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# Multilayer Thin Films Dielectric Double Chirped Mirrors Design

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**ABSTRACT**

The double chirped mirror DCM appeared to meet the need to compensate for the gain crystal dispersion of solid state lasers in a broad wavelength range. Compared to earlier dispersion compensation techniques, they enabled remarkable improvements in the field of generating ultra short pulses. When ultra broad band gain media are used inside laser cavities, cavity dispersion plays an important role in determining the duration of the pulses when the laser is operating in mode locking regime. The aim of these notes is then to investigate which the act of cavity dispersion is on the shape and duration of a laser pulse that is propagating inside a femtosecond laser cavity, and how this dispersion can be compensated with the aid of suitable optical systems. In this paper a simple analytical equation takes an arbitrarily group delay dispersion GDD as an input function and gives the chirp law as an output. The chirp law determines the local Bragg wavelengths in the mirror. It allows the calculation of the thicknesses of the high and low index layers if the double chirp of the layers in the front part of the mirror is taken into account.

A simple chirped mirror (CM) can be achieved through dielectric coating with alternate layers of high and low index materials such as TiO2/SiO2 or TiO2LZH/SiO2LZH with varying thicknesses.

**Index Terms-** Double Chirped Mirror, Bragg Wavenumber, Chirp Law, Group Delay.

## INTRODUCTION

The design rule of chirped mirrors CM consists of two main issues. The first issue is the initial multilayer design. The design procedure of chirped mirrors is usually to start with a favorable initial structure, then to perform optimization. In this procedure, the initial design is very crucial. If the initial design is not close enough to the target, the optimization procedure is impossible to reach a satisfactory result. The commonly used initial designs are double chirp and modulated layer thickness MLT. The second issue is the optimization process including the choices of targets and optimization methods. Although a CM is characterized by a certain value of group delay dispersion GDD i.e., the second derivative of the phase shift on reflection with respect to the angular frequency. GD was mostly chosen as the target, because the second derivative of the phase has two problems: the accuracy and the time consumption in the optimization [1].

The design of standard dielectric double chirped mirror includes four sections as shown in Fig. 1:

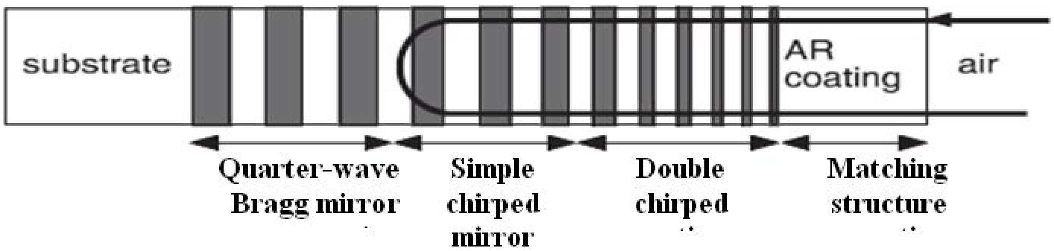



Fig. 1 Standard dielectric double chirped mirror [2].

Fig. 1 depicts a simplified diagram showing an embodiment of the double chirped mirror [2-4]. The number of layers represented is not intended to depict the actual number of layers for an embodiment of the device, but rather it shows the basic differences in the layering of the different sections [2-4].

Using the analytical equation [5]:

$$m(k_B)=\frac{1}{2\pi}\sum_{\nu=0}^{\infty}\sum_{\mu=0}^{\nu}\left\{\frac{1}{\nu!(\mu+2)}\binom{\nu}{\mu}D_{\nu+2}c^{\nu+2}(-k_0)^{\nu-\mu}\left(1-\frac{|\kappa_0|}{\pi}\right)^{\mu+1}\left(\left(k_B^{\max}\right)^{\mu+2}-k_B^{\mu+2}\right)\right\} \qquad (1)$$

Where:

$\nu =$ natural number, $\mu =$ natural number, $D =$ dispersion coefficient, $k_0 =$ center wavenumber of the Taylor expansion, $\kappa_0 =$ constant coupling coefficient with a maximum negative value, $k_B^{\max} =$ maximum Bragg wavenumber and $k_B^{\mu+2} =$ maximum Bragg wavenumber at $\mu+2$.

This equation lays the basis for the generation of an initial DCM design. The chirp law gives the Bragg wavenumber or the Bragg wavelength as a function of the normalized position $|m|$.

