A High-Performance Bandwidth-Tunable Optical Filter in Silica-on-Silicon Platforms

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Project Thrust 2

Connection to CIAN Strategic Plan

Bandwidth-tunable filters have several applications in CIAN systems and testbeds. They can be used for dynamic allocation of bandwidth and/or channel banding. We are working closely with Thrust 1 researchers (Prof. Alan Willner and his group).

Connection to Thrust 2

A practical bandwidth-tunable optical filter will expand the signal processing and reconfiguration capabilities of current optical technology. The size and fabrication process of this device will make it easily integrable with other optoelectronics and CMOS.

State of the Art

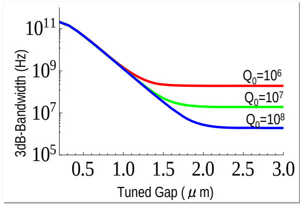
Tunable bandwidth filters are a key enabling component for optical access networks. Using a Si microtoroid structure, we have achieved a tuning range from 3 to 80 GHz. To further reduce the lower limit, we are exploring materials with lower optical loss such as glass. Using glass instead of Si, it is possible to create microtoroid resonators with quality factors as high as 30 million [2], corresponding to a theoretical lower tuning limit of about 6 MHz, but the fabrication method used to produce such resonators does not lend itself to a parallel, wafer-scale fabrication process.

Silica and Bandwidth-Tunability

Tuning the gap between a waveguide and a resonator adjusts the coupling efficiency (κ) and consequently the bandwidth of the filter. The lower end of the tuning range is limited by the intrinsic resonator loss (γ).

$$Q = \left(\frac{1}{Q_0} + \frac{1}{Q_{coupling}} \right)^{-1} = \frac{\omega_0 T}{\gamma + \kappa}$$

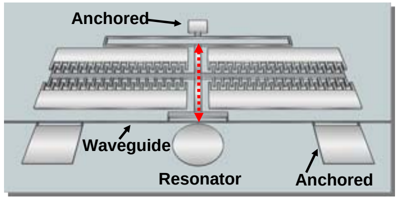
Because of the ***lower optical loss of silica*** compared to silicon, it is possible to achieve bandwidths as narrow as 10 to 100 MHz, depending on the eventual Q_0 of our resonator. To estimate the required gap tuning before the actual Q_0 is known, we plot several possibilities to the right.



Bandwidth Tuning (Silica Resonator)

MEMS Actuator Design

This comb drive actuator is designed to displace the waveguide toward and away from the resonator up to ~2 μm at 100V in accordance with the bandwidth tuning calculations.

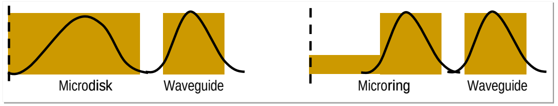


Resonator Options and Phase Matching

We are testing three possible designs for the resonator for the filter: microdisk, pseudodisk [1], and microring. Between the three, there is a trade-off between mode-matching and fabrication complexity:

	Microdisk	Pseudodisk	Microring
Fabrication	Easier	Easier	Requires additional hardmask
Mode-matching	Mode mismatch	Modes match by waveguides and expand elsewhere; causes extra <u>loss</u>	Modes match

Pseudodisk



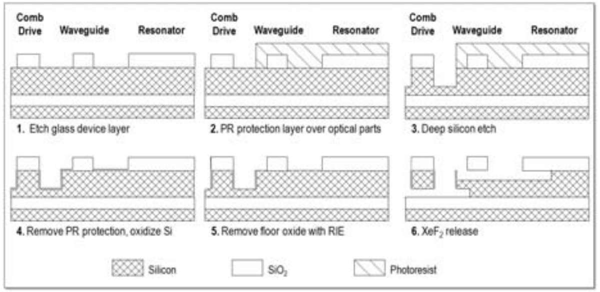
The mode in the microdisk is much wider than in the waveguide, resulting in poor coupling. This can be solved by confining the mode in a microring or in a pseudodisk.

Fabrication

The optical components of the filter must be made and suspended entirely on ~1 μm thick silica in order to accommodate single-mode propagation in the waveguide. However, the waveguide is displaced by a MEMS electrostatic comb drive. This leads to a couple of challenges in making the MEMS actuator:

- The actuator must be electrically conductive (unlike silica)
- The actuator's comb fingers must be thick enough to provide a reasonably large electrostatic force

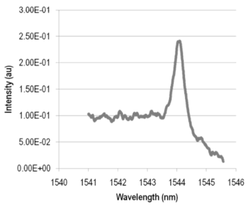
To solve these problems, we use a photoresist protection layer over the optical components to etch the device such that the actuator components retain several microns of conductive silicon under the silica surface while the optical components are still strictly silica:



We have honed this fabrication process such that it can be repeated reliability in our own microfabrication facilities.

Initial Optical Characterization

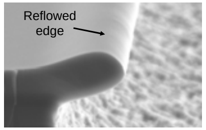
After successfully fabricating our device using the optimized fabrication method, we initiated preliminary optical characterization of the filter characteristics. The graph to the right shows one of the peaks in the drop port intensity with respect to frequency when the device is at the equilibrium gap spacing. The devices showed resonance peaks at the expected free spectral range of about 5.5nm. The peaks had FWHM bandwidth of ~50GHz, from which we estimate the resonator quality factor to be about 3,800.



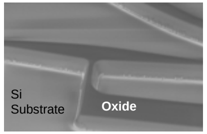
Strategies to Increase Quality Factor

As the measured microdisk resonator *Q*-factor is undesirably low, we are currently developing techniques to increase it. We hypothesize that the primary source of *Q*-factor degradation is sidewall roughness, which is clearly visible in the SEM image to the right.

We are pursuing two techniques to potentially decrease sidewall roughness:



PSG will reflow at high temperatures, possibly smoothing out edge roughness



Modifying the oxide etch chemistry can potentially decrease sidewall roughness

Summary

By changing the resonator and waveguide material from silicon to silica, we expect to achieve MEMS-actuated bandwidth tuning with a lower limit up to 100 times narrower than in silicon. We have designed a device structure to overcome the optical and electrical challenges that this new material poses, and developed a process flow to address the fabrication challenges of this design. <u>Future work</u> includes:

- Reducing sidewall roughness to increase *Q*-factor
- Characterizing the MEMS and optical performance of the higher-*Q* device

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References

[1] K. Amarnath, T.N. Ding, and P.T. Ho, "All-Optical Non-Linear Switching in Active Microdisks," Lasers and Electro-Optics, 2007. CLEO 2007. Conference on, 2007, pp. 1–2.

[2] M. Hossein-Zadeh and K.J. Vahala, "Free ultra-high-Q microtoroid: a tool for designing photonic devices," Optics Express, vol. 15, Jan. 2007, pp. 166-175.

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