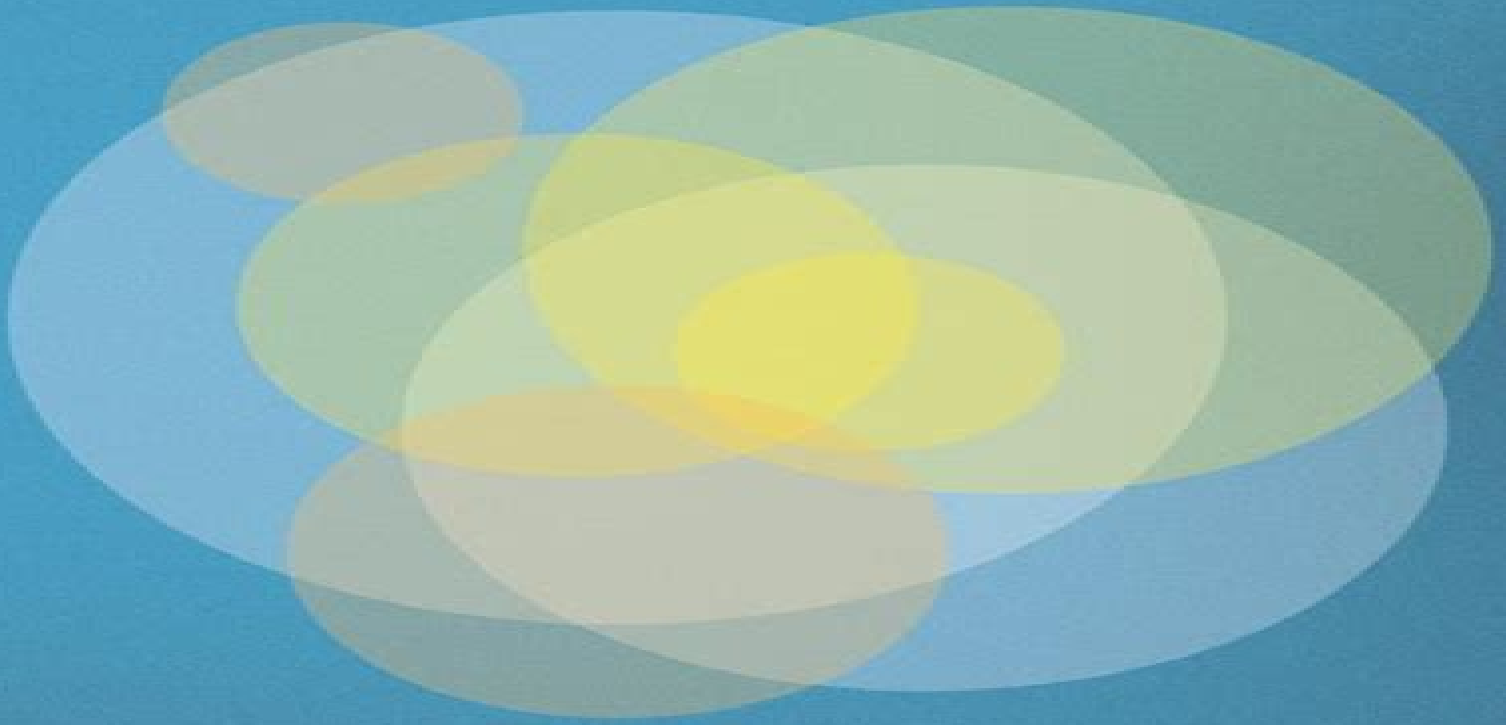
Iraj Sadegh Amiri, Abdolkarim Afroozeh & Harith Ahmad

INTEGRATED MICRO-RING PHOTONICS

Principles and Applications as Slow Light Devices, Soliton Generation and Optical Transmission



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Lakshmi Narayana Deepak Kallepalli

