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Transmittance Properties of 18-Layered Interference Filters

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Key words
Interference filters; Lowpass; Highpass; Multi-layer

Abstract

In this study, the design and transmittance properties of lowpass (having low transmittance region) and highpass (having high transmittance region) interference filters, formed by using SiO_2 and TiO_2 were investigated. The absorption edge of light filtered through a single layered filter is not very sharp. In this regard, single layered system can not yield the desired result. However, multilayered interference filters sharpen the absorption edge of the filtered light and absorb the region completely where transmittance is not desired. In this study, transmittance properties of the interference filters formed with vacuum evaporation technique were investigated with UV spectroscopy and the main absorption edge and peak transmittance of the light passing through lowpass and highpass filters were found to be 580 and 500 nm and 91% and 93.5% in visible region, respectively. In addition, EDX spectra were obtained to determine the characteristics of the layers.

18 Katmanlı İnterferans Filtrelerinin Geçirgenlik Özellikleri

Anahtar kelimeler
İnterferans Filtre; Düşük Geçirgen; Yüksek Geçirgen; Çok katmanlı

Özet

Bu çalışmada, SiO_2 ve TiO_2 kullanılarak oluşturulan lowpass (düşük geçirgenlik bölgesine sahip) ve highpass (yüksek geçirgenlik bölgesine sahip) girişim filtrelerinin tasarımı ve geçirgenlik özellikleri araştırılmıştır. Tek katmanlı filtreden süzülen ışığın absorpsiyon kenarı istenen sonucu veremez. Ancak çok katmanlı girişim filtreleri filtreden geçen ışığın absorpsiyon kenarını keskinleştirmekte ve geçişi istenmeyen bölgeyi tamamen absorbe etmektedir. Bu çalışmada vakumda buharlaştırma tekniği ile oluşturulan girişim filtrelerinin geçirgenlik özellikleri UV spektroskopisi ile incelenmiş ve lowpass ve highpass filtreden geçen ışığın görünür bölgedeki temel absorpsiyon kenarı ve maksimum geçirgenliği sırasıyla 580 ve 500 nm ve %91, %93,5 olarak bulunmuştur. Ayrıca katmanların karakteristiklerini belirlemek amacıyla EDX spektrumları alınmıştır.

1. Introduction

Interference may be observed in transparent substance layers from the ones smaller than the wavelength of a light wave to a couple of centimeters. When the thickness of a substance is as much as a certain wavelength of electromagnetic radiation, this layer is called thin layer for this wavelength. Before the start of 1940's, though interference related to thin dielectric layers was well known, it had a limited practical application. Although beautiful colorations due to thin oil and soap layers provided esthetic and theoretical satisfaction, they could not go far from exciting interest. Since well controlled coatings could be produced in commercial scale due to the development of appropriate deposition techniques in 1930's, the interest in thin dielectric layers was rekindled (Bach et al.,1997; Baumeister et al.,1970; Clauss et al.,1970).

An interference filter may be highpass, lowpass, bandpass or band-rejection.(Baillard et al.,2006).

The preparation of multilayered interference filters is actually harder than the preparation of single layered interference filters. Full-width half-maximum (FWHM) of the light filtered from a single layered filter prepared by this way is at least as big as the FWHM of the absorption filter (Epstein,1952). In this respect, single layered system can not yield the desired result. However, multilayered bandpass interference filters narrow the spectral width too much and the light passing through the filter transforms to monochromatic light. Controlling the wavelength of light is a desired property mainly in the design of optical instruments, photography and in all studies in which color filters are used. Because glasses colored with metal ions can not yield successful results. The biggest disadvantage of this issue is its decreasing transmittance significantly. An interference filter consists of multiple thin layers of dielectric material having different refractine indices. Multilayered coatings sharpen the transmittance margin in lowpass and highpass filters (Knittl,1952; Macleod,1986; Pulker,1984; Thelen,1986; Thelen,1992; Harper,2001). In this study, transmittance properties of the interference filters formed with vacuum evaporation technique were investigated with UV spectroscopy.

2. Experimental

The single dielectric layer found in the interference filter prepared with a single layer is found between the two metal layers. FWHM of the light filtered from a single layered filter prepared by this way is at least as big as FWHM of the absorption filter. In this respect, single layered system cannot yield the desired result. However, multilayered bandpass interference filters narrow the spectral width too much and the light passing through the filter transforms to monochromatic light. Transparent silica glass is used as the base in preparation of the samples. The term lowpass filter is used to define a filter that passes low wavelengths starting from a certain margin.

