Abstract

In recent years, photonic devices have outperformed their electronic counterpart in most applications. This new technology holds the potential to completely replace traditional electronic technology soon. Photonic-based devices have many lucrative advantages such as compactness, stability, scalability, customizability, reproducibility, low power consumption, and absence of electromagnetic interference. Photonic devices have been demonstrated on various material platforms such as silicon, silicon nitride, polymer, silicon dioxide, and many more over the years. Modern fabrication techniques have opened the possibility to design innovative devices with multifunctional components and advanced materials. Optical fiber and silicon-based microring resonator (MRR) devices have seen explosive growth in the last two decades among this broad spectrum of devices. This dissertation aims to design and study new devices based on these two platforms for sensing applications, mainly chemical and biological.

Besides their wide application in communication, optical fiber has been successfully used in many sensing applications over the years. At the beginning of the dissertation, a novel compact sensor based on the surface corrugated etched multimode optical fiber is proposed. The gratings are drawn directly to an etched conventional multimode fiber (MMF) side surface by using a focused ion beam (FIB) milling. The gratings have a period of 1050 nm producing a high refractive index contrast. The strong reflection peak is utilized for refractive index sensing. Experimental results show the sensitivity of 70 nm/RIU.

MRR has been the central component in integrated Silicon photonics circuits for their high refractive contrast, enabling them to tightly confine the light in a waveguide of sub-wavelength dimensions. However, this tight confinement obstructs the light-matter interaction, which is not desirable in many sensing applications. In the next part of the thesis, we have proposed a novel scheme to enhance the light-matter interaction by integrating a tapered section for nanoparticle

sensing. A comprehensive theoretical and finite difference time domain (FDTD) simulation-based study is carried out to analyze the device characteristics and sensing performance. The device can detect a single metallic nanoparticle of 100 nm radius by producing resonance splitting of 310 GHz in the output spectrum. Further, theoretical study confirms the device's ability to quantify the size and number of the nanoparticles. A conventional MRR can not have a wide free spectral range (FSR) and high Q-factor simultaneously. Both the quantities are designed to be large for the majority of applications especially sensing. To overcome this issue, we have designed a compact MRR device that integrates two Fabry-Perot cavities in the MRR. The inclusion of these two cavities results in a single resonance dip in the output where the others get suppressed. Theoretical analysis shows that the FSR of the proposed device is more than 150 nm without compromising the Q-factor. Simulation results show the proposed device possesses an enhanced sensitivity of 185 nm/RIU.
In the last section of the thesis, we have proposed a new kind of silicon-based coupling region-free on-chip resonator that produces equidistant Lorentzian-shaped resonance dips similar to an MRR. In a conventional MRR, the device performance is susceptible to any change in the coupling gap between the ring and the bus. Due to this, the device becomes prone to fabrication errors. In our proposed design, the cavity is placed inline with the input and output waveguide, making it more compact and less prone to fabrication errors. The device can be a potential alternative to conventional MRR for a multitude of applications such as filters, communication, and sensing.

Keywords: Optical fiber, Integrated silicon photonics, Microring resonator, Sensing.