Investigation and Fabrication of Integrated Waveguide Racetrack Resonator Filter in Glass Material*

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Abstract A racetrack resonator filter is fabricated by Ag^+-Na^+ ion-exchange technique in K9 glass. The free spectrum rang (FSR) and contrast ratio (C_r) of the resonator are tested to be 0.177 nm and 7.5 dB. With fitted results, the coupling ratio is $\kappa=0.916$, the loss factors of the coupler and the resonator are $\delta=0.55$ and $\gamma=0.48$, respectively. The relative large losses of the waveguide device are due to the almost connection of the coupler waveguides, irregularity of the strip waveguide side and flaw of waveguide surface after one-step ion-exchange. By decreasing loss, this integrated waveguide resonator filter may be used in optics communications or sensing fields and can be combined with other waveguide structures to perform further functions.

Keywords Integrated optics; Waveguide resonator; Ion-exchange

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0 Introduction

Integrated optical ring resonators, as basic waveguide device unit, have received considerable attention due to their potential for next-generation photonic integrated circuits. They can be used as filter, all-optical switch, modulator, and bio-sensor, etc[1~5]. Ring resonators have been demonstrated previously based on different materials by various techniques, such as, molecular-beam epitaxy, flame hydrolysis déposition, sol-gel, and ion exchange and so on. The ion-exchange technique is a powerful and simple method to fabricate good quality optical waveguides[6~8]. The glass waveguide components fabricated by ion exchange are widely used for their compatibility with optical fibers, potentially low cost, low transmission loss and the ease of their integration into the system[9~11].

In this paper, it reports the fabrication of racetrack resonator filter by Ag^+-Na^+ ion-exchange in K9 glass. The resonant effect is tested and its characteristic is investigated.

1 Device design and fabrication

A racetrack resonator filter is illustrated in Fig. 1. The racetrack structure has advantages over conventional ring structure where ring is

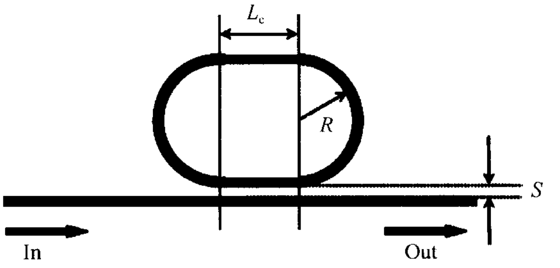

Fig. 1 Sketch of racetrack resonator filter

coupled to input and output waveguides via a "point contact". The length of coupling section in the racetrack resonator can be adjusted alone to attain a given coupling ratio without requiring a very small gap, which decreases the difficulty of fabrication. According to transfer matrix method[12], the transmission of the resonator can be expressed as

$$T=\left|\frac{E_4}{E_1}\right|^2=\left|\frac{\sqrt{\delta(1-\kappa)}-\sqrt{\gamma}\delta\exp(\mathrm{j}nkL)}{1-\sqrt{\gamma}\sqrt{\delta(1-\kappa)}\exp(\mathrm{j}nkL)}\right|^2 \quad (1)$$

where κ is the cross intensity coupling ratio of the coupler, δ is the loss factor of the coupler, γ is the intensity loss per circuit around the resonator, n is the refractive index of the waveguide, $k=2\pi/\lambda$, λ is the wavelength and $L=2\pi R+2L_c$ is the perimeter of the resonator, R is the radius of the curved waveguide, L_c is the straight waveguide length of the coupler . If there were no loss, the resonator would be an all-pass filter. Due to the loss, the transmission spectrum presents periodical resonant curve with the interval

$$FSR=\frac{\lambda_0^2}{nL} \quad (2)$$

where λ_0 is the resonant wavelength.

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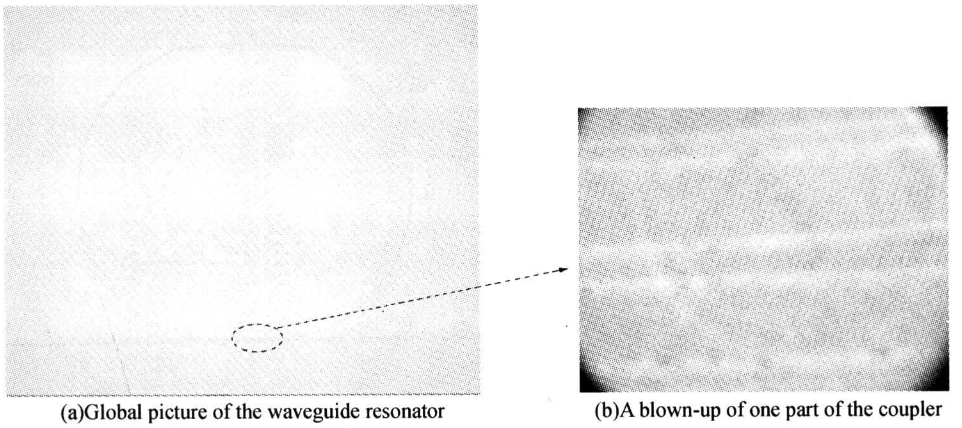
The waveguide racetrack resonator was fabricated by Ag^+-Na^+ ion-exchange in K9 glass. Potassium nitrate was used to dilute silver nitrate in order to decrease the eroding by using silver nitrate alone and control easily the variation of refractive index[13]. The mask of the racetrack resonator was designed with the following parameters, $R=1.2$ mm, $L_c=0.5$ mm, the waveguide width $w=6$ μm, and the space between the coupler waveguides $S=4$ μm. Fabrication procedure of the waveguide resonator was as follows: High-frequency sputtering was used to deposit a 150 nm thick layer of titanium onto the glass substrate. The resonator pattern was etched into the titanium using conventional photolithography techniques. The ion exchange was performed in a mixed molten salt of silver nitrate and potassium nitrate (2mol%:98mol%) at 340℃ for 4 hours. After exchange, the titanium layer was removed and the substrate′ s edges were properly polished. Fig. 2 shows the photograph of the waveguide resonator. Due to the lateral expansion during photolithography and pattern etching, the waveguides of coupler are almost connected.