Lowpass filter was prepared as consisting of 18 layers and the order of these layers is as

$$g(HLHL(HL)^5HLHL)a$$

This expression shows the coating order of dielectric substances with high (*H*) and low refractive indices (*L*), respectively, starting from the glass (*g*) to air (*a*).

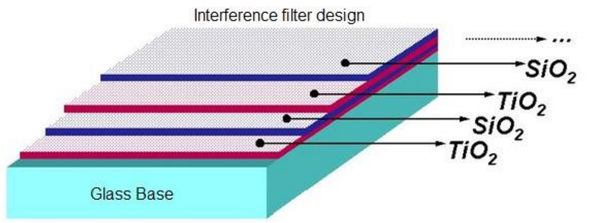

Figure 1. Schematic diagram of lowpass and highpass multilayered interference filter design

As it can be seen in Figure 1, one side of the glass was covered with TiO_2 in powder form, having a refractive index of 2.34867 by calculating the physical thicknesses with the help of equation 1 in the molybdenum melting pot of the vacuum evaporation unit of Univex 300LH. Then, SiO_2 with refractive index 1.4618 is coated with the same method. Coating of these layers continued till the expression of layer order

$$g(HLHL(HL)^5HLHL)a$$

is completed. $(HL)^5$, in the middle of the expression are optical thicknesses named as quarter-wave stack and the others are thicknesses that are calculated according to the computer aided corrections to adjust only the sharpness of the transmittance margin. Each layer within the expression has a different thickness value. Layers were coated as according to these thickness values. Changing the thickness values or performing coatings independent of the layer order expression do not provide the desired transmittance and sharpness. The coating that we have formed on the other base glass is called highpass filter. Highpass filter is the filter that transmits high wavelengths starting from a certain margin.

The formed highpass filter also consisted of 18 layers and the order of these layers was as follows:

$$g(HL(HL)^6HLHL)a$$

The method applied is identical to the one performed for lowpass filter.

The arrangement of layers is very important for both type of filters, however, the issue that is more important is the thicknesses of these layers. Optical thickness values are determined for layers with "Kidger Optics Thin Film" software by entering the number of layers and reference wavelength data. Optical thickness is the coefficient of each layer. Accordingly, the layer arrangements and optical thicknesses of lowpass and highpass filters that we have formed are given as follows.

For lowpass filter;

$$g\begin{pmatrix} \mathbf{0.296}H\mathbf{0.282}L\mathbf{0.257}H\mathbf{0.268}L \\ (\mathbf{0.250}H\mathbf{0.250}L)^5 \\ \mathbf{0.259}H\mathbf{0.274}L\mathbf{0.253}H\mathbf{0.131}L \end{pmatrix}a$$

For highpass filter;

$$g\begin{pmatrix} \mathbf{0.227}H\mathbf{0.164}L(HL)^6\mathbf{0.178}H \\ \mathbf{0.310}L\mathbf{0.183}H\mathbf{0.450}L \end{pmatrix}a$$

The actual physical layer thickness may be calculated by multiplying the optical thickness with reference wavelength and by dividing the resultant value to the refractive index of the coated material. Here, t is the optical thickness (dimensionless parameter), λ_{ref} is the reference wavelength, n is the refractive index of the coated material, and e is the physical film thickness;

$$e = \frac{t.\lambda_{ref}}{n} \tag{1}$$

Calculations were made according to this equation and layers were coated on the base glass with approximately these physical thicknesses and two filters were formed.

3. Results and Discussion

Peak transmittance of the lowpass filter was found to be ~91%, and was found to be half this value 45.5% (Figure 2). The wavelength corresponding to FWHM was observed to be 565 nm. The main absorption edge of the light passing through lowpass filter is found to be 580 nm in the visible region. The difference of 15 nm between 565 nm, the value corresponding to FWHM and the main absorption edge of 580 nm demonstrates the sharpness of the absorption edge. Maximum transmittance of highpass filter was found to be ~93.5%, and semi-transmittance was found to be 46.75%, half of the value obtained for peak transmittance (Figure 3). The wavelength corresponding to FWHM was observed to be 515 nm. The main absorption edge of the light passing through highpass filter was found to be 500 nm in visible region. The difference of 15 nm between 515 nm, the value for FWHM and main absorption edge of 500 nm also shows the of the absorption edge.

