ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0025

Design of an Optical Ring Resonator Filter

Pu Zeng[1], Congji Liu[1,*], Jieping Luo[1], Ou Wang[1], Hongying Fan[1], Yu Qian[1], Bo Zhang[2], and Dongyao Wang[3]

[1] Southwest Institute of Technical Physics, Chengdu 610041, China

[2] China Telecom Chengdu branch, Chengdu 610066, China

[3] School of Life Science and Biotechnology, Mianyang Teacher's College, 621000, China

*Corresponding Author Email: congjiliu@qq.com

Abstract

This article discusses the application of an optical filter with waveguide ring resonator filter structure. Adopting DWDM technology is the key way to expand communication. A stable and tunable filter system is the key to DWDM. With the rapid development of DWDM, optical filters have also developed and become indispensable devices. In recent studies, the most commonly used filters are Fabry-Perot, Manh-Zenhder, and waveguide ring resonators. This paper analyzes the performance, characteristics, parameters and output of the waveguide ring resonator, and designs and optimizes it.

Keywords

Optic Communication; Filter; Waveguide; Ring Resonator; Filter.

1. Introduction

Nowadays the Fabry-Perot cavities are widely used in optical communications such as filters, switchers,amplifiers,attenuators,routers and so on. After the invention of fiber coupler, fiber ring resonator was invented and used as filters for it’s properties which are similar to Fabry-Perot interferometer,and it is convenient to tuning,but it also has the disadvantages such as great fiber loss and large volume[1].

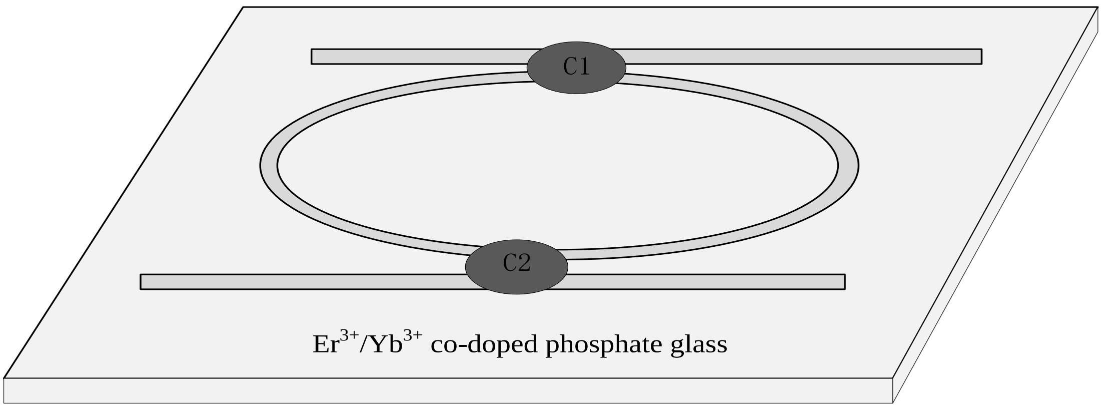

Figure 1. Integrated optical waveguide ring resonator

As is known in actual situations, the loss will dramatically affect the filter performance[2], and the large volume will makes it hard to be integrated into other optical devices, so an integrated optical

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0025

waveguide ring resonator is made by etching this fiber ring resonator structure on Er3+/Yb3+ co-doped phosphate glass(illustrated as Fig1), which have many merits such as:high gain, small volume, compact structure, compatible with Si processing and convenient integration. For it's high gain, if properly doped, the gain can compensate it's loss.(This can be considered as no loss),and by etching it on the Er3+/Yb3+ co-doped phosphate glass, the fiber length can be set at millimeter level or even nanometer level, this will dramatically lower the cost and be quite popular in application[3].

2. Principle of Ring Resonator Filter

According to related literatures, there are many factors that will affect the characteristics of the ring resonator filters such as coupling coefficient (k), coupler loss, round trip length(L),round trip loss, fineness, free spectrum range(FSR) and so on. Neglect the coupler loss, all the factors are related to k and L. So we can get all the changes of characteristics from k and L. In this paper because of the ring resonator is etched on Er3+/Yb3+ co-doped phosphate glass, its gain can be controlled by different doping concentration, so we consider there is no round trip loss, and we set the round trip length at millimeter level.

The basic theories of the ring resonator and the Fabry-Perot cavity are just the same (multi-beam interference),illustrate as Fig2 and Fig3,if we consider E1 as the incident light I of Fig3,E2 as the transmitted light,E3 and E4 as the reflected lights in the F-P cavity, then we can use some conclusions of the F-P cavity to analyze the ring resonator, which will make things much easier.