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Integrated Micro-Ring Photonics Iraj Sadegh Amiri,Abdolkarim Afroozeh,Harith Ahmad,2016-12-08 Micro ring resonators MRRs are employed to generate signals used for optical communication applications where they can be integrated in a single system These structures are ideal candidates for very large scale integrated VLSI photonic circuits since they provide a wide range of optical signal processing functions while being ultra compact Soliton pulses have sufficient stability for preservation of their shape and velocity Technological progress in fields such as tunable narrow band laser systems multiple transmission and MRR systems constitute a base for the development of new transmission techniques Controlling the speed of a light signal has many potential applications in fiber optic communication and quantum computing The slow light effect has many important applications and is a key technology for all optical networks such as optical signal processing Generation of slow light in MRRs is based on the nonlinear optical fibers Slow light can be generated within the micro ring devices which will be able to be used with the mobile telephone Therefore the message can be kept encrypted via quantum cryptography Thus perfect security in a mobile telephone network is plausible This research study involves both numerical experiments and theoretical work based on MRRs for secured communication **NASA Tech Briefs** ,2017-03 **Network World** ,1990-04-23 For more than 20 years Network World has been the premier provider of information intelligence and insight for network and IT executives responsible for the digital nervous systems of large organizations Readers are responsible for designing implementing and managing the voice data and video systems their companies use to support everything from business critical applications to employee collaboration and electronic commerce *Handbook of Silicon Photonics* Laurent Vivien,Lorenzo Pavesi,2013-04-26 The development of integrated silicon photonic circuits has recently been driven by the Internet and the push for high bandwidth as well as the need to reduce power dissipation induced by high data rate signal transmission To reach these goals efficient passive and active silicon photonic devices including waveguide modulators photodetectors multiplexers light sources and various subsystems have been developed that take advantage of state of the art silicon technology Suitable for both specialists and newcomers Handbook of Silicon Photonics presents a coherent and comprehensive overview of this field from the fundamentals to integrated systems and applications It covers a broad spectrum of materials and applications emphasizing passive and active photonic devices fabrication integration and the convergence with CMOS technology The book s self contained chapters are written by international experts from academia and various photonics related industries The handbook starts with the basics of silicon as an optical material It then describes the building blocks needed to drive integrated silicon photonic circuits and explains how these building blocks are incorporated in complex photonic electronic circuits The book also presents applications of silicon photonics in numerous fields including biophotonics and photovoltaics With many illustrations including some in color this handbook provides an up to date reference to the broad and rapidly changing area of silicon photonics It shows how basic science and innovative

technological applications are pushing the field forward **Integrated Photonics for Data Communication Applications** Madeleine Glick,Ling Liao,Katharine Schmidtke,2023-07-26 Integrated Photonics for Data Communications Applications reviews the key concepts design principles performance metrics and manufacturing processes from advanced photonic devices to integrated photonic circuits The book presents an overview of the trends and commercial needs of data communication in data centers and high performance computing with contributions from end users presenting key performance indicators In addition the fundamental building blocks are reviewed along with the devices lasers modulators photodetectors and passive devices that are the individual elements that make up the photonic circuits These chapters include an overview of device structure and design principles and their impact on performance Following sections focus on putting these devices together to design and fabricate application specific photonic integrated circuits to meet performance requirements along with key areas and challenges critical to the commercial manufacturing of photonic integrated circuits and the supply chains being developed to support innovation and market integration are discussed This series is led by Dr Lionel Kimerling Executive at AIM Photonics Academy and Thomas Lord Professor of Materials Science and Engineering at MIT and Dr Sajan Saini Education Director at AIM Photonics Academy at MIT Each edited volume features thought leaders from academia and industry in the four application area fronts data communications high speed wireless smart sensing and imaging and addresses the latest advances Includes contributions from leading experts and end users across academia and industry working on the most exciting research directions of integrated photonics for data communications applications Provides an overview of data communication specific integrated photonics starting from fundamental building block devices to photonic integrated circuits to manufacturing tools and processes Presents key performance metrics design principles performance impact of manufacturing variations and operating conditions as well as pivotal performance benchmarks

