Enhanced Nonlinear Optical Response and All-Optical Switching in AlGaAs Microring Resonators

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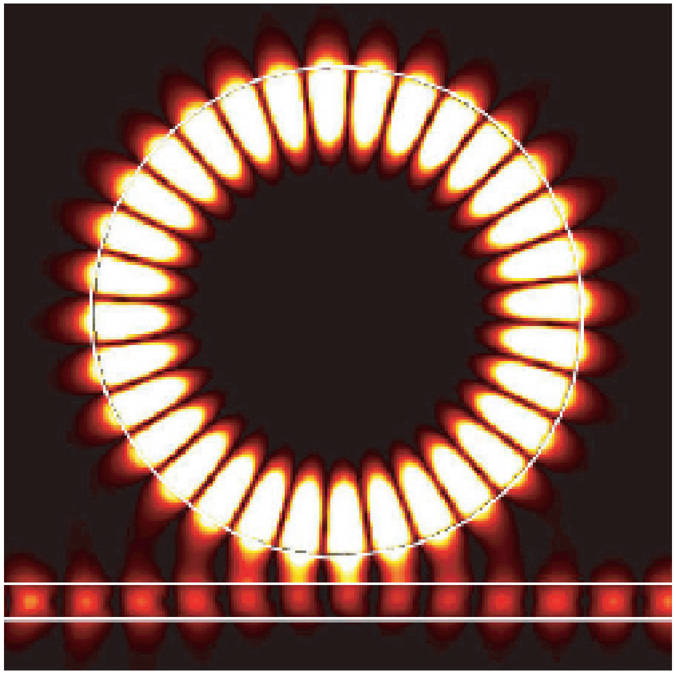
Properties of Nonlinear Ring Resonators

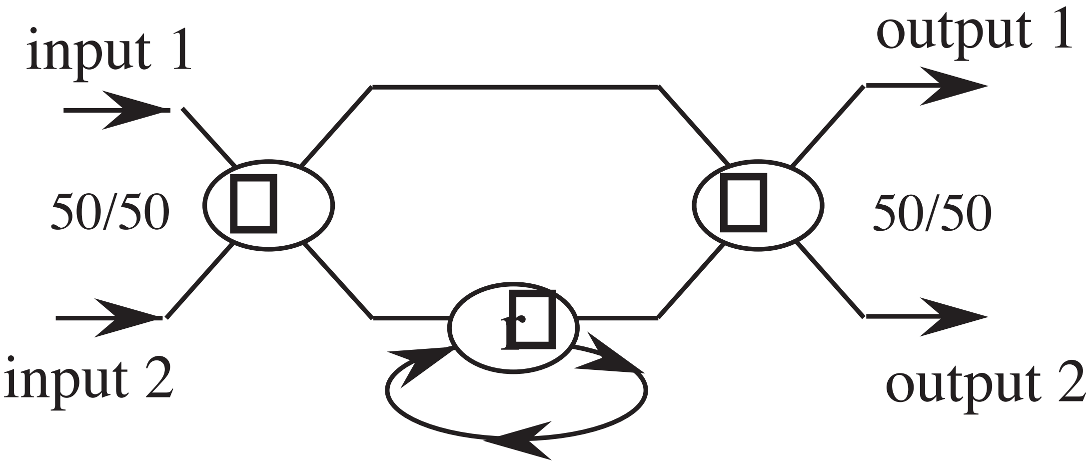
Excite an azimuthal mode of a disk or ring resonator.

Nonlinear phase shift acquired by light scales as square of finesse of resonator.