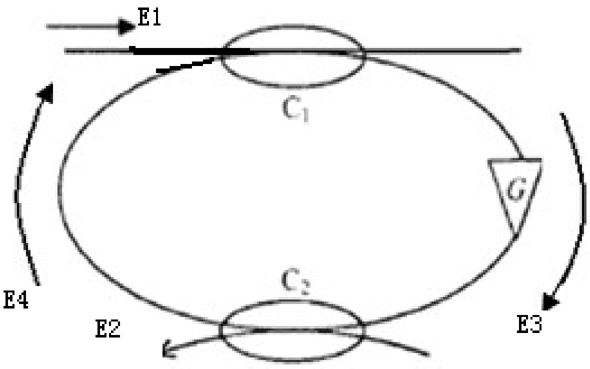

Figure 2. Fiber ring resonator

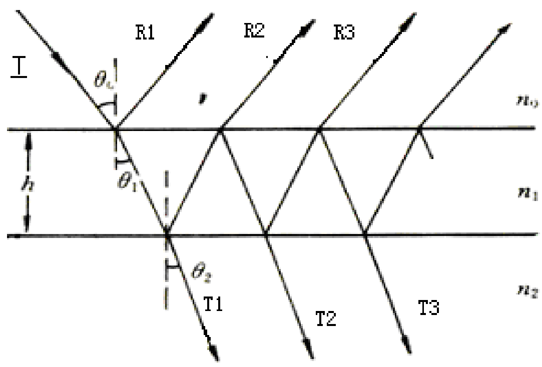

Figure 3. Fabry-Perot cavity

According to the F-P theory,

Full width half maximum (FWHM)

$$\Delta v_{1/2} = C(1-R) \big/ L\sqrt{R}\pi \tag{1}$$

As can be seen from Eq.1, by increasing the reflectivity R or optical length L, narrower $\Delta v_{1/2}$ can be obtained.

3. Analysis of the Filter Performance

To further discuss the characteristics of the filter, we considering two situations:

(1)C1=C2 and (2) C1≠C2.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0025

3.1 When the Coupling Coefficient C1=C2

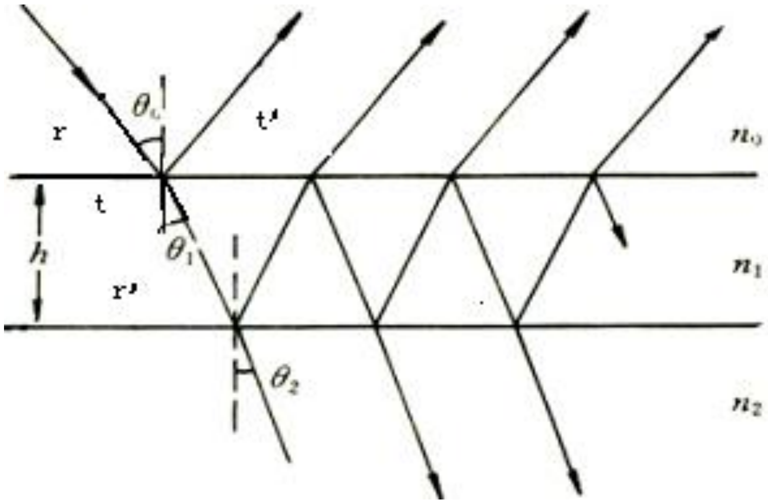

Figure 4. Fabry-Perot cavity(C1=C2)

$$F = \frac{4R}{(1-R)^2}, \tag{2}$$

$$I_t = \frac{1}{1 + F\sin^2(\frac{\varphi}{2})} \cdot I^{(i)} \tag{3}$$

First we consider the round trip length L as a constant, change the coupling coefficient k, the results are shown in Fig5 and Fig6.

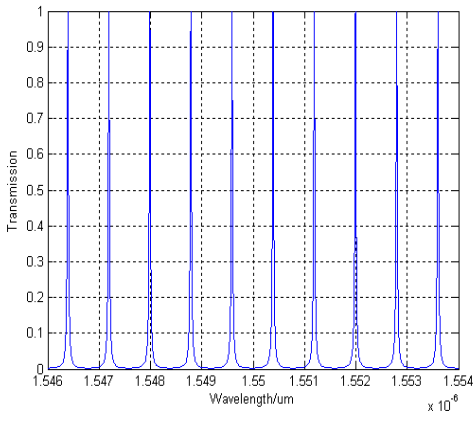

Figure 5. k=0.01,L=0.002m

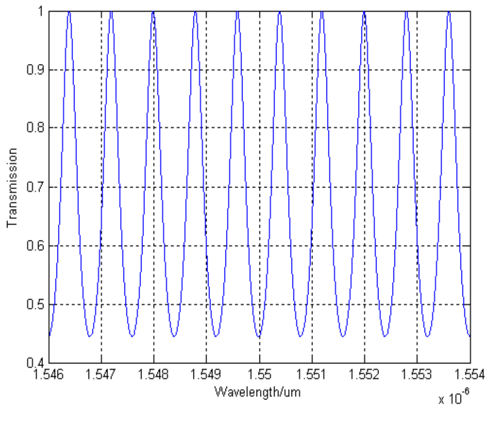

Figure 6. k=0.8,L=0.002m

Fig5 and Fig6 shows clearly that the peak separation remains the same as k changes, but the FWHM will become wider as k increases.

