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Design and Analysis Gires-Tournois-Interferometer Mirrors

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Abstract

We report the implementation and operation of GTI with high-reflectivity negative-dispersion dielectric mirrors for use in tunable ultrafast laser systems. The mirror structure is divided into two distinct regions: an underlying high-reflectivity dielectric quarter-wavelength stack and an overlying negative-dispersion section consisting of only a few layers and forming simple multiple Gires–Tournois interferometers. The example that we present was designed two structures with different spacers for operation from 670-860 nmand680-840nm has a near-constant group-delay dispersion of ±3000fs^{2}and a peak reflectivity greater than 98%. We can usingand application of these mirrors in a mode-locked Ti: Sapphire laser.

Keywords: *Gires-Tournois**,** Femtosecond**,** dispersion compensation*

1. Introduction

Gires-Tournois interferometers are generally used to compensate highly chirped picoseconds or femtosecond pulses the way they exist, especially in narrow gain band-width lasers like Nd:YAG. Large amounts of intracavity negative GDD are essential in ultra-short pulse lasers, in order to compensate for the gain bandwidth and self-phase modulation (SPM) due to nonlinear elements [2]. In comparison to a prism pair sequence, the GTI is easily three orders of magnitude more dispersive but also linear over a much smaller bandwidth. The amount of available group delay dispersion can be further increased by reacting the intracavity pulse several times of the surface of the GTI, because the introduced dispersion is proportional to the number of bounces from the surface. Several schemes of GTI have been proposed introducing these large amounts of group delay dispersion (GDD) [3]. This is done by changing the pulse angle of incidence upon the GTI, which thereby correctly compensates a narrow bandwidth ofintracavity dispersion [4].

2. Theory

A Gires–Tournois interferometer is an optical standing-wave resonator similar to Fabry–Pérot interferometer, which however is operated in reflection and designed for generating chromatic dispersion. The front mirror is partially reflective, whereas the back mirror has a high reflectivity. If no losses occur in the resonator, the power reflectivity is unity at all wavelengths, but the phase of the reflected light is frequency-dependent due to the resonance effect, causing chromatic dispersion. The phase change of reflected light and the dispersion (including group delay dispersion and higher-order dispersion) change periodically with optical frequency, if material dispersion is negligible. There is no second-order dispersion exactly on-resonance or anti-resonance, and positive or negative dispersion between these points [7].

A Gires-Tournois interferometer consists of two parallel surfaces, the second of which is 100 % reflective as show in Figure 1. Therefore, the two quantities which characterize theGTI are the reflection coefficient *r* of the first surface and the distance between them [6]. Gires-TournoisInterferometer (GTI) is essentially a Fabry-Perot resonator with a 100% reflector. As with an ideal high-reflectivity mirror, the whole reflectivity of the device stays 100%. In contrast,

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the phase delay is, as with a Fabry-Perot, frequency-dependent. Thus the GTI can be used in a laser resonator for dispersion compensation.

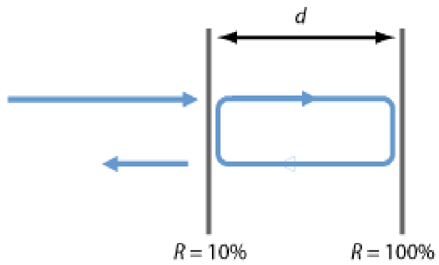

Figure 1. Schematic Setup of a Gires–Tournoisinterferometer [6]

Therefore, the two quantities which characterize the GTI are the reflection coefficient *r* of the first surface and the distance d between them. The round trip time inside the GTI for an angle of incidenceϴ is then given by [4].

$$t_o = \frac{2nd}{c}\sqrt{1-\frac{\sin^2\theta}{n^2}} \quad (1)$$

Where: **c** is the speed of light and n the refractive index of the medium between the mirrors. If the pulse duration is longer thant_0, the fieldsof successive reactions of the same pulse do temporally overlap and the pulse envelope may be reshaped. This puts an upper limit to the distance between the reacting surfaces. But, as the distance d becomes shorter, the GDD becomes smaller too, as can be seen from the equation below [4].

$$GDD = 2\pi\frac{dT}{d\omega} = -2\pi\frac{d^2\phi}{d\omega^2} = 2\pi t_2^2\frac{(r^2-1)2r\sin\omega t_o}{(1-r^2-2r\cos\omega t_o)^2} \quad (2)$$

Where,
T = group delay, **ω**=angular frequency,**ϕ**= phase ,**r**= reflectivity.