FDTD

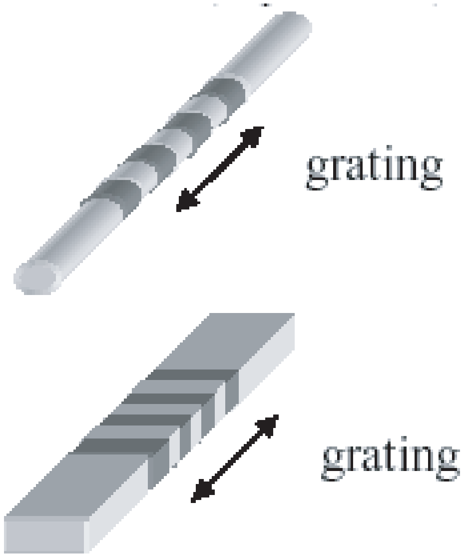
Typical application: enhanced all-optical switching

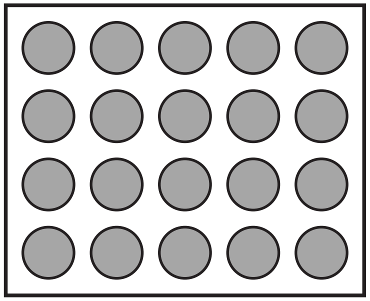


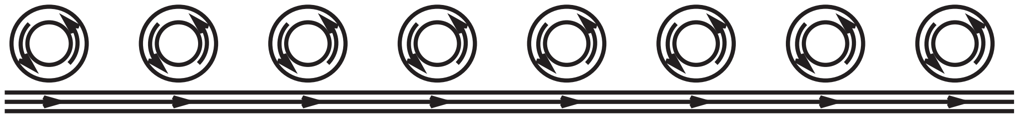
Artificial Materials for Nonlinear Optics

Artifical materials can produce
- Large nonlinear optical response
- Large dispersive effects

Examples
- Fiber/waveguide Bragg gratings
- PBG materials
- CROW devices (Yariv et al.)
- SCISSOR devices

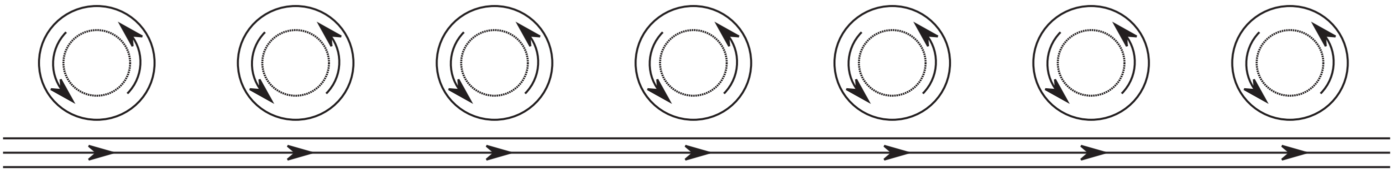






NLO of SCISSOR Devices

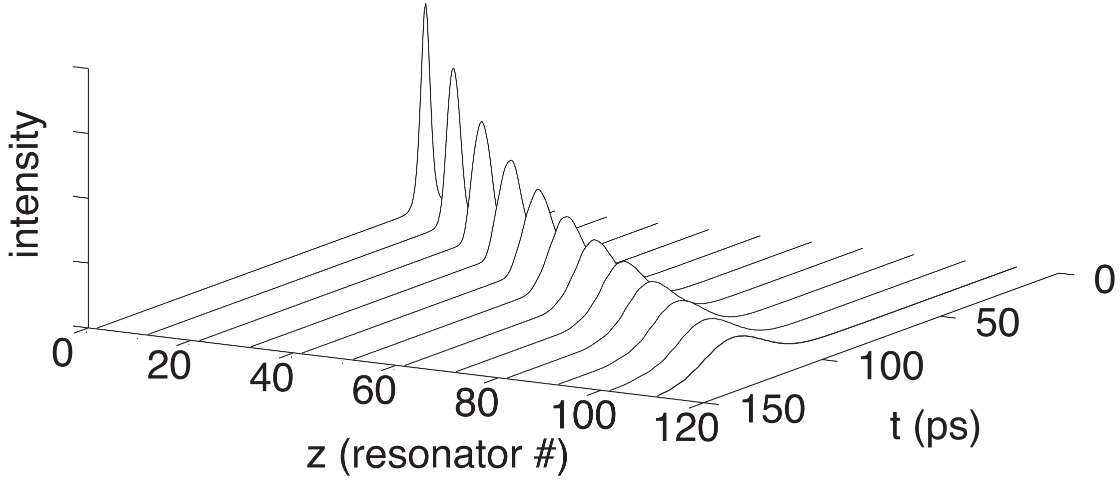
(Side-Coupled Integrated Spaced Sequence of Resonators)



