Efficient Silicon Photonic Add-Drop Microdisk Filters for DWDM Systems

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Abstract: We propose add-drop microdisk filters for demultiplexing in DWDM systems and demonstrate a 41% reduction in thermal tuning energy with smaller 1.6 μm radius microdisks, requiring only 1.5 mW tuning on average.

1. Introduction

The exploding demand for data centers and high-performance computing will require integrated photonic interconnects to keep up with growing bandwidth density. Tightly integrated dense wavelength division multiplexing (DWDM) optical links offer vastly improved energy-per-bit metrics relative to traditional interconnects, especially at higher per-link bandwidths [1, 2]. Microresonator-based add-drop filters can be leveraged in highly parallel DWDM systems for demultiplexing wavelengths in receivers [3]. Among microresonator-based filters, microdisks are of particular interest due to their large potential free spectral range (FSR) and small footprint, allowing many to be integrated together.

Integration of microdisk filters into DWDM systems requires careful design of their parameters, such as FSR, quality factor, and target resonant wavelength. DWDM links require each filter to be operating at a specific wavelength, but due to fabrication and ambient temperature variations the filters will not achieve this. To address this it is common to integrate a small heater in each filter, shown in Fig. 1a, so that by changing the local temperature its resonant wavelength can be shifted to compensate for these variations, as seen in Fig. 1c. The power required for this thermal tuning increases the link's total energy consumption. Through wafer-scale measurements of disks of varying size and across different reticles we show that reducing the radius of the microdisks from 4.5 μm to 1.6 μm reduces the power required for thermal tuning by 41%.

2. Measurement-Validated Microdisk Filter Characteristics

Add-drop microdisk filters over a range of radii from 1.6 μm to 4.5 μm were fabricated on a dedicated 300 mm wafer run through AIM Photonics, offering us the ability to collect reticle-to-reticle statistics. After grating coupling to each device, the transmission spectrum is measured using a tunable laser system (TLS) and an optical power meter (OPM). Fig. 1b shows the effect of variation in fabrication on resonances of a particular microdisk measured across 8 reticles.

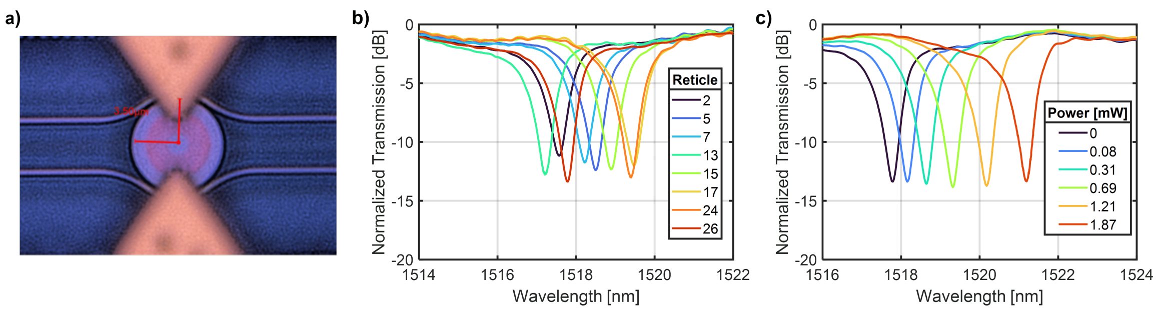

Fig. 1. **a)** Micrograph of a microdisk filter with radial couplers showing doped silicon heater geometry in redder ring at center. Bright red lines indicate scale. **b)** Transmission spectra of microdisk filters across 8 reticles. **c)** Optical sweeps of one particular microdisk device at varying heater powers.