In order to obtain constant negative GDD over finite bandwidth, $\Delta\omega > 0$, the phase has to be adjusted such that the GDD is a minimum. This phase is a function of ***r,*** as seen in above equation. In order to obtain high values of negative dispersion and large bandwidth(for short pulse duration), one has to increase the reflectivity of the intermediate mirror in a controlled manner. The commonly used round trip time (1) shows no dependency with the intermediate surface reflectivity. We know, that the higher the reflectivity, the longer the delay time within the GTI. Therefore, as the reflectivity increases, the pulse, coming out of the GTI, gets stretched in time. Taking into account the reflectivity we derive an expression for the decay time of a pulse in a passive resonator, τ [4, 5].

$$\tau = t_o.\left[1+\frac{1}{\ln(1/_{r^2})}\right] \quad (3)$$

Where $t_0$is given by (1). By analyzing numerically various GTI's we found that this expression gives a very good estimate in the case of Fourier transform limited pulse width. Amore useful approximation is obtained by calculating the bandwidth**,** Δv**GTI**, over which the group delay is linear. We therefore expand the group delay as a function of frequency about the points of maximum GDD. At these points the second derivative of the group delay is zero and we obtain:

$$T(\omega)=T(\omega_0)+\frac{dT(\omega_0)}{d\omega}\Delta\omega + \frac{d^3T(\omega_0)}{6d\omega^3}\Delta\omega^3 \quad (4)$$

Linearity of the group delay is guaranteed as long as the third term in above equation is smaller than the second term:

$$\frac{dT(\omega_0)}{d\omega^3} = \frac{dT(\omega_0)}{d\omega}\Delta\omega \tag{5}$$

Where we have dropped in the denominator of the third term. Using the above criteria for linearity we obtain:

$$\Delta vGTI = \frac{2\Delta\omega}{2\pi} = \frac{1}{\pi}\sqrt{\frac{dT(\omega_0)}{d\omega}\cdot(\frac{d^3T(\omega_0)}{d\omega^3})^{-1}} \tag{6}$$

3. Design and Discussion

To design GTI we take these parameters the reference wavelength is 750nm and the spectral range 300–1000nm. Figure 2 and Figure 3 shows the reflectance and reflectance GDD, where H and L are quarter wave layers with indices high and low which correspond to HfO_2 and BaF_2, respectively, and the refractive index of substrate are FusedSilica. The bandwidth of high reflectance (>98%)and the reflectance GDD value is (±3000). Table 1 shows the layer structure for the first design.

Table 1. Layer Structure of the First Design

*	Materials	Thicknesses	Index
1	HfO2	98.736	1.8990
2	BaF2	128.205	1.4625
3	HfO2	98.736	1.8990
4	BaF2	128.205	1.4625
5	HfO2	98.736	1.8990
6	BaF2	128.205	1.4625
7	HfO2	98.736	1.8990
8	BaF2	128.205	1.4625
9	HfO2	98.736	1.8990
10	BaF2	128.205	1.4625
11	HfO2	98.736	1.8990
12	BaF2	128.205	1.4625
13	HfO2	98.736	1.8990
14	BaF2	128.205	1.4625

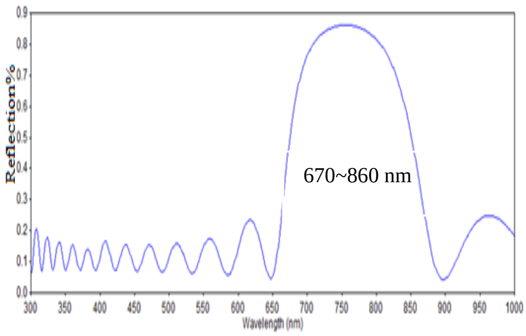

Figure 2. Reflection vs. Wavelength for the First Design

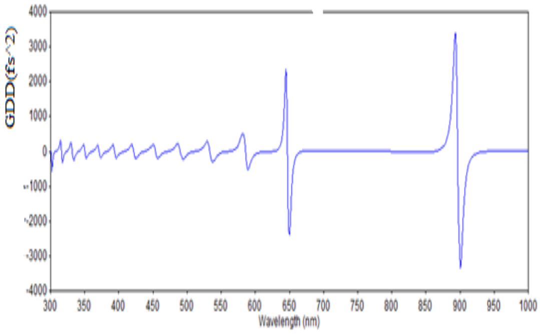

Figure 3. Group Delay Dispersion vs. Wavelength for the First Design

Then if we add a spacer 2H and a low reflectance stack (HL) to the stack formalas shown below:

Air /**HLHLHLHLHLHLHL**/Glass…….stack formal for 1st design
Air /**HLHLHLHLHLHLHLHLH**/Glass…….stack formal for 2nd design

The reflectance and reflectance GDD of the stack are showing in Figure 4, Figure 5. Table 2 shows Layer structure of the second design.

