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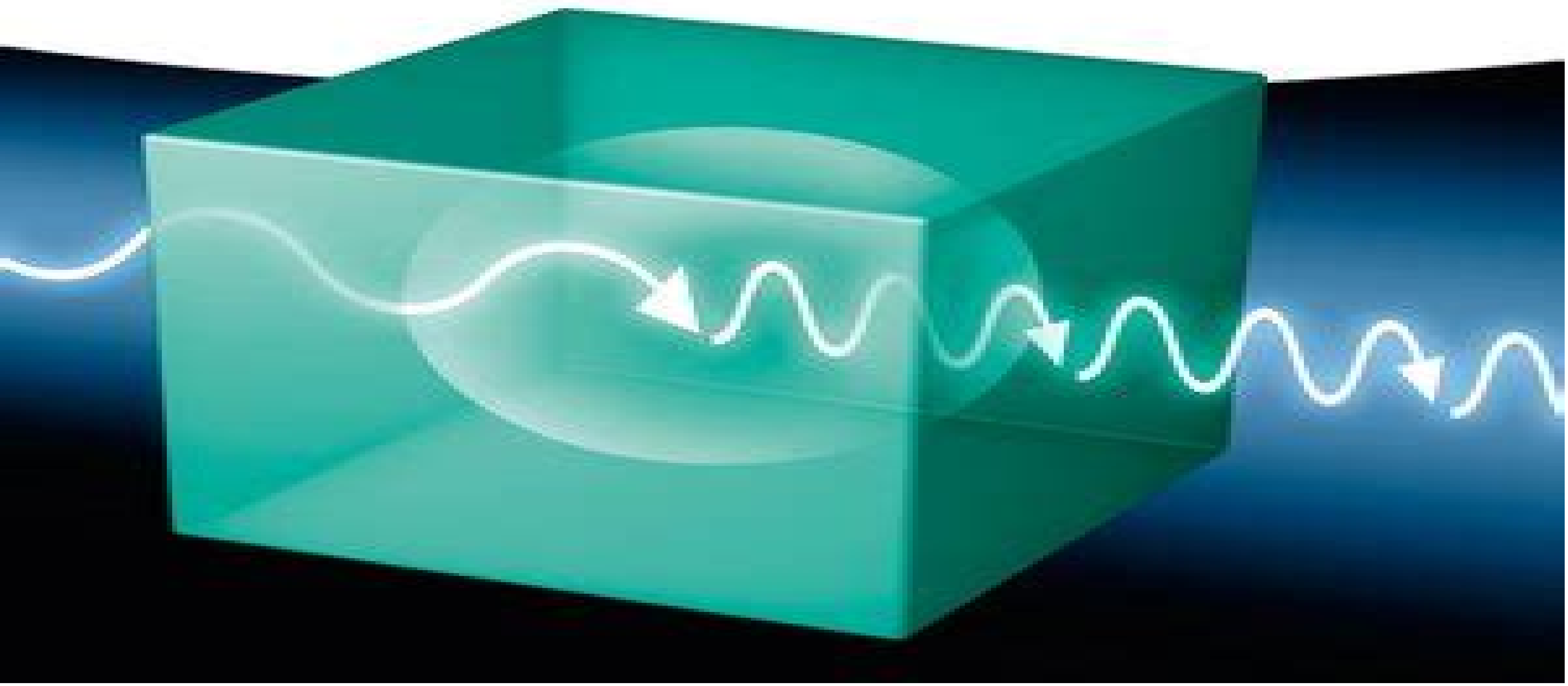
Nonlinear Optical Cavity Dynamics

From Microresonators to Fiber Lasers



Nonlinear Optical Cavity Dynamics Microresonators Ebook

Zachary Vernon

Nonlinear Optical Cavity Dynamics Microresonators Ebook:

Nonlinear Optical Cavity Dynamics Philippe Grelu,2015-12-23 By recirculating light in a nonlinear propagation medium the nonlinear optical cavity allows for countless options of light transformation and manipulation In passive media optical bistability and frequency conversion are central figures In active media laser light can be generated with versatile underlying dynamics Emphasizing on ultrafast dynamics the vital arena for the information technology the soliton is a common conceptual keyword thriving into its modern developments with the closely related denominations of dissipative solitons and cavity solitons Recent technological breakthroughs in optical cavities from micro resonators to ultra long fiber cavities have entitled the exploration of nonlinear optical dynamics over unprecedented spatial and temporal orders of magnitude By gathering key contributions by renowned experts this book aims at bridging the gap between recent research topics with a view to foster cross fertilization between research areas and stimulating creative optical engineering design **Novel Nonlinear Interactions and Synchronization Dynamics in Micro-resonators** Yanan Henry Wen,2015 This thesis investigates two systems in chip based nonlinear optical microresonators First is the generation of broadband frequency combs through parametric four wave mixing and the associated phenomenon of cavity soliton formation in micro resonators We begin by investigating the relationship between cavity soliton based modelocking and traditional saturable absorber based modelocking We find that a saturable absorber based modelocked laser with stimulated emission gain on only one cavity mode is dynamically equivalent to a parametrically driven cavity soliton comb We also study the phase dynamics of the cavity soliton formation process for which we derive a set of phase equations from the governing Lugiato Lefever equation which exhibit synchronization mechanisms akin to the Kuramoto model for coupled oscillators These equations predict that phase anti symmetrization preceeds phase synchronization in the cavity soliton formation process and explains the origin of the pump phase offset seen in parametrically driven cavity solitons We then extend the concept of synchronization to systems of multiple cavity soliton frequency combs We show that cavity solitons in evanescently coupled micro resonators can synchronize to one another generating synchronized pulses in the time domain and frequency locked combs lines in the spectral domain Second is the demonstration of all optical switching using nonlinear loss in micro resonators We achieve this through two means The first is through the stimulated Raman response of silicon Here we fabricate a silicon micro ring that is co resonant with both a pump field and the anti Stokes field of the silicon material The presence of the pump field stimulates optical loss at the antiStokes field modulating the cavity resonance across all three regimes of coupling and demonstrating a single resonance all optical switch Secondly we use the two photon absorption process of highly nonlinear organic dye molecules embedded in a polymer host We achieve nonlinear loss induced decoupling of a cavity resonance of more than 7 dB and demonstrate the on chip nonlinear loss of 18 cm GW of the organic polymer Optical Microresonators John Heebner,Rohit Grover,Tarek Ibrahim,2007-12-19 Optical Micro Resonators are an exciting new field of research that has gained prominence in the past few years due to the emergence of new fabrication technologies This book is the first detailed text on the theory fabrication and applications of optical micro resonators and will be found useful by both graduate students and researchers in the field Novel Dynamics of Driven Nonlinear Resonators Ian Hendry,2020 This Thesis is comprised of theoretical and experimental investigations designed to shed light on novel dynamics of nonlinear optical resonators The theoretical investigations focus on cavity soliton CS dynamics in the presence of pulsed or amplitude modulated driving elds while the experimental investigation focusses on frequency comb generation in second order nonlinear microresonators First we describe theoretical investigations into the dynamics of CSs in the presence of amplitude inhomogeneities of the driving eld such as pulsed driving where the repetition rate of the inhomogeneity and the soliton are synchronised