Tunable MEMS Actuated Microring Resonators

Ming-Chun Tien[1], Sagi Mathai[2], Jin Yao[1], and Ming C. Wu[1]
[1]*Berkeley Sensor & Actuator Center (BSAC) and Dept. Electrical Engineering and Computer Sciences*
University of California, Berkeley, California 94720, USA, Tel +1-510-642-1023, Fax +1-510-643-6637, E-mail mctien@eecs.berkeley.edu
[2]*Quantum Science Research, Hewlett-Packard Laboratories, Palo Alto, California 94304, USA*

Abstract

A simplified process has been developed to fabricate MEMS tunable microring resonators on six-inch silicon-on-insulator wafers. Deep UV lithography is used to create 220-nm-wide waveguides and microrings. The process is CMOS compatible. The transmission spectra change from a double resonance dip (under-coupling) to a broader single resonance dip (over-coupling) when the waveguide is moved closer to the microring. This is explained by coupled mode theory that includes the effect of backscattering in the microring.

Keywords: optical resonator, MEMS, optical filter, doublet

1. INTRODUCTION

Silicon microresonators, including microdisks, microtoroids, and microrings, are versatile components to realize high density photonic integrated circuits (PIC). A parameter widely used to evaluate the performance of a resonator is its quality factor (Q). Ultra-high Q silica microtoroidal resonators and silicon microdisk resonators evanescently coupled to an off-chip tapered fiber have been reported [1, 2]. Waveguide integrated microresonators, patterned by e-beam lithography, with fixed power coupling ratio were also demonstrated [3]. Previously, our group reported tunable Si microdisk and microtoroidal resonators with integrated Microelectromechanical-system (MEMS) actuators on two-layer silicon-on-insulators (SOI) using wafer bonding process [4, 5].

In this paper, we report on a simplified process for MEMS tunable *microring* resonator integrated with laterally coupled waveguides and electrostatic actuators for coupling control on the SOI platform. Combining thermal oxidation and deep ultraviolet (DUV) photolithography, 220-nm-wide waveguides and microring resonators were fabricated. No wafer bonding is needed. The process is compatible with complementary metal-oxide-semiconductor (CMOS). Thermal oxidation provides an additional advantage of smoothing out surface imperfections [6], which results in a Q ~ 80,000.

2. CMOS COMPATIBLE FABRICATION PROCESS

The integrated device is fabricated from a 150 mm SOI wafer with 0.8 μm device layer and 3 μm buried oxide (BOX) layer. The process starts with thermal oxide hardmask growth followed by two DUV lithographies and silicon dry etch steps to form the microring, submicron waveguides, and MEMS actuators. Thermal oxidation is then utilized to reduce the surface roughness. Finally, the MEMS actuated waveguides are released in buffered oxide etchant (BOE) followed by super critical drying. The remaining silicon in the center of the microring prevents the microring from being released. All the processes are CMOS compatible and e-beam lithography is not needed. The SEM picture of a fabricated microring resonator is shown in Figure 1. The waveguide dimensions are 220 nm wide by 500 nm high, which satisfies the single mode condition for TE and TM polarizations. By controlling the gap between the waveguide and the microring using electrostatic force, different coupling regimes can be achieved. At 80 V, the travel of the waveguide is ~ 1 μm.

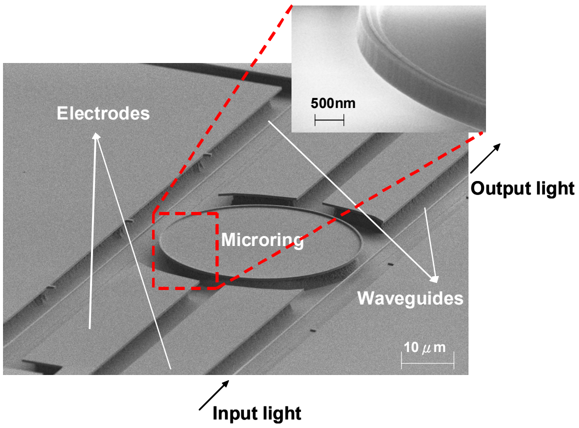

Figure 1: SEM of a released tunable MEMS actuated microring resonator. The upper right image zooms in on the microring edge.

3. OPTICAL CHARACTERIZATION

The tunable microring resonator is tested using an Agilent 81680A tunable laser. Light is coupled into the waveguide through a polarization maintaining (PM) lensed fiber, and another single mode lensed fiber collects the transmitted light. The measured transmittance is shown in Figure 2. Only one waveguide is actuated while the other parallel waveguide is decoupled from the microring resonator. In this case, the device behaves as an optical notch filter.