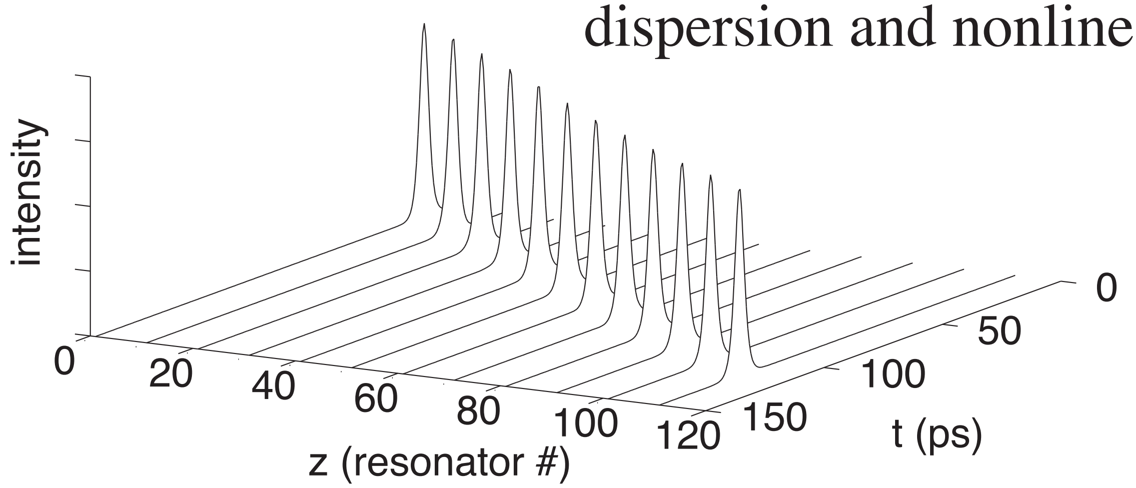
Shows slow-light, tailored dispersion, and enhanced nonlinearity