Microring-based Electronic-photonic Integrated Circuits Shang Wang,2012 Silicon photonics is a promising solution to meeting the increasing bandwidth demands in future terabit per second data communications It takes advantage of the ultra wide optical bandwidth and ultrafast transmission speed of photonics while at the same time inheriting the existing manufacturing infrastructures from the microelectronics industry Silicon photonics has advanced rapidly in recent years highlighted by the demonstration of various high performance passive and active silicon photonic devices As all the necessary building blocks are individually realized on the silicon platform the next challenge will naturally be the integration of photonic devices with electronic circuits in a single silicon chip As previously demonstrated on the III V semiconductor based photonic integrated circuits PICs electronic photonic integration is challenging both in physical device fabrication as well as in system and circuitry design The device fabrication challenges lie in the development of a low cost complementary metal oxide semiconductor CMOS compatible process that effectively integrates photonics within the limitations posed by CMOS electronics On the system and circuit design side electronic photonic integrated circuits EPICs need to address the

fundamental mismatch between the large potential bandwidth of photonics and the significantly lower speed of CMOS electronics To overcome this challenge many previous works use wavelength division multiplexing WDM to split the optical bandwidth in the wavelength domain and achieve a larger aggregated data rate However on chip WDM systems are usually complicated to design and dicult to implement including the issues of channel cross talk integration of a large number of source detector pairs clock synchronization between multiple sources etc We propose to time share the optical bandwidth by applying time interleaving circuit techniques in photonics Time interleaving schemes have been widely employed in high speed electronics which increases the overall bandwidth of the system by operating several low speed subsystems in parallel Applying time interleaving techniques in high speed EPICs would effectively relax the bandwidth requirement in each subsystem and hence the relatively low speed electronics can be used to achieve the large bandwidth enabled by the photonics As an example of utilizing the time interleaving technique in silicon photonics this thesis presents a new EPIC concept based on microrings In addition to their wavelength domain properties as add drop filters the time domain properties of microrings are explored In this new microring based optical pulse train generator MOPTG multiple microring add drop filters are cascaded in a series of stages and resonate at the same wavelength which is shifted from the input wavelength by design The microrings are used as compact couplers to equally divide the input pulse energy The stage outputs are then time interleaved by the delay lines between the stages and combined at the circuit output to form an optical pulse train The circuit can be used for optical arbitrary waveform generation OAWG by controlling the amplitude and timing of the output pulses It can also be easily developed into an ultrafast optical transmitter by actively modulating the microrings As a methodology the transfer matrix method combined with full wave electromagnetic EM simulation is developed to analyze large microring based EPIC systems A four stage M OPTG prototype is designed and fabricated on silicon oninsulator SOI using e beam lithography Four identical pulses that are 50 ps apart duplicate the 10 ps wide input pulse at the output indicating a high pulse repetition rate of 20 GHz The preliminary experimental results verify the multiply by 4 circuit function with pulse repetition rates of 18 GHz and 33 GHz demonstrated by two prototypes respectively To fully utilize the filter function of microrings as well as the time interleaving circuit technique to boost the repetition rate of the input pulse train WDM and time division multiplexing TDM are combined in a new multi wavelength M OPTG concept Different from the single wavelength design all the stages resonate at different wavelengths and are used as WDM multiplexers to filter the wideband input spectrum and multiplex it to the output Moreover the multi wavelength operation removes the power loss introduced by the asynchronous optical combining at the circuit output by using a single output waveguide to combine the stage outputs A design of a 30 wavelength M OPTG impressively demonstrates this circuit concept by multiplying the input repetition rate 30 times at the output which can be used as a guideline for the future implementation of the circuit A four wavelength prototype is fabricated on SOI as an experimental demonstration of the multi wavelength M OPTG To solve the

