Modeling of a Cold mirror based on TiO_2/MgF_2 and TiO_2/SiO_2 at 45^o angle of incidence

V.V. Elyutin[a], M.A. Butt[a], S.N. Khonina[a,b]

[a] *Samara National Research University, 443086, 34 Moskovskoe Shosse, Samara, Russia*
[b]*Image Processing Systems Institute - Branch of the Federal Scientific Research Centre "Crystallography and Photonics" of Russian Academy of Sciences, 443001, 151 Molodogvardeyskaya street, Samara, Russia*

Abstract

In this paper, a modeling of a multilayer dielectric cold mirror based on TiO_2/SiO_2 and TiO_2/MgF_2 alternating layers is presented. A cold mirror is a specific dielectric mirror that reflects the complete visible light spectrum whereas transmitting the infrared wavelengths. These mirrors are designed for an incident angle of 45^o, and are modeled with multilayer dielectric coatings similar to interference filters. Our designed mirror based on TiO_2/SiO_2 shows an average transmission of less than 5% in spectrum range of 425-610 nm whereas it has an average transmission of 95% in the spectrum range of 710-1500 nm.

Keywords: Cold mirror; TiO_2; MgF_2; SiO_2; dielectric materials

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1. Introduction

Thin film optics is a well-developed technology and many devices such as passband filters, stopband filters, polarizers and reflectors are successfully developed with the help of multilayer dielectric thin films [1, 2, 3]. These optical elements comprise of alternating layers of high and low refractive index materials with specific thicknesses and awareness of their refractive index and absorption. Multilayer dielectric filters are based on the principle of multiple reflections that takes place between the interfaces of high and low index materials. Generally, these filters are used depending on the purpose or requirement. In particular, spectral filters are promising for hyperspectrometers [4, 5]. Distributed Bragg Reflectors (DBRs) are one of the widely used filters which are quarter wave thick of the center wavelength. The high reflection region of a DBR is known as the DBR stopband and can be obtained by the refractive index contrast between the constituent layers [2]. Cold mirror is a specific dielectric mirror that reflects the visible light spectrum while transmits the infrared wavelengths. These mirrors work on the principle of multiple reflections between high and low index material interface. The visible spectrum of light spans ~380-770 nm and the region beyond 770 nm in the near infrared, which is heat. Radiations from a tungsten lamp contain at least six times as much heat as useful light in the visible. The term cold light defines radiation in which the IR spectrum is removed [6].

A hot mirror is just the opposite of cold mirror which is designed to reflect infrared region while transmits the visible portion of the beam. These mirrors can separate visible light from UV and NIR which helps in separating the heat from the system as shown in figure 1. Cold mirror has many practical applications such as in projectors, copy machines, medical instruments and fiber optical illuminations [6, 7].

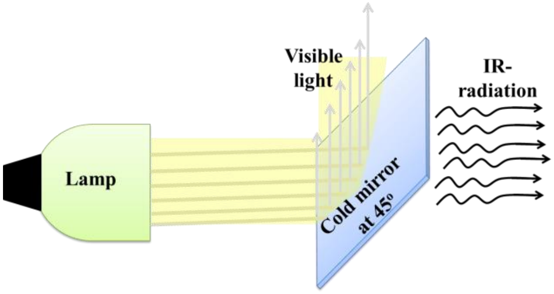

Fig. 1. Schematic of a cold mirror.

2. Filter design

In this work cold mirrors are designed in the wavelength range of 425-1500 nm by using open source software Open Filter to selectively pass the wavelengths of interest and rejecting the undesired wavelengths in visible spectrum. TiO_2 (n=2.5), SiO_2 (1.45) and MgF_2 (n=1.37) materials are carefully selected based on their high and low refractive indices, respectively. Open filter uses transfer matrix method to analyze transmission and reflection of light from layers based on thickness and type of materials. Designs are optimized to maximum transmission required wavelengths using needle synthesis method (addition of thin layers called needle and analyze transmission till the best results obtained). The maximum transmission for wavelength range 710-1500 nm is obtained by using needle synthesis method. It adds an extra layer called needle to the design and every time when it adds a needle, transmission spectrum of the filter is calculated. The optimal position of the needle is a derivative of Merit Function with respect to thickness of thin layer. The position where derivative is negative, needle is added. Mostly single needle is added and transmission spectrum is calculated. Addition of needle stops at the point where there is no improvement in the target transmission spectrum [8]. The thicknesses of the layers for cold mirror based on TiO_2/MgF_2 and TiO_2/SiO_2 are shown in table 1.

