A numerical analysis on the homogenous property for integrated narrow band pass filter

S.K. Lu, L. Chen
Shanghai Marine University, 1550 Harbor Ave., Lingang New City, Shanghai 201306, China
latterguy@yahoo.com.cn

***Abstract*—The integrated narrow band pass filter is an important photonic device. The performance of this device is limited by the two problems, absorption coefficient and thickness homogeneous in the resonant cavity layer. We has developed a numerical simulation method to analysis the influence of these factors on the behavior of integrated filters. It is found that the non-homogeneous of layer thickness will dominate the band width of transmission spectra for the 32-chanels integrated narrow band pass filter device in near infrared.**

I. INTRODUCTION

The optical wave behavior in the multi-layer thin film is very important to improve the photonic device[1]. Recently, the integrated optical narrow band pass filters technology has been developed. A systematic study on the step like optical resonant cavity giving a bright future for the integration of very narrow band pass filters, since in each channel the thickness of optical cavity is the same[2]. However, it is very difficult to guarantee a homogeneous thickness in a channel with the area in order of square millimeter. Meanwhile, both the absorption and non-homogeneous will affect the spectrum property in a similar way, which complicates the optimization on fabrication process for the integrated multi-channels narrow band pass filter. It will be interesting to have a method to estimate the homogeneous property in one filter channel. In this paper, we will report on this method by the combining the numerical simulation with the optical filter transmission spectrum.

II. RESULTS

Nowadays people can utilize step equipment or even the atomic force microscope to measure the homogeneous of the resonant cavity. But these kinds of methods can only measure in a small range or some spots in larger area. What's more the measure process can only be realized just after the finish of resonant cavity by the interruption of the thin-film coating process. Compared with other layers in the thin film series, the resonant cavity layer will influence the spectrum features most in the narrow band-pass optical filter. This paper adopts the method to judge the homogeneous of the resonant cavity layer by analyzing the spectrum features of the narrow band-pass optical filter. We also combined this method with the differences observed among the spectra of 32 channels in the integrated optical filter to analyze the non-homogeneous feature of the thickness in resonant cavity.

A. Narrow band-pass integrated optical filter and its Spectrum

According to the integrated optical filter fabrication methods by literature [3-5], 32 channels integrated narrow band-pass optical filter which made by the optical thin film coating is fabricated as the sample to be investigated in this paper.

The spectrum of each channel in the narrow band-pass filter is shown in figure 1. Each channel has its own light transmission peak at different wavelength. The transmission at peak of each channel is different from each other but mainly stay in the range of 25% to 30% with bandwidth to be about 0.5nm.

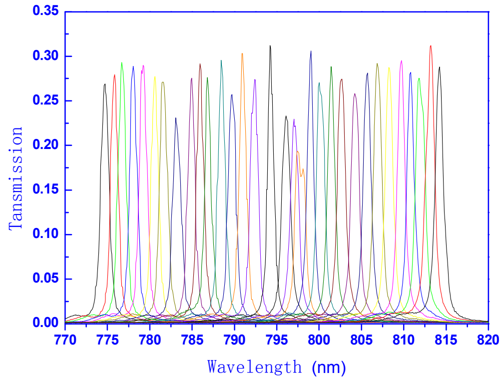

Figure 1. The spectrum of each channel in 32 channels integrated narrow band-pass optical filter.

B . The data analyze of the spectrum

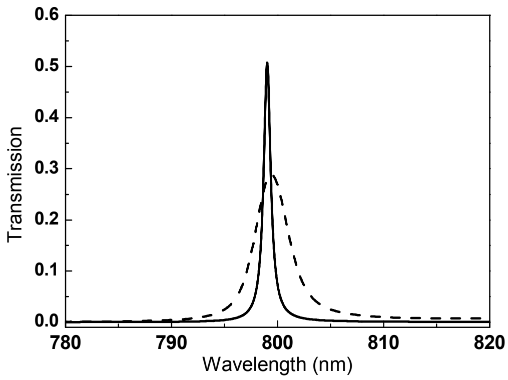

Figure 2. The spectra of theoretical designed narrow band-pass filter and the fabricated sample shown in solid and dashed lines, respectively.

To analyze the spectrum features in figure 1 carefully, we can find out the data as following:

The spectrum maximum transmission at peak I_{max}=31%, the minimum is I_{min}=19%, the average is I_{av}=28%, the standard deviation of the peak transmission distribution is I_{sd}=2.6%. Then for the band width of the spectrum, W, we have the following statistic data: The maximum value is W_{max}=0.74nm, the minimum is W_{min}=0.42nm, the average is W_{av}=0.54nm, the standard deviation of the band width distribution is W_{sd}=0.06nm. The maximum integral intensity is S_{max}=0.19, the minimum is S_{min}=0.12, the average is S_{av}=0.15, the standard deviation of the integral intensity distribution is S_{sd}=0.01. Checking the relative deviation (standard deviation for the distribution /average value) among these parameters, it is found that the integral intensity has the value of 0.07 being minimum and the band-width 0.11 being maximum.

