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Design Bragg Reflectors Consisting of Quarter-Wave Stack and Impedance Matching Concept

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Abstract

The control of the group delay and group delay dispersion in the design of chirped mirror is difficult. To reduce this difficult it is important to adopt what is so called impedance matching design. This paper presents a design of quart wave mirror which includes the impedance matching. The design is divided into two stages. In the first stage a quarter waves stack to provide high reflectivity of $> 99\%$ over a bandwidth of the design and within certain limits is considered. The control on average group delay depends upon wavelengths that are function of penetration depth. However, the group delay as a function of wavelength shows periodic variations due to the impedance mismatch between the ambient medium and the mirror surface and its layers. In the second stage of the design tapered Bragg stack over a wavelength range (600-1100nm) is adopted as a single chirp.

تصميم عاكس براك المتكون من كومة بربع طول موجي وفكرة موائمة الممانعة

الخلاصة

من الصعب السيطرة على تاخرالمجموعة وتشتت تاخرالمجموعة في تصميم مرايا السقسقة لتقليل هذه الصعوبة يجب ان يملك التصميم خاصية موائمة الممانعة. يقدم هذا البحث تصميم لمرايا بربع طول موجي والتي تتضمن موائمة الممانعة بتذبذب واطيء. ان تصميم السقسقة يقسم الى مرحلتين. . الاولى هي مرايا بسيطة تزودنا بانعكاسية عالية اكبرمن 99$^0/_0$ ضمن عرض ألحزمة لموجة ألتصميم. تعتمد السيطرة على معدل تاخرالمجموعة على الاطوال الموجية والتي هي بدورها دالة لعمق الاختراق. ان تاخر المجموعة كدالة للاطوال الموجية يظهر تغيرات دورية ناتجة عن عدم موائمة الممانعة بين الوسط المحيط وسطح المراة وطبقاتها. اما بالنسبة للجزء الثاني من التصميم يتكون من كومة براك المستدقة لمدى الاطوال الموجية 600-1100نانومتر كسقسقة مفتردة

Introduction

Since the invention of the laser a lot of scientific effort was put into the generation of shorter and shorter light pulses. Nowadays state-of-the art mode-locked lasers can produce pulses as short as a few femtoseconds. These ultrashort pulses have found a wide range of applications in fundamental science as well as in industry: they are used to study ultrafast processes in semiconductors, to trace and control chemical reactions, to explore light-matter interactions at very high

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intensity levels, as well as for precision processing of materials, for precise frequency measurements, and even for early diagnosis and treatment of eye diseases. Although the duration of pulses emitted from an oscillator can be decreased by external compression, the pulses cannot be made shorter than one optical cycle, which is approximately three femtoseconds for a Ti: Sapphire oscillator, for which the centre of the luminescence region lies at 800 nm. The main obstacle to approaching the theoretical limit of pulse duration remains the necessity of accurate dispersion control over a broad wavelength range. An indispensable tool for this purpose is provided by chirped mirrors: multilayer dielectric mirrors, where the thickness of each layer is carefully chosen so that the whole system has special dispersion properties. Dispersive dielectric multilayer's (henceforth chirped mirrors (CM_S) have contributed significantly to enhancement of the performance, compactness and reliability of femtosecond laser sources [1]. The generation of sub-10fs pulses directly from oscillators requires accurate, broadband, higher-order dispersion control [2-3], which can now be achieved routinely with CM dispersion controlled oscillators. Progress in CM-design and manufacturing in conjunction with advanced oscillator architectures has permitted the direct generation of sub-6fs pulses [4- 6].

2. Theoretical concepts:

The underlying physical principle of CMs in all other kinds of interference optical coatings: interference of light waves reflected from different plane-parallel interfaces results in a certain frequency-dependent reflectance R (λ) and phase shift φ (λ) of the incident light, where φ (λ) is directly connected to the group delay (GD) and the group delay dispersion (GDD) introduced by the mirror:

$$GD(\omega) = -\varphi'(\omega) \qquad \text{..... (1)}$$

$$GDD(\omega) = -\varphi''(\omega) \qquad \text{.....(2)}$$

The same principle works, for example, in a Bragg reflector: a stack of layers with a fixed optical thickness equal to $\lambda_0/4$ that have a high reflectance for wavelength close to λ_0. However, CMs posses another very important property: they can be designed in such a way that the frequency-dependent phase shift φ (λ) matches dispersion properties of materials common in laser systems (e.g. fused silica or Ti:Sapphire), which is essential for the generation of ultrashort pulses.

