Study the effect of the substrate on the FWHM pulses for the chirped mirrors

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Abstract : We consider the design of double chirped mirror(D.C.M) with the various substrates that fused Silica BK7, as well as appearance in current study the FWHM for the reflected pulses is reducing when the lowest levels of dispersed oscillations are achieving if the matching index of substrate with index of one of the coated material and if the double-chirping is using for chirping mirrors (CM)arrangement.

Keyword: FWHM pulses, chirped mirrors

تأثير مادة القاعدة على عرض النبضات المنعكسة لمرايا الزقزقة

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الخلاصة

تمت الدراسة والتحقيق من استخدام مادة السليكا القاعدية لمرايا الزقزقة،واتضح بأن عرض النبضات المنعكسة بأمكانها ان تقل الذبذبات اذا كانت المادة قاعدي لمادة تركيب مرايا الزقزقة.

الكلمات المفتاحية:عرض النضات المنعكسة،مرايا الزقزقة.

Introduction

The layers with increased thickness (as quarter-wave with gradually increased Bragg wavelength) are considered as simple idea which stands behind a chirped mirror(CM) , these layers can be penetrate deeply into the mirror based on their lengths ; in other words; deeper penetration into mirror structure ; longer wavelength and negative group delay dispersion (GDD) is generated accordingly , thus the dispersion of the others elements in the laser cavity is improving .

As well as, when the standard dielectric quarter-wave mirrors compare with the bandwidth of high-reflectance enhancing ,the producing outcome through these kinds of the mirrors, so the effect as highly efficient compensation of the greater- pattern’s dispersion with a spectral extent which was broader than what prisms do. *Tempa et.al.,* (1997) reported that " ≈ 7.5-fs pulses for a prism-less ring oscillator by simply using the chirped mirrors(CMs). So, through that a $\Delta v \approx 85\ TH_z$ at wave length ranges from(710 - 890) nm, the dispersion compensation on a bandwidth is formed , Through the designed mirrors dispersion ,the unnecessary spectral oscillations attend around target function, these oscillations originate from the impedance disparity of the chirped mirrors(CMs) structure to ambient medium that typically be from the air".

In general, the amplitude of mirror oscillation was dramatically increased in line with mirror bandwidth. For this problem-solving, designing concept of the double chirped mirrors (DCMs) is a powerful technique to conform (3), through these DCMs various matched problems were remarked due to various multilayer subsections (4). In figure (1a), the technique of the DCMs was characterized by the fittingness with impedance of chirped mirror section of the coating material for both the low or high index, which goes well with ambient air by adding an additional anti-reflection coating on top of the chirped mirror(CM).

The pulses of 6.5-fs duration are generated by the first sets of the double chirped mirrors (DCMs) (5). So the dispersion compensation, we find the bandwidth is of $\Delta v \approx 115$ THs (680- 920 nm).The incorporating of additional improvements consolidates the understanding of DCMs (4) and accuracy in layer disposition that creates the system of optical-circle.

Sutter et.al (1999) said that "In this laser, the dispersion compensation bandwidth supported by DCM $\Delta v \approx 180$ THs is used". However inevitable imperfection of AR coating that generates the impedance suitable step to the air may be considered as a limiting factor in terms of ultra-broadband designs, as a result no support to the enormous bandwidth except for the additional cancellation of dispersion oscillations can be obtained. By applying combinations of DCM under the various angles of the incidence (7 ,12), this cancellation becomes archived. Various coated mirrors can be used as appropriate. Due to limited balance between dispersion oscillation amplitude and bandwidth, it is difficult to incorporate additional improvements in terms of pulse bandwidth of conventional chirped mirrors.

As shown in the Fig-1b, the front side is coated by AR coating where as the back side is of the chirped mirror (CM). This kind of mirror is called back-side-coated (BASIC) mirrors. This technique stands as most appropriate resolution for the impedance matching problem in the chirped mirror (CM) pattern.