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By applying different voltages, the resonator can be operated in the under-coupled or over-coupled regimes. In the under-coupled regime, a double resonance dip (doublet) caused by backscattering inside the resonator is observed. The clockwise (CW) and counterclockwise (CCW) propagating modes couple to each other via backscattering, which lifts the degeneracy and splits the resonance dip. However, in the over-coupled regime, the doublet is not observable, as shown in Figure 2 at a bias of 70.2 V.

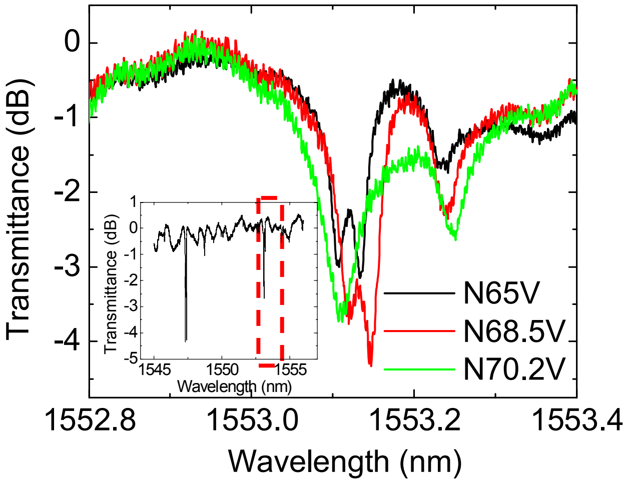


Figure 2: Measured transmission spectra near the resonance at 1553.1 nm under different bias voltages. (Inset) Measured transmittance over the 1550 nm regime.

4. COUPLED MODE MODEL FOR DOUBLETS

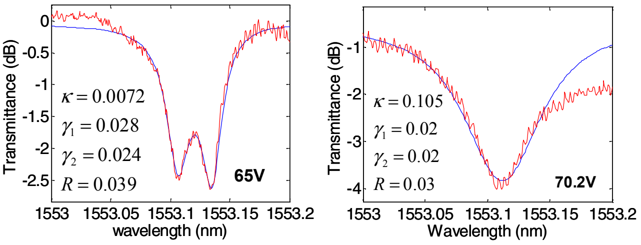
In order to investigate the doublet behavior caused by coupling between the CW and CCW modes in the microring resonator, a modified coupled mode theory is used [7, 8]. The coupled mode equations are written as follows.

$$\frac{da_{cw}}{dt}+\left[\frac{1}{2}\left(\frac{\gamma}{T}+\frac{\kappa}{T}\right)+i\Delta\omega\right]a_{cw}=i\frac{R}{2T}a_{ccw}+i\frac{\sqrt{\kappa}}{T}A_{in},$$

$$\frac{da_{ccw}}{dt}+\left[\frac{1}{2}\left(\frac{\gamma}{T}+\frac{\kappa}{T}\right)+i\Delta\omega\right]a_{ccw}=i\frac{R}{2T}a_{cw}$$

where a_{cw} and a_{ccw} are the amplitudes of the CW and CCW modes. T is the round-trip propagation time inside the resonator. κ is the power coupling ratio between the waveguide and resonator while γ is the round-trip intrinsic loss. The excitation frequency is detuned by Δω with respect to the resonance frequency. R is the backscattering power ratio, and A_{in} is the input amplitude.

The measured transmission spectra for the under-coupled and over-coupled regimes were fitted to the coupled mode model as shown in Figure 3 (a) and (b), respectively. In the under-coupled regime, an obvious doublet was observed due to backscattering in the resonator. The asymmetric doublet is caused by different intrinsic round-trip loss experienced by each eigenmode, represented by γ_1 and γ_2 in Figure 3. In the over-coupled regime, the doublet is no longer observable because the loaded Q broadens the linewidth and hides the doublet. The measured asymmetry in the maximum transmission is due to the overlap between the adjacent resonant modes as shown in Figure 2. Due to backscattering in the resonator, the condition for critical coupling is shifted and obtained when $\kappa^2=\gamma^2+R^2$ for a high-Q resonator [7, 8]. The extracted intrinsic Q is around 80,000 and the backscattering power ratio is around 3.5%.



(a) (b)

Figure 3 Transmittance curves fitting in the (a) under-coupling (b) over-coupling regimes. Blue lines are theoretical fits with the coupled mode theory while red lines are measured spectra.

5. SUMMARY

We have successfully demonstrated a CMOS compatible tunable microring resonator based on MEMS actuators using thermal oxidation and DUV photolithography techniques. An obvious doublet was observed in the transmission spectrum when the resonator was operated in the under-coupled regime. With a modified coupled mode model, the behavior of the doublet was analyzed, and the measured Q of the resonator was around 80,000.

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