This demonstrates that for narrow band-pass optical filter the thin film coating process fluctuation has strong impact on the band width compared with the transmission at peak. It is similar with the previous work[4]. We can also deduce it from the difference between spectra of theory designed narrow band-pass optical filter and measured on fabricated filter. As shown by figure 2, the solid and dashed lines stand for the designed spectrum and measured one for the corresponding channel of filter, respectively. Those two are basically the same in peak-position, but obviously difference in the line shape of spectrum. They have difference in peak integral intensity about 3 times and peak value about 1.6 times, whereas the difference in band-width is up to 5 times. So does the band width influenced by the fluctuation of film coating process most.

From the simulation on the properties of narrow band-pass filter, it is found that the wavelength at transmission spectral peak is determined by the optical thickness of resonant cavity, following the rule of Fabry-Perot interferometer. We can judge from the spectra in figure 2 that the sample resonant cavity thickness is consistent with the design value. The optical field will form a quasi standing wave in the resonant cavity around the wavelength of peak. Thus the absorption coefficient would increase and lead not only the decrease of transmission at peak but also widen the line width of the transmission spectrum.

When the nano-scale fluctuation encounter to resonant cavity thickness of any certain channels in the optical filter, the actual spectrum of those channels are the sum of transmission spectrum from small area with different optical thickness resonant cavity over the total area in the order of 1 square millimeter of one channel. Influenced by the nano-scale fluctuation on the shift of peak position, the transmission at peak value would decrease with line width widen which own a similar feature of absorption coefficient. However the most different aspect is that the increase of absorption coefficient would lead to an obviously decrease of spectrum integral intensity but the fluctuation in the optical thickness of the resonant cavity will not.

Judged from the spectrum analyze to the 32 channels integrated optical filter, it is found a small change in spectrum integral intensity in each channel while the line width variation is big. We can conclude the main factor to cause the homogeneous problem among 32 channels is the fluctuation of the thickness in the resonant cavity.

We zoom in the spectrum of lowest peak transmission in 32 channels optical filter in figure 3. The dot is experimental data, the solid line is a curve fitting by two Lorenzian peaks. The two dash line stand for the two Lorenzian components. The good agreement between the experimental data with the fitting curve means the double-peak feature. The peak wavelength, band width, and peak intensity of two Lorenzian components are (797.4nm, 1.44nm, 0.18) and (798.2nm, 1.38nm, 0.13), respectively. The difference in wavelength at peak of two components is 0.8nm. Because the optical thickness of resonant cavity in design is the same as wavelength of peak, the difference of optical thickness in resonant cavity is determined to be 0.8nm. Infer from the double-peak of the spectrum, we can conclude that for this channel the optical thickness of the resonant cavity is mainly distributed in two kinds of thickness with 0.8nm difference in view of statistics. This double peak property was also observed in the spectrum of previous work[6].

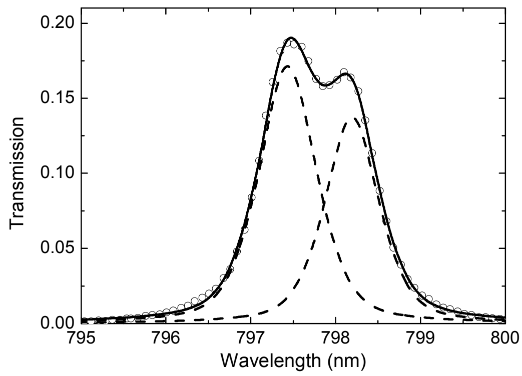

Figure 3 The spectrum of lowest transmission in 32-channels integrated optical filter.

In summery, the spectroscopy analysis method is useful to evaluate the homogeneous property of resonant cavity in the integrated multi-channels optical filter. It will be helpful in the fabrication process improvement.

REFERENCES

[1] S.W. Wang, C.S. Xia, X.S. Chen, W. Lu, M. Li, H.Q. Wang, W,B. Zheng, T. Zhang, Concept of a high-resolution miniature spectrometer using an integrated filter array, Optics Letters, 32 (6), 632-634 (2007)

[2] S.W. Wang, XS. Chen, W. Lu, L. Wang, Y.G. Wu, Z.S. Wang, Integrated optical filter arrays fabricated by using the combinatorial etching technique, Optical Letters,31 (3):332 (2006)

[3] H.F. Jiao, Y.G. Wu, G.X. Tan, S.W. Wang, H. Cao, L. Zhang, L.X. Fu, "Integrated Multi-channel Narrowband Filter Prepared by Multi-step Deposition and Etching Method", Applied Optics 46 (6), 867-871 (2007)

[4] S.W. Wang, M. Li, C.S. Xia, H.Q. Wang, X.S. Chen, W. Lu, 128 channels of integrated filter array rapidly fabricated by using the combinatorial deposition technique, Appl. Phys. B 88, 281–284 (2007)

[5] Z.S. Wang, T. Sang, L. Wang, H.F. Jiao, Y.G. Wu, J.T. Zhu, L.Y. Chen, S.W. Wang, X.S. Chen, W. Lu, Narrowband multichannel filters and integrated optical filter arrays, Applied Optics, 47(13), p. C1 (2007)

[6] S.W. Wang, D. Liu, B. Lin, X.S. Chen and W. Lu, 16 × 1 integrated filter array in the MIR region prepared by using a combinatorial etching technique, Applied Physics B: Lasers and Optics ,Volume 82, Number 4, 637-641(2006)