer for group-delay measurement of dielectric mirrors. L_1, L_2, achromatic lenses; S_1, S_2, slits; M_S, sample mirror; M_R, reference mirror; G, transmission grating.

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