Silicon Micro-Ring Weight Stabilization with Nonlinear Self-Heating

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Abstract: Micro-ring resonators can tunably weight wavelength-division-multiplexed signals, but they face high sensitivity to temperature. In this work, we take advantage of micro-ring self-heating to experimentally stabilize a silicon micro-ring weight, nearly halving its thermal sensitivity. © 2024 The Author(s

1. Introduction

A broadcast-and-weight photonic system performs linear combination of a set of wavelength-division-multiplexed (WDM) signals, with application to radio-frequency (RF) interference cancellation and photonic neural networks [1, 2]. Such a system uses micro-ring resonators (MRRs) to apply tunable weights to each wavelength of light, with the weight applied a function of the wavelength-dependent intensity buildup in the micro-ring. On the silicon-on-insulator (SOI) platform, the weight is typically tuned by changing the temperature of the micro-ring using an embedded heater. Such a temperature change produces a refractive index change due to the thermo-optic effect in silicon, in turn resulting in a shift in the resonant wavelength due to the sensitivity of micro-rings to refractive index variation [3].

The thermal sensitivity of micro-ring weights is a double-edged sword; while it provides a simple and effective way of fully tuning the weights, it also makes the weights susceptible to environmental temperature variation and other on-chip heat sources (such as the heaters of adjacent micro-rings). Reducing the micro-ring quality factor can lower this sensitivity by widening the resonance, at the cost of either increased optical cross-talk or a reduced maximum number of WDM signals. Instead, we take advantage of negative feedback associated with nonlinear self-heating in silicon micro-ring resonators to stabilize a micro-ring weight with respect to temperature without any impact on instantaneous resonance shape.

2. Micro-Ring Self-Heating

1550 nm light can be absorbed in silicon via intensity-dependent two-photon absorption, resulting in the generation of free carriers which cause further absorption (free carrier absorption). In both cases, carriers can fall back to the valence band, generating heat that raises the silicon refractive index and red-shifts resonances. This effect is particularly strong in MRRs due to the resonant buildup of optical intensity [4].

We consider an operating wavelength slightly to the "blue" side (the short-wavelength side) of a resonance near 1550 nm, with the system in steady state. A perturbation of additional applied heat causes a red-shift of the resonance, reducing the optical intensity buildup as the resonant wavelength and operating wavelength diverge. This in turn, results in reduced optical absorption and self-heating, *counter-acting* the perturbation—negative feedback. (Conversely, if we operated to the "red" side of the resonance, the feedback would be positive.) This negative feedback has the effect of reducing the impact of heat perturbations, stabilizing the micro-ring weight.

3. Experimental Setup

Our experimental setup is diagrammed in Fig. 1a. We create a simple one-MRR broadcast-and-weight system using a single integrated SOI add-drop MRR and an external set of balanced photodetectors (PDs). Input optical power is controlled by a variable optical attenuator (VOA), and the input source signal is a pure 950 MHz tone produced by a continuous wave generator (CWG) and modulated by a Mach-Zehnder modulator (MZM) with quadrature biasing. The DC component of the modulated signal, tunable by the VOA, controls the level of self-heating. Source-measurement units (SMUs) control the MRR heater current and measure the DC output signal, while an oscilloscope monitors the AC signal. The applied weight is the normalized amplitude of the 950 MHz component of the AC output signal.

a

DC Optical Power
AC Optical Power
MRR Weight

Laser — VOA — MZM — CWG — MRR — PDs — Bias Tee — SMU — Scope

SMU

DC
RF

b

Weight

Sensitivity (mW⁻¹)

Heater Power (mW)

c

Output Amplitude (mV)

Time (µs)

d

Sensitivity (mW⁻¹)

Pump Optical Power (dBm)

Pump Optical Power (dBm)