

Wavelength- and Bandwidth-Tunable Filters Based on MEMS-actuated Microdisk Resonators

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Abstract: A wavelength- and bandwidth- tunable filter with microelectromechanical-system (MEMS)-actuated waveguides is first demonstrated on a silicon-based microdisk resonator. Integrated microheaters enabled wavelength tuning up to 125GHz. Bandwidth can be tuned from 12.0 to 41.2GHz by coupling control.

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1. Introduction

Tunable optical filters are key components in wavelength-division-multiplexing (WDM) networks. Wavelength-tunable filters can select, drop, add, switch, or block individual wavelength channels. On the other hand, narrowband filters with tunable bandwidth and wavelength are useful for optical performance monitoring, which is deemed imperative for dynamic optical networks [1]. One of the powerful techniques for dispersion monitoring is measuring the relative group delay time between the upper and lower vestigial-sideband (VSB) signals of the transmitted data [2]. Bandwidth tunable filter has been demonstrated using mechanically stretched fiber Bragg gratings [3], however, such filters are bulky and cannot be integrated.

In this paper, we report on the first monolithically integrated bandwidth- and wavelength-tunable filters using MEMS (micro-electro-mechanical-system)-actuated microdisk resonators. Microring and microdisk resonators have been widely studied for various filtering functions [4]. Microresonators can be thermally tuned, which shifts the center wavelength of the filter [5]. Previously, we have demonstrated a novel MEMS-actuated tunable microdisk resonator whose power coupling ratio can be continuously tuned [6]. Here, we further integrate a microheater with the MEMS-actuated microdisk to achieve simultaneous bandwidth and wavelength tuning. A bandwidth tuning range of 12 – 41.2 GHz and wavelength tuning range of 125 GHz have been achieved. Potentially, such filters can be used to monitor multiple effects such as chromatic dispersion, polarization mode dispersion, possibly over multiple channels for WDM optical networks.

2. Design, Fabrication, and Measurement

The tunable filter consists of a high-Q microdisk resonator, an input and an output deformable waveguides, and a microheater, as shown in Fig. 1. The waveguide is suspended around the microdisk. Upon actuation, the waveguide is deformed and attracted towards the microdisk, changing the power coupling ratio. The microheater is integrated to control the resonant wavelength.

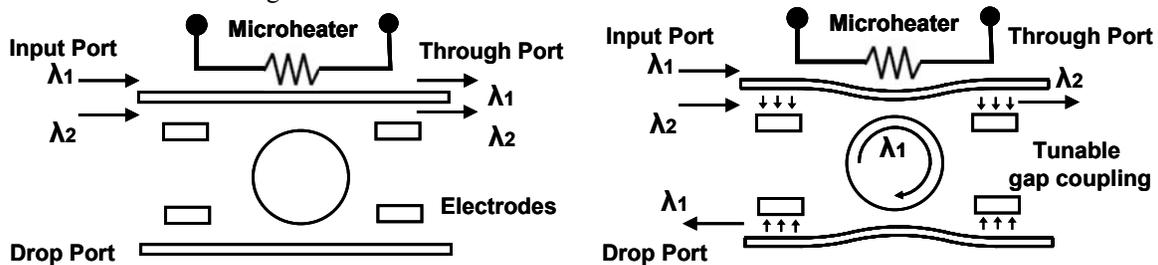


Fig. 1 Schematic of the microdisk resonator tunable filter. By varying the gap spacing of microdisk and the waveguides, resonant wavelengths (e.g. λ_1) coupled to the drop port can be tunable.

According to the time-domain coupling theory [4], the optical transmission can be expressed as a function of resonant frequency (ω_0), power coupling ratio of the input and output waveguides (κ_1 and κ_2 , respectively), round-trip propagation time (T), and round-trip resonator loss (γ):

$$T_{\text{through}}(\omega) = \frac{j(\omega - \omega_0) + (\gamma + \kappa_2 - \kappa_1)/2T}{j(\omega - \omega_0) + (\gamma + \kappa_2 + \kappa_1)/2T} \quad \text{and} \quad T_{\text{drop}}(\omega) = \frac{\sqrt{\kappa_1 \kappa_2} / T}{j(\omega - \omega_0) + (\gamma + \kappa_2 + \kappa_1)/2T}$$

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where $T_{\text{through}}(\omega)$ and $T_{\text{drop}}(\omega)$ represent the amplitude transfer functions at the through and the drop ports, respectively. For resonators with high intrinsic Q , γ is small and the filter bandwidth is dominated by coupling. By controlling κ_1 and κ_2 simultaneously, we can vary the bandwidth without changing the extinction ratio of filter.

Thermo-optic effect has been extensively used in planar lightwave circuits (PLCs) [5]. The thermal optic coefficient of Si ($1.8 \times 10^{-4} / ^\circ\text{C}$ at room temperature for 1.55 μm wavelength range [7]) is ten times larger than glass, making it more efficient to tune the resonant wavelength by integrated microheaters.