We show that in contrast to phase inhomogeneities CSs are attracted towards and trapped to speci c values of the driving eld We link our ndings to a spontaneous symmetry breaking instability that physically arises from a competition between coherent driving and nonlinear propagation e ects We then consider the impact due to the presence of desynchronization between the CS and the repetition rate of the inhomogeneity We show that the trapping positions can be manipulated and even erased such that single soliton operation can be assured Further investigation into the interplay of this desynchronization and stimulated Raman scattering has allowed us to explain recent experimental observations The experimental portion of this Thesis focusses on the demonstration of internally pumped optical parametric oscillations in a lithium niobate microresonator We demonstrate through numerical simulations that frequency combs can form around the pump and the second harmonic in a doubly resonant second order nonlinear microresonator We then report on our experimental method for comb generation in a naturally phase matched lithium niobate microresonator by thermally tuning the birefringence of the crystal Our observations of cascaded internally pumped optical parametric oscillation producing sidebands around the pump and the second harmonic bring us one step closer to achieving full comb generation in quadratically nonlinear optical microresonators *Applications of High-Q Microresonators in Cavity Optomechanics and Nonlinear Photonics* Wei C. Jiang,2016 Optical microresonators confining light to small volumes are indispensable for a great variety of studies and applications This thesis is devoted to a study of cavity optomechanical and nonlinear optical phenomena in high Q microresonators with different materials and structures Based on that it proposes and demonstrates several novel schemes and device platforms that exhibit great potential for various applications ranging from frequency metrology and quantum photonics to information processing and sensing The thesis starts with a demonstration of a high frequency above 1 GHz regenerative optomechanical oscillator based on a 2 mm radius high Q silicon microdisk resonator in the silicon on insulator platform with an ultra low threshold pump power at room temperature and atmosphere It then continues to explore the cavity optomechanics in single crystal lithium niobate A compact lithium niobate microdisk optomechanical resonator with high optical and mechanical qualities large optomechanical coupling and high mechanical frequency is achieved enabling the demonstration of regenerative oscillation in the ambience Meanwhile I propose and investigate a novel approach for single molecule detection that utilizes the optical spring effect in a high Q coherent optomechanical oscillator to dramatically enhance the sensing resolution by orders of magnitude compared with conventional resonator based approaches In particular a high Q silica microsphere is employed to experimentally demonstrate the detection of single Bovine Serum Albumin proteins with a molecular weight of 66 kDalton at a signal to noise ratio of 16 8 On the other hand the thesis focuses on the theoretical and experimental investigation of the generation of high purity bright photon pairs in a silicon microdisk based on the cavity enhanced four wave mixing The device is able to produce multiple photon pairs at different wavelengths in the telecom band with a high spectral brightness of 6 24x10 7 pairs s mW2 GHz and photon pair correlation with a coincidence toaccidental ratio of 1386 278 while pumped with a continuous wave laser Finally an intriguing approach is proposed for dispersion dynamic tuning and micro engineering by taking advantage of the optical forces in nano optomechanical structures The proposed approach exhibits great potential for broad applications in dispersion sensitive processes which not only offer a new root towards versatile tunable nonlinear photonics but may also open up a great avenue towards a new regime of nonlinear dynamics coupling between nonlinear optical and optomechanical effects Pages xi xii Microresonators for Nonlinear Quantum Optics Zachary Vernon,2017 In this thesis I study in detail the quantum dynamics of several nonlinear optical processes in microresonator systems A Heisenberg picture input output formalism is developed from first principles that includes the effects of scattering losses and independent quality factors and coupling ratios for different resonances The task of calculating the device output is then reduced to solving a set of driven damped ordinary differential equations for the resonator mode operators alone This theoretical framework