Low reflection loss ion-beam sputtered negative dispersion mirrors with MCGTI structure for low pump threshold, compact femtosecond pulse lasers

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Abstract. Low reflection loss, ion-beam sputtered, multiple-cavity Gires-Tournois interferometer mirrors are used for dispersion compensation in different configurations of compact, low pump threshold, femtosecond pulse Cr:LiSAF and Ti:sapphire laser oscillators.

OCIS codes: (140.4050) Mode-locked lasers

1. Introduction

A number of practical femtosecond pulse laser systems require minimum reflection losses in the laser cavity and high-order dispersion-free group delay control over a frequency range of 50..80 THz, that still support (i) clear, pedestal free sub-15-fs pulses or, (ii) sub-100-fs pulses tunable over a 100..120 nm around 800 nm. Such application might include diode pumped femtosecond pulse Cr:LiSAF and Cr:LiSGaF lasers [1, 2] or low pump threshold, mirror-dispersion-controlled femtosecond pulse Ti:sapphire [3,4] lasers. For this purpose, we proposed negative dispersion dielectric mirrors referred to as multi-cavity Gires-Tournois Interferometer (MCGTI) mirrors [5], and reported on our first experimental results on application of MCGTI mirrors exhibiting reflectivities R > 99.97% and a negative group delay dispersion of -50+/-1 fs^2 over a bandwidth of 56 THz at around 800 nm. Compared to chirped laser mirrors, they exhibit simpler structure (hence relatively low manufacturing costs), higher reproducibility and lower reflection losses. These mirrors were applied for intracavity dispersion control in a tunable, 100 fs Ti:sapphire laser comprising a built in, high power 532 nm laser (Vitesse XT, product of Coherent Inc.) [6], but no experimental data on these laser experiments were reported.

In this paper, we report on an improved version of ion-beam sputtered MCGTI mirrors with increased negative GDD and red shifted reflection band aiming for applications in directly diode pumped, femtosecond pulse Cr:LiSAF lasers or in low pump threshold, 100-fs, tunable Ti:sapphire lasers.

2. Ion beam sputtered, low reflection loss MCGTI mirrors

Reflection losses on negative dispersion mirrors can be minimized by (i) reducing the absorption and surface roughness of the dielectric mirror and (ii) reducing the maximum value of the reflection delay in the cavity mirrors [6]. The former requirement can be met by state of the art coating deposition technologies, such as ion-beam-sputtering (IBS) [5]. By properly choosing superpolished fused silica substrates, coating materials (Nb$_2$O$_5$ and SiO$_2$) and the technology for coating deposition (IBS), we were able to significantly decrease the surface roughness of our MCGTI mirrors.

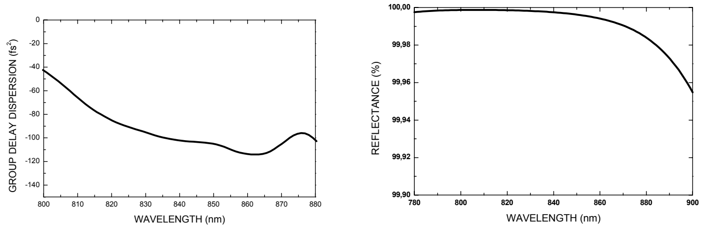

Fig. 1. Computed group delay dispersion and reflectance functions of the MCGTI mirrors developed for our femtosecond pulse, diode pumped Cr:LiSAF and low pump threshold, tunable Ti:sapphire oscillators

In case of dispersive dielectric mirrors such as chirped mirrors and multi-cavity Gires-Tournois interferometers, in which the group delay difference ($\Delta\tau$) over the high reflectivity band is practically limited by the overall optical thickness of the multilayer, the maximum value of the group delay dispersion (GDD) is traded off against the bandwidth of the mirror ($\Delta\omega$), as follows from the definition of the $GDD = d\tau / d\omega \cong \Delta\tau / \Delta\omega$. The reflection losses on the dispersion compensating mirrors, however, can be minimized by reducing the overall group delay difference ($\Delta\tau$) on reflection in the cavity, since the reflection losses ($R = 1 - \Delta A$) are proportional to the group delay ($\Delta\tau$) in a certain dielectric mirror [6]: $\Delta A(\lambda) \propto \tau(\lambda)$.