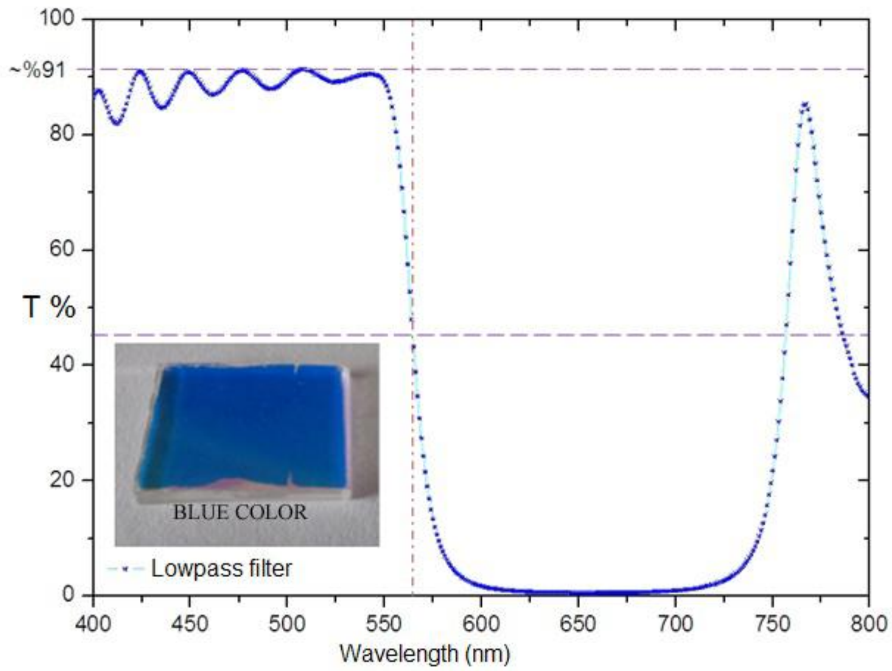

Figure 2. Transmittance spectrum of lowpass interference filter

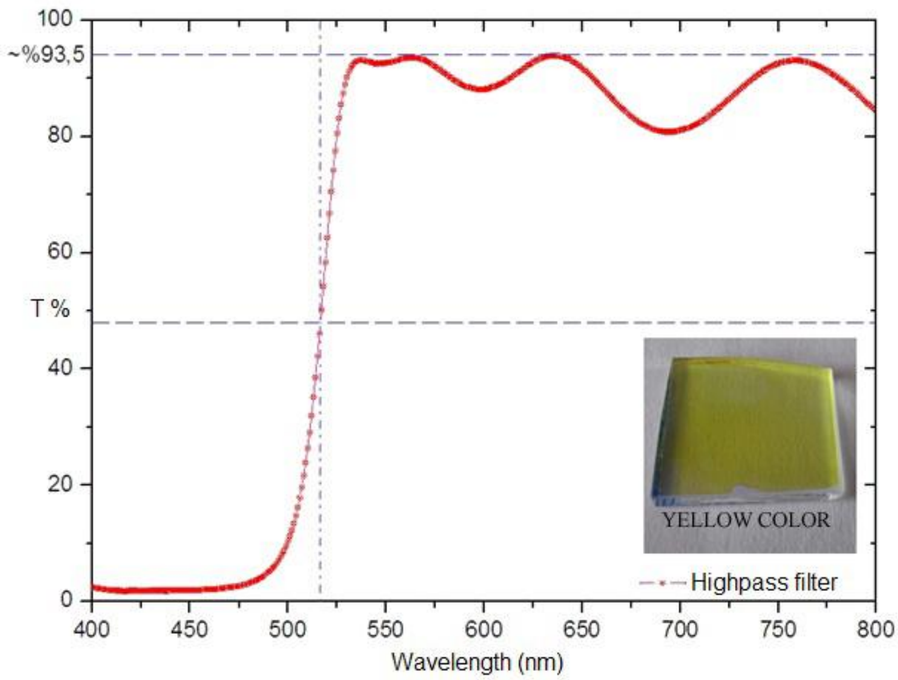

Figure 3. Transmittance spectrum of lowpass interference filter

In Figure 4, the transmittance curves of lowpass and highpass filters according to the wavelength were combined in a common graphic. This provides a basis for bandpass filter formation. The top layer of both filters consist of SiO_2 having low refractive index. As it can be seen from the EDX spectra of the layers, TiO_2 coatings were observed to contain this element to a high extent and besides, the presence of Si, Al and even Na belonging to other layers or the base glass were seen. Similarly, in addition to Al, Ti, Na and Mn elements, high levels of Si were seen as expected from SiO_2 coatings. Mn, Al and Na are especially know to originate from the base glass.These coatings performed on two sides of the same glass will provide a common bandpass