is used to study photon pair generation via spontaneous four wave mixing in the weakly pumped regime on which the effects of scattering losses are appraised A more strongly driven regime is studied for continuous wave pumps demonstrating when self and cross phase modulation and multi photon pair generation become important and their effects on the spectral and power scaling properties of the system are examined A detuning strategy is presented that compensates for some of these effects The results of the weak pump regime are applied to study microresonator based her alded single photon sources The impact of scattering losses is studied revealing that typical systems suffer from low heralding efficiency due to these losses A technique to improve heralding efficiency is presented through over coupling the resonator channel system and a resultant trade off between heralding rate and heralding efficiency is un covered Limitations to the spectral purity of the heralded single photon output for conventional microresonator systems are also analysed and a more sophisticated cou pling scheme presented to overcome the upper bound for spectral purity of 93% that exists in typical systems permitting the generation of single photons with spectral pu rity arbitrarily close to 100% without spectral filtering or sophisticated phase matching techniques The theory of quantum frequency conversion in microresonators using four wave mix ing is then developed in detail and the spectral conversion probability and conversion efficiency studied Efficiencies exceeding 90% using less than 100 mW of pump power are predicted to be achievable with current technology A dressed mode picture is developed to better understand the conversion dynamics Rabi like spectral splitting and temporal oscillations of the intraresonator mean photon number are predicted exhibiting a novel regime of strongly coupled photonic modes **Practical Applications of Microresonators in Optics and Photonics** Andrey B. Matsko,2018-09-03 Assembling an international team of experts this book reports on the progress in the rapidly growing field of monolithic micro and nanoresonators The book opens with a chapter on photonic crystal based resonators nanocavities It goes on to describe resonators in which the closed trajectories of light are supported by any variety of total internal reflection in curved and polygonal transparent dielectric structures The book also covers distributed feedback microresonators for slow light controllable dispersion and enhanced nonlinearity A portion of coverage is dedicated to the unique properties of resonators which are extremely efficient tools when conducting multiple applications Nonlinear Optics for the Information Society Alfred Driessen,2001-11-30 Proceedings of the Third Annual Meeting of the COST Action P2 held in Enschede The Netherlands 26 27 October 2000 *Nonlinear Optical Whispering Gallery Microresonators for Photonics* John E. Heebner,2003 **Cavity Optomechanics** Markus Aspelmeyer,Tobias J. Kippenberg,Florian Marquardt,2014-07-05 During the last few years cavity optomechanics has emerged as a new field of research This highly interdisciplinary field studies the interaction between micro and nano mechanical systems and light Possible applications range from novel high bandwidth mechanical sensing devices through the generation of squeezed optical or mechanical states to even tests of quantum theory itself This is one of the first books in this relatively young field It is aimed at scientists engineers and students who want to obtain a concise introduction to the state of the art in the field of cavity optomechanics It is valuable to researchers in nano science quantum optics quantum information gravitational wave detection and other cutting edge fields Possible applications include biological sensing frequency comb applications silicon photonics etc The technical content will be accessible to those who have familiarity with basic undergraduate physics *Fiber-Based Optical Resonators* Deepak Pandey,2024-01-29 After laying the foundation by explaining the fundamental principles of light propagation and optical resonators this book delves into the realm of implementing resonators through a fiber based approach It extensively explores fiber based resonators encompassing a comprehensive discussion spanning from their intricacies of design to their pivotal roles in advancing quantum optics experiments Furthermore it details the design techniques meticulously explaining the latest developments within this dynamic field There are vivid illustrations highlighting the various applications of resonators in experimental optics and cavity quantum electrodynamics Also a discourse is presented regarding the future potential of fiber based resonators in quantum technology The book serves as a valuable resource for individuals with an interest in optical resonators and their boundless possibilities **Physics of Dissipative Kerr Solitons in Optical Microresonators and Application to**