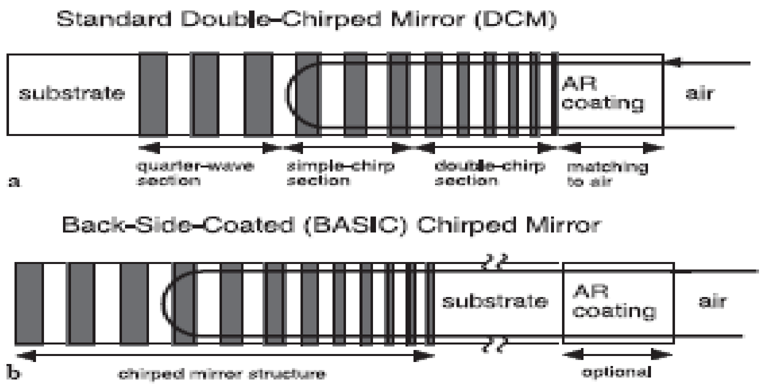


Figure (1): The comparison technique between (a) Standard Double Chirped Mirror(DCM) and (b) Back Side Coated mirror (BASIC).

The applied approaches have the same applicable material as substrate; an anti-reflection coating (AR) and chirped structure of mirror (CM), so in the practical approach, AR and chirped mirror (CM) are covered each other on top, while in of $BASIC_s$ mirror state , AR coating was optional that coated on the opposite side of substrates . The subsection of chirped was coated into a double chirp section. The same practical approach can be operated for chirped mirror structure of the BASICs mirror. as following, example of BASICs mirror with plain chirped coated.

2. Theoretical concepts

In this study, the basic parameters of multilayer structure can be identified as (N is the number of layers, n_r refractive index, k_r - extinction, d_r - thickness for each layer, and k_m - substrate optical constants, n_0 and k_0 - optical constant of the external media, θ_0 – angle of incidence ; spectrum and phase changes of reflection and transmission). The delay group and dispersion delay group can be calculated. By using the matrix method (14), the reflection coefficient can be written:

[1] $$R=\left(\frac{\eta_0 B-C}{\eta_0 B+C}\right)\left(\frac{\eta_0 B-C}{\eta_0 B+C}\right)^{*}$$

phase change was :

[2] $$tg\,\varphi=\frac{\mathrm{Im}\left[\eta_0(CB^*-BC^*)\right]}{\mu_0^2 BB^*-CC^*}$$

where characteristic matrix of the assembly was :

[3] $$\begin{pmatrix}B\\C\end{pmatrix}\left(\prod_{r=1}^{N}\begin{bmatrix}\cos\delta_r & \dfrac{i\sin\delta_r}{\eta_r}\\ i\eta_r\sin\delta_r & \cos\delta_r\end{bmatrix}\right)\begin{pmatrix}1\\ \eta_m\end{pmatrix}$$

The phase thickness of the layer r is

[4] $$\delta_r=\frac{2\pi N_r d_r\cos\theta_r}{\lambda}$$

The layer admittances are for

[5] $$\eta_r=\chi_{vac}N_r\cos\theta_r \qquad (TE\ \ waves)$$
$$\eta_r=\frac{\chi_{vac}N_r}{\cos\theta_r} \qquad (TM\ \ waves)$$

[6] $$\eta_m=\chi_{vac}N_m\cos\theta_m \qquad (TE\ \ waves)$$
$$\eta_m=\frac{\chi_{vac}N_m}{\cos\theta_m} \qquad (TM\ \ waves)$$

The symbol λ mean wavelength ; $N_r = n_r - ik_r$, χ_{vac}= 2.6544 × 10^{-2}S the vacuum admittance, η_0 and η_m were external and substrate admittances , respectively.

value of the θ_r that be founded from the Snell's law:

[7] " $$N_0 \sin\theta_0 = N_r \sin\theta_r = N_m \sin\theta_m$$ "

The group delay is

[8] " $$GD = -\frac{d\varphi}{d\omega} = \frac{\lambda^2}{2\pi c}\frac{d\varphi}{d\lambda}$$ "

So the φ was given in the Eq.[2] and C = 3×10^8 m/s was speed of the light.

The group delay dispersion is

[9] " $$GDD = -\frac{d^2\varphi}{d\omega^2} = -\frac{\lambda^2}{(2\pi c)^2}\left(\lambda^2\frac{d^2\varphi}{d\lambda^2} + 2\lambda\frac{d\varphi}{d\lambda}\right)$$ "

3. Chirped mirror design

The structure of design chirped mirror(CM) consists of 60-layers. The refractive indices at 880 nm are n_L= 1.4865 and n_H= 2.0976, for SiO_2 and Ta_2O_5 respectively. The incident angle is normal, and the s-polarization is considered. Table (1), shows the layer thicknesses of double chirped mirror (DCM)as a functional of the layer number and layer material for stacks.