It follows that having a minimum value of negative GDD that should be provided in a cavity for dispersion compensation, the reflection losses can be minimized at the expense of the reduced bandwidth ($\Delta\omega$). For this purpose, we developed a new MCGTI design for dispersion compensation in diode pumped Cr:LiSAF and low pump threshold Ti:sapphire lasers, whose computed group delay dispersion and reflectance functions are displayed in Fig. 1.

2. Experiment

For demonstration of performance of ion-beam sputtered MCGTI mirrors, we built Ti:sapphire and Cr:LiSAF laser oscillators pumped by compact laser sources with power as low as 1.2 W and 350 mW, respectively. Generally, we used semiconductor saturable absorber mirror (SESAM) for modelocking, but in some cases Kerr-lens modelocking could be also used.

Our experimental setup for a Kerr-lens mode-locked Ti:sapphire oscillators comprising a 4 mm long crystal is shown in Fig. 2 (left). Dispersion of a highly doped crystal is compensated by low reflection loss, negative dispersion MCGTI mirrors (M3-M5, M7-M10). The ion-beam sputtered mirrors were manufactured at MLD Technologies LLC [5]. The mirrors exhibit reflection R > 99.97% and negative GDD of 100 +/ -10 fs^2 in the 780-880 nm wavelength range. The relatively long Ti:sapphire crystal requires a high number of reflections on dispersive mirrors for proper dispersion-compensation (21 reflection in one roundtrip).

A relatively low pump power (1.2 W) at 532 nm provided enough intracavity power for using hard aperture Kerr-lens modelocking (placing a shaped slit into the cavity). Using Kerr lens mode-locking, output powers as high as120 mW could be achieved with a T = 5% output coupler. In case of a T = 2% output coupler, we obtained mode-locked output powers of 40 mW and 85 fs pulse duration. The corresponding measured spectrum and autocorrelation trace are shown in Fig. 2. (right).

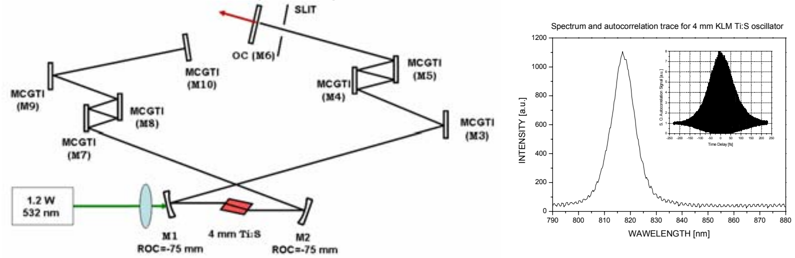

Fig. 2. Experimental setup of a Kerr-lens modelocked Ti:sapphire oscillator using 21 reflections on MCGTI mirrors for intracavity dispersion control. Using a T = 5% output coupler, mode-locked output powers up to 120 mW were measured (left). Corresponding measured autocorrelation trace (inset) and spectrum (τ_{FWHM}=85 fs, right).

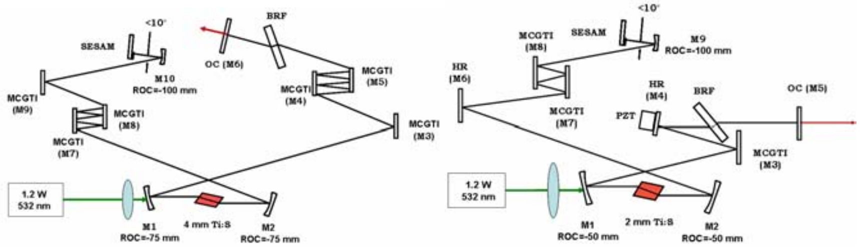

Fig. 3. Experimental setups of femtosecond laser oscillators comprising PL=4 mm (left) and PL=2mm (right) Ti:sapphire crystals. The lasers are modelocked by a semiconductor saturable absorber mirror (SESAM) and their intracavity dispersion is set by 28 and (left) 10 (right) reflections on negative dispersion MCGTI mirrors.

Fig. 3 (left) shows the slightly modified experimental setups for the SESAM modelocked Ti:sapphire laser. The laser beam is focused by a spherical mirror (M10) with focal length of 50 mm onto the surface of the SESAM. The SESAM is mounted onto a copper plate for proper cooling. A birefringent filter (BRF) with thickness of 1T is installed into the resonator for tuning the laser. After having the laser aligned, mode-locking was obtained without any adjustment of any element of the cavity. The SESAM and BRF introduce an additional dispersion compared to the setup shown in Fig. 2. Additionally, longer pulses require higher negative dispersion in the cavity in order to reduce losses on the filtering element. The increased negative dispersion was introduced by additional reflections on the M7-M8 and M4-M5 mirror pairs. Accordingly, the number reflections on dispersive MCGTI mirrors was increased to 28 in one roundtrip in case of the Ti:sapphire laser. The corresponding measured average mode-locked output power vs. wavelength functions are shown in Fig. 4 (left) and 4 (right) using T = 2% and T= 5% output coupling, respectively.