Microdisks do not have an inner waveguide wall, giving them one less dimension affected by variations in fabrication than microring filters. Decreased variation in fabrication, which is inversely proportional to radius, leads to reduced need for thermal tuning to offset fabrication variation-induced resonance shift. However, we show that lower-radius microdisk filters offer increased thermal tuning efficiency. We analytically describe this relationship in Eq. (1), where P is the power dissipated in the thermo-optic phase shifter (heater), λ is wavelength, T is temperature of the disk, n_{eff} is the effective index, and ϕ is the phase. We relate the heater power P to the thermo-optic effect $\frac{\partial n_{eff}}{\partial \mathrm{T}}$ and finally to shift in resonant wavelength λ, where the term $\frac{\partial \lambda}{\partial \phi} \sim$ FSR and has a radial dependence shown in Fig. 2b. The term $\frac{\partial \mathrm{T}}{\partial \mathrm{P}}$ increases with radius, as less power is required to heat a smaller volume of silicon to a certain temperature.

$$\frac{\partial \lambda}{\partial \mathrm{P}} = \frac{\partial \mathrm{T}}{\partial \mathrm{P}} \times \frac{\partial n_{eff}}{\partial \mathrm{T}} \times \frac{\partial \phi}{\partial n_{eff}} \times \frac{\partial \lambda}{\partial \phi} \tag{1}$$

As shown in Fig. 2a, the radius of the microdisk indeed plays a significant role in both statistical variation and thermal tuning efficiency. Wafer-scale measurements indicate a linear relationship between radius and mW/nm tuning efficiency, and a reciprocal relationship between radius and 1 σ resonant wavelength variation due to variations in fabrication. Fig. 2c shows the combined effect of reduced variation for larger disks along with reduced tuning efficiency, leading to increased thermal tuning power consumption. In fact, we see an overall reduced power consumption required to tune lower-radius microdisks. Although we encounter additional design trade-offs at such low radii, such as increased intra-cavity loss and a smaller coupling region, we demonstrate a 41% reduction in required tuning power moving from a 4.5 μm to a 1.6 μm radius microdisk filter.

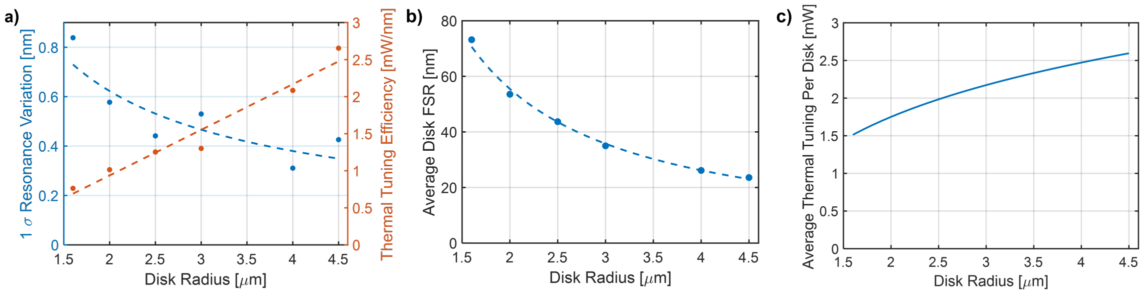

Fig. 2. **a)** 1 σ resonance wavelength variation across disk radius. 48 resonator devices were measured in a checkerboard pattern across a quarter wafer. Thermal tuning efficiency for a single reticle is also shown as an inverse of Eq. (1) to emphasize the inverse relationship with 1 σ variation. **b)** Average FSR of microdisks across radius, over quarter wafer. **c)** Average thermal tuning in power required per disk, calculated using the measured variation and tuning efficiency, and assuming a 3 σ distance to tune. Designing for a wavelength 3 σ lower than the nominal allows ~99.7% of fabricated disks to be tuned to the correct carriers assuming a normal distribution [4].

3. Conclusion

We describe and experimentally demonstrate an inverse relationship between the thermal tuning efficiency and intra-wafer fabrication variation of add-drop microdisk filters with respect to device radius, and thus FSR. Using this relationship, we show a large reduction in required thermal tuning is possible with low-radius microdisks. Add-drop filters are used ubiquitously in highly parallelized integrated photonic DWDM interconnects, therefore these low-radius microdisk filters are a promising solution to increase energy-per-bit efficiency of such systems.

References

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