To obtain a smooth dispersion curve on reflection, one must suppress the interference between the light reflected from the front interface and the light reflected within the multilayer structure. This problem is sometimes referred to as the problem of impedance matching. In order to achieve negative GDD upon reflection, the inequality $\lambda_1 < \lambda_2 < \lambda_3$ must be fulfilled. Rays reflected at the front interface (represented by dots) can interfere with rays reflected within the multilayer (full lines) giving rise to GDD oscillations in the case of the standard CM as in figure (1a). The wedge attached to the tilt front interface (TFI) mirror prevents this effect as in figure (1b).Because of the close analogy between chirped mirrors and inhomogeneous electric transmission lines that was recognized in [7]. Recently proposed implementations of CMs solve this problem by separating the two beams in space, achieving thus ideal impedance matching [8-10]. For the periodic λ/4 –Bragg stack the layer thicknesses d_{HB} of the high index material and d_{LB} of the low index material are calculated using equations (3) and (4):

$$d_{HB} = \frac{\lambda_B}{4n_H} \quad ......(3)$$

$$d_{LB} = \frac{\lambda_B}{4n_L} \quad ....(4)$$

In these equation λ_B is the Bragg wavelength, n_H and n_L are the refractive indices. In order to achieve impedance matching, using equations (5) and (6) [11].

$$d_{HBIM}(P) = \frac{\lambda_B}{4n_H}\left[\frac{p}{p_{DC}}\right]^{1.05} \quad ......(5)$$

$$d_{LBIM}(P) = \frac{\frac{\lambda_B}{2} - \frac{\lambda_B}{4}\left[\frac{P}{P_{DC}}\right]^{1.05}}{n_L} \quad .....(6)$$

The chirp law equation (7) is chosen such that a linear shift as a function of wavelength is obtained [11].

$$\lambda_B(p) = \frac{\lambda_B}{\sqrt{1-0.02541fp}} \quad ..... (7)$$

Where p is the period number, f factor take different values (0.5, 0.33, 0.2, 0.1, and 0). For investigation we use the transfer matrix method [11].

The phase changes on reflectance are given by [12-13].

$$\varphi = arg\left(\frac{\eta_0 B - C}{\eta_0 B + C}\right) \quad ......(8)$$

3.Results and discussion

In this simulation two design have been used the first one is quarter wave Bragg mirror with stack of SiO_2 _bulk / $(LH)^{30}$/Air and the second illustration how can achieve impedance matching. The proposal design consist of two dielectric materials SiO_2 considered as low index material of index n_L=1.4865 at 880nm (thickness =147.99nm) and Ta_2O_5 as high index material of index n_H=2.0976 at 880nm (thickness = 104.88nm), alternatively arranged as 60-layer (30 period). Deposited on SiO_2_bulk as a substrate (n=1.45379 at 880nm). Considered to operating within wavelength range 600- 1100nm, with normal incidence and S-mode of polarization. The behavior studied at design wavelength $\lambda_o = 880$nm. Results given in Fig.1A reveal almost high reflector at design wavelength ($\lambda_o = 880nm$) when the distribution Bragg reflectors consist of alternating periodic quarter-wavelength stack of low and high refractive index. Fig.1B shows the characteristics of group delay as a function of wavelength, which shows high oscillation of spectral ripple. While Fig.1C shows the reflectance of group delay dispersion (GDD) of the design as a function of wavelength, the reflectance GDD value is $-12(fs)^2$. Look at phase change (φ) when different incident angles are being used. The formula to determine (φ) is obtained from equation (8). In this example, the refractive index for first layer is equal to (2.0976) and the refractive index for the second layer is equal to (1.4865). Four different incident angles will be used, namely 0,20,40,60 degrees. Figure.1D shows the result as mentioned previously; when the incident angle is being increased, high reflectance band boundaries will tend to shift towards the shorter wavelength as can be seen in figure.1A'. It can also be observed that increase in incident angle dose not have a significant effect on the phase changes. Figure.1E depicted the result in case n_1=n_L, n_2=n_H. Another factor that can be investigated for phase is to look at the results when different numbers of layers are being used. The results are depicted in figure .1F, where in this figure show which by increasing the number of layers in the stack, there is no significant effect on the phase change. Hence, it can be concluded that by changing the number of layers in the stack dose not alter phase changes. The variation of physical thickness against layer number for quarter wave mirror can be seen in Fig.1G. Obviously; this mirror structure does not provide any impedance matching and exhibits strong dispersion oscillation. Also found, though, that part of the incident light is lost by reflection off the front of the dielectric stack and by transmission through the stack. The reflection off the front of the stack is due to an impedance mismatch between the substrate and the periodic dielectric stack that is caused mainly by sudden periodicity and not as much by the difference in the refractive index.

