

Ultra-Wide FSR Vertical-Junction Microdisk Modulator With Efficient External Heater

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Abstract: We describe a wide-FSR vertical-junction microdisk modulator design (radius= $2\mu\text{m}$) featuring an efficient, external half-height doped-silicon heater that affords aggressive size reductions. We measure FSR= 58.6 nm and demonstrate data transmission at 16 Gb/s . © 2024 The Author(s)

1. Introduction & Background

Dense wavelength-division multiplexing (DWDM) systems can leverage the inherent wavelength selectivity of resonant structures, such as filters and modulators, by cascading many along a single bus waveguide. In this configuration, each resonator effectively filters a distinct wavelength channel with minimal inter-channel crosstalk [1]. The finite free spectral range (FSR) and off-resonance insertion loss (IL) limit the number of resonators deployable on a single bus, with links often requiring multiplexing and demultiplexing circuitry [2]. Wide FSR resonator designs are desirable since more channels can fit within one FSR to reduce or eliminate this requirement [3]. However, to achieve wider FSRs, resonant structures must be made smaller while accommodating an integrated heater and without violating commercial foundry design rules. This challenge is further compounded in resonant modulators that house both heater and modulation circuitry, typically limiting disk radii to $\sim 2\mu\text{m}$ for internally heated structures [4]. External heater structures are an alternative that can free valuable space for radius reduction, although previous demonstrations have required additional undercut processes to approach the efficiency of internal heaters [5].

Here, we propose and demonstrate the placement of a half-height, doped-silicon heater externally and coradially to a $2\mu\text{m}$ radius vertical junction (VJ) microdisk modulator that pushes the limits of both modulator FSR and thermal efficiency, with a clear path for further radius reduction. This design leverages the phase mismatching and reduced overlap integral afforded by half-etching the external doped-silicon heater, permitting close placement of the heater to the resonator with a 200 nm gap and without disturbing the whispering gallery mode [6]. The disk exhibits a wide 58.6 nm FSR and a high thermal tuning efficiency of 0.6 nm/mW with an extinction ratio (ER) of 18.9 dB . Modulation is demonstrated with an open-eye diagram at 16 Gb/s non-return-to-zero (NRZ) with ER of $\approx 3.6\text{ dB}$ at 1.3 V peak-to-peak driving signal. The performance of this device provides valuable insight for future externally-heated resonant modulator designs that rival internally-heated structures while achieving wider FSRs to meet growing DWDM channel count demands.

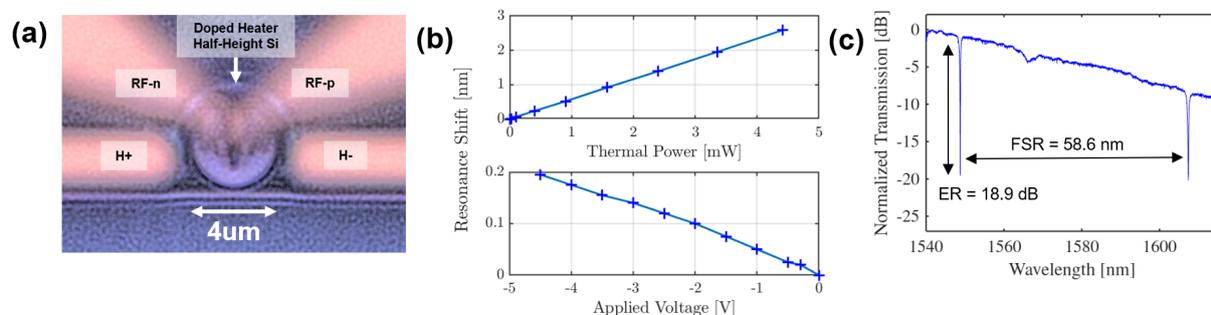


Fig. 1. (a) Micrograph image of the fabricated microdisk modulator with the half-etched doped silicon external heater. (b) Measured thermal tuning efficiency of 0.6 nm/mW (top) and depletion response of 43 pm/V (bottom). (c) Spectral transmission showing $\text{ER} = 18.9\text{ dB}$ and $\text{FSR} = 58.6\text{ nm}$.

2. Optical Characterization and Modulation

The proposed wide FSR microdisk modulator design, shown in Figure 1a, was fabricated on a photonic integrated circuit (PIC) through AIM Photonics. Figure 1b shows the measured thermal tuning efficiency of 0.6 nm/mW, in line with the thermal tuning efficiencies of equivalent FSR resonators with internal doped silicon heaters [7]. The DC depletion response was also measured at 43 pm/V. Figure 1c plots the spectral transmission showing ER = 18.9 dB and FSR = 58.6 nm.

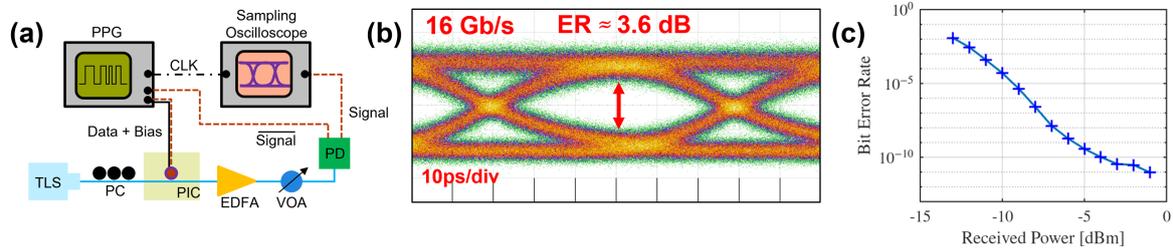


Fig. 2. (a) Schematic of modulation experiment. (b) Open-eye diagram at 16 Gb/s with PRBS31, driving voltage of 1.3 V peak-to-peak, and ER \approx 3.6 dB. (c) Bit-error rate (BER) curve of the modulator transmitted data received by a commercial receiver at 1.3 V driver voltage.

The experimental setup is shown in Figure 2a. A Keysight 8164B continuous wave (CW) tunable laser source (TLS) centered at 1549.95 nm excites the modulator via a single mode fiber (SMF) coupled to an edge coupler after passing through a polarization controller (PC). Modulation is driven by an Anritsu MP1900A Pulse Pattern Generator (PPG) with an NRZ pseudo-random bit sequence $2^{31} - 1$ bits long (PRBS31), peak-to-peak voltage of 1.3 V, and reverse bias of 650 mV supplied by the PPG. The modulated optical signal is coupled back into SMF, amplified through an erbium doped fiber amplifier (EDFA), and converted to the electrical domain by a 40 GHz bandwidth Thorlabs RXM40AF photodetector (PD), with a Keysight N7764A variable optical attenuator (VOA) placed before the optical input. The non-inverted signal is measured by a Keysight N1092C sampling oscilloscope for monitoring, and the inverted signal is returned to the PPG for bit error rate (BER) testing at 60s intervals (Figure 2c). The oscilloscope receives a clock trigger directly from the PPG and pattern locks on the 16 Gb/s NRZ PRBS31 signal. Figure 2b is captured by sending the VOA output directly to the oscilloscope's optical port, showing ER \approx 3.6 dB.

3. Conclusion

We describe and experimentally demonstrate an efficient microdisk modulator exhibiting wide FSR and high thermal efficiency achieved by a novel integrated heater design compatible with commercial foundry processes. The efficiency metric rivals internal heater structures and can be improved over $3 \times$ through previously demonstrated wafer-scale undercut methods [8]. FSRs > 60 nm are possible via radius reduction without changes to design rules, making this a viable design for achieving highly efficient and scalable DWDM interconnects.

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