Optical solitons described by nonlinear Schrodinger equation

- Weak pulses spread because of dispersion

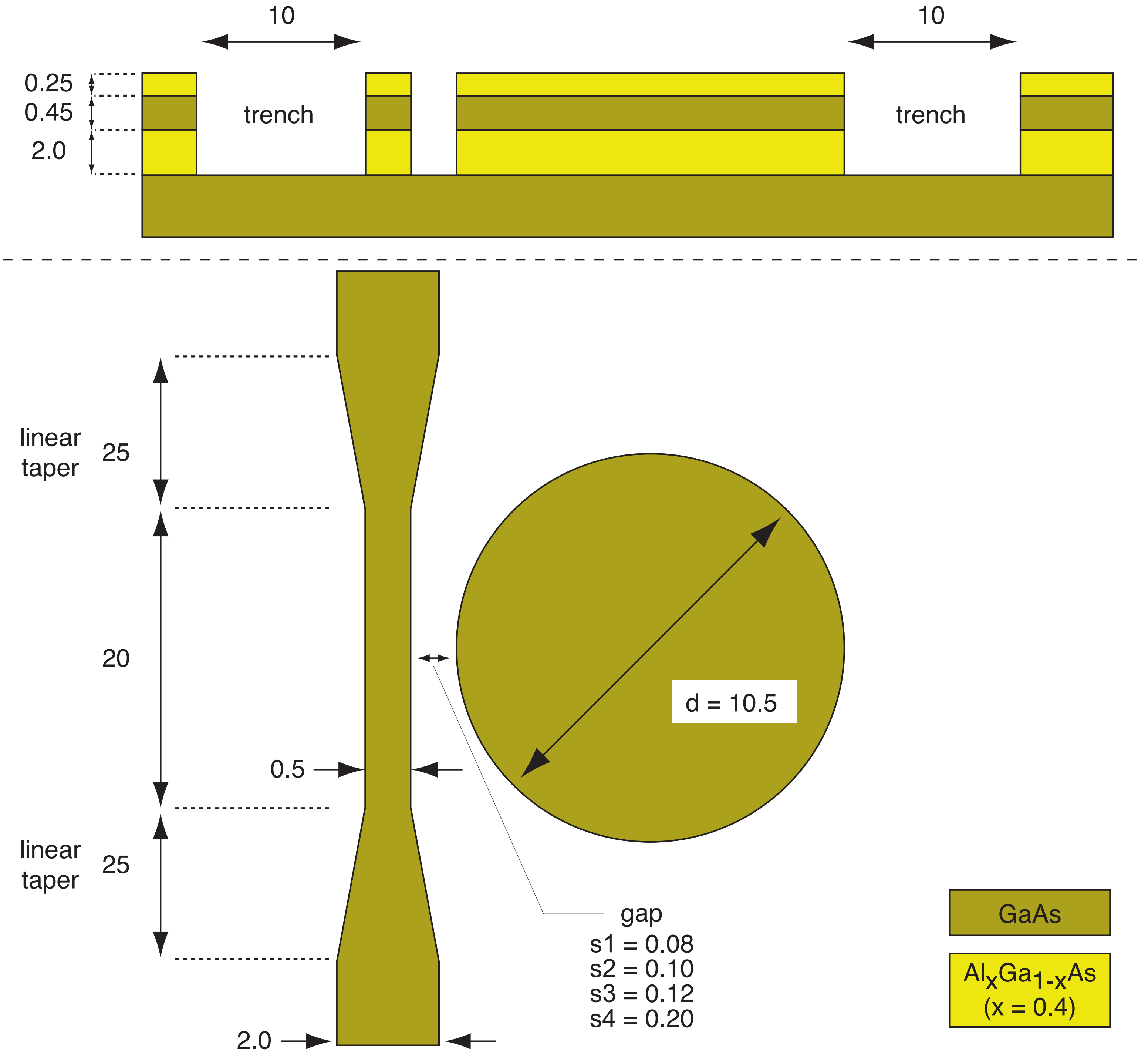


- But intense pulses form solitons through balance of dispersion and nonlinearity.



