# Bandwidth-Tunable Add-Drop Filters Based on MEMS-Actuated Single-Crystalline Silicon Microtoroidal Resonators

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**Abstract:** A bandwidth-tunable filter has been demonstrated by MEMS-actuated single-crystalline silicon microtoroidal resonator. Bandwidth is tuned from 2.8 to 78.4 GHz by voltage control. A 21.8 dB extinction ratio is attained as a dynamic add-drop filter.

**OCIS codes:** (130.3120) Integrated optics devices; (140.4780) Optical resonators; (120.2440) filters

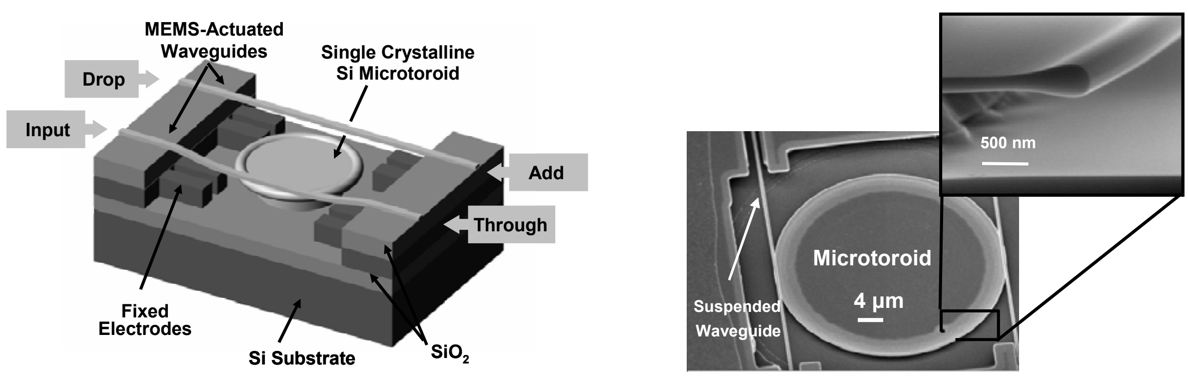
## 1. Introduction

Tunable optical filters are key components in smart wavelength-division-multiplexing (WDM) networks. Wavelength-tunable filters can add, drop, switch, or block specific wavelength channels. Filters with tunable bandwidth are useful in dynamic bandwidth allocation for optimal spectral efficiency and in optical performance monitoring. Bandwidth-tunable filters have been demonstrated using mechanically stretched fiber Bragg gratings [1]. However, they are bulky and can not be integrated.

Microresonators have been widely studied for various filtering functions [2]. Previously, we have reported a MEMS-actuated tunable microdisk resonator with a bandwidth tuning range from 12 to 41 GHz [3]. System level functions such as matched filtering, dynamic channel banding and wavelength demultiplexing have been demonstrated [4]. However, the lack of radial mode control in microdisk resonators limits the maximum tuning range due to excitation of high-order modes. Here, we report on a reconfigurable and bandwidth-tunable add-drop filter with a large tuning range using a single-crystalline silicon microtoroidal resonator. Microtoroidal resonators offer tighter optical confinement and eliminate multiple radial modes observed in the microdisks. A full-width at half-maximum (FWHM) bandwidth tuning range of 2.8 GHz to 78.4 GHz has been achieved.

## 2. Device Introduction and Operation principles

The tunable filter consists of a high-Q silicon microtoroidal resonator, an input and an output deformable waveguides, all integrated in a two-layer SOI structure, as shown in Fig. 1(a). The waveguides are suspended around the microtoroid. Upon electrostatic actuation, the waveguide is deformed and pulled towards the microtoroid, changing the power coupling ratio. Fig. 1(b) shows SEM images of a fabricated microtoroidal resonator. The resonator has a ring radius of 19.5µm and a toroidal radius of 200 nm. The waveguides are 0.69µm wide and 0.25µm thick. Details of the device design and fabrication process were reported elsewhere [5].




(a) (b)

Fig. 1(a) Schematic of the microtoroidal resonator tunable filter. (b) SEM of a fabricated microtoroidal resonator, with the inlet showing the toroid edge

According to the time-domain coupling theory [2], the optical transmission is determined by the relationship between the resonator intrinsic loss and the power coupling ratios of the input and output waveguides. For resonators with high quality factor Q, the loss is small and the filter bandwidth is dominated by coupling. By controlling the coupling ratios, we can achieve the dynamic add-drop function and vary the bandwidth of the signal spectra.

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### 3. Measurement Results and Discussion

A broadband amplified spontaneous emission (ASE) source is used to measure the spectral response of the through and the drop ports. The input light is controlled to be TE polarized by a polarizer and a polarization controller. Spherical lensed fibers with spot sizes of 2.5 μm are used as the input and receiving fibers. The input fiber is polarization maintaining.

Without voltage biases, the input power is transmitted to the through port with negligible coupling to the drop port. When the electrostatic actuators are biased, the optical powers at resonant wavelengths decrease at the through port as they are transferred to the drop port. Fig. 3(a) shows the spectral response of the through and the drop ports at biases of 32.8V. The measured free spectral range (FSR) is 5.1 nm. Fig. 3(b) shows the transmittance versus the applied voltages for both the through port and the drop port at a resonant wavelength of 1552.1 nm. A 21.8 dB extinction ratio is measured when the voltages are changed from 0 V (decoupled) to 58.1 V (over-coupled) for both waveguides. This device can be used as a dynamic add-drop filter.

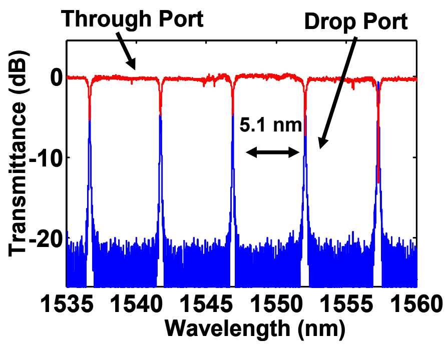


Fig. 3(a) Measured spectral response of the through port and the drop port at actuation voltages of 32.8V.

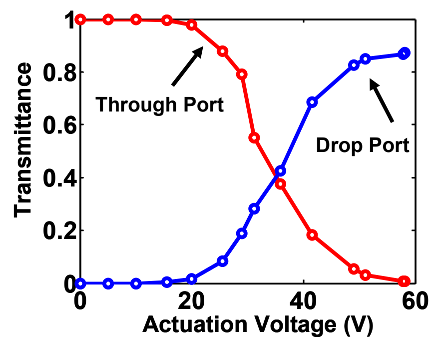


Fig. 3(b) Measured transmittance versus actuation voltages at the resonant wavelength of 1552.1 nm.

To demonstrate bandwidth tunability, we control the bias of each waveguide separately and measured the FWHM spectra bandwidth of the drop port. Fig. 4 shows the transmission spectra of the drop port for various power coupling ratios at a resonant wavelength of 1552.1 nm. When the bias voltages of input and drop waveguides are 32.7V and 35.9V, respectively, the FWHM bandwidth is 2.8 GHz, as shown by curve (a). As the actuation voltages increase, the power coupling ratios also increase, which leads to increased bandwidth, as shown by curves (b) through (g). With 48.6V (input) and 58.1V (drop), the bandwidth increases to 78.4 GHz, as shown by curve (g). To our knowledge, this is the largest bandwidth tuning range in microresonator-based filters.

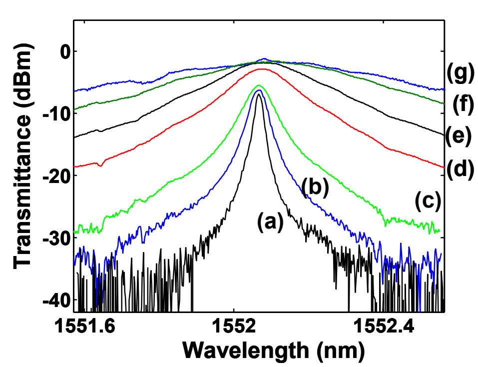


Fig. 4. The measured full-width at half-maximum (FWHM) spectra at the drop port with different actuation biases

### 4. Conclusion

A monolithically integrated dynamic add-drop filter with tunable bandwidth has been realized using a MEMS-actuated silicon microtoroidal resonator. The FWHM bandwidth is continuously tunable from 2.8 GHz to 78.4 GHz. As a dynamic add-drop filter, wavelength switching with a 21.8 dB extinction ratio is attained. This type of tunable filters has applications in dynamic bandwidth allocation, optical performance monitoring, signal processing, and sensing.

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