修士学位論文要約（令和４年３月）

スラブ導波路型チャネル・ドロップ・フィルターに関する研究

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Research on slab waveguide type-channel-drop filter

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In recent years, with the advancement of micro-nano fabrication technology, the application of micro-optical devices has been vigorously developed. Micro-optical devices have good applications in biological detection, all-optical communication, molecular detection, etc. This study focuses on investigating the properties of a new type of miniature passive optical filter at the wavelength of 1550 nm. The waveguide and substrate materials are Si and SiO_2, respectively. Under a certain size, better performance can be achieved by adjusting the parameters between the resonator and the external waveguide. At the same time, the shape of the resonator resonance region can be modified to change its spectral characteristics, retains its basic mode, which is beneficial to the application of bio-detectors.

1. Introduction and background

Compared with other waves, light waves have the physical characteristics of short wavelength and fast frequency, so they can be well applied to the fields of optical communication, sensors and detection. This study mainly explores a filter with parallel coupling waveguides with quadrilateral curved sides as the resonance region. If this micro-optical resonator structure is used in detection, its important parameters include Q value, transmittance, FSR and so on. This experiment is based on a continuation of research conducted by [1]Liu Jiawen of the Yamada Matsuda Laboratory. Compared with the ring resonator of the same size, the quadrangular curved-edge structure proposed by it has a greater improvement in the Q value.

Based on Liu's idea, [2]Cai Peng in our lab proposed an external waveguide via oblique coupling. The advantage of this approach is that there is always only one spectral mode of the resonator, and the Q value is high. But the disadvantage is the low transmittance. The parallel coupling method I used was connected to the external waveguide. Although the Q value was relatively low, the transmittance was significantly improved. The method of this study is carried out by the optical simulation software Rsoft, which can approximate the actual situation with a certain accuracy.

The radius of the resonance region in this experiment (the distance from the center to the edge in the horizontal and vertical directions) is set to be 5 nm, because this study mainly explores the spectral characteristics of the resonator at a certain size, depending on other parameters of the device (including the radius of the curved edge r, the center distance a, the distance gap from the waveguide to the resonance region, etc.) changes with the specific situation.

2. Determination of effective refractive index

At the beginning, determine the materials for this study. In the simulation software, the setting of the refractive index needs to be different from the refractive index of the actual material. in optical waveguide devices. The effective refractive index is a very important parameter, and the simulation conditions used in this study mainly consider the 2D case (considering the performance of the computer), so the effective refractive index of the waveguide in the 3D case should be the same as the 2D case required by the simulation. are equal to the refractive index. As shown in Figure 1 below, when the refractive index of SiO_2 is unchanged compared with the actual one, the refractive index of Si in the 2D case is set to 2.73.

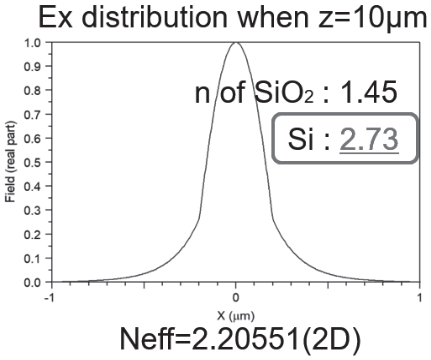

Figure 1 Si index setting with constant effective index

3. Adjustment of various parameters of the filter

The parameters of the filter, including the radius of curvature r of the edge, the distance a from the center to the edge, the width of the waveguide, and the gap between the waveguide and the resonance area of the quadrilateral curve, will all have a certain impact on the spectral characteristics of the filter. In order to achieve the expected experimental purpose, each parameter needs to be adjusted. The basic structure is shown in Figure 2.

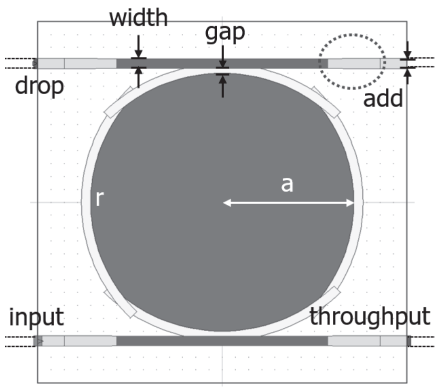

Figure 2 The basic structure of the filter

For example, the Q value required in this experiment is greater than 2000, and the transmittance is above 80%. In order to meet this requirement, the width is set to 0.3 μm and the gap is 0.37 μm.

4. Modes inside the resonator and single-mode properties.

In a resonator, resonance occurs when the length of the light propagation path in the cavity is an integer multiple of the wavelength.

In the case of a ring resonator, the light is tightly confined within the ring waveguide, almost in a single mode. In the case where the resonant region is a planar waveguide, the light is confined in only one direction, so it is possible to generate a variety of different propagation path modes. As shown in Figure 3.

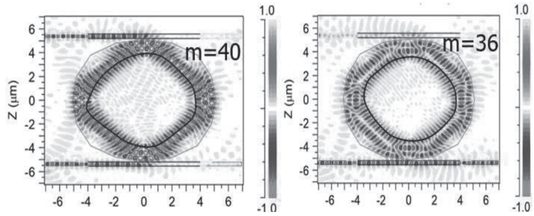

Figure 3 Different propagation modes at different wavelengths

The simulation results show that when used as a filter, the transmittance and Q value of the basic mode (shown on the left) are much higher than those of the multi-mode (shown on the right), so the higher-order mode is removed, and only the basic mode is retained. It has certain research value.

By taking the four vertices of the quadrilateral curved edge resonance region as the center of the circle, when removing the material with a radius of 0.5 μm Si (replacing it as the base SiO_2), basically only the fundamental mode is retained, and other spectral properties will not be adversely affected .

5. Conclusion

This research discusses characteristics of squared-ring resonator. Simulation shows that width of waveguide, gap, center to edge distance(**a**) and radius(**r**) can affect the performance. The Q factor reaches near 2500 while the drop selecting wavelength transmittance exceeds 80%.

Under parallel coupling situation, slab squared-ring resonator emerge multimode. Cutting corners of this structure can only keep fundamental mode and performance doesn’t become worse.

The Q value of the quadrilateral curved-edge filter with parallel coupling is low, and its structure needs to be further improved.

Reference

1) J. W. Liu, Research on ring resonator by SOI slab optical waveguide” Master Degree Thesis (2020).
2) Cai Peng, Channel-drop Filter by Using a Slab Ring-resonator” Master Degree Thesis (2021).