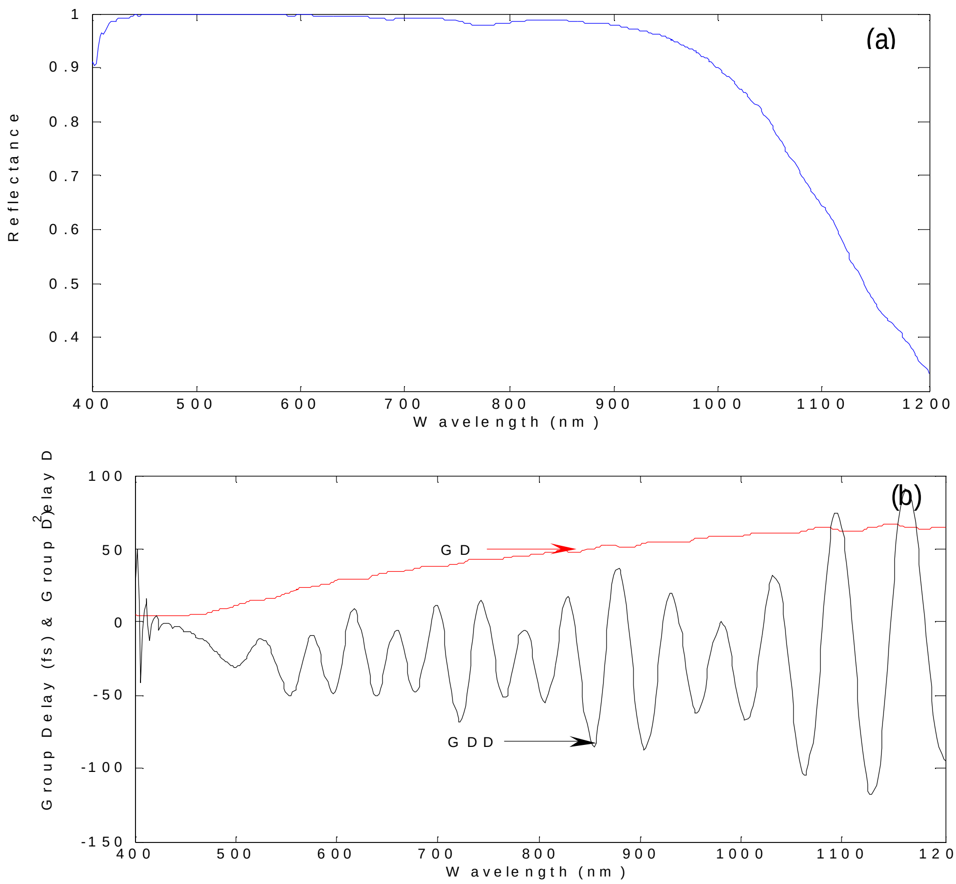
## THEORETICAL DESIGN INFORMATION

1. Number of layers: (62) layers.

2. Structure: Incident medium/AR coating/Substrate: KB7/SiO2LZH/TiO2LZH/KB7
3. For the visible region and near infrared region, the most common coating materials are titanium dioxide TiO2 and the silicon dioxide SiO2. The wavelength range $400-1200nm$ for normal incidence of light from air, with $n_{SiO2LZH} = .(1.5,-0.0)$, $n_{TiO2LZH} = (2.5,-0.0)$, for the refractive indices of SiO2LZH and TiO2LZH respectively. The Bragg wavelength $\lambda_B = 600nm$, p-polarization and the number of bounces= 6.

## EXPERIMENTAL RESULT AND DISCUSSION

One major advantage of the design method described in this paper is that situations, in which the optimum range is left, are clearly indicated in tables by analyzing the chirp law. The chirp law allows for the generation of an analytical design of a DCM with a custom tailored dispersion characteristic. All the result for the theoretical design is shown below:




Figs. 2 Reflectance, group delay and the group delay dispersion for the 2nd design mirror. (a) The reflectance is extremely high= 0.9996 over the range $\approx 450-700nm$. (b) The small oscillations in the group delay are visible. The average group delay dispersion is in excellent agreement with $-21.63\,fs^2$.