4.Conclusion

The bandgap was increased with increase of Mg concentration from 3.3eV to 4.2eV as well as with the change of thickness. The absorption edge was found to shift toward lower wavelength with increase in Mg (x) value. X-ray diffraction studies show that the $Mg_xZn_{1-x}O$ film has singlecrystilline structure (hexagonal) correspond to (002) orientation,and there is a slightly shifted to larger 2θ angle with increasing x from (x=0 to x=0.3). The refractive index decreases with increasing Mg concentration x.

To prevent the reflection off the front of the thin film stack, therefore could use a "tapered" Bragg stack" [64]. In order to achieve impedance matching the first 25 of the 30 periods are single chirped using equations (5) and (6). Table (1-1) gives a list of the layer thicknesses as a function of the layer number and the layer material for the stacks. Fig.2A & B shows the reflectivity and group delay as a function of wavelength after impedance matching and that the group delay dispersion as a function of wavelength in Fig.2C depicted the effect of impedance matching which mitigates these oscillations. Fig.2D demonstrate the physical layer thickness as a function of the layer number for 60-layer $\lambda/4$ - Bragg stack and for a 60-layer impedance matched Bragg stack.

3. Conclusions

Clearly seen from these designs that the quarter wave are the worst possible case in terms of dispersion oscillations and when achieve impedance matching at the interface to air and consider a plain simple-chirped mirror structure. The oscillation is still high because the impedance matching requires that the equivalent refractive index at the mirror front equals the refractive index of the ambient medium (n_a=1). Also see in such a Bragg stack the periodicity is slowly "turned on" by increasing the amount of high index material in each period. All of the designs illustrated above are front coated chirped mirrors SiO_2/Ta_2O_5 therefore the oscillations are high and providing worst impedance matching between coating and ambient medium.

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Table (1-1) layer structure of chirped mirror with impedance matching.

No	materials	Thickness (nm)	No	materials	Thickness (nm)
1	SiO2	290.95	31	SiO2	203.36
2	Ta2o5	3.57	32	Ta2o5	65.64
3	SiO2	285.56	33	SiO2	197.28
4	Ta2o5	7.39	34	Ta2o5	69.95
5	SiO2	280.02	35	SiO2	191.17
6	Ta2o5	11.31	36	Ta2o5	74.28
7	SiO2	274.39	37	SiO2	185.05
8	Ta2o5	15.31	38	Ta2o5	78.62
9	SiO2	268.68	39	SiO2	178.91
10	Ta2o5	19.35	40	Ta2o5	82.97
11	SiO2	262.92	41	SiO2	172.75
12	Ta2o5	23.43	42	Ta2o5	87.33
13	SiO2	257.11	43	SiO2	166.58
14	Ta2o5	27.55	44	Ta2o5	91.70
15	SiO2	251.26	45	SiO2	160.40
16	Ta2o5	31.70	46	Ta2o5	96.08
17	SiO2	245.37	47	SiO2	154.20
18	Ta2o5	35.87	48	Ta2o5	100.43
19	SiO2	239.44	49	SiO2	147.99
20	Ta2o5	40.07	50	Ta2o5	104.88
21	SiO2	233.49	51	SiO2	147.99
22	Ta2o5	44.29	52	Ta2o5	104.88
23	SiO2	227.51	53	SiO2	147.99
24	Ta2o5	48.52	54	Ta2o5	104.88
25	SiO2	221.51	55	SiO2	147.99
26	Ta2o5	52.78	56	Ta2o5	104.88
27	SiO2	215.48	57	SiO2	147.99
28	Ta2o5	57.05	58	Ta2o5	104.88
29	SiO2	209.43	59	SiO2	147.99
30	Ta2o5	61.34	60	Ta2o5	104.88