microring resonant wavelength shift problem Ti Au heaters are implemented on top of the microrings to thermally control their resonant wavelengths When thermal tuning is applied the output waveform of the prototype shows four identical pulses with a pulse width of 25 ps and a timing delay of 60 ps between the adjacent pulses The total power consumption for the thermal tuning is about 13 75 mW The pulse repetition rate is demonstrated to be 17 GHz Leaves vi viii **Silicon Photonics III** Lorenzo Pavesi,David J. Lockwood,2016-01-08 This book is volume III of a series of books on silicon photonics It reports on the development of fully integrated systems where many different photonics component are integrated together to build complex circuits This is the demonstration of the fully potentiality of silicon photonics It contains a number of chapters written by engineers and scientists of the main companies research centers and universities active in the field It can be of use for all those persons interested to know the potentialities and the recent applications of silicon photonics both in microelectronics telecommunication and consumer electronics market **Photonic Applications for Radio Systems Networks** Fabio Cavaliere,Antonio D'Errico,2019-09-30 This hands on practical new resource provides optical network designers with basic but necessary information about radio systems air interface and radio access network architecture protocols and interfaces using 5G use cases as relevant example The book introduces mobile network designers to the transmission modeling techniques for the design of a radio access optical network The main linear and non linear propagation effects in optical fiber are covered The book introduces mobile network designers to the optical technologies used in digital and analog radio access networks such as optical amplifiers and transmitters and describes different deployment scenarios including point to point fiber systems wavelength division multiplexing systems and passive optical networks New integrated photonic technologies for optical switching are also discussed The book illustrates the principles of optical beamforming and explains how optical technologies can be used to provide accurate phase and frequency control of antenna elements The new architecture of the optical transport network driven by the new challenging requirements that 5G poses in terms of high capacity high energy efficiency low latency and low cost is discussed The use of photonic devices to perform tasks as radio frequency generation and beamforming with improved accuracy and cost compared to traditional electronic systems especially when moving to mm waves is also explored Readers also learn the replacement of electric interconnect systems with higher speed and more energy efficient optical lines to perform more effectively computationally demanding baseband processing in 5G All presented propagation models can be implemented in a spreadsheet in order to provide the designer with simple rules of thumbs for network planning **Silicon Photonics for Telecommunications and Biomedicine** Sasan Fathpour,Bahram Jalali,2016-04-19 Given silicon s versatile material properties use of low cost silicon photonics continues to move beyond light speed data transmission through fiber optic cables and computer chips Its application has also evolved from the device to the integrated system level A timely overview of this impressive growth Silicon Photonics for Telecommunications **Applications of Silicon Photonics in Sensors and Waveguides** Lakshmi

Narayana Deepak Kallepalli,2018-11-14 This book is a collection of five original research articles on silicon photonics The discussed issues are organized into two parts Part 1 describes the science behind the silicon photonics emphasizing the role of photonic circuits on silicon and Part 2 describes applications in waveguide and optical transmissions This book should be of interest to academic researchers and engineers The chapters included are fundamental science and applications of silicon photonics optical properties of thin nanocrystalline silicon films microporous silicon in gas sensing Mach Zehnder interferometer cell based silicon waveguide experimental study of porous silicon films and integrated optical switches and their applications **Optical Modulation** Le Nguyen Binh,2017-11-22 This books aims to present fundamental aspects of optical communication techniques and advanced modulation techniques and extensive applications of optical communications systems and networks employing single mode optical fibers as the transmission system New digital techqniues such as chromatic dispersion polarization mode dispersion nonlinear phase distortion effects etc will be discussed Practical models for practice and understanding the behavior and dynamics of the devices and systems will be included **Silicon Photonics and Its Applications in Microwave Photonics** Weifeng Zhang,2017 Thanks to its compatibility with the current CMOS technology and its potential of seamless integration with electronics silicon photonics has been attracting an ever increasing interest in recent years from both the academia and industry By applying silicon photonic technology in microwave photonics on chip integration of microwave photonic systems could be implemented with improved performance including a much smaller size better stability and lower power consumption This thesis focuses on developing silicon based photonic integrated circuits for microwave photonic applications Two types of silicon based on chip devices waveguide Bragg gratings and optical micro cavity resonators are designed developed and characterized and the use of the developed devices in microwave photonic applications is studied After an introduction to silicon photonics and microwave photonics in Chapter 1 and an overview of microwave photonic signal generation and processing in Chapter 2 in Chapter 3 a silicon based on chip phase shifted waveguide Bragg grating PS WBG is designed fabricated and characterized and its use for the implementation of a photonic temporal differentiator is experimentally demonstrated To have a waveguide grating that is wavelength tunable in Chapter 4 a tunable waveguide grating is proposed by incorporating a PN junction across the waveguide grating to use the free carrier plasma dispersion effect in silicon to achieve wavelength tuning The use of a pair of wavelength tunable waveguide gratings to form a wavelength tunable Fabry Perot resonator for microwave photonic signal processing is studied Thanks to its electrical tunability a high speed electro optic modulator a tunable fractional order photonic temporal differentiator and a tunable optical delay line are experimentally demonstrated To increase the bandwidth of a waveguide grating in Chapter 5 a linearly chirped waveguide Bragg grating LC WBG is designed fabricated and evaluated By incorporating two LC WBGs in two arms of a Mach Zehnder interferometer MZI structure an on chip optical spectral shaper is produced which is used in a photonic microwave waveform generation system based on spectral shaping and wavelength

