# Microring resonators with niobium pentoxide for tunable wavelength filters featuring ferroelectric liquid crystal


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***Abstract*— A tunable wavelength filter consisting of a niobium pentoxide microring resonator and a ferroelectric liquid crystal was theoretically investigated. Furthermore, we fabricated a microring resonator using niobium pentoxide and obtained its resonance characteristics.**



**Keywords— Niobium-oxide, Tunable wavelength filter, Micro Ring Resonator, Ferroelectric liquid crystal**


## I. INTRODUCTION

Wavelength tunable filters are important for high-speed, large-capacity next-generation networks [1]. In order to realize wavelength tunable filters with low power consumption and excellent integration, we have been researching wavelength tunable filters that combine optical waveguides and a ferroelectric liquid crystal (FLC). FLC have a large refractive index change and a relatively fast response time [2]. Niobium pentoxide ($Nb_2O_5$) material is often used for antireflection coatings on lenses, and its refractive index is between 2.1 and 2.3, higher than that of SiN waveguides. Furthermore, fabrication of relatively low-loss $Nb_2O_5$ waveguides has also been reported [3, 4]. In this paper, we analyzed characteristics of micro ring resonators (MRR) using $Nb_2O_5$ with FLC cladding. We also report a fabricated microring resonator using $Nb_2O_5$ and the obtained resonance characteristics.

## II. DEVICE STRUCTURE

The proposed device is shown in Fig. 1. This device has a racetrack structure with tunable phase shifters. The tunable phase shifter parts are loaded with FLC as an upper cladding layer. When the polarity of the voltage applied to the FLC is changed, the molecules of the FLC rotate in the horizontal plane with respect to the waveguide as shown in Fig. 2, changing the equivalent refractive index of the waveguide for TE mode light. A change in the equivalent refractive index of the variable wavelength shifter waveguide changes the resonance condition of the ring waveguide and shifts the wavelength characteristics.

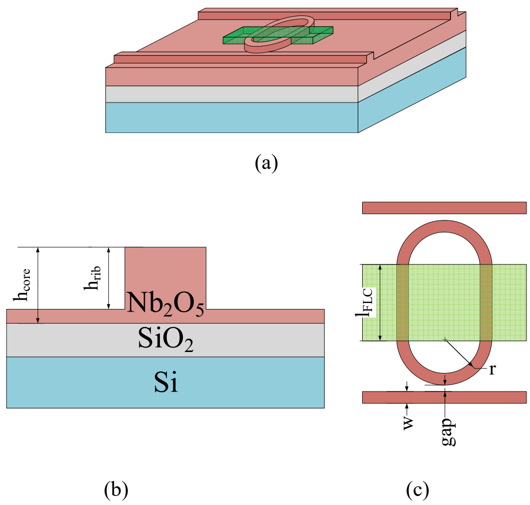


Fig. 1. Schematic diagram of the $Nb_2O_5$ racetrack waveguide, (a) Bird's view, (b) Cross-sectional view, (c) Top view

The FLC used this time has the following three features: relatively fast response speed, large refractive index change, and memory property. The memory characteristic is also called latching characteristic, which is effective in reducing power consumption because the state of FLC molecules is maintained even when the electrode is released after operation [2].

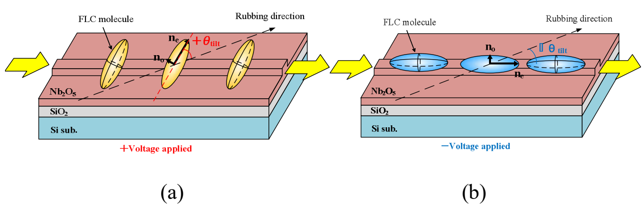


Fig. 2. Molecule inclination corresponding to the applied voltage polarity: (a) +Voltage applied, (b) -Voltage applied.

## III. THEORETICAL ANALYSIS OF RACETRACK RESONATOR

First, a theoretical analysis was performed using the finite difference time domain method (FDTD). The design dimensions are shown in Fig. 3. The initial theoretical analysis was set up based on data from previous studies. Since a wet etching process with hydrofluoric acid is required for FLC loading and the $SiO_2$ layer cannot be exposed, the design was made with the aim of realizing operation in a ribbed structure.

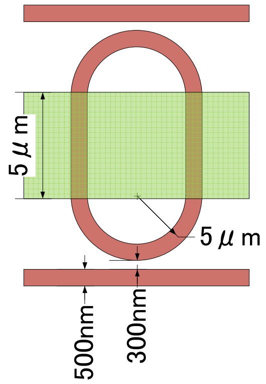


Fig. 3. Top view of the racetrack resonator with FLC for the calculations.

Figure 4 shows the theoretical analysis results for this design with the upper cladding in Air, and Fig.5 shows a graph of the theoretical analysis results when the FLC is operated (polarity is switched and the transmitted refractive index changes).

From Fig. 5, the theoretical analysis confirms that wavelength shift is possible when the FLC is operated.