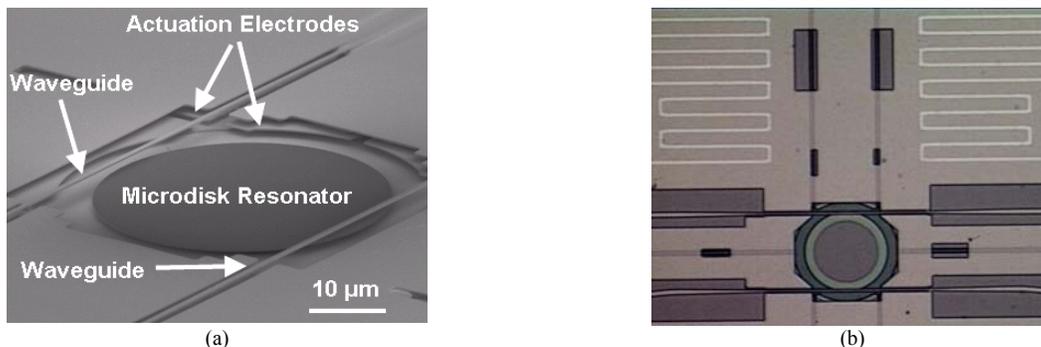


Fig. 2 (a) SEM pictures of a fabricated microdisk resonator, and (b) Device top view with the integrated microheater

The tunable filter comprises a fixed microdisk with 20 μm radius and two vertically-coupled deformable optical waveguides with 0.8 μm width. The waveguides are aligned to the edge of the microdisk. Both the microdisk and the waveguides are made in 0.25- μm -thick single crystalline silicon. The device is fabricated by thermally bonding two silicon-on-insulator (SOI) wafers with a 1- μm -thick silicon oxide in between. The optical waveguide is fabricated on the top SOI layer, and the microdisk and the electrodes for electrostatic actuators are fabricated on the bottom SOI layer. The waveguides around the microdisk are suspended by selectively removing the oxide underneath the waveguides.

The electrostatic actuator functions as a vertical comb-drive actuator with one movable finger and two fixed comb fingers. This design avoids the pull-in instability and permits the waveguide to be pulled down continuously from an initial gap spacing of 1 μm to almost touching. A novel hydrogen-assisted annealing process has been employed to reduce the root-mean-square (rms) sidewall roughness to less than 0.26 nm [8]. A 2 μm wide, 3.4 mm long Cr/Pt serpentine wire heater is patterned by lift-off process in the vicinity of the microdisk. The scanning electron micrograph (SEM) of the fabricated device is shown in Fig. 2(a). The top view of the overall device with integrated microheater is shown in Fig. 2(b).

A broadband amplified spontaneous emission (ASE) source is used to measure the spectral response of the through port and drop port. The input polarization is controlled by a polarizer and a polarization controller. The near-field profiles from the waveguides are imaged through a 40X objective lens to an IR camera for alignment and monitoring. Spherical lensed fibers with 2.5 μm spot size are used as the input and receiving fibers and the input fiber is polarization maintaining.

3. Results and Discussion

To demonstrate tunable bandwidth in our device, we actuated both waveguides and measured the full-width at half-maximum (FWHM) of spectral response of the drop port when varying the actuation biases.

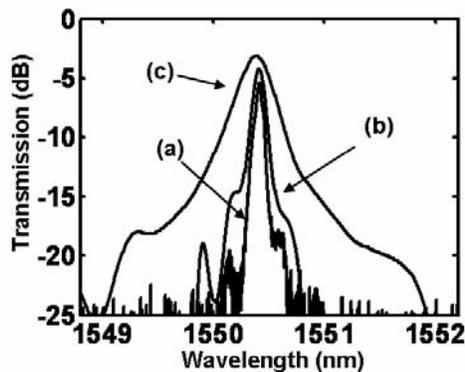


Fig. 3 The measured full-width at half-maximum (FWHM) spectra at the drop port with different actuation bias.

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Fig. 3 shows the transmission spectra at the drop port for various power coupling ratios. When controlling the actuation voltages of input and drop waveguide to be 60.0V and 64.3V, the FWHM bandwidth is 12.0 GHz, shown as curve (a). At the voltages of 62.6V and 67.5V, the bandwidth increases to 18.1 GHz, shown as curve (b). At the voltages of 67.0 V and 74.0 V, the bandwidth increases to 41.2 GHz, shown as curve (c). These results indicate that a bandwidth-tunable optical filter can be realized.

By applying current to the on-chip microheater, tuning of the resonant wavelength was also successfully demonstrated. With ambient environment at room temperature 25°C, applying a heater current of 1.7 mA yielded a red shift of 0.3 nm for the resonant wavelength. Fig. 4 shows the transmission spectra at the through port for four heater currents: (a) 0 mA, (b) 1.7 mA, (c) 3.1 mA, and (d) 3.7 mA. Over 1 nm tuning range (125 GHz) has been achieved. The extinction ratio remains the same throughout the tuning process.

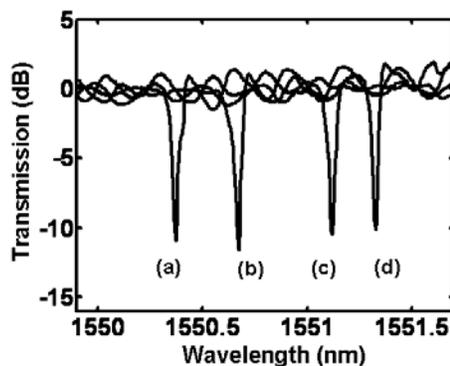


Fig. 4 Measured Spectra at the through port with different applied currents through on-chip microheater.

The Free Spectrum Ranges (FSRs) of our fabricated device are 5.1 nm for TE mode and 3.7 nm for TM mode, which are also verified by numerical simulation of the 20 μm -radius microdisk. Based on the high index contrast of the silicon/oxide and silicon/air, the microdisk resonator size can be further decreased with negligible increase of the optical loss [9]. The FSR can be greatly increased using the vernier architecture [10]. FSR greater than the entire C-band can be achieved.

4. Conclusion

A bandwidth- and wavelength-tunable filter has been successfully demonstrated using a MEMS-actuated Si microdisk resonator with integrated microheater. The FWHM bandwidth is continuously tunable from 12 to 41.2 GHz, while the peak resonant wavelength is tunable over 125 GHz. This type of versatile tunable filters has extensive applications in optical performance monitoring, signal processing, and sensing.

5. Reference

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