

Athermal Operation in Polymer-Clad Silicon Microdisk Resonators

Payam Alipour, Ehsan Shah Hosseini, Ali Asghar Eftekhar, Babak Momeni, and Ali Adibi
School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA
payam.alipour@gatech.edu, ehsan@gatech.edu, eftekhar@ece.gatech.edu, momeni@ece.gatech.edu,
adibi@ece.gatech.edu

Abstract: We have used a urethane polymer as cladding to reduce the temperature sensitivity of resonance in high-Q silicon microdisk resonators. A two-order-of-magnitude improvement in resonance stability is demonstrated, and effects on the Q-factor are discussed.

Travelling-Wave Resonators (TWRs) in SOI have become a fundamental building block in silicon photonics, due to their extremely high Q-factors, as well as design simplicity and excellent mechanical stability. Qs in the 10^6 range have been demonstrated for state-of-the-art microdisk resonators; while Qs of microrings are typically an order of magnitude lower. Therefore, high-Q applications require microdisks.

TWRs in SOI still have practical issues that need to be addressed. One of them is the strong temperature-dependence exhibited by the refractive index of silicon. The Thermo-Optic Coefficient (TOC) of Si is $+1.8 \times 10^{-4} \text{ K}^{-1}$, and as a result, TWRs made of Si are highly temperature-sensitive. For a typical microdisk with a radius of $10 \mu\text{m}$ and a thickness of 220 nm, the resonance wavelength shifts about 80 pm/K (10 GHz/K) at 1550 nm. This degree of thermal variation is not acceptable in many applications that rely on stable resonance properties, such as delay lines and narrow-band filters.

One way to solve this issue is to coat the resonators with a negative TOC polymer. The competing TO effects in Si and polymer can compensate for each other, leading to a constant effective index and making the resonance athermal. Ultimately, the magnitude of the thermal shift depends on the TOC of the polymer, as well as the field confinement. This method has been successfully applied to microring resonators [1]. However, it is more challenging for microdisks because of their higher levels of field confinement. Using Poly-Urethane Acrylate (PUA) as cladding, which has one of the largest available TOCs ($-4.5 \times 10^{-4} \text{ K}^{-1}$), the thermal shift of a $10\mu\text{m}$ -220nm microdisk reduces by only about 15%.

To increase the effect of the polymer, we need to reduce the confinement by shrinking the size of the resonator. However, the potential negative effect on the Q must be considered. Fig. 1(b) shows the decrease in temperature-sensitivity as we reduce the radius and the thickness by 50%, simulated using the finite element method (FEM). It is clear that changing the radius has a much smaller effect on the magnitude of the thermal shift, while its negative effect on Q is observed to be comparable or even worse than that of thickness reduction.

Even the best results in Fig. 1(b) are still far from full compensation, and the practicality of size reduction is limited by the need for high Qs. To break this trade-off, we propose to undercut the buried oxide (BOX) layer, in order for the polymer to flow underneath the disk. Since the TOC of the BOX layer was negligible, replacing it with polymer will boost the compensation effect by a factor of ~ 2 . Fig. 2(b) shows the change of resonance shift with thickness at 1450 nm for a $10\mu\text{m}$ undercut disk. The shift is close to zero for a thickness of 110 nm, but dramatically increases for larger thicknesses. Therefore, undercutting and thinning are both necessary to achieve zero shift.

To test these ideas, microdisks are fabricated on SOI wafers with thin Si layers. The thinning is done through dry oxidation. The patterns are written on ZEP or HSQ electron-beam resists, and etched in Si using inductively-coupled plasma. Then, the devices are coated with 1827 photoresist, and small openings are created around each disk by optical lithography. These openings allow for selective undercutting using Buffered Oxide Etchant (BOE). An SEM micrograph of an undercut device is shown in Fig. 3(a). As far as the mechanical stability of the suspended bus waveguide is concerned, we did not face any issues for suspension lengths as large as $20 \mu\text{m}$. An example of a nearly-zero thermal shift ($\sim 0.2 \text{ pm/K}$) is shown in Fig. 3(b).

Currently, using the same fabrication process, we are observing a factor of 2 difference in the Qs of 220nm and 110nm microdisks. Intrinsic Qs of 10^6 and 5×10^5 with critical coupling have been achieved respectively, as shown in Fig. 4. Same levels of Q are observed before and after putting the PUA cladding. The Qs can be improved by using resist reflow and surface passivation techniques.

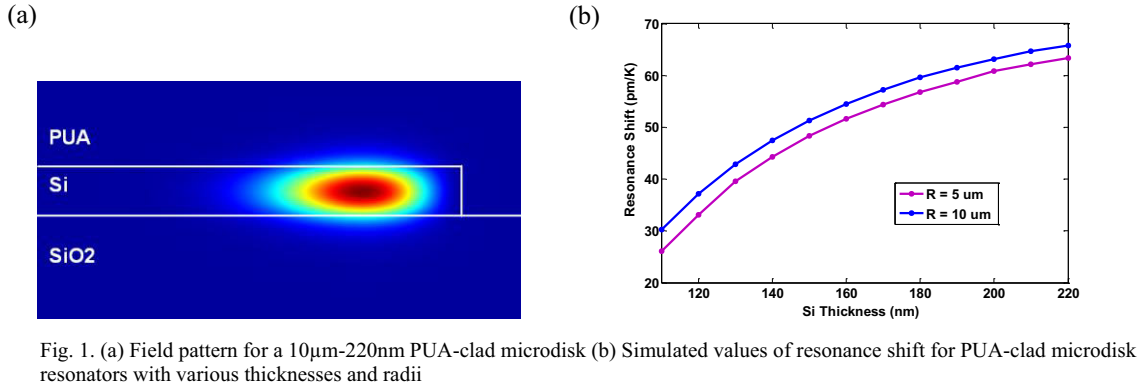


Fig. 1. (a) Field pattern for a 10µm-220nm PUA-clad microdisk (b) Simulated values of resonance shift for PUA-clad microdisk resonators with various thicknesses and radii