transmittance for these coatings and provide the formation of bandpass filters. This is a study that we have performed previously (Kılıç, 2000). Since maximum value of light passing through both filters is within the range of 91-94%, and since the transmittance of pure silica glass is approximately 97%, we can conclude that interference filters are more advantageous than absorption filters that are used in various filtering devices that are used in various fields.

Though studies of multi-layered coatings are seen in the literature (G-Berasategui et al., 2004; Shou et al., 2012), similar studies that we can make comparisons with could not be found. In addition, multi-layered coatings are extensively being studied and similarly high leves of transmittance are given (Barshilia et al., 2009; Shanblogue et al., 1998).

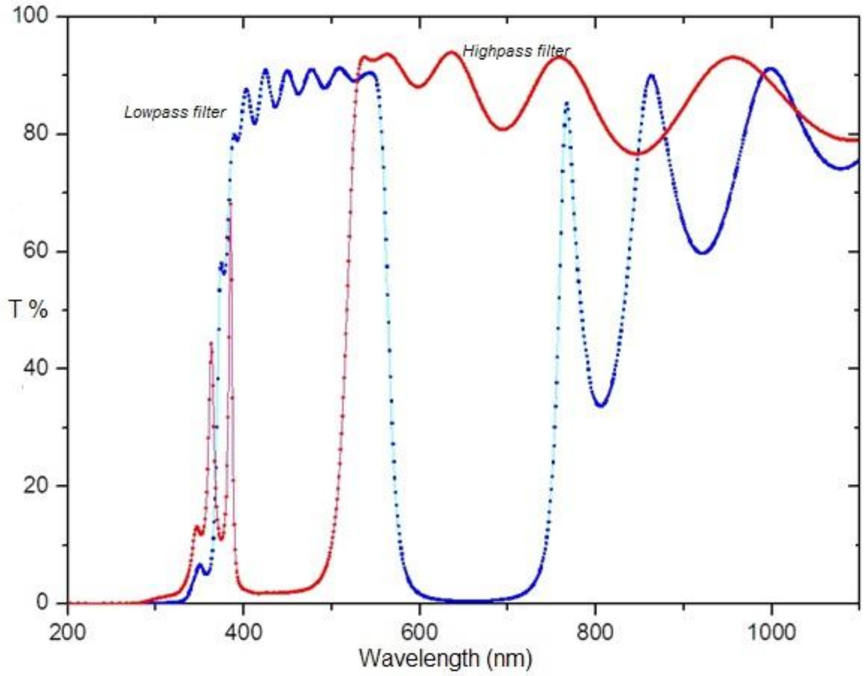

Figure 4. Transmittance spectrum of highpass and lowpass interference filters in 200-1100 nm range