Then we consider the coupling coefficient k as a constant, change the round trip length L, the results are shown in Fig7 and Fig8.

 Volume 8 Issue 8, 2022
DOI: 10.6919/ICJE.202208_8(8).0025

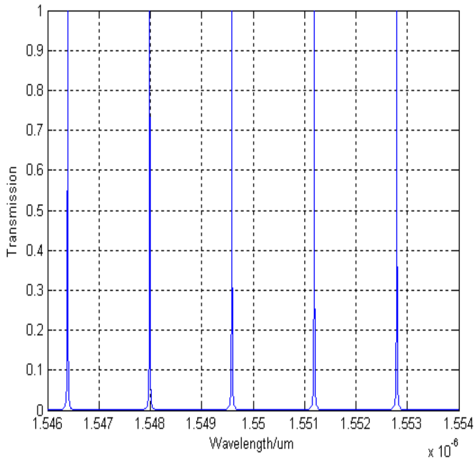

Figure 7. k=0.02,L=0.001m

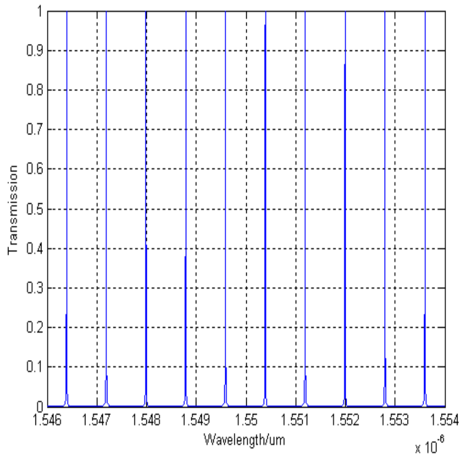

Figure 8. k=0.02,L=0.002m

Fig7 and Fig8 shows that the FWHM remains the same as L changes, but the peak separation will become narrower as L increases.

From the analysis above: by changing the round tripr length L and the coupling coefficient k, ideal filtering characteristics can be obtained. But this is the situation when C1=C2, in application sometimes the coupling coefficient C1≠C2.

3.2 When the Coupling Coefficient C1=C2

This equals to the situation when r1≠r2≠r3.

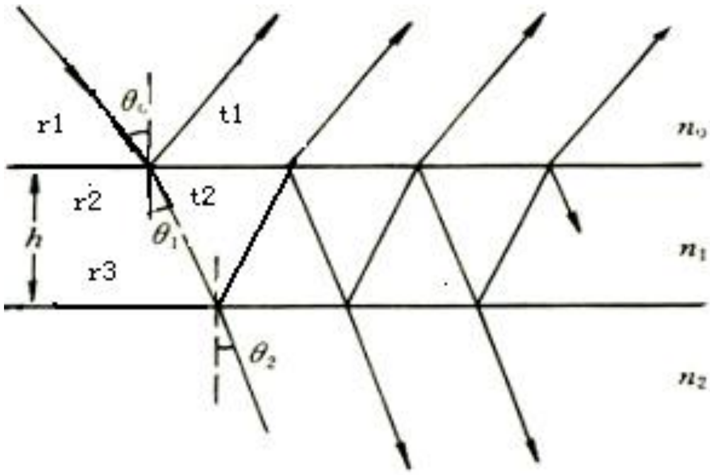

Figure 9. Fabry-Perot cavity(C1≠C2)

Where r1 is the reflection coefficient from air into cavity, r2 is the reflection coefficient from cavity into the upper surface,r3 is the reflection coefficient from cavity into the lower surface,t1 is transmission coefficient from cavity into the upper surface, t2 is transmission coefficient from air into the cavity, Ei is the incidental field.

According to the theory of multi-beam interference.

$$\frac{I_t}{I_i}=\frac{K_1K_2}{2+2\sqrt{(1-K_1)(1-K_2)}\cos\phi-K_1-K_2+K_1K_2} \tag{4}$$

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0025

Now we set L=0.002m, then set different coupling coefficient k1 and k2, the results are shown as Fig10,Fig11 and Fig12.