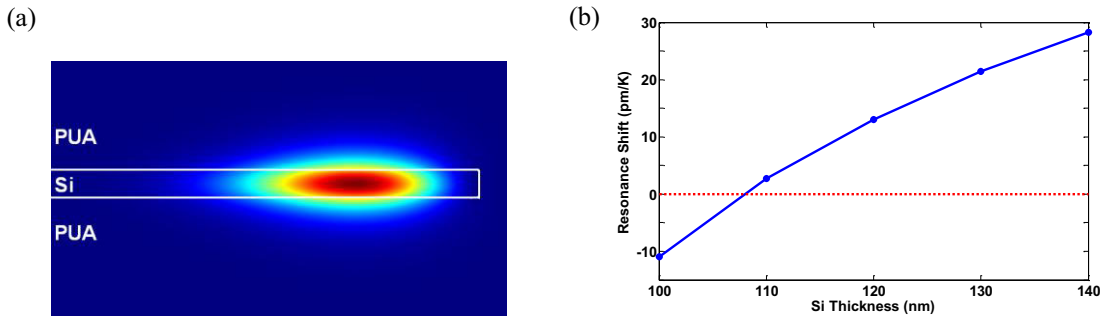


Fig. 2. (a) Field pattern for a 10µm-110nm PUA-clad undercut microdisk (b) Simulated values of resonance shift for 10µm PUA-clad undercut disks with different thicknesses

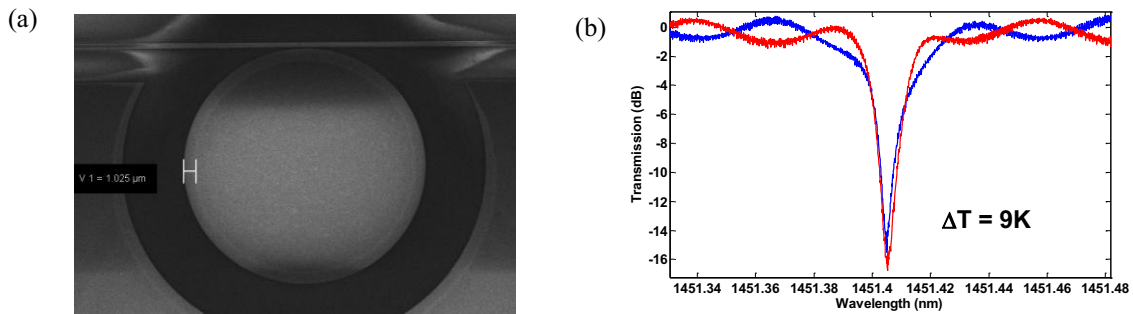


Fig. 3. (a) SEM image of a 10µm-110nm microdisk with 1µm of undercutting (b) Resonance shift of a 10µm-110nm undercut microdisk over 9 degrees of temperature change

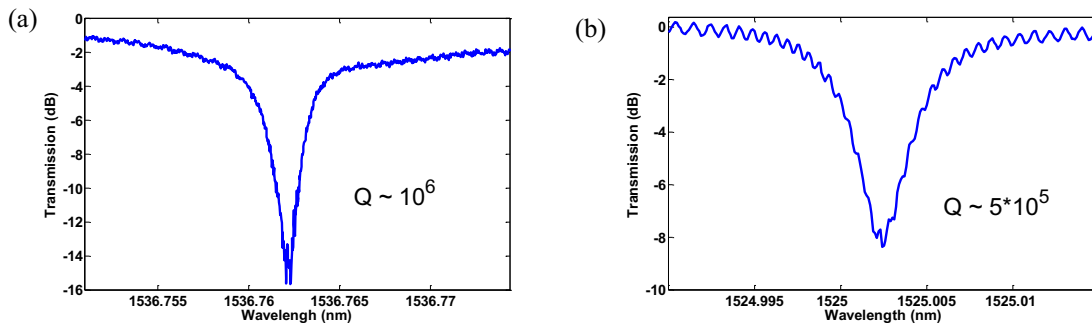


Fig. 4. (a) Intrinsic Q of 10^6 in a 10µm-220nm microdisk (b) Intrinsic Q of 500,000 in a 10µm-110nm PUA-clad microdisk

References

[1] J. M. Lee, D. J. Kim, H. Ahn, S. H. Park, and G. Kim, "Temperature Dependence of Silicon Nanophotonic Ring Resonator with a Polymeric Overlayer," *J. Lightwave Technol.* **25**, 2236–2243, (2007).