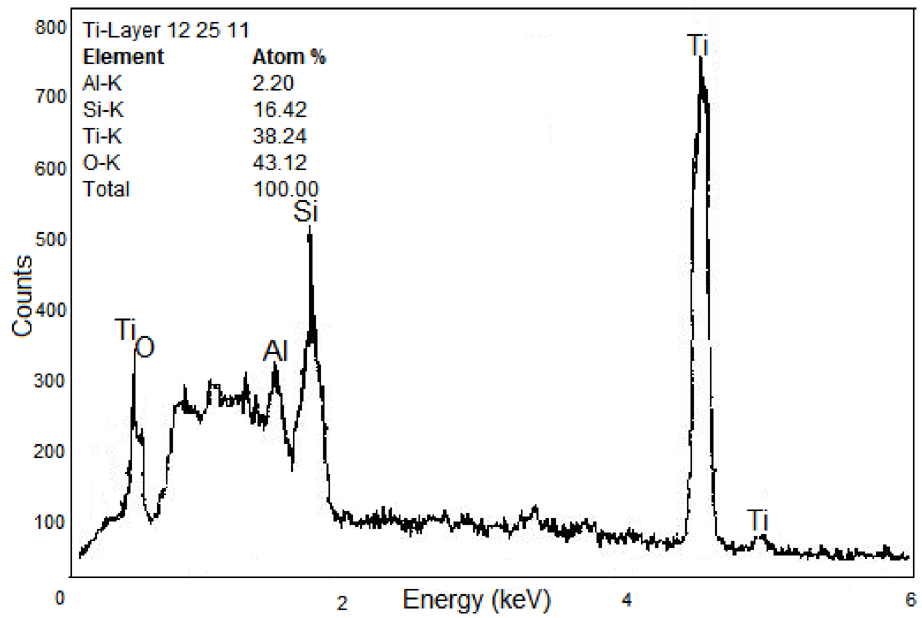

Figure 5. EDX spectrum belonging to TiO_2 coated layer

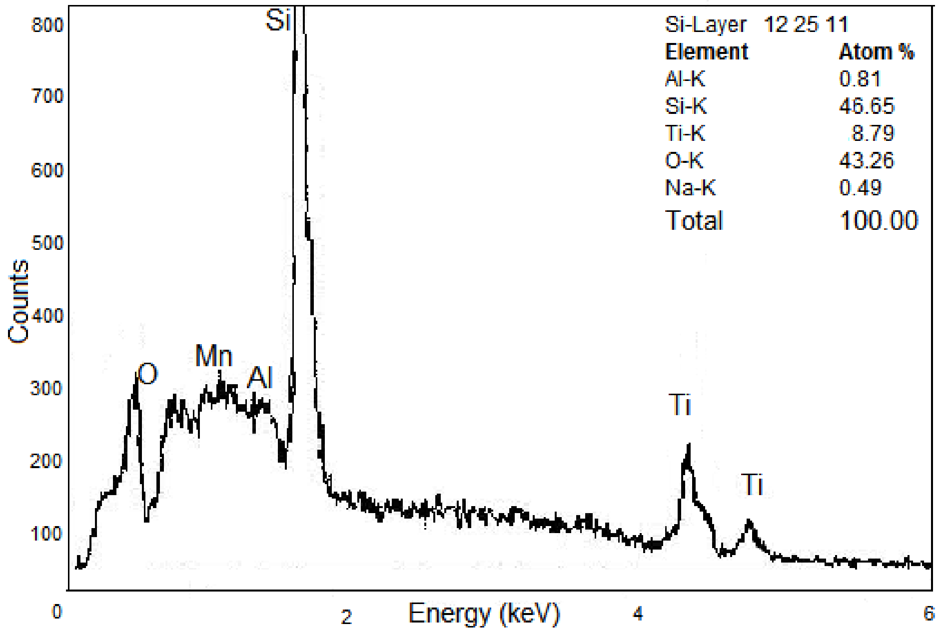

Figure 6. EDX spectrum belonging to SiO_2 coated layer

4. Conclusion

Interference filters were focused on in this study. Peak transmittance of lowpass filter that we have designed and formed was found to be ~91%, and its FWHM was found to be 45.5%, half the value of maximum transmittance. The wavelength corresponding to FWHM was found to be 565 nm and main absorption edge of the light passing through lowpass filter is found to be 580 nm in the visible region. The difference of 15 nm was obtained between FWHM and the main absorption edge.

Peak transmittance of highpass filter was found to be ~93.5%, and FWHM was found to be 46.75%, i.e. half of the value obtained for maximum transmittance. The wavelength corresponding to FWHM was observed to be 515 nm and the basic absorption edge was found to be 500 nm. Coating of lowpass and highpass filters to different sides of a substrate enables the formation of bandpass filters with the desired band width. Bandpass filter is an indispensable optical element in situations in which the performance of net color differentiation is essential. Maximum values of the passing light in visible region were found to be within the range of 91-94% for both filters.

From the EDX spectra of the layers of the specimens, the coatings were found to consist of TiO_2 and SiO_2. In addition, the presence of the elements coming from the base glass were observed..

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