Near-IR and Mid-IR (1.55 μm – 2 μm) Silicon Photonics Devices on Silicon-on-Insulator (SOI) Platform

Abstract

In the last several decades, there has been considerable research interest in silicon photonics based on silicon-on-insulator (SOI) platform. Many useful applications have been developed in the near-infrared (NIR) data- and tele- communication band (1.3-1.6 μm), such as sensors, switches, modulators, and various passive devices. Furthermore, the mid-infrared (MIR, 2-15 μm) band is also very crucial as many gases and molecules have unique absorption fingerprints in this regime. Hence there is enormous interest in practical realization of passive and optoelectronic devices operating in the MIR range, including optical sensing and environmental monitoring, free-space communications, bio-medical and thermal imaging. Besides, 2 μm wavelength is a promising solution to extend the operating wavelength of communication system to short MIR wavelengths. The objective of this project is to develop SOI platform-based on-chip photonic devices including passive devices, sensors and optical modulators operating in the NIR and MIR bands.

In order to build various photonic systems, several key on-chip fundamental passive components operating at 2 μm wavelength are developed and analyzed at the beginning of this project. These fundamental building blocks include waveguides, grating couplers, and microresonators. These components are successfully fabricated with good performance. For example, the grating coupler operating at 2 μm

wavelength was firstly fabricated and experimentally measured as 6.5 dB, which is comparable to the widely used grating couplers operating at 1.55 μm communication band. The extinction ratio (ER) and the quality factor (Q factor) of the compact microring resonator (radius = 10 μm) integrated with above grating couplers were firstly measured as 12 dB and 11200 respectively.

As a practical method to improve the performance of sensors and modulators, Fano devices with a sharp asymmetric transmission lineshape and electromagnetically induced transparency (EIT) devices with time delay at the narrow optical transparency peak residing in a broader transmission absorption valley are designed, fabricated and characterized. In this work, an EIT transmission lineshape was experimentally generated with an all-pass microring-Bragg grating coupled resonant system for the first time. Based on the same system, the conversion between EIT and Fano transmissions was experimentally verified and the inner mechanism was discussed in detail. Subsequently, tunable and convertible EIT and Fano transmissions were experimentally realized in a Mach–Zehnder interferometer (MZI)-assisted microring-Bragg grating based coupling resonant system, which is believed to be the first report of its kind.

Optical filters are also vital for modulators. For the dual-band optical filter (DBOF), since it can double the available modulating channels, it is also an effective solution to improve the efficiency of signal processing. In this work, two types of DBOFs based on partial-reflective-element-embedded microring resonators were theoretically and experimentally demonstrated for the first time. As measured, the separation between two resonance dips and the insertion loss are 0.5 nm and <0.5 dB respectively. The Q factors of the two dips achieve 30900 and 34400 respectively. The performance is comparable to the up-to-date reported works.

By utilizing the fundamental building blocks and taking the advantages of suspended structure, the bio-chemical sensor operating at 2 μm wavelength based on a suspended microracetrack resonator with sub-wavelength-grating (SWG) lateral metamaterial cladding is designed, fabricated and characterized for the first time. The expected sensitivities of the fundamental TE and the fundamental TM mode were calculated as 203 nm/RIU and 592.5 nm/RIU respectively. This is believed to be the first demonstration of on-chip photonic bio-chemical sensor operating at 2 μm wavelength with sensitivities comparable to the latest reported results at 1.55 μm wavelength.

With additional implantation and electrode fabrication processes, thermal-optical (TO) and electro-optical (EO) modulators operating at 2 μm wavelength were also experimentally demonstrated for the first time in this work. The DC shifting rate and the 3 dB bandwidth of the TO modulator are measured as 0.05 nm/V and ~30.8 KHz respectively. The 3 dB bandwidth of the EO modulator is measured as ~5GHz. Although the preliminary performance of these modulators is not as good as the latest reported modulators operating in the NIR communication band, they pave the way for extending the operating wavelength of communication system to short MIR wavelengths.