Table (1): Layer structure of Double Chirped Mirrors(DCMs)

No	materials	Thickness (nm)	No	materials	Thickness (nm)	No	materials	Thickness (nm)
1	SiO_2	266.20	21	SiO_2	228.86	41	SiO_2	183.41
2	Ta_2O_5	3.26	22	Ta_2O_5	43.41	42	Ta_2O_5	92.72
2	SiO_2	262.96	23	SiO2	224.66	43	SiO_2	178.41
4	Ta_2O_5	6.80	24	Ta_2O_5	47.92	44	Ta_2O_5	98.21
5	SiO_2	259.56	25	SiO_2	220.39	45	SiO_2	173.33
6	Ta_2O_5	10.49	26	Ta_2O_5	52.51	46	Ta_2O_5	103.83
7	SiO_2	256.03	27	SiO_2	216.05	47	SiO_2	168.15
8	Ta_2O_5	14.28	28	Ta_2O_5	57.20	48	Ta_2O_5	109.56
9	SiO_2	252.40	29	SiO_2	211.62	49	SiO_2	162.87
10	Ta_2O_5	18.18	30	Ta_2O_5	61.98	50	Ta_2O_5	115.42
11	SiO_2	248.68	31	SiO_2	207.12	51	SiO_2	164.41
12	Ta_2O_5	22.16	32	Ta_2O_5	66.85	52	Ta_2O_5	116.51
13	SiO_2	244.88	33	SiO_2	202.54	53	SiO_2	165.99
14	Ta_2O_5	26.24	34	Ta_2O_5	71.82	54	Ta_2O_5	117.63
15	SiO_2	240.99	35	SiO_2	197.88	55	SiO_2	167.62
16	Ta_2O_5	30.40	36	Ta_2O_5	76.89	56	Ta_2O_5	118.78
17	SiO_2	237.02	37	SiO_2	193.14	57	SiO_2	169.30
18	Ta_2O_5	34.65	38	Ta_2O_5	82.06	58	Ta_2O_5	119.97
19	SiO_2	232.98	39	SiO_2	188.32	59	SiO_2	171.03
20	Ta_2O_5	38.99	40	Ta_2O_5	87.33	60	Ta_2O_5	121.20

For investigations two types of substrate will be used, Fused Silica with refractive index n_s=1.4520 at 880 nm and BK7 with n_{BKr}= 1.509321 at 880 nm.

4. Results and discussions

Figures below show the characteristics reflectivity, delay group and dispersion delay group for two designs. The reflectivity of the stack versus wavelength appears in Fig.2a. This stack has a peak in the reflectivity at 880 nm (R = 0.999997), R drops to 0.98 at 830 nm and 1050 nm which is a bandwidth of about 175 nm. As it illustrate in Fig.2b. The delay group has high oscillation at the range 800 – 875 nm but the GD is nearly constant over the bandwidth of about 175 nm. The GDD as a function of wavelength has a high non-linear value in the range 800 – 875 nm (Fig.2c). Figure.2d shows the profile of refractive index as a function of depth (nm) inside the stack (15).