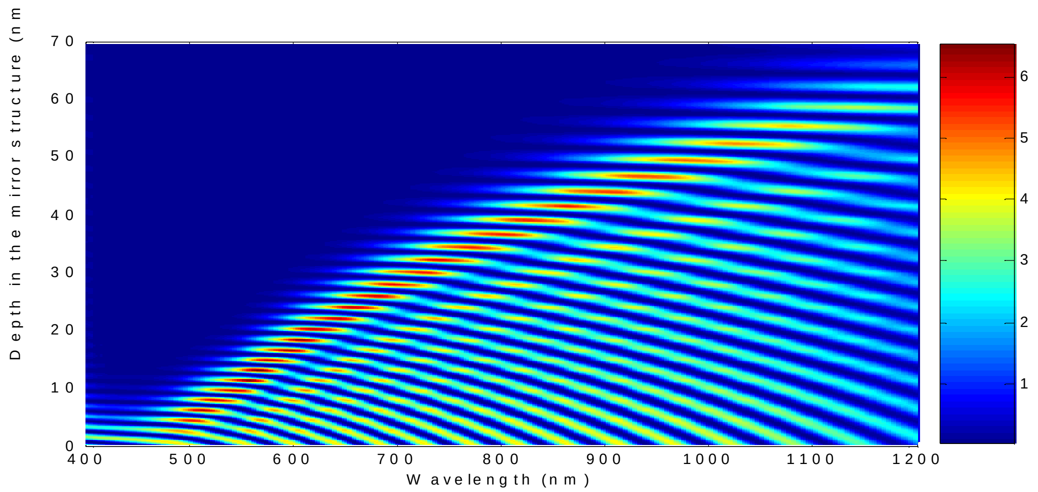



Fig. 3 The field penetration into the chirped mirror. It is apparent that within the wavelength range 500-800 nm, the field penetrates more deeply into the structure for longer wavelengths.

In Figs. 2, the reflectance is very high for wavelengths from about 450 nm to 700 nm. The bandwidth is limited by the number of index steps used for chirping the Bragg wavenumber. The maximum value of the reflectance equal to 0.9997. The median and standard deviation are equal to 0.9862 and 0.1998 respectively. It is interesting to note that even if the value of the reflection coefficient is small for a particular interface because of small difference of refractive indices of the materials of the layers surrounding it, it is still possible to obtain a very high overall reflectivity of the component because of the contributions of the reflection from other interfaces, based on constructive interference in a certain wavelength range.

The reflection properties of a multilayer (ML) mirror can be calculated by matrix method, in which each layer is associated with $2\times 2$ matrix, and the matrix of the design is obtained by multiplying together the matrices of all the layers. The resultant matrix can be used to calculate the complex amplitudes of the reflected and the transmitted waves, along with the field distribution in the multilayer structure.

The theoretically designed GD has a small oscillations around $(3.687\,fs-65.65\,fs)$ are visible. Of course, the same behavior can be found for the GDD. The oscillations are due to imperfections in the double chirp section, essentially caused by the finite thickness of the thin layers and the linear chirp of the high index layers. The average GDD are around $-20.36\,fs^2$.

The median and standard deviation for GD and GDD are equal to (46.67, 19.63) , (-19.9,38.42) respectively. Fig. 3, show with a color scale how the optical field penetrates into the mirror. The image plot of the field intensity inside the DCM illustrates the chirp of the Bragg wavelength. The increasing penetration depth of the electromagnetic field for longer wavelengths is obvious. The colors indicate the optical intensity inside the mirror as a measure for the penetration depth of a DCM, we define the wavelength dependent physical distance from the mirror surface to the classical turning point as derived from the analytical chirp law.

## CONCLUTION

The results above shows the spectral response characteristics of the mirror designs obtained with the chirp law. For the computation of the mirror properties, the Bragg wavenumber is taken at discrete points defined by $|m| - 0.5$ with $|m| = 1,2,......$, which correspond to the $|m|th$ discrete index step. For this case, the Bragg wavenumber is chirped over 28 index steps. The reflectance and phase properties upon reflection are exactly calculated with the transfer matrix formalism. It is important to note that in the case of real layer materials the wavelength dependence of the refractive indices as well as the absorption and scattering losses have to be taken into account for the calculation of the mirror properties. In contrast, this is not necessary for the determination of the discrete Bragg wavenumber from eq. (1), because these effects are considered to be small. In order to avoid undesired oscillations, the impedance is matched very slowly over the first 20 index steps by an appropriate slow tapering of the coupling coefficient.

The thickness of the high index layers is linearly increased according to $d_{h,m} = \pi /(2k_B(20)n_h)(|m|/20)^{10}$, which leads to an almost linear increase of the coupling coefficient. The reason is that an increase with a higher power law.

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