Table 2. Layer Structure of the Second Design

*	Materials	Thicknesses	Index
1	HfO2	98.736	1.8990
2	BaF2	128.205	1.4625
3	HfO2	98.736	1.8990
4	BaF2	128.205	1.4625
5	HfO2	98.736	1.8990
6	BaF2	128.205	1.4625
7	HfO2	98.736	1.8990
8	BaF2	128.205	1.4625
9	HfO2	98.736	1.8990
10	BaF2	128.205	1.4625
11	HfO2	98.736	1.8990
12	BaF2	128.205	1.4625
13	HfO2	98.736	1.8990
14	BaF2	128.205	1.4625
15	HfO2	98.736	1.8990
16	BaF2	128.205	1.4625
17	HfO2	98.736	1.8990

The reflectance is boarding from 2250nm to 3250nm(650 ~900nm), but the reflectance GDD has a high non-linear value in the bandwidth of 630~645nm. Finally, if the spacer 2H in Figure 4 changed to 16H.

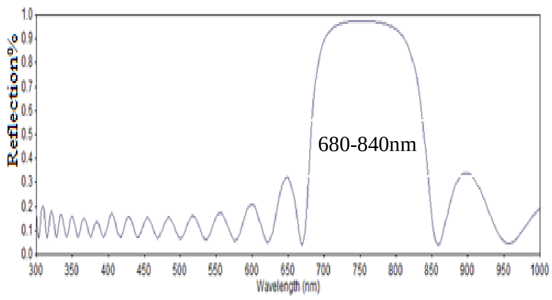

Figure 4. Reflection vs. Wavelength for The Second Design

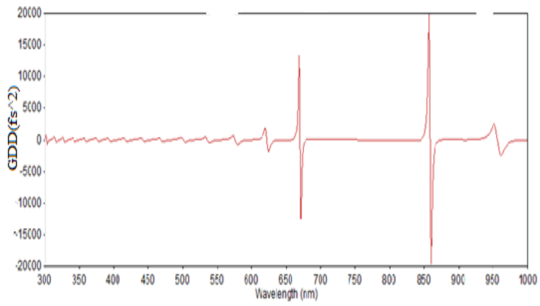

Figure 5. Group Delay Dispersion vs. Wavelength for the Second Design

4. Conclusion

GTI mirrors are used mainly for pulse compression in Yb:YAG, Yb:KGW femtosecond lasers The main drawbacks of the GTI are the fundamentally limited bandwidth (proportional to the square root of the given magnitude of GDD) and the limited amount of control of higher-order dispersion. Dispersive mirrors with significantly broader optical bandwidth can be designed as chirped mirrors. Ideally, the GTI is operated near a maximum or minimum of the GDD, and the usable bandwidth is some fraction (e.g. one-tenth) of the free spectral range, which is inversely proportional to the resonator length. In the time domain, this means that the pulse duration needs to be well above the round-trip time of the GTI. The maximum magnitude of GDD scales with the square of the resonator length. From the above result, we can see that the layer structure can be easily adapted for any other wavelength regime. We believe that this compensator of thin-film has more potential to be deployed in ultrafast optics and optical communication.

References

[1] F Gires, P Tournois. Interferometreutilisable pour la compression d'impulsion slumineuses modulees en frequence", C. R. Acad. Sci. Paris. 1964; 258: 6112.
[2] EP Ippen. Principles of Passive mode Locking. *Appl. Phys B.* 1994; 58: 159.
[3] J Kuhl, J Heppner.Compression of Femtosecond Optical Pulses with Dielectric Multilayer Interferometers. *IEEE J. Quant. Electron.* 1986; QE-22; 182.
[4] JD Kafka, ML Watts, JWJ Pieterse. Pi-cosecond and Femtosecond Pulse Generation in a Regeneratively Mode-Locked Ti: Sapphire Laser. *IEEE J. Quant. Electron.* 1992; QE-28: 2151.
[5] L Orsila, Interferometric Dielectric Reflectors for Dispersion Compensation in Fiber Lasers, Ms.C. thesis, Tampere University of Technology, Finland. 2003.
[6] http://www.rp-photonics.com/gires_tournois_interferometers.html.