to time SS WTT mapping for linearly chirped microwave waveform LCMW generation To enable the LC WBG to be electrically tuned in Chapter 6 a lateral PN junction is introduced in the grating and thus an electrically tunable LC WBG is realized By incorporating two tunable LC WBGs in a Michelson interferometer structure an electrically tunable optical spectral shaper is made By applying the fabricated spectral shaper in an SS WTT mapping system a continuously tunable LCMW is experimentally generated Compared with a waveguide Bragg grating device an on chip optical micro cavity resonator usually has a much smaller dimension which is of help to increase the integration density and reduce the power consumption Different on chip optical micro cavity resonators are studied in this thesis In Chapter 7 an on chip symmetric MZI incorporating multiple cascaded microring resonators is proposed By controlling the radii of the rings the MZI could be designed to have a spectral response with a linearly varying free spectral range FSR which could be used in photonic generation of an LCMW and to have a multi channel spectral response with identical channel spacing which could be used in the implementation of an independently tunable multi channel fractional order temporal differentiator To further reduce the footprint of an optical micro cavity resonator in Chapter 8 an ultra compact microdisk resonator MDR with a single mode operation and an ultra high Q factor is proposed fabricated and evaluated and its use for the implementation of a microwave photonic filter and an optical delay line is experimentally demonstrated To enable the MDR to be electrically tunable in Chapter 9 an electrically tunable MDR is realized by incorporating a lateral PN junction in the disk The use of the fabricated MDR in microwave photonic applications such as a high speed electro optic modulator a tunable photonic temporal differentiator and a tunable optical delay line is experimentally demonstrated Silicon Photonics II David J. Lockwood,Lorenzo Pavesi,2010-10-13 This book is volume II of a series of books on silicon photonics It gives a fascinating picture of the state of the art in silicon photonics from a component perspective It presents a perspective on what can be expected in the near future It is formed from a selected number of reviews authored by world leaders in the field and is written from both academic and industrial viewpoints An in depth discussion of the route towards fully integrated silicon photonics is presented This book will be useful not only to physicists chemists materials scientists and engineers but also to graduate students who are interested in the fields of micro and nanophotonics and optoelectronics **Silicon Photonics** Graham T. Reed,2008-05-23 Silicon photonics is currently a very active and progressive area of research as silicon optical circuits have emerged as the replacement technology for copper based circuits in communication and broadband networks The demand for ever improving communications and computing performance continues and this in turn means that photonic circuits are finding ever increasing application areas This text provides an important and timely overview of the hot topics in the field covering the various aspects of the technology that form the research area of silicon photonics With contributions from some of the world s leading researchers in silicon photonics this book collates the latest advances in the technology Silicon Photonics the State of the Art opens with a highly informative foreword and continues to feature the integrated