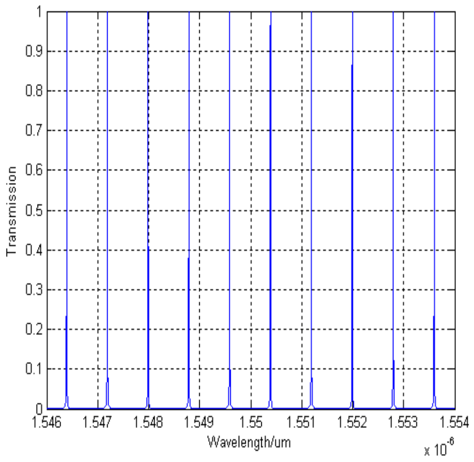

Figure 10. k1=0.02,k2=0.02

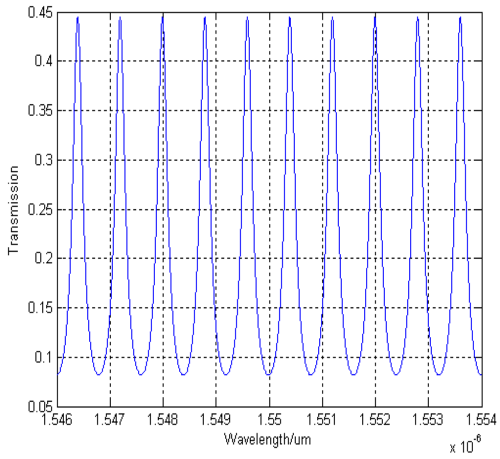

Figure 11. k1=0.2,k2=0.8

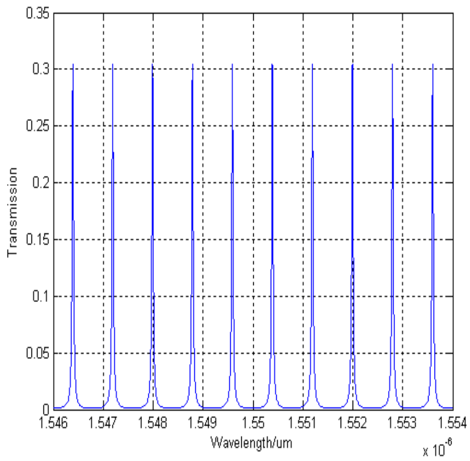

Figure 12. k1=0.02,k2=0.2

As can be sees in Fig10, the transmission reaches nearly 1 when k1=k2.And as the difference between k1 and k2 increase, the transmission decrease. From this result we can draw a conclusion that if k1=k2,then the loss can be neglected, if k1≠k2,the loss must be considered, and the loss will increase as the difference between k1 and k2 increases. Thus to achieve better filter performance, the coupling coefficient k1 should equals to k2.

Considering the input wave is 1550nm,and according to the experiment, the peaks can be separated only when FSR>1.6nm.In application ,we usually need greater FSR for greater peak separation, but as the FSR increases, the round trip length decrease($FSR = \lambda^2 / L$), and the bending loss of the ring will increase which will dramatically affect the filter performance. So here we set round trip length L=0.24mm,FSR=10nm.And according to the experiment we need $\Delta\lambda$ <0.8nm, $\Delta\lambda = \frac{\lambda^2}{c}\Delta v \Rightarrow$.

$\Delta v < 0.998\times10^8$ Hz.According to Eq.1 $\Delta v_{1/2} = C(1-R)/L\sqrt{R}\pi \Rightarrow$ R=0.9996,1-R= $k^2 \Rightarrow$ k<0.02,So we choose the round trip length L=0.24mm, coupling coefficient $k_1 = k_2$ =0.02.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202208_8(8).0025

4. Conclusion

In this paper we discussed a novel structure of integrated waveguide ring resonator which is etched in Er3+/Yb3+ co-doped phosphate glass, and described the principle of the ring resonator. We analyzed and simulated the performance of the filter, by analyzing and experiments we find when the round trip length L=0.24mm,coupling coefficient k1=k2=0.02,the filter achieves the best performance. The analysis is based on an ideal model with a lossless coupler.

References

[1] Stone.J, Stulz.L.W: IIinh-performance fiber Fabr-Perot filter, IJlectronicsLetters,1999,27(24),2239-2240.

[2] C. Li, W.Q. Yin, X.B. Feng, et al:Brushless DC motor stepless speed regulation system based on fuzzy adaptive PI controller, Journal of Mechanical & Electrical Engineering, vol. 29 (2012), 49-52.Chew H·Thiana Tjena, Tjhuna and Chvvs.FY: An optical filter of adjustable fineseusing a fiber resonator. Journal of Lightwave Tech, 2003, 15(2),314-370.

[3] P.P.Ahsil, J.V.Hrvnicwicz,B.E, et al. CompaqMiororingnotch fillers[J].IEEE Photo. Techaal. Let,2000, 12(4),398-400.