Both mirrors have 20 layers with almost similar total thickness. Special attention has been given to keep the thickness of the filters within economic limits.

Table 1. Layer thicknesses of TiO_2/MgF_2 and TiO_2/SiO_2 based Cold mirrors

Layer no.	Material	Thickness (nm)	Layer no.	Material	Thickness (nm)
1	TiO_2	14	1	TiO_2	25
2	MgF_2	114	2	SiO_2	121
3	TiO_2	45	3	TiO_2	55
4	MgF_2	84	4	SiO_2	82
5	TiO_2	62	5	TiO_2	55
6	MgF_2	71	6	SiO_2	65
7	TiO_2	43	7	TiO_2	44
8	MgF_2	87	8	SiO_2	99
9	TiO_2	44	9	TiO_2	51
10	MgF_2	107	10	SiO_2	110
11	TiO_2	66	11	TiO_2	71
12	MgF_2	90	12	SiO_2	92
13	TiO_2	68	13	TiO_2	72
14	MgF_2	130	14	SiO_2	123
15	TiO_2	48	15	TiO_2	54
16	MgF_2	118	16	SiO_2	106
17	TiO_2	87	17	TiO_2	93
18	MgF_2	54	18	SiO_2	53
19	TiO_2	79	19	TiO_2	80
20	MgF_2	228	20	SiO_2	218
Total thickness		1639	Total thickness		1669

Assuming the incident angle of unpolarized light equals 45^o, these mirrors have reflective properties in the spectral range from 425-610 nm and 710-1500 nm up to 95% and 5%, respectively. When the light incident angle decreases from 45^o to 0^o, the transmission spectrum shifts from 710 to 750 nm.

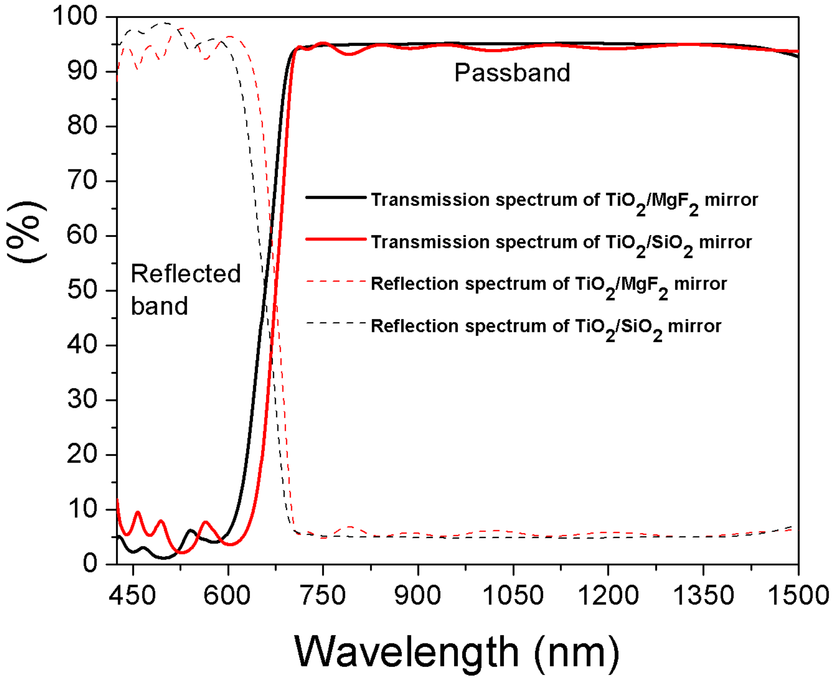

Fig. 2. Transmission and reflection spectrum of cold mirror in the wavelength range of 425-1500 nm.

3. Conclusion

In this work, we presented the modeling results of cold mirrors based on TiO_2/MgF_2 and TiO_2/SiO_2 for 45^o of un-polarized incident light. Both mirrors show the reflection of 95% in the spectral range of 425-610 nm and 95% of transmission in the spectral range of 710-1500 nm. The designs are optimized to maximum transmission required wavelengths using needle synthesis method. We observed a right shift in a spectrum, when the angle of incidence of light was reduced from 45^o to 0^o.

Acknowledgements

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