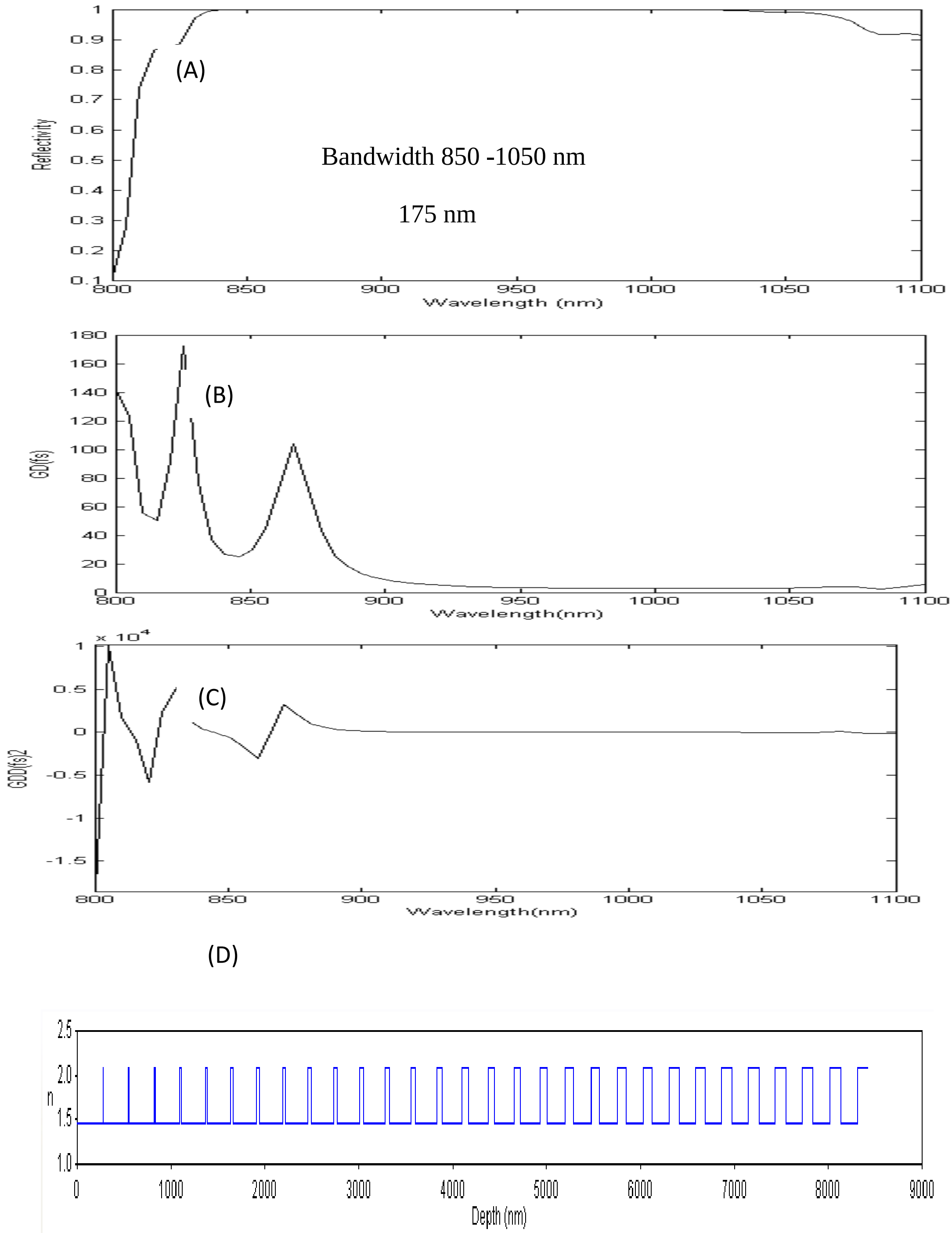
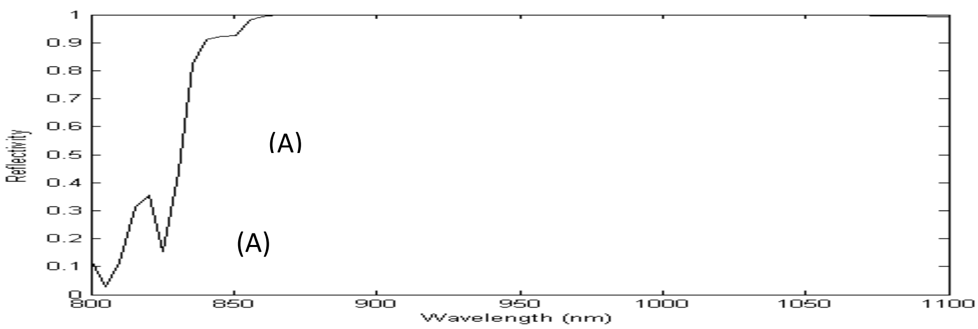
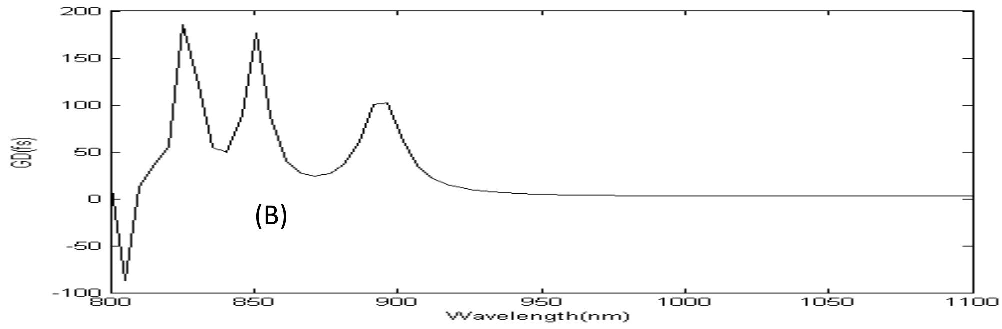