photonic circuit silicon photonic waveguides photonic bandgap waveguides mechanisms for optical modulation in silicon silicon based light sources optical detection technologies for silicon photonics passive silicon photonic devices photonic and electronic integration approaches applications in communications and sensors Silicon Photonics the State of the Art covers the essential elements of the entire field that is silicon photonics and is therefore an invaluable text for photonics engineers and professionals working in the fields of optical networks optical communications and semiconductor electronics It is also an informative reference for graduate students studying for PhD in fibre optics integrated optics optical networking microelectronics or telecommunications *Mode- and Wavelength-division Multiplexing in Silicon Integrated Photonics* Lian Wee Luo,2013 Significant effort in optical fiber research has been directed in the past few years towards creation of mode division multiplexing on fiber platforms to further scale the communication bandwidth transmitted per fiber At the world s leading global conference for optical communications i e Optical Fiber Communication Conference mode division multiplexing MDM has been one of the hottest topic in the recent years depicted by the large amount of contributed and invited talks in this field David Richardson et al Nature Photonics May 2013 wrote a review letter to discuss the importance of space division multiplexing in optical fibers to meet the increasing transmission capacity demand In contrast current integrated photonics operate almost exclusively in the single mode regime and typically utilize wavelength division multiplexing WDM alone MDM is rarely considered to be implemented in integrated photonics due to several challenges The challenges include creating mode de multiplexers with low modal crosstalk and loss and concurrently support WDM a key feature of many integrated optics interconnect designs Here in this dissertation we show the first demonstration of simultaneous mode and wavelength division multiplexing with low modal crosstalk and low loss in integrated photonics Our approach would potentially increase the aggregate data rate for on chip ultra high bandwidth communications We first start off with the discussion of the current status of the data traf fic demand by the consumers and why there is a need for silicon photonics to meet this demand We then propose a new silicon waveguide technique to improve the optical loss of silicon waveguides We make use of this fabrication technique in fabricating high quality factor microring resonators We also investigate the nonlinear effects in microring resonators Acquiring this knowledge about the nonlinear effects in microring resonators we can engineer the microring resonators design to suit the needs of our system We utilize adddrop microring filters as the de multiplexers in the wavelength division multiplexing platform We also introduce an interleaver based on triple microring integrated with Mach Zehnder interferometer to separate a comb of closely located channels The highlight of the dissertation is to discuss how we can implement mode division multiplexing simultaneously with wavelength division multiplexing in integrated photonics Finally we propose a future work for a truly integration of on chip multiplexing system

Applications of Silicon Photonics in Sensors and Waveguides Lakshmi Narayana Deepak Kallepalli,2018 This book is a collection of five original research articles on silicon photonics The discussed issues are organized into two parts Part 1

describes the science behind the silicon photonics emphasizing the role of photonic circuits on silicon and Part 2 describes applications in waveguide and optical transmissions This book should be of interest to academic researchers and engineers The chapters included are fundamental science and applications of silicon photonics optical properties of thin nanocrystalline silicon films microporous silicon in gas sensing Mach Zehnder interferometer cell based silicon waveguide experimental study of porous silicon films and integrated optical switches and their applications **Flexible Silicon Photonic Integrated Circuits for Optical Interconnects and WDM Networks** Yang Ren,2020 In response to the continuous growth in the demand for higher speed and volume of data transmission optical networks are evolving to become more elastic to maximize spectrum utility This in turn is driving the development of flexible optical devices and circuits that can be reconfigured to adapt to fast changes in network conditions Over the past decade silicon photonics has gained widespread industry acceptance as a platform for photonic integrated circuits for optical communication due to its low cost potential for dense integration and compatibility with the CMOS fabrication process In spite of its promising benefits several important challenges remain in the development of flexible silicon photonic circuits namely broadband wavelength tunability fast recon figurability and scalability This thesis addresses these issues through the development of flexible and scalable silicon photonic components for elastic optical networks including a widely tunable reconfi gurable optical add drop multiplexing ROADM circuit a universal variable bandwidth optical filter and a fast wavelength selection circuit The ROADM circuit can provide wavelength reconfi gurability over more than 4 Tb s data transmission bandwidth The variable bandwidth filter is based on a novel microring loaded Mach Zehnder interferometer that can provide insertion loss free bandwidth tuning by only tuning the microring resonant frequencies The wavelength selection circuit combines the wide band tunability of thermo optic microring filters with fast switching by free carrier injection to achieve best case wavelength selection time of a few nanoseconds over a 32 nm wavelength range As silicon photonic circuits grow in functionality and complexity it also becomes necessary to monitor their performance and optical signal quality throughout the system To address this issue we proposed and investigated two novel methods for on chip optical monitoring The first method is the use of on chip thermistors for tracking the centre wavelength and bandwidth of microring add drop filters The second method is the use of silicon photodetectors based on two photon absorption for on chip signal detection These devices and methods can be seamlessly integrated into silicon photonic circuits for real time monitoring of their performance **Photonic Integration and Photonics-Electronics Convergence on Silicon Platform** Koji Yamada,Jifeng Liu,Toshihiko Baba,Laurent Vivien, Dan-Xia Xu,2015-11-10 Silicon photonics technology which has the DNA of silicon electronics technology promises to provide a compact photonic integration platform with high integration density mass producibility and excellent cost performance This technology has been used to develop and to integrate various photonic functions on silicon substrate Moreover photonics electronics convergence based on silicon substrate is now being pursued Thanks to these features silicon photonics will have