Low-noise Frequency Synthesis Erwan Guillaume Albert Lucas,2019 Mots cl s de l auteur Optical frequency combs Optical microresonators Nonlinear optics Frequency metrology Dissipative Kerr cavity solitons Low noise microwave synthesis Dual triple comb generation Mode Dynamics in Coupled Disk Optical Microresonators Carsten Schmidt,2013 **Photonic Microresonator Research and Applications** Ioannis Chremmos,Otto Schwelb,Nikolaos Uzunoglu,2010-06-08 This book details how to design and fabricate microresonators It covers the latest in microresonator research and discusses them in photonic crystals microsphere circuits and sensors It includes application oriented examples Solitons and Dynamics of Frequency Comb Formation in Optical Microresonators Tobias Herr,Tobias Kippenberg (Physicist),2013 **Whispering Gallery Microresonator for Second Harmonic Light Generation** Jorge Luís Domínguez Juárez,2014 In recent years it has been proposed that circular microresonators may become an important element in the core of many photonic devices The high Q factors seen in fused silica micro spheres and micro toroids for light coupled in the whispering gallery modes WGMs inside the micro resonator led to many new developments in a diversity of fields Indeed WGM micro resonators have found applications in laser oscillation optical filtering bio and chemical sensing frequency stabilization quantum electrodynamics experiments nonlinear parametric conversion and in many other light matter interaction processes where light recirculation is an essential ingredient For second and third order nonlinear optical phenomena a high Q micro circular cavity is an ideal framework to lower the light intensity or material density and still obtain a measurable interaction This may become particularly useful when the nonlinear interaction is considered on the sphere surface because at an interface centro symmetry is always broken In this thesis we approach the problem of obtaining SHG with the smallest amount of material possible Our goal is to demonstrate that WGMs in micro sphere resonators are an optimal option to consider such type of non linear interaction SHG from a small amount of material may found interesting applications in high sensitivity unmarked detection of low numbers of very small objects such as molecules viruses or other types of nano particles The different experimental and theoretical developments we implemented to achieve such goal are reported in the four chapters of the current thesis In chapter 1 we introduce basic concepts of spherical micro resonators an their interest Theoretical aspects of light propagation and nonlinear light generation in the whispering gallery modes in such micro resonators are discussed in Chapter 2 A new method to obtain patterns of non linear material is presented in Chapter 3 In Chapter 4 the developments presented in the previous chapters are combined to obtain second harmonic generation in the whispering gallery modes of microspheres In this chapter we report the design and fabrication of a nonlinear spherical resonator to experimentally measure SHG from molecules deposited on its surface Such nonlinear interaction is quasi phase matched by implementing the periodical patterning reported in Chapter 3 on a molecular layer deposited on the surface of a micro sphere By coupling laser light pulses at the fundamental frequency into the whispering gallery modes of the high Q spherical micro resonators we demonstrate that a signal at the second harmonic SH frequency can be measured when less than 100 molecules contribute in the nonlinear interaction Finally applications of such type of generation in highly sensitive sensing are discussed **Cavity Solitons in Silicon Nitride Microresonators** Chaitanya Suhas Joshi,2019 Silicon Photonics is a field of research that has attracted a lot of interest in the past few decades and has led to the development of compact structures on chip for the confinement and manipulation of light The ability to confine light in a small mode area in waveguides has enabled the exploration of nonlinear optical phenomena on chip including frequency conversion using four wave mixing Recently demonstrations of chip based optical frequency combs generated in microresonators fabricated using CMOS compatible materials and fabrication processes has become a rapidly developing field of research The ability to generate a broadband optical spectrum on chip by injecting a