Figure (2): Double Chirped Mirror (DCM) design that based on back-side-coated using Fused Silica. (A) Characteristic Reflectivity vs. wavelength; (B) Group Delay vs. Wavelength; (C) Dispersion of Group Delay vs. wavelength; (D) Back Side Coated Profile refractive index vs. depth through substrate.

Figures. 3(A , C) show the characteristics of reflectivity, delay group and dispersion group delay when the substrate is BK7, the results revealed clearly the alterations of reflectivity at short wavelength for delay group and dispersion delay group , since the refractive index of the substrates were selected relatively near to the low refractive index (R.I) of the coated material, these prevents disruption of R.I at the interface to air as well as near to the total destruction of dispersed oscillations through the non-interfering back surface. The substrate material selection may be deflect with the exact matching index (M.I), since R.I of the sputter or the evaporate materials may be deviate significantly against the R.I of bulky materials.

In this study, The reduction can be perform by means of the fused silica with R.I, $n_{\text{fused silica}}$ = 1.4520 at 880 nm and merely caused Fresnel reflection coefficient (R.C) of 0.0117 at normal incidence. A R.I n_{SiO2} = 1.4865, for example the sputtered Silica, compared with the bulky value R.I n_{FS} =1.4520 about 880 nm. Like disruption index between coating and substrate at the interface, however, that causes a slightly reflection of 1.37×10^{-4} found in normal incidence. Additional reduction can be accomplish by using an optical glass with a R.I near to sputtered SiO_2 (e.g., BK7 with n_{BK7} = 1.509321 about 880 nm). Therefore, difference between R.I for sputtered Silica and a bulk substrate is n_{diff} = 0.0228. By any means, the residual mismatch struggle between coating index and substrate is less confining than the air matching problem. A residual mismatch can be resolve easily by the differential upgrading of layers progression.





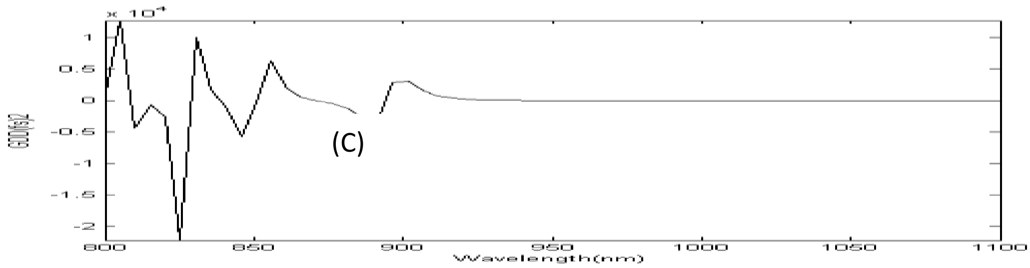
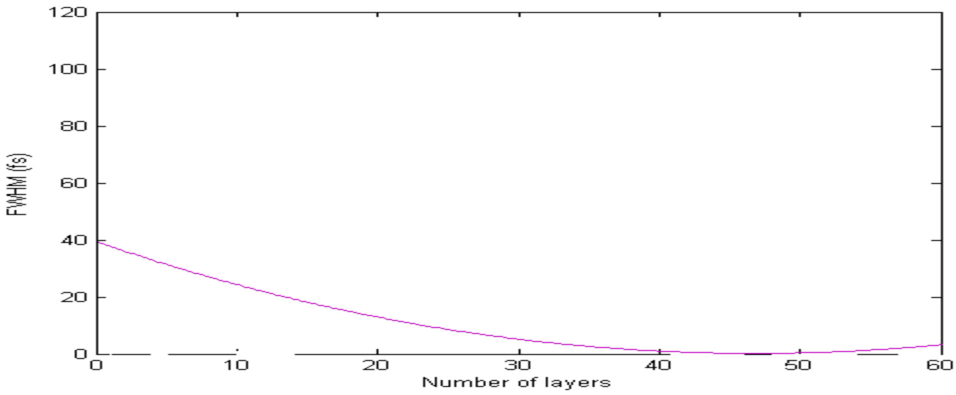


Figure (3) : Design double chirped mirror (DCM) on back side coated using BK7 substrate (A) Reflectivity vs. wavelength; (B) Group delay vs. wavelength; (C) Group delay dispersion vs. wavelength.



