**Novel Resonance-based Silicon Nanophotonic Structures**

Mohammad Soltani, Amir H. Atabaki, Qing Li, Ali A. Eftekhar, Siva Yegnanarayanan, and Ali Adibi, *Member, IEEE*

**Abstract**—The development of ultra-compact integrated nanophotonic structures for communications, sensing, and signal processing has been of great interest lately. In this review paper, we first present the requirements for practical realization of integrated nanophotonic chips and then explain how these requirements are met by using low-loss waveguides and high quality resonators with careful engineering of the coupling between them. We will show that the ultimate realization of high Q microresonators can enable a wide range of applications including very compact on-chip spectrometers, tunable filters, and sensing modules.

I. INTRODUCTION

The development of ultra-compact integrated nanophotonic structures for communications, sensing, and signal processing has been of great interest lately [1]. The use of compact microresonators (e.g., microrings, racetracks, and microdisks) with high quality factors has resulted in order of magnitude reduction in the size of functional integrated photonic structures that used to be formed using waveguides [2]. Such resonators can be effectively tuned using free carrier injection and/or using the thermo-optic effect. This feature can be used to form reconfigurable photonic structures. Among existing substrates, silicon (Si) is the most promising one for infrared wavelengths due to the existence of excellent CMOS-based fabrication facilities. With recent advances in the design and fabrication tools for photonic nanostructures, Si-based integrated photonic platforms are a strong candidate for the realization of ultra-compact functional photonic microchips for a wide range of applications including signal processing, communications, and sensing.

II. HIGH-Q PHOTONIC RESONATORS

A high-Q resonator is a building block component for any large-scale integrated photonics system. The two key attributed are the strongly enhanced light-matter interaction at the resonance and their realization as a compact device which enables their dense on-chip integration [3]. In integrated optical sensing applications, optical resonators with enhanced light-matter interaction have been identified as critical for enhanced sensitivity of the sensor and also for reducing the sensor area. Figure 1 shows the spectrum of the microdisk resonator. As can be seen from Fig. 1(a), several different resonant modes with Q’s ranging from $1.5 \times 10^5$ up to $2.0 \times 10^6$ were observed, corresponding to different radial mode orders. Figure 1(b) shows a spectrum of an $\lambda=1535 \text{ nm}$ with an FSR larger than 60 nm.
III. EFFICIENT COUPLING TO PHOTONIC RESONATORS

For high-$Q$ resonators, efficient coupling of the light into the resonator is an important task in realizing a functional system. Depending on the application, undercoupled, overcoupled, or critically coupled resonators are needed. We have developed extensive coupling optimization strategies for these requirements. Figure 1 shows normal coupling, where phase matching was used to achieve a critical coupling to a high-$Q$ microdisk mode. Figure 2 shows two different coupling conditions, namely strong over-coupling and interferometric coupling. For strong over-coupling we have developed a novel pulley-coupling architecture where the waveguide is wrapped around the resonator. The long interaction length enables enabling strong over-coupling while the high sensitivity to phase-mismatch strongly suppresses coupling to undesired modes of the microdisk resonator, enabling single-mode operation. We have also developed interferometric coupling architectures that enable highly controllable and reconfigurable coupling to desired modes of the photonic resonator.

IV. THERMAL RECONFIGURATION

The luxury of reconfigurability in Si photonics not only relaxes the tolerance to fabrication errors but also opens the door to a plethora of applications such as adaptive filtering, reconfigurable add-drop multiplexing (ROADM) and dispersion compensation. Strong thermo-optic effect in Si enables efficient reconfiguration. We have performed extensive numerical modeling and optimization of geometry of the thin-film heaters to achieve higher heat transfer and speed. Figure 3 shows a 34.7 GHz resonance frequency shift in a 20µm diameter microring is achieved per milli-watt dissipated power by using 0.5µm wide heaters which is the highest value reported [4].

In conclusion, recent advances in the fabrication of efficient nanophotonic devices and the implementation of novel highly-efficient thermo-optic tuning have led to the emerging field of reconfigurable Si nanophotonics. The available expertise in the fabrication of these devices in current silicon foundries and the possibility of realizing hybrid systems with electronic components on the same chip provides low-cost manufacturing opportunities of chip-scale systems with a multitude of functionalities for optical sensing and signal processing applications.

REFERENCES