Modeling of a multilayer dielectric stack Notch filter for visible spectrum

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Abstract

In this work, a multilayer dielectric optical notch filters design for visible spectrum 450-700 nm is proposed based on TiO_2 and SiO_2 alternating layers. Titanium dioxide (TiO_2) is selected for its high refractive index value (2.5) and Silicon dioxide (SiO_2) as a low refractive index layer (1.45). These filters are conventionally anticipated for overpowering of powerful laser beams in research experiments, to obtain good signal-to-noise ratios in Raman laser spectroscopy. The designed filter shows a high quality with average transmission of more than 90% in 450-535 and 587-700 nm wavelength ranges. And a stop band region between 536-586 nm with a FWHM of 50 nm shows a transmission of 3% with an optical density of greater than 3, which makes it a promising element to be used as notch filter.

Keywords: Notch filter; Optical density; Distributed Bragg Reflector (DBR); visible spectrum.

1. Introduction

Thin film optics is well established technology. Many devices such as band pass filters, band-stop filters, polarizers and reflectors are realized with the help of multilayer dielectric thin films [1]. Notch filters are usually known as band-stop or band-rejection filters which are designed to transmit most of the wavelengths with low intensity loss while diminishing the light within a specific wavelength range to a very low level. These filters are conventionally envisioned for overpowering of powerful laser beams in research experiments, to obtain good signal-to-noise ratios in Raman laser spectroscopy. It is precarious that light from the pump laser should be blocked. This is attained by inserting a notch filter in the detection channel of the setup. In addition to spectroscopy, notch filters can also be used in laser-based florescence instrumentation and biomedical laser systems. They are also used for eye protection and as a camera accessory. These filters contain alternating layers of high (H) and low (L) refractive index materials with precise thicknesses with good knowledge about their refractive index and absorptions. These filters work on the principle of multiple reflections between high and low index materials interface. Distributed Bragg Reflectors (DBRs) has λ/4 thickness of the central wavelength. The high reflection region of a DBR is known as the DBR stop band, and can be attained by the refractive index contrast between the constituent layers. A broad stop band can be realized by using high index contrast thin films.

In this work, the design of Notch filter based on TiO_2/SiO_2 is proposed at a central wavelength of 561 nm with a FWHM of 50 nm. We designed this filter with less possible number of layers with high transmission in pass band region and high reflection is obtained in the stop band. Open-source software, Open Filters, is used in this work to design and optimize the required filter. Transmission and reflection properties of interference filters are dependent on materials refractive index and layer thickness of materials. Open filter calculates optical properties of filters. It uses transfer matrix method to calculate the transmission and reflection properties of filters based on the absorption and materials refractive indices [2]. Optimization techniques are available in this software like needle synthesis (Adding extra layer to give targeted transmission).

2. Optical density of the notch filter

A filter plate made of a isotropic material with smooth and parallel surfaces, the transmittance depends on the thickness, optical constants of the material, the angle of incidence and polarization state of the incident light, and the degree of coherence between multiple reflected waves [3,4]. Optical density (OD) is used to see the blocking specification of a filter and is associated to the amount of energy transmitted through it. It uses a logarithmic scale to describe the transmission of light through a highly blocked optical filter, particularly useful when the transmission is extremely small. A high optical density value indicates very low transmission of light and low optical density indicates high transmission. It can be expressed as [5]:

$$T\ (transmission\%) = 10^{-OD} x100$$
$$OD = -\log(T/100) \quad (1)$$

3. Filter design and discussion

Distributed Bragg Reflectors (DBRs)[6,7] consisting of alternating high and low refractive index material pairs are the most commonly used mirrors in FP filters, due to their high reflectivity. However, DBRs have high reflectivity for a selected range of wavelengths known as the stop band of the DBR. In our previous work, we proposed multilayer dielectric filter based on TiO_2 and SiO_2 materials because of their excellent optical properties [8]. Therefore, TiO_2 and SiO_2 are chosen as high and low refractive index materials, respectively. The choice of materials is made on the basis of low absorption and high index contrast in the wavelengths of interest. The notch filter is designed for visible spectrum ranges from 450-700 nm with FWHM of 50 nm. The optimized thickness of the layers is shown in table 1. The total thickness of the filter is estimated to be 3627 nm with total of 27 alternating layers of TiO_2 and SiO_2 deposited on a substrate.

Table 1. Layer thickness of Notch filter based on TiO_2/SiO_2

Layer no.	Layer name	Thickness (nm)	Layer no.	Layer name	Thickness (nm)
1	SiO_2	548	15	SiO_2	147
2	TiO_2	11	16	TiO_2	164
3	SiO_2	28	17	SiO_2	149
4	TiO_2	280	18	TiO_2	127
5	SiO_2	153	19	SiO_2	165
6	TiO_2	124	20	TiO_2	42
7	SiO_2	151	21	SiO_2	25
8	TiO_2	164	22	TiO_2	116
9	SiO_2	148	23	SiO_2	80
10	TiO_2	123	24	TiO_2	16
11	SiO_2	153	25	SiO_2	39
12	TiO_2	52	26	TiO_2	120
13	SiO_2	153	27	SiO_2	227
14	TiO_2	122	-	-	-

The transmission spectrum of the filter shows a stop band at 536 nm to 586 nm with a central wavelength at 561 nm. The transmission in the spectral range of 450-536nm and 586-700nm is more than 90%. In all dielectric stack filters, the transmission depends on the angle of incidence of light. The central wavelength of the blocking region shifts to shorter wavelengths and FWHM increases as the angle of incidence increases as shown in fig. 1.

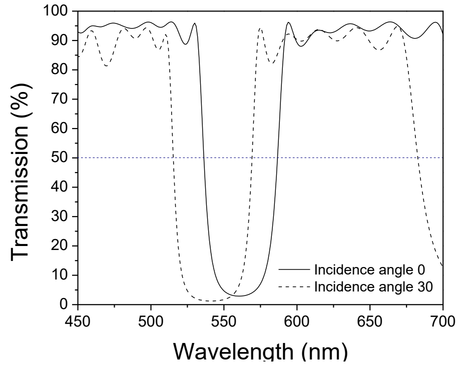

Fig. 1. Transmission spectrum of a notch filter at 0^o and 30^o of incidence light.

The design filter has maximum transmission of 3% in the stop band. The OD of the filter is calculated by using an eq. (1) which provides a value greater than 3.5 (Transmission is 0.0003%). It shows a promising result for the notch filter. The optical density of the notch filter is plotted in fig. 2.

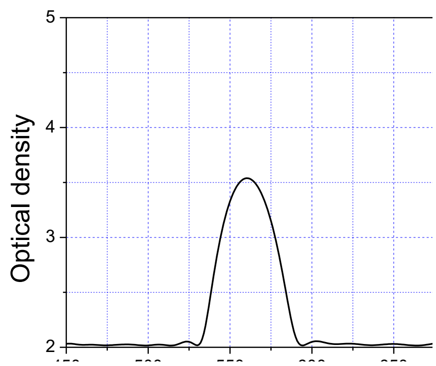

Fig. 2. Optical density of the notch filter.

4. Conclusion

In this work, a multilayer dielectric optical notch filter design is presented which is based on TiO_2/SiO_2 alternating layers. These filters provide an average transmission of more than 90% in region 450-535nm and 587-700 nm. The transmission of the stop band 536-586 nm is around 3%. The OD of this filter is greater than 3.5 which shows the high blocking specification of a filter and is associated to the amount of energy transmitted through it. With an increase in the incident angle of light, the central wavelength of the notch filter shifts toward smaller wavelength.

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