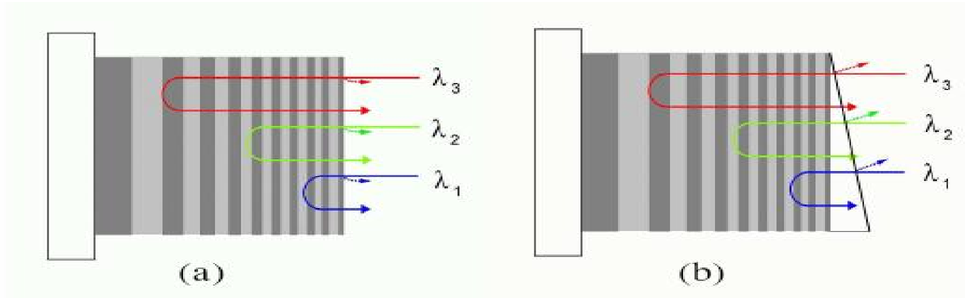

Figure1(A)Shematic representation of a standard CM (a) and of a TFI CM (b).

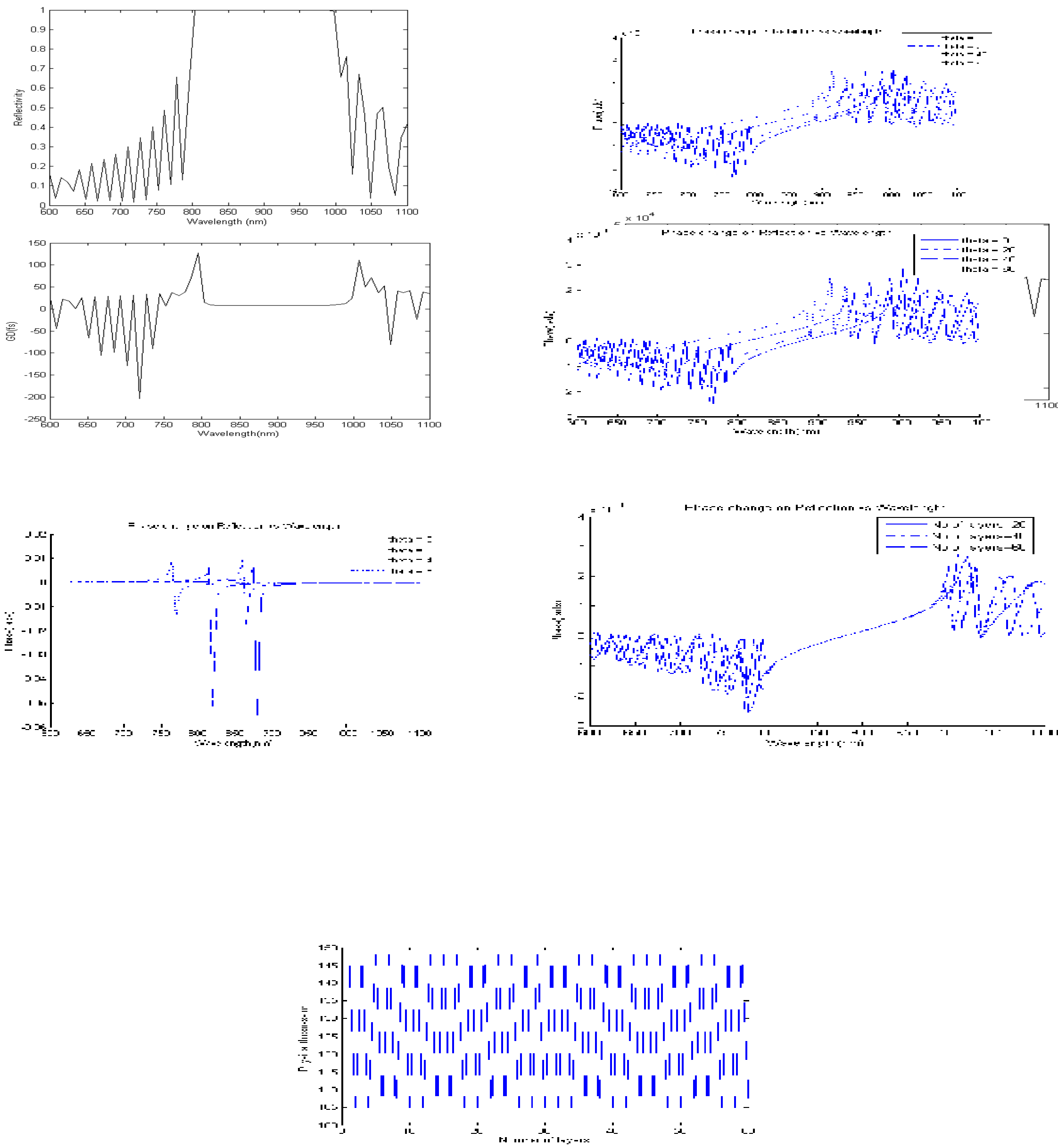

Figure1(B) Design of quarter wave Bragg mirror (QWBM) SiO_2_bulk / $(LH)^{30}$/Air (A) Reflectivity vs. wavelength. (A') Effect of angle of incident on reflectivity. (B) Group delay vs. wavelength (C) Group delay dispersion vs. wavelength (D) Phase change on reflection vs. wavelength (nm) in