the potential to be a superior technology used in the construction of energy efficient cost effective apparatuses for various applications such as communications information processing and sensing Considering the material characteristics of silicon and difficulties in microfabrication technology however silicon by itself is not necessarily an ideal material For example silicon is not suitable for light emitting devices because it is an indirect transition material The resolution and dynamic range of silicon based interference devices such as wavelength filters are significantly limited by fabrication errors in microfabrication processes For further performance improvement therefore various assisting materials such as indium phosphide silicon nitride germanium tin are now being imported into silicon photonics by using various heterogeneous integration technologies such as low temperature film deposition and wafer die bonding These assisting materials and heterogeneous integration technologies would also expand the application field of silicon photonics technology Fortunately silicon photonics technology has superior flexibility and robustness for heterogeneous integration Moreover along with photonic functions silicon photonics technology has an ability of integration of electronic functions In other words we are on the verge of obtaining an ultimate technology that can integrate all photonic and electronic functions on a single Si chip This e Book aims at covering recent developments of the silicon photonic platform and novel functionalities with heterogeneous material integrations on this platform Silicon Photonics Lorenzo Pavesi,2004-03-04 This book gives a fascinating picture of the state of the art in silicon photonics and a perspective on what can be expected in the near future It is composed of a selected number of reviews authored by world leaders in the field and is written from both academic and industrial viewpoints An in depth discussion of the route towards fully integrated silicon photonics is presented This book will be useful not only to physicists chemists materials scientists and engineers but also to graduate students who are interested in the fields of microphotonics and optoelectronics **Silicon-Based Photonics** Erich Kasper,Jinzhong Yu,2020-07-24 Silicon photonics has evolved rapidly as a research topic with enormous application potential The high refractive index contrast of silicon on insulator SOI shows great promise for submicron waveguide structures suited for integration on the chip scale in the near infrared region Ge and GeSn Si heterostructures with different elastic strain levels already provide expansion of the spectral range high speed operation efficient modulation and switching of optical signals and enhanced light emission and lasing This book focuses on the integration of heterostructure devices with silicon photonics The authors have attempted to merge a concise treatment of classical silicon photonics with a description of principles prospects challenges and technical solution paths of adding silicon based heterostructures The book discusses the basics of heterostructure based silicon photonics system layouts and key device components keeping in mind the application background Special focus is placed on SOI based waveguide configurations and Ge and GeSn Si heterostructure devices for light detection modulation and light emission and lasing The book also provides an overview of the technological and materials science challenges connected with integration on silicon The first half of the book is mainly for readers who are interested in the topic because of its increasing

importance in different fields while the latter half covers different device structures for light emission detection modulation extension of the wavelength beyond 1 6 m and lasing as well as future challenges

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