Microdisk Resonator Design

All dimensions in microns



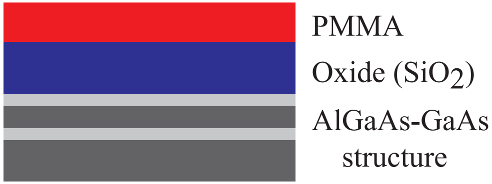
J. E. Heebner and R. W. Boyd

Photonic Device Fabrication Procedure

(1) MBE growth

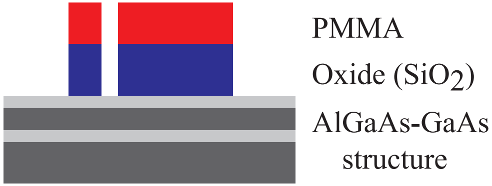
(2) Deposit oxide

(3) Spin-coat e-beam resist



(4) Pattern inverse with e-beam & develop

(5) RIE etch oxide

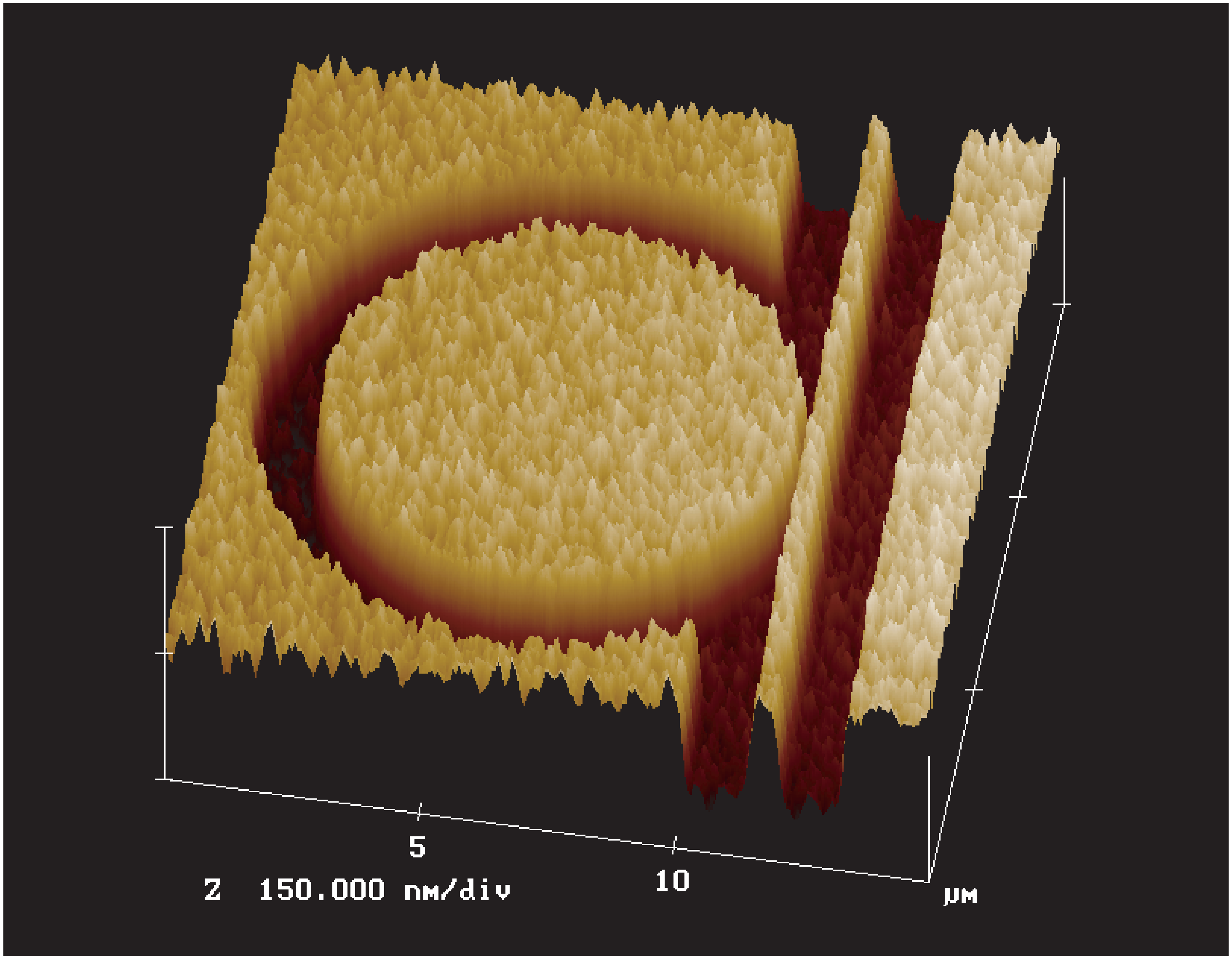


(6) Remove PMMA

(7) CAIBE etch AlGaAs-GaAs

(8) Strip oxide

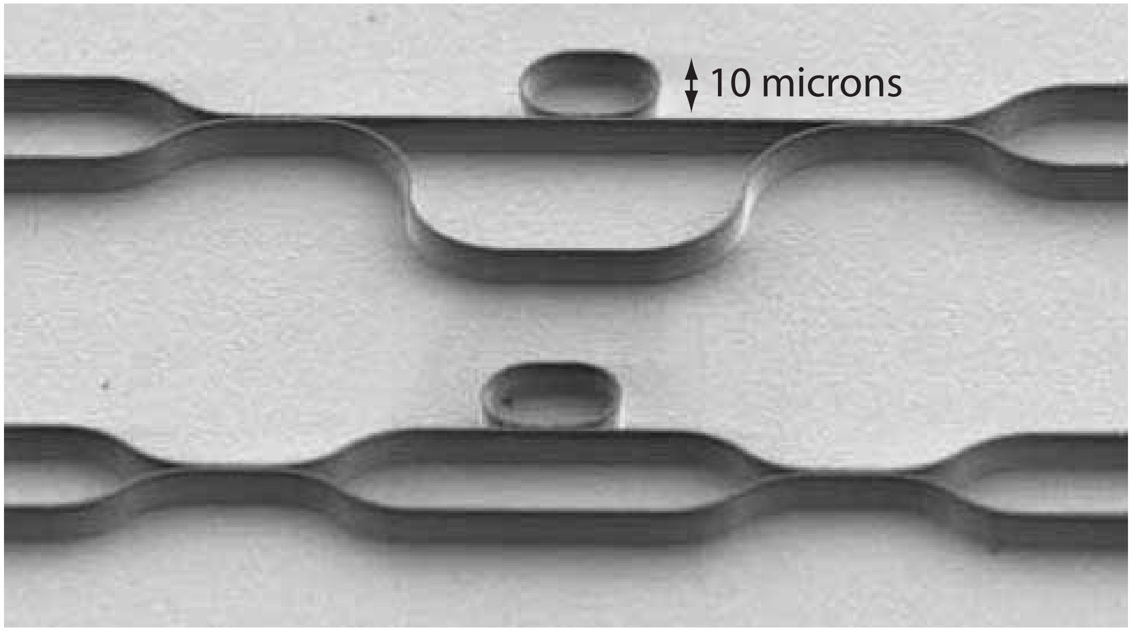
Disk Resonator and Optical Waveguide in PMMA Resist