case n_1=n_H, n_2=n_L. (E) Phase change on reflection vs. wavelength (nm) in case n_1=n_L, n_2=n_H. (F) The effect on phase change on reflection as the number of periods N. (G) Physical thickness (nm) vs. layer numbe

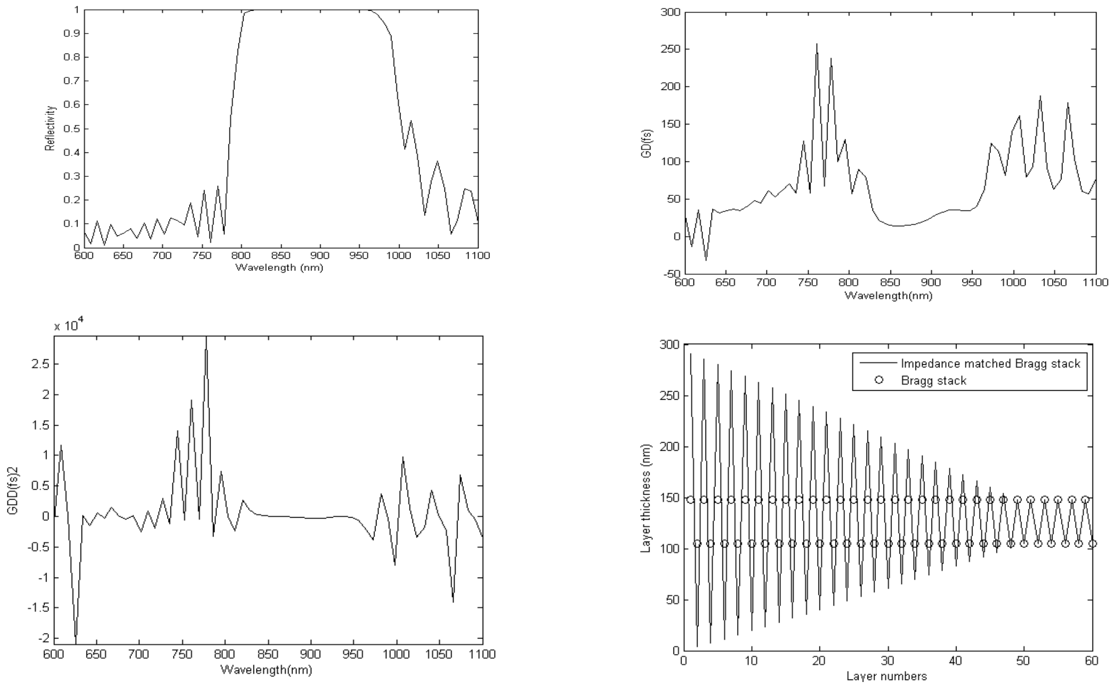

Figure (2) Design mirror with impedance matching (A) Reflectivity vs. wavelength (B) Group delay vs. wavelength (C) Group delay dispersion vs. wavelength (D) physical thickness (nm) vs. layer number.