single frequency continuous wave laser into the microresonator holds promise in enabling applications of these combs in spectroscopy metrology and optical data communications The ability to precisely control the generation of an optical frequency comb and repeatedly achieve low noise operation is especially important to these applications In this dissertation we set out to solve the problem of precise control and repeatable low noise frequency comb generation in microresonators In the first part of the dissertation we investigate thermally controlled cavity soliton generation in silicon nitride microresonators by means of current control of integrated heaters We report a method to stably and repeatably access cavity soliton states in a silicon nitride microresonator and control the detuning dependent properties of the soliton states using the integrated heaters We characterize the RF noise characteristics of these soliton modelocked states and study the ability to generate single and multiple solitons within one cavity round trip In the second part of the dissertation we investigate some of the applications of cavity solitons in silicon nitride microresonators We study the bidirectionally pumped regime of operation of silicon nitride microresonators and demonstrate tunable generation of counter rotating solitons in a single cavity We also study the tunability of the soliton trains in opposite directions as a function of pump power ratio in the two directions We also study a dual comb source consisting of soliton trains generated in two distinct microresonators by maintaining them at a fixed offset in their repetition rates determined by electircal feedback on one of the heaters The tunability of the offset frequency between the two soliton trains is studied The tunable dual comb source is applied to a distance ranging measurement where the ambiguity imposed by the fixed repetition rate of the signal comb is lifted by tuning it with respect to the other comb that acts as a local oscillator The work presented in this dissertation paves the way for further exploration of applications of cavity solitons generated in silicon nitride microresonators in a reliable and precisely controlled manner **Microresonators as Building Blocks for VLSI Photonics** American Institute of Physics,2004-06-08 The aim of the course was to provide state of the art information in the field of advanced devices for large scale integrated photonics The course focused on the theory and application of optical microresonators for wavelength selection and routing for switching and for high speed modulation Also materials aspects design and manufacturing of integrated optics devices based on these resonators for use in optical communication networks were discussed In particular micro ring and micro disk resonators and photonic bang gap structures were addressed At a more fundamental level some lectures were devoted to promising phenomena that could allow new applications in photonics such as entangled pairs generation and single quantum dot emission in a cavity *Control of Dynamical Regimes in Optical Microresonators Exploiting Parametric Interaction* Luigi Di Lauro,2019 **Finite-difference Time-domain Integration of Ultrafast Dynamics in Optical Resonators** Scott Alan Basinger,1993 This thesis discusses optical pulse discrimination in nonlinear resonators The goal is to design a system which interacts strongly with an optical pulse of a specific temporal shape but rejects all others The resonator is a Fabry Perot cavity that has a nonlinear absorbing material in the center When an optical field of the resonant frequency is incident upon the cavity the field intensity increases inside the cavity As this happens the refractive index of the nonlinear material is modified by the intensity of the field This causes the cavity to shift off resonance since the change in index changes the relative wavelength of the optical field inside the cavity This in turn causes the intensity in the middle section to decrease since the frequency of the field is no longer matched to the resonance frequency of the cavity However if the incident field s frequency is dynamically changed to track the shifting resonance of the cavity the intensity of the interior field can be built up higher than is possible with just monochromatic light By looking at the total absorption in the cavity it will be possible to determine whether or not a pulse of the correct temporal shape has passed through the system The absorption is strongly dependent on the shape of the incoming pulse since only a pulse that tracks the nonlinear change in index will build up to a high enough intensity to be measured

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