A similar setup was also tested using a 2 mm long Ti:sapphire crystal (see Fig. 3, right), in which 10 reflections on MCGTI mirrors was used for intracavity disperion control. The corresponding mode-locked average output power vs. wavelength functions are shown in Fig. 4. The tuning range of both lasers is limited by the reflection bandwidth of the SESAM we used.

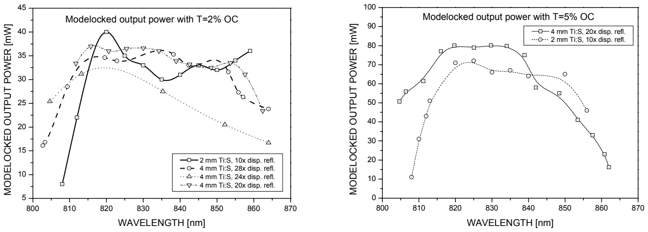

Fig. 4. Mode-locked average output power vs. wavelength functions of Ti:sapphire oscillators comprising of the 2 mm and 4 mm long Ti:sapphire rods when using T=2% (left) and T=5% (right) output couplers. The lasers were tuned by a 1T birefingent filter (BRF).

In order to investigate the role of the dispersion compensation in the resonator comprising two filtering elements (BRF and SESAM), the output power (see Fig. 4, left) and spectral bandwidth (see Fig. 5, left) were measured at different number of reflections. Fig. 5 (right) shows the corresponding measured pulse durations and time-bandwidth product values.

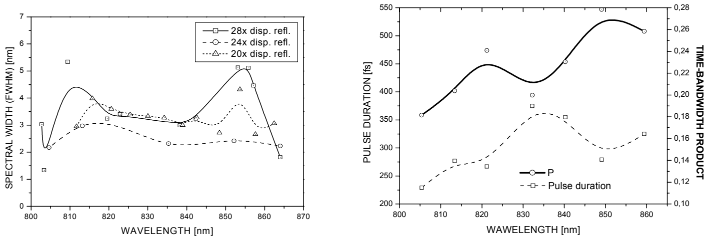

Fig. 5. The change of spectral as a function of intracavity dispersion for the Ti:sapphire laser comprising a 4 mm long crystal (left). Measured pulse durations and time-bandwidth products when using a T=2% output coupler and 28 reflection on negative dispersion MCGTI mirrors.

The MCGTI mirrors were also tested in a fs pulse Cr:LiSAF laser pumped by a single, high-brightness diode laser with maximum output power of 350 mW at 670 nm wavelength. The experimental setup is shown in Fig. 6 (left). The relatively low pump power enables us to use only a low output coupling (T=0.7% was chosen) to have high enough intracavity power for modelocking. Modelocking started spontaneously at 10 mW of cw output power and up to 21 mW of ML output power could be achieved. The corresponding measured spectrum and autocorrelation trace are shown in Fig. 6 (right).

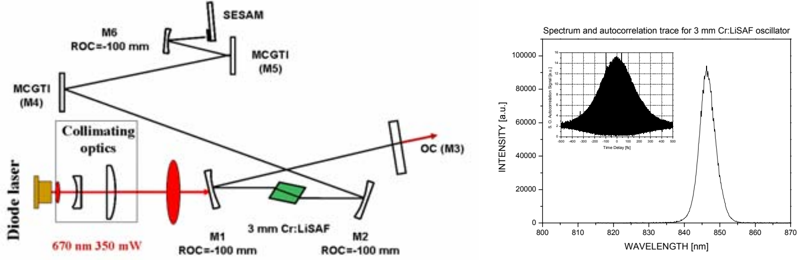

Fig. 6. Femtosecond pulse oscillator with 3 mm Cr:LiSAF crystal that is modelocked by SESAM, 4 reflection on negative dispersion MCGTI mirrors (left). Measured spectrum and autocorrelation function of the Cr:LiSASF laser with pulse duration of τ_{FWHM}=210 fs and modelocked average output power of P = 21 mW (right).

3. References

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