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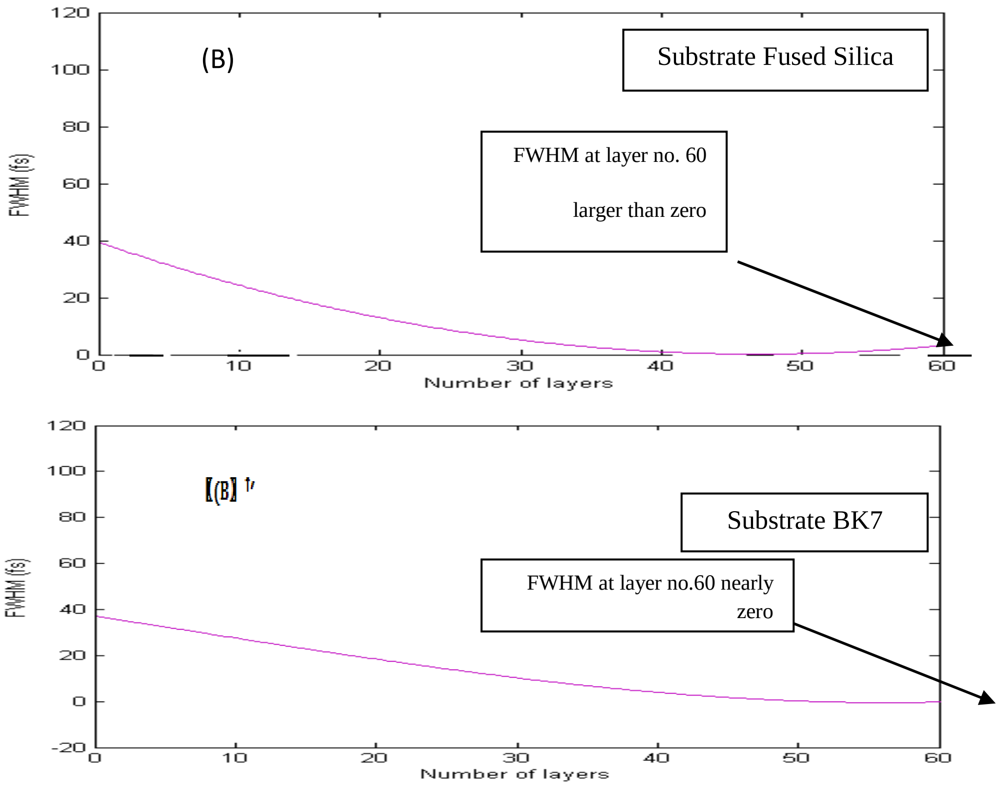

Figure (4): Relation between FWHM and number of layer for design double chirped. (A) In case of back-side coated using Fused Silica; (B') In case of back side coated when using BK7 substrate.

In figure (4) that showed the dependence of the FWHM for pulse reflection from the chirped mirror(CM) with the varying number of the layers , as well as the appearance that FWHM of the reflected pulse reduced below the 10 fs at number of the layers 60.

The critical values of dispersion coefficients, above that dispersion caused substantial changes of pulse ; obey simple scaling law $D \approx \tau_p^2$ is the full-width at half maximum (FWHM) pulse duration (16-20). Using the numerical simulation to calculate the group delay and group delay dispersion (18), the simple scaling law can be simulated to calculate the FWHM, of the pulse reflected.

5. **Conclusion**

We revealed the matched troubles of the chirped mirror to ambivalent medium, as well as our results that showed the double-chirped mirror (DCM) technique with the BK7 as substrates furnishes a best possible solutions to impedance-matching (I.M) difficulty if ambient intermediate with the index equal to one of layers materials was selected.

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