(a)Global picture of the waveguide resonator (b)A blown-up of one part of the coupler

Fig. 2 Photograph of the integrated waveguide racetrack resonator filter fabricated by ion exchange

2 Characteristic test

The measurement setup is illustrated in Fig. 3. The broadband ASE light source is injected into the racetrack resonator, and the output spectrum is measured by OSA (ANDO,AQ6317C). Melting cone fibers are used to facilitate light into waveguides. A pair of 5-dimension translation stages (Newport 516-FC) ensures the coupling between fiber and waveguide. The square dot curve in Fig. 4 displays the resonant effect of the resonator. From Fig. 4, we can obtain that the contrast ratio is 7. 5 dB, and the FSR of the resonator is 0. 177 nm. From Eq. (2), the effective refractive index of the waveguide is 1. 5565, corresponding to the resonant wavelength $\lambda_0 = 1529.69$ nm.

According to Eq. (1) the experiment result is fitted with the following parameter values, $\kappa=0.916$, $\delta=0.55$, $\gamma=0.48$, $n=1.5565$, and the solid curve in Fig. 4 depicts the result, which is consistent with the experiment one. Due to the almost connected waveguides of the coupler, which cause much scatter, the loss of the coupler is large relatively. The coupler loss can be improved by exact control of the techniques during photolithography and pattern etching. Based on the perimeter of the resonator, L, and the intensity loss per circuit around the resonator, γ, the loss of per unit length is about $\alpha=-10\log(\gamma)/L\approx3.7$ dB/cm. It is not little yet, mainly due to the irregularity of the strip waveguide side and flaw of waveguide surface after one-step ion-exchange, and it may be decreased when the waveguide is buried by two-step ion-exchange. the relevant work is performing and it will be reported latter.

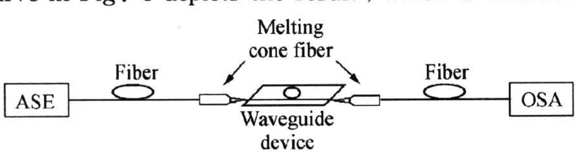


Fig. 3 Measurement setup for the optical waveguide device

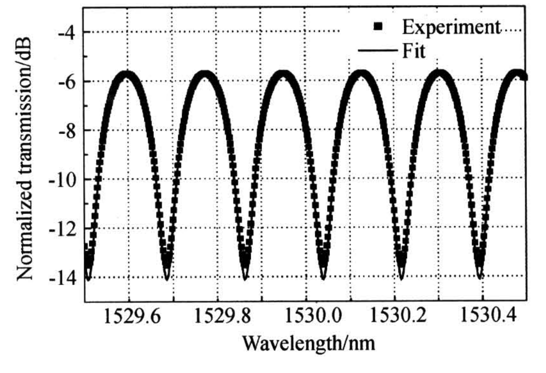


Fig. 4 Resonant spectrum of the racetrack resonator filter

3 Conclusion

A racetrack ring resonator has been fabricated by Ag^+-Na^+ ion-exchange in K9 glass. The resonance effect is observed, the free spectrum rang of the resonator is 0. 177 nm and contrast ratio reaches to 7. 5 dB. By decreasing loss, this racetrack resonator may be used in optics communications or sensing fields and can be combined with other waveguide structures to perform further functions.

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跑道形玻璃波导谐振腔滤波器的研制

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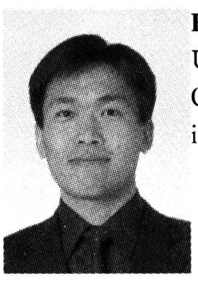
摘 要 采用 Ag^+-Na^+ 离子工艺,在K9玻璃上制备了跑道形波导谐振腔滤波器．测试得到该滤波器自由光谱范围为 $FSR=0.177$ nm,对比对为 $C_r=7.5$ dB. 同时分析得到耦合器的耦合系数为 $\kappa=0.916$,耦合器和环形腔的损耗因子分别为 $\delta=0.55$,$\gamma=0.48$. 耦合器的两波导几乎相连、条波导边缘不规则和一次离子交换波导表面缺陷是造成该波导滤波器具有较大损耗的主要原因．通过改进工艺技术降低波导损耗,该滤波器可以用于光通信、传感等领域,也可与其它波导结构相结合实现新的功能．

关键词 集成光学;波导谐振腔;离子交换



Han Xiuyou was born in 1977. He received his M. S. degree from Hebei Normal University in 2003, and Ph. D. degree from Shanghai Institute of Optics and Fine Mechanic, Chinese Academy of Sciences in 2006, respectively. His current research interests are integrated optics, optical communication devices and systems.