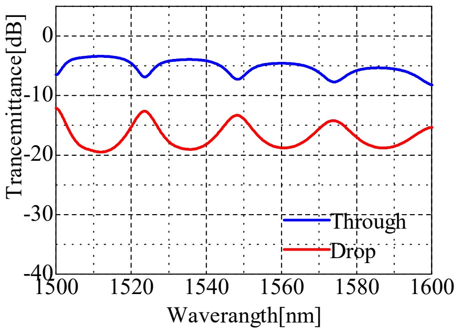


Fig. 4. Calculated wavelength characteristics of the racetrack resonator.

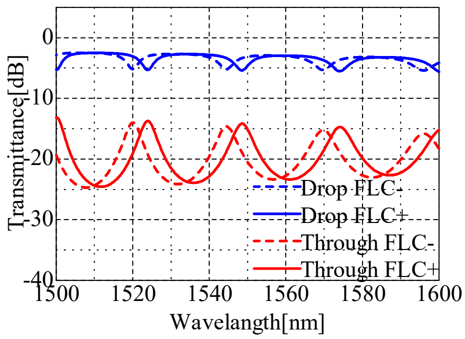


Fig. 5. Calculated switching characteristics of the racetrack resonator with FLC.

## IV. FABRICATION OF A RACETRACK RESONATOR

The fabrication process of the MRR is shown in Fig. 6. First, $Nb_2O_5$ is deposited on the surface of a Si substrate with a thermal oxide film using a reactive DC sputtering system. Next, patterning is performed using an electron beam lithography (EB) system. After vacuum deposition of Cr as a metal mask on the pattern, the waveguide is formed by dry etching.

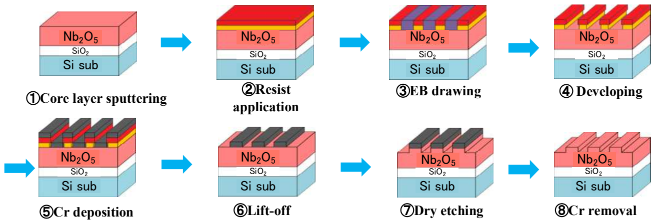


Fig. 6. Fabrication process

Based on the results of the theoretical analysis described in III, we proceeded to repeat the study and theoretical analysis in the actual device fabrication. The actual device was measured by the end-face coupling method.

The cross-sectional structure of the fabricated device is shown in Fig. 7(a) and the top view is shown in Fig. 7(b). Figure 8 shows the scanning electron microscope (SEM) image and Fig. 9 shows the near-field pattern, and the graph of the measurement results in Fig. 10.

From Fig. 10, a periodic resonance peak is observed on the Drop port side. Therefore, the resonance operation was confirmed with an MRR.

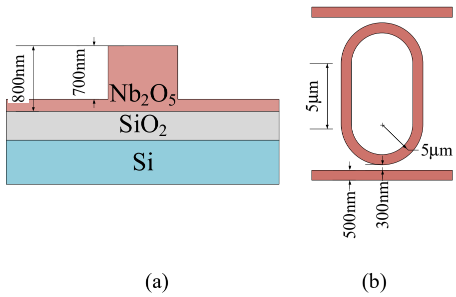


Fig. 7. Parameters of the fabricated racetrack resonator : (a) Cross-sectional view, (b) Top view.

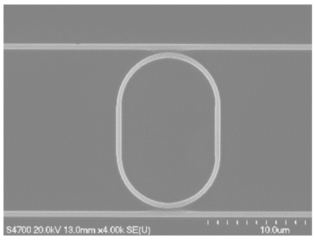

Fig. 8. SEM image of the fabricated racetrack resonator.

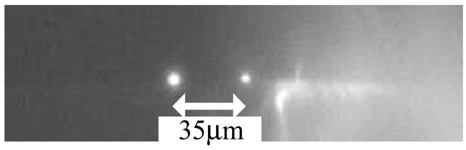


Fig. 9. Photograph of the near-field pattern of the output light through the fabricated racetrack resonator.

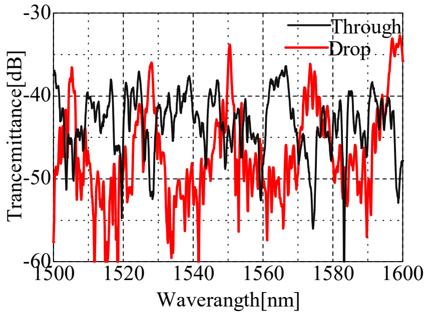


Fig. 10. Measured wavlength characteristics of the fabricated racetrack resonator.

## V. Conclusions

We proposed a tunable wavelength filter using a niobium pentoxide microring resonator featuring a ferroelectric liquid crystal and calculated the characteristics. Theoretically, the switching operation was obtained by changing the polarity of the voltage applied to the FLC. In addition, we fabricated a microring resonator using niobium pentoxide and obtained its resonance characteristics.

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