AFM

Microresonator-Based Photonic Devices

Resonator-Enhanced Mach-Zehnder Interferometers



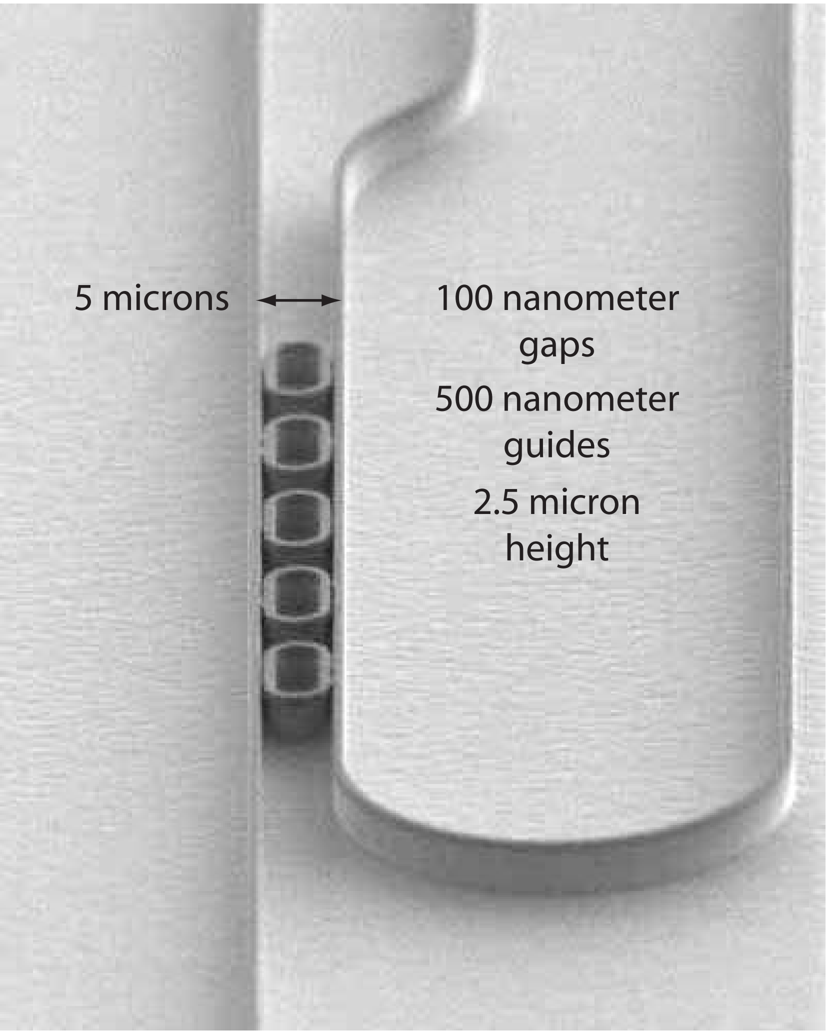
~100 nanometer gaps

500 nanometer guides

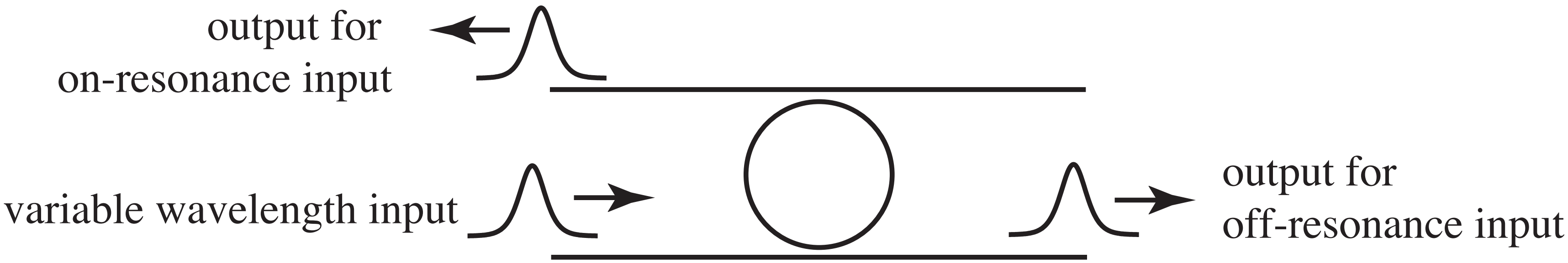
2.5 micron height

J. E. Heebner et. al, Optics Letters, 2004

Five-Cell SCISSOR with Tap Channel



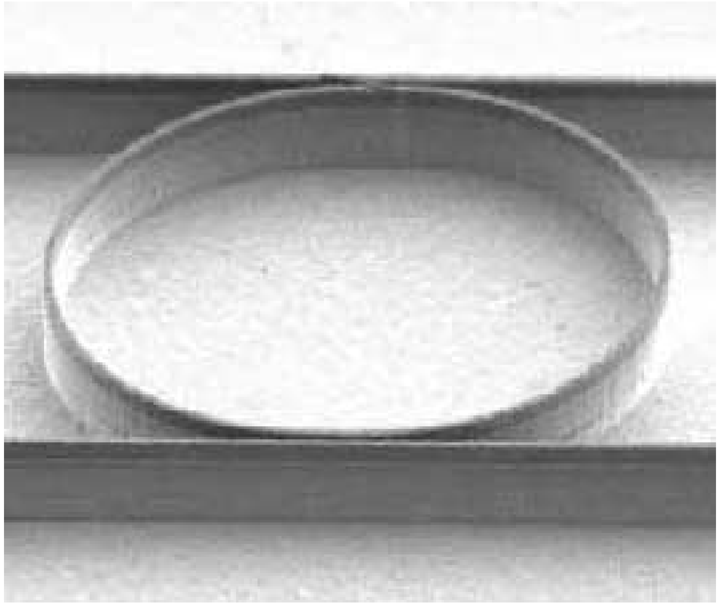
Microresonator-Based Add-Drop Filter

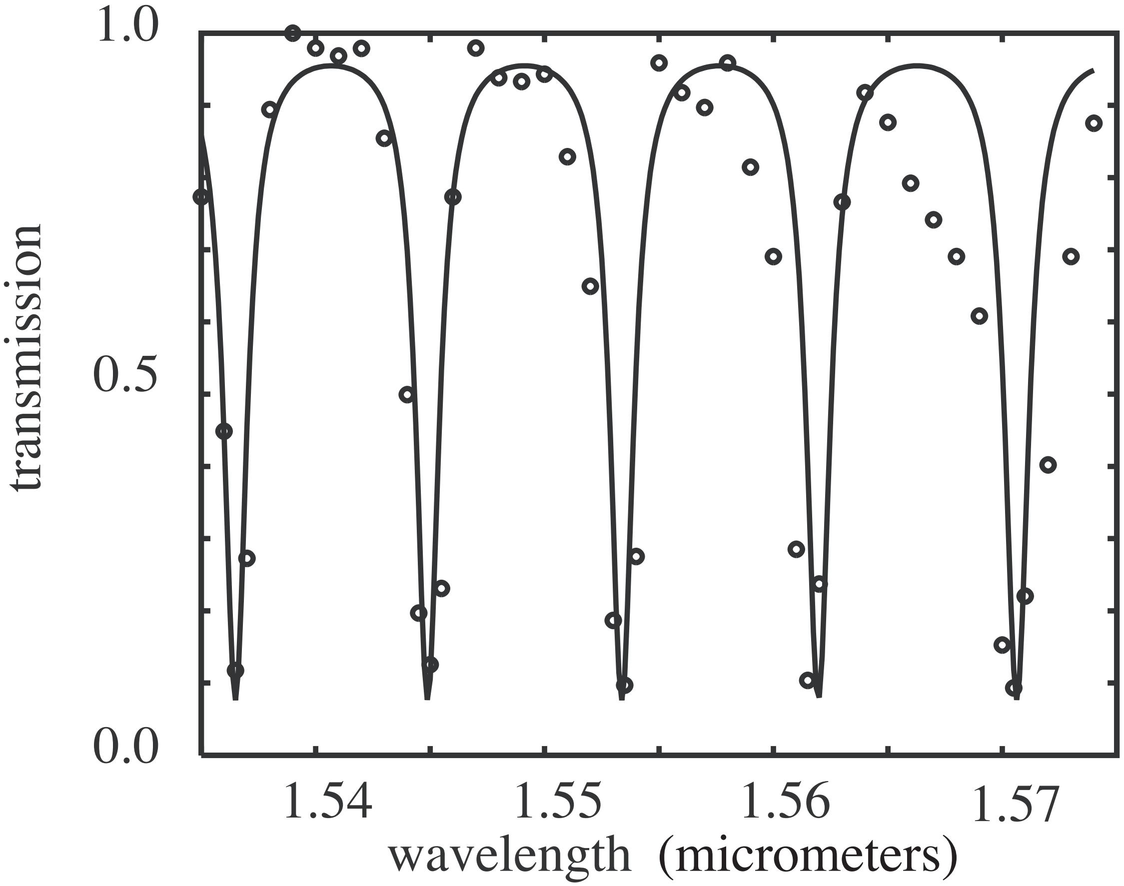


output for
on-resonance input

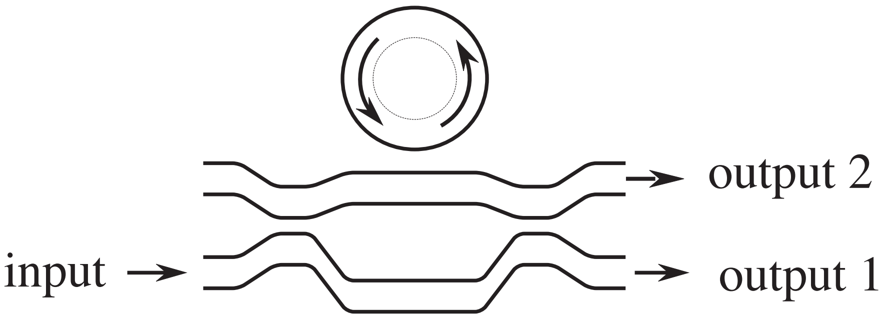
variable wavelength input

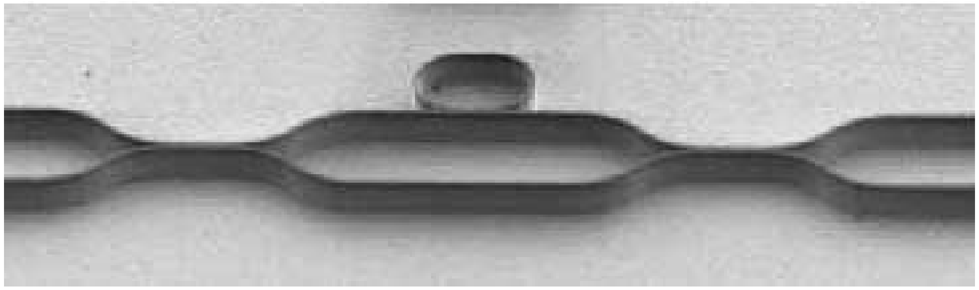
output for
off-resonance input

