Wide Spectral Modulation in Highly Efficient Thermally Undercut Foundry Fabricated Resonant Modulators

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Abstract: We experimentally investigate optical modulation in thermally undercut microdisk modulators. Optical modulation is realized over a spectral range many times wider than the resonators linewidth due to the enhancement of optically induced thermal nonlinearity.

1. Introduction

The wavelength selectivity, compact size and low energy utilization of resonant modulators, such as microdisk resonators (MDR), enables them to be a promising component for highly energy-efficient wavelength division multiplexing (WDM) photonic integrated circuits systems. However, integrated micro-heaters are required to compensate for fabrication and thermal variations. We previously demonstrated ultra-efficient thermal tuning of MDR modulators ($P\pi$=8.4mW) by thermally isolating the devices through wafer-scale selective substrate removal [1], resulting in a 3x enhancement in thermal tuning efficiency. However, the ultra-compact size of the devices (4.5μm radius) results in strong light confinement which creates high optical power densities in a very compact structures. This can lead to higher order nonlinear effects, in particular absorption-induced optical thermal bistability [2]. The impact of this effect is enhanced by the thermal undercut, which thermally isolates the device and causes the optically generated heat to stay in the confined device longer. Consequently, this thermal instability could complicate the management of high optical powers in the resonant based modulators.

Here we investigate the impact of high optical powers in thermally isolated resonant modulators in order to understand the performance impacts. We found that input powers as low as -14dBm have measurable thermal instability. However, we found that robust high-speed optical modulation can be realized over a wide spectral range as the optical power is increased. Specifically, we characterized the modulation at varying optical powers as high as 10dBm and found that the resonant modulation is achieved over a spectral range many times wider (6x) than the resonators passive linewidth. This is due to thermally-induced red-shifting of the resonance. Consequently, we conclude that thermal isolation also enhances the ability to achieve modulation and lowers the requirements on the amount of micro-heater tuning.

2. Design, Experimental Setup and Results

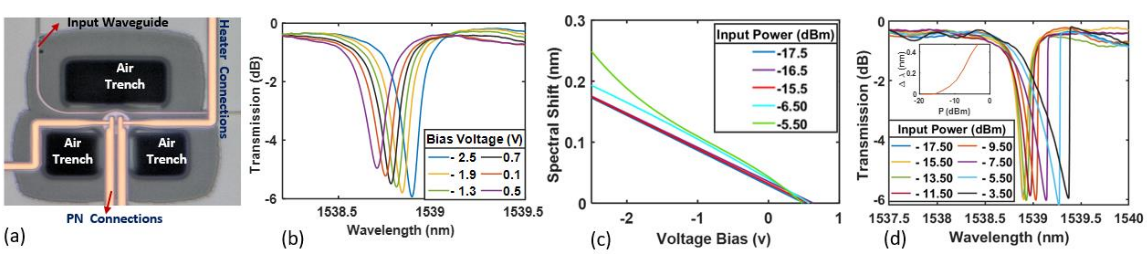

Fig. 1: (a) Optical microscope image of the resonant modulator device, (b) Electro-optic depletion response of the device for the DC sweep of voltages from 0.5 V to −2 V and low optical power (-17.5 dBm). (c) Spectral shift for increasing laser input powers. Thermally-induced red-shifting occurs at laser powers above -14dBm. (d) Transmission spectrum of the ring resonator with a fixed DC bias voltage of -2.5V and increasing laser powers. Inset is the spectral shift induced (y-axis) due to the laser power (x-axis).

A detailed explanation of the MDR modulator's design layout, fabrication process and optical characterization is provided in [1]. In summary, the modulator is thermally isolated through wafer-scale undercut etching with lithographically defined trenches around each device, as seen in Fig. 1 (a). Here we focus on the electro-optic modulation of the PN junction in the device for different laser powers. First, we characterize the DC spectral response of the modulator (Fig. 1(b)) under different bias voltages (0.5 to -2.5V) at a low optical power (-17.5dBm), achieving a modulation efficiency of 95pm/V.

However, as the laser power is increased the spectral shift increases and becomes nonlinear (Fig. 1(c)). This can be seen in detail in Fig. 1(d) where the resonance both red-shifts and broadens due to thermal instability [2]. Specifically, when the laser is near-resonance a portion of the lights intensity is absorbed via a combination of two-photon and free-carrier absorption, which generates heat. The heating is enhanced in the device due to the thermal isolation of the undercut structure (Fig. 1(a)), resulting in significant thermal instability at laser powers as low as -14dBm.

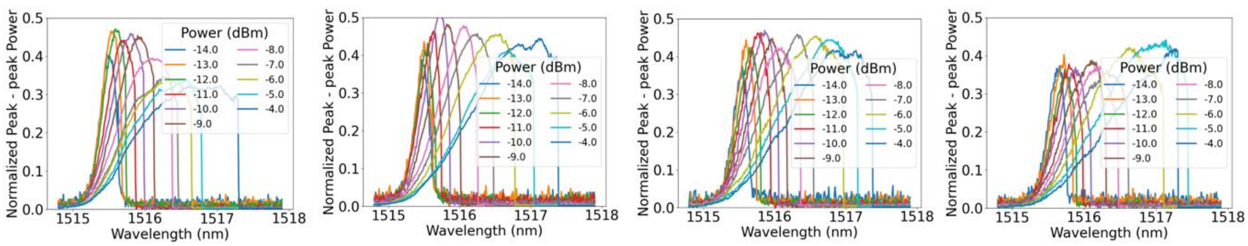

Fig. 2: Modulation at different input lasers powers and modulation frequencies of (a) 1 MHz, (b) 25 MHz, (c) 300 MHz, (d) 1 GHz

We investigated the modulation at increasing operating frequencies and laser powers in Fig. (2). Specifically, a square-wave with amplitude of 2Vpp was applied at different frequencies and the peak-to-peak optical modulation was characterized and normalized in order to compare the modulation depth under different operating conditions. For all of the modulation frequencies, as the laser power is increased the modulation is achieved over an increasingly wider spectral range. At low frequencies (<1 MHz) the spectral range increases but there is a reduction in the peak-to-peak modulation at higher laser powers. We believe this is due to the thermal response of the device, however, our biasing circuit did not allow us to assess the modulation at even lower frequencies where the thermal response of the device would dominate. In contrast, for high data frequencies (>25 MHz) (Fig. 2(b-d)), the modulation depth is not affected as we increase the laser power and modulation is achieved over a wide spectral range that is >6x more than the passive resonators linewidth at a laser power of -4dBm. Consequently, at high data rates, the thermal sensitivity becomes a desirable nonlinear effect, broadening the spectral range where robust modulation can be achieved.

3. Conclusion

We conducted a comprehensive investigation of optically induced thermal nonlinearity in highly efficient thermally isolated resonant modulators. The absorption-induced thermal nonlinearity enables modulation to be achieved over a spectral range >6x the passive resonators linewidth. This consequently reduces the requirements on electrically controlled heater based tuning.

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