Ring Resonators for Integrated Optics Applications

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Integrated ring resonators have attracted a considerable interest in optical communications because of their small size and wide range of applicability. Here we consider several aspects of these devices, beginning with a tunable hybrid ring resonators consisting of a silicon over insulator (SOI) ring covered with a polymer layer in a variable electric field. Varying the field changes the polymer refractive index and consequently the resonance condition of the cavity. This device offers a large degree of optical confinement together with a high modulation speed. Subsequently, we design and present fabrication results for a Wavelength Division Multiplexing (WDM) multiplexer/demultiplexer formed from a series of ring resonators with two channels separated by $50\,GHz$ each that is predicted to exhibit a free spectral range (FSR) of $100\ GHz$, signal dispersion less than $30\ ps/nm$ and a signal cross-talk less than $-23\,dB$. Finally, we analyze the application of the coupled ring waveguide circuit to rotation sensors based on the Sagnac phase shift. Here, however our analysis indicates that a single ring, of the same area exhibits a higher degree of sensitivity to rotational motion than a multiple ring circuit.

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Dedication

I would like to dedicate this effort to the soul of my father, the members of my supportive family, my mother, Merit, Joseph, Daniel, Mina and Mona and also my friends in Canada who helped me a lot through this trip, Albert Wasif, Ayad Fekry, George Bassem, George Beskales, George Shaker, George Soliman, Michael Naeim, Michel El-Naggar, Hany Lewis, Hany Samuel, John Saad, Mina Farid, Mina Saleeb and Salam Gabran.

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Chapter 1

Introduction

Integrated optics is increasingly employed in miniaturizing components that perform fundamental processing functions such as generating, detecting, filtering, amplifying, routing and multiplexing of signals in telecommunications and data processing systems. While standard integrated optics components such as arrayed waveguides and multi-mode interference (MMI) devices are well established in device applications, the ring resonator (RR) is becoming increasingly competitive in alternative designs because of its small size and functionality. The objective of this thesis is to propose new RR based circuits that are optimized for high speed applications. Here we build on previous work that has included the application of ring resonators to integrated RR cavities, [0] have been employed in numerous contexts such as polarization converters [2], filters [3] optical delay lines [4], demultiplexers [5], reflectors [6], rotational motion detectors [7-8] and logic circuits [9]. Fabrication platforms for RR devices include silicon over insulator (SOI) [10], polymers [11-13] and group III-V semiconductors [14-15].

Accordingly, in the first chapter of this thesis we overview the waveguide theory and then demonstrate the manner in which RR device parameters are calculated in order to establish the basic principles of the RR circuit operation. In the next chapter we propose a novel hybrid ring resonator structure that employs the best features of two well established platforms, namely, polymer and SOI to obtain a high tuning speed while preserving compatibility with CMOS technology. In Chapter 3, we study a ring resonator (RR) structure with internal feedback that label a "compound ring resonator structure" and demonstrate the distinguished features of this structure by incorporating it into a standard wavelength division multiplexing (WDM) interlaver/deinterleaver circuit. We then analyze this circuit with three numerical approaches, the coupling of modes in space (CMS), the coupling of modes in time (CMT) and the finite difference time domain (FDTD) simulations. We further design the circuit layout and fabricate copies of the device for testing. The measurements agree well with theoretical calculations except for minor deviations that presumably could be eliminated with a more optimized design. In Chapter 4 we apply our RR design to gyroscopes for rotational motion detection and compare the performance to previously proposed RR based gyroscopes. We confirmed as other authors have noted previously that a single resonant ring provides a higher sensitivity than any more complex design proposed to date. We finally conclude our work and discuss possible future avenues for exploration.

1.1 Electromagnetic Background

To begin, we discuss electromagnetic field propagation in a 2D waveguide [16] followed by the effective index method (EIM) [17-20], which is useful to reduce a 3D waveguide into 2D. Next, we discuss electromagnetic field propagation in a 2D ring waveguide [21] and finally we overview the beam propagation method (BPM) that forms the basis for the waveguide simulator employed in much of the remainder of this thesis [22-28].