Silicon Microresonators with MEMS-Actuated Tunable Couplers

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Abstract: We review the current state-of-the-art of tunable microdisk/microtoroidal resonators with MEMS-actuated couplers. They are key enabling elements of many wavelength-division-multiplexing switches and tunable filters. The performance of dynamic add-drop and bandwidth-tunable filters will be discussed.

Introduction

Microring and microdisk resonators are compact building blocks for large scale photonic integrated circuits [1]. The functionalities of these circuits include wavelength-division-multiplexing (WDM) filters, switches, wavelength-selective switches and crossconnect [1], dynamic dispersion compensators [2], WDM lasers [3] and modulators [4]. For many of these functions, it is necessary to tune the properties of the microresonators. The most commonly used tuning mechanisms is thermal optic effect [5], in which the refractive index, and hence the resonance wavelength, of the resonator is varied by integrated heaters. Direct modulation of the refractive index has also been demonstrated using free-carrier plasma effect in Si [4] or electro-optic effect in III-V or lithium niobate [6]. Another tuning mechanism is to vary the loss or gain of the microresonators themselves. This changes the quality factor (Q) of the resonator and the critical coupling distance.

Aside from the Q and the resonance wavelength, the most important parameters for microresonator circuits are their power coupling ratios. The characteristics of microresonators depend critically on the coupling ratios. In most integrated microresonators, the coupling ratios are fixed by the fabrication process and are not easily tunable. In 2003, we reported the first microresonator with integrated tunable couplers [7]. This is achieved by physically varying the spacing between the microdisks and the coupling waveguides using micro-electro-mechanical-system (MEMS) actuators. Later, with improved design and fabrication process, high performance tunable microdisk resonators with vertically coupled waveguides were reported [8, 9]. These resonators can be operated in uncoupled, under-coupled, critically coupled, or over-coupled regimes by simply varying the voltages on the MEMS actuators. Various functions have been demonstrated. Dynamic wavelength add-drop filters have been demonstrated, with a switching voltage of 30V. The pass bandwidth of the filter is also tunable. We have achieved a tuning range of 3 to 78 GHz in a similar device with Si microtoroidal resonator [10]. In this paper, we will review the current state of the art of the MEMS tunable microresonators. Their applications in wavelength add-drop filters/multiplexers and bandwidth-tunable filters will be described.

Basic Device Structures

Figure 1 shows the schematic of the MEMS tunable microresonator. It consists of a microdisk or microtoroidal resonator and two vertically coupled waveguides. The waveguides are suspended on top of the microresonator. Using integrated electrostatic actuators, the waveguides can be selectively pulled down towards the microresonator. Since the coupling ratio is an exponential function of the gap spacing between the waveguide and the resonator, it can be tuned effectively over a wide range (many orders of magnitude) by simply moving the waveguide over a distance of 1 μm. Figure 2 shows the scanning electron

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micrograph (SEM) of a tunable microdisk resonator with 20 μm radius. The two waveguides are 800 nm wide and 250 nm thick. The device is fabricated on two-layer silicon-on-insulators (SOI), with the microdisk patterned on the first layer, and the waveguides defined on the top Si layer. Detailed fabrication process can be found in [11]. After etching, the microdisks are annealed in hydrogen ambient to smoothen the sidewall roughness [12]. Typical Qs of the annealed microdisk are ~ 100,000 to 300,000. The single crystalline Si microtoroidal resonators are created by hydrogen annealing [13]. Compared with microdisks, the microtoroidal resonator has single radial mode and thus exhibits cleaner spectra without spurious high-order modes.

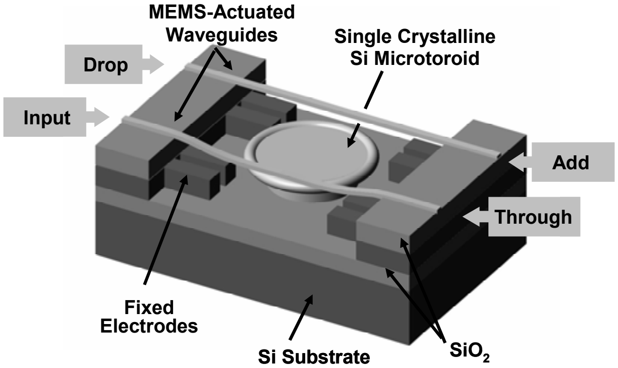

Fig. 1. Schematic of MEMS microtoroidal resonator with integrated tunable couplers.

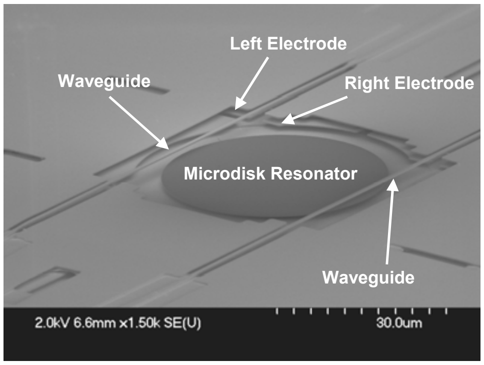

Fig. 2. SEM of MEMS tunable microdisk resonator. The waveguides on top of the microdisk are suspended by sacrificial etching.

Dynamic Wavelength Add-Drop Multiplexers

The schematic illustrating the principle of the dynamic add-drop filter is shown in Fig. 3. When the waveguides are far away, the microresonator is essentially uncoupled. All input power travels directly to the Through port. With decreasing distance between the waveguides and the resonator, the resonant wavelength is increasingly switched to the Drop port. The distance can be controlled precisely by the electrostatic actuator. The experimental results are shown in Fig. 4. At 0V, the waveguide-disk spacing is 1 μm and the microdisk is uncoupled. At 30V, the disk is over-coupled, and the resonant wavelengths are effectively switched to the Drop port.

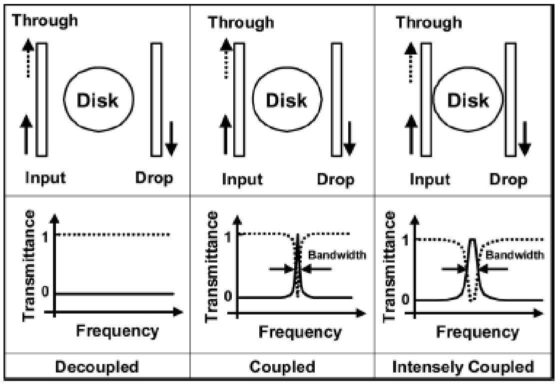

Fig. 3. Schematic illustrating the principle of MEMS dynamic add-drop filter.

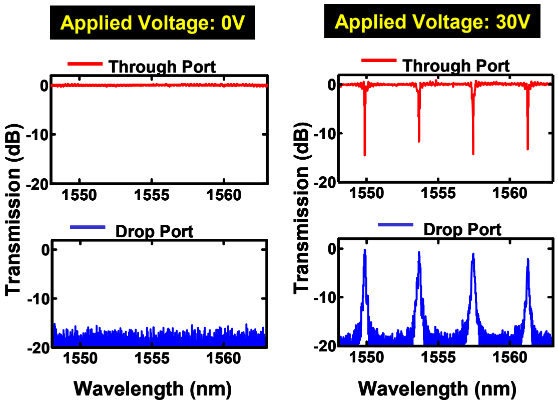

Fig. 4. Measured spectra of the Through (top) and Drop (bottom) ports with the MEMS actuators biased at 0V (left) and 30V (right), respectively.

Bandwidth-Tunable Filters

In the over-coupled regime, the overall Q of the resonator is dominated by coupling. Therefore, varying coupling can directly tune the loaded Q and hence the pass bandwidth of the Drop port. Using microtoroidal resonators [10], we have demonstrated a record wide bandwidth tuning range of 3 to 78 GHz, as shown in Fig. 5.

Conclusion

We have described a class of novel optical microresonators with integrated tunable couplers. This is achieved by integrating MEMS actuators with suspended optical waveguides. Using vertically coupled MEMS microdisk resonators, dynamic add-drop multiplexers have been demonstrated. Bandwidth-tunable filters with record tuning range (3 to 78 GHz) have also been attained.

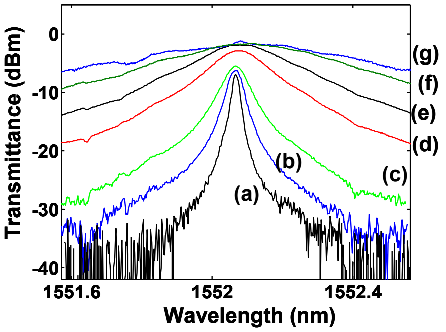

Fig. 5. The spectra of a bandwidth-tunable filter under various bias voltages. The FWHM bandwidth is continuous tunable from 3 to 78 GHz.

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