A Reconfigurable Add-Drop Filter Using MEMS-Actuated Microdisk Resonator

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Abstract— A novel vertically coupled tunable microdisk resonator with integrated MEMS tunable optical couplers is demonstrated. A reconfigurable add-drop filter based on this device shows an extinction ratio of 20 dB.

I. Introduction

Optical microdisk or microring resonators with high index contrast have attracted a great deal of attentions recently because they can reduce the footprints of a variety of wavelength-division-multiplexed (WDM) photonic integrated circuits (PICs). Adding tuning mechanisms to microresonators is desirable for reconfigurable optical systems. Shifting of resonant wavelength has been demonstrated by thermo tuning [1] and free-carrier injection [2]. The optical properties of microresonator circuits depend on the input and output coupling ratios, which can be effectively tuned by varying the gap spacing between the waveguides and the microresonator. Previously, we have demonstrated a laterally coupled microdisk resonator integrated with MEMS actuators [3]. However, the device can only operate in under-coupling regime.

In this paper, we present a vertically coupled microdisk resonator capable of operating in under-coupling, critical coupling, and over-coupling regimes. A reconfigurable add-drop filter with 20-dB extinction ratio is successfully demonstrated. A salient feature of MEMS-actuated microdisk circuits is that the disk can be completely decoupled from waveguide, and multiple disks can be cascaded without increasing the insertion loss.

II. Device Design and Fabrication

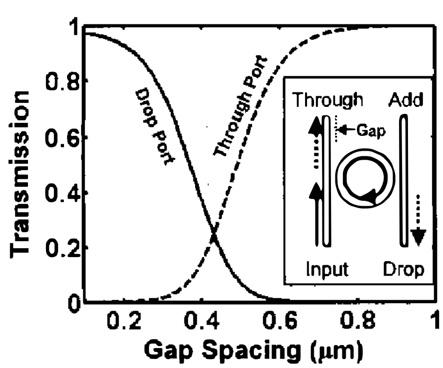

Figure 1. The calculated transmittance at resonance versus the gap spacing between waveguide and microdisk.

Figure 1 shows the calculated power transfer characteristics of a Si microdisk add-drop filter. The resonant wavelength is switched from the through port to the drop port when the waveguide-to-disk spacing is reduced from 0.8 μm, at which the microdisk is under-coupled, to 0.2 μm, at which the microdisk is over-coupled.

The schematic structure of the vertically coupled Si microdisk is depicted in Figure 2. It consists of two 0.25-μm-thick single-crystalline silicon layers. The microdisk (20-μm radius) and the MEMS electrodes are patterned on the bottom layer, while the waveguides (0.8-μm width) are fabricated on the top layer. These two layers are separated with 1-μm thick SiO_2 as a spacer. The waveguides around the microdisks are suspended by removing the underlying SiO_2, enabling them to deform when a voltage is applied on the electrodes. The gap spacing between the waveguide and the microdisk can thus be controlled by voltage. To allow continuous variation of the gap spacing from 1 μm to nearly touching, we have employed comb-like electrostatic actuators on both ends of the suspended waveguide, as shown in the cross-sectional views in Fig. 2.

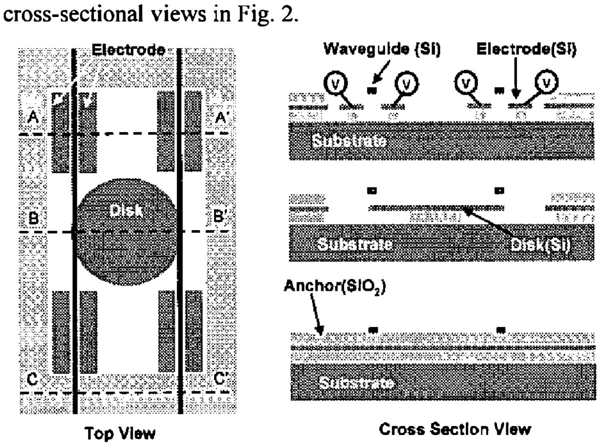

Figure 2. Schematic diagram of a vertically-coupled microdisk resonator. The waveguides are suspended on top of the disk edges. The cross sections of the device are shown at various locations: actuator (AA'), microdisk (BB'), and waveguide anchor (CC').

The fabrication process is described in the following. First a thin thermal oxide was grown on the SOI wafer as a hard mask for silicon etching. The microdisk and electrode patterns were transferred to the oxide layer by photolithography and reactive

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ion etch. The silicon layer was patterned by magnetically-enhanced reactive ion etch (MERIE) with HBr plasma. To reduce the scattering loss due to surface roughness [4], a novel hydrogen annealing process was employed. More detailed description of this process can be found in [5]. The patterned SOI was bonded to another SOI wafer coated with 1-μm-thick oxide. After bonding at high temperature (900°C), the substrate and buried oxide of the second SOI wafer was removed. Waveguide patterns were aligned to the microdisks and transferred to the bonded silicon layer. Finally, the waveguides are released in buffered oxide etch (BOE) through lithographically patterned photoresist windows. The fabricated device is shown in Figure 3.

Compared with our previous device [3], this vertically coupled microdisk exhibits several advantages from both optical and MEMS point of views. Because the waveguide has a rectangular cross section (width = 0.8 μm, thickness = 0.25 μm), the optical coupling is stronger in the vertically coupled geometry. In addition, the operating voltage is lower since the waveguide is easier to bend in the thinner dimension. This is confirmed by our experimental measurement: the actuation voltage is 35V in the current device while it is > 70V in the laterally coupled device.

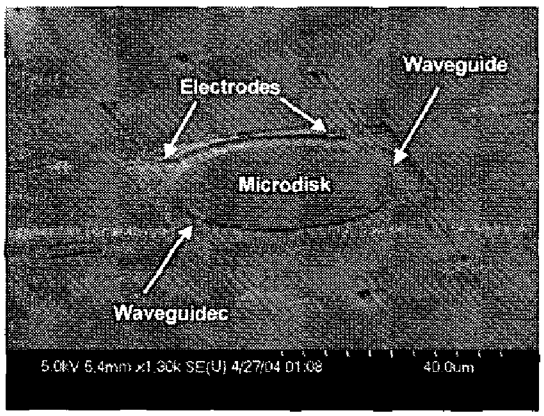

Figure 3. The SEM image of fabricated device.

III. Measurements

The length of suspended waveguides is 100 μm. Without bias, the initial gap between waveguide and disk is 1 μm and there is essentially no optical coupling. The waveguides are electrically grounded, and voltage is applied to the MEMS electrodes. The voltage at maximum displacement is 35 V. To characterize the optical performance of the microdisk, two lensed fibers are aligned to the input port and the through port. Another lensed fiber is aligned to the drop port. The input fiber is connected to an erbium-doped fiber amplified spontaneous source with TM polarization. Figure 4 shows the measured optical transmission at the through and the drop ports versus the applied voltage. The resonant wavelength is 1,555.46 nm. At zero bias, all optical power is transferred to the through port. As the applied voltage increases, the power decreases at the through port but increases at the drop port. The threshold voltage, defined as the voltage at which the two curves cross, is 19 V, At 35 V, almost all of the input power is transferred to the drop port. The extinction ratio is measured to be 20 dB. The unloaded Q of the microdisk (100,000) is characterized by operating the microdisk in critical coupling condition, where the bias is 17 V.

IV. Summary

We have successfully demonstrated a vertically coupled microdisk resonator with integrated MEMS tunable couplers for the first time. This microdisk can be operated in any of three coupling regimes (under-, critical and over-coupling). A reconfigurable add-drop filter is demonstrated with an extinction ratio of 20 dB and a switching voltage of 35 V. The unloaded Q of the microdisk is measured to be 100,000. Potentially, this device can be cascaded to implement a large-scale reconfigurable add-drop multiplexers.

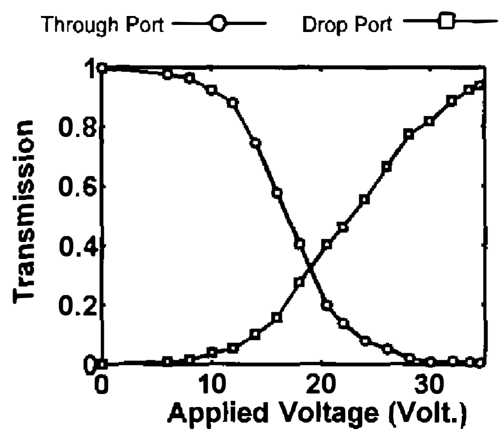

Figure 4 Measured transfer curves at the through port (circle) and the drop port (square). It is measure at resonant wavelength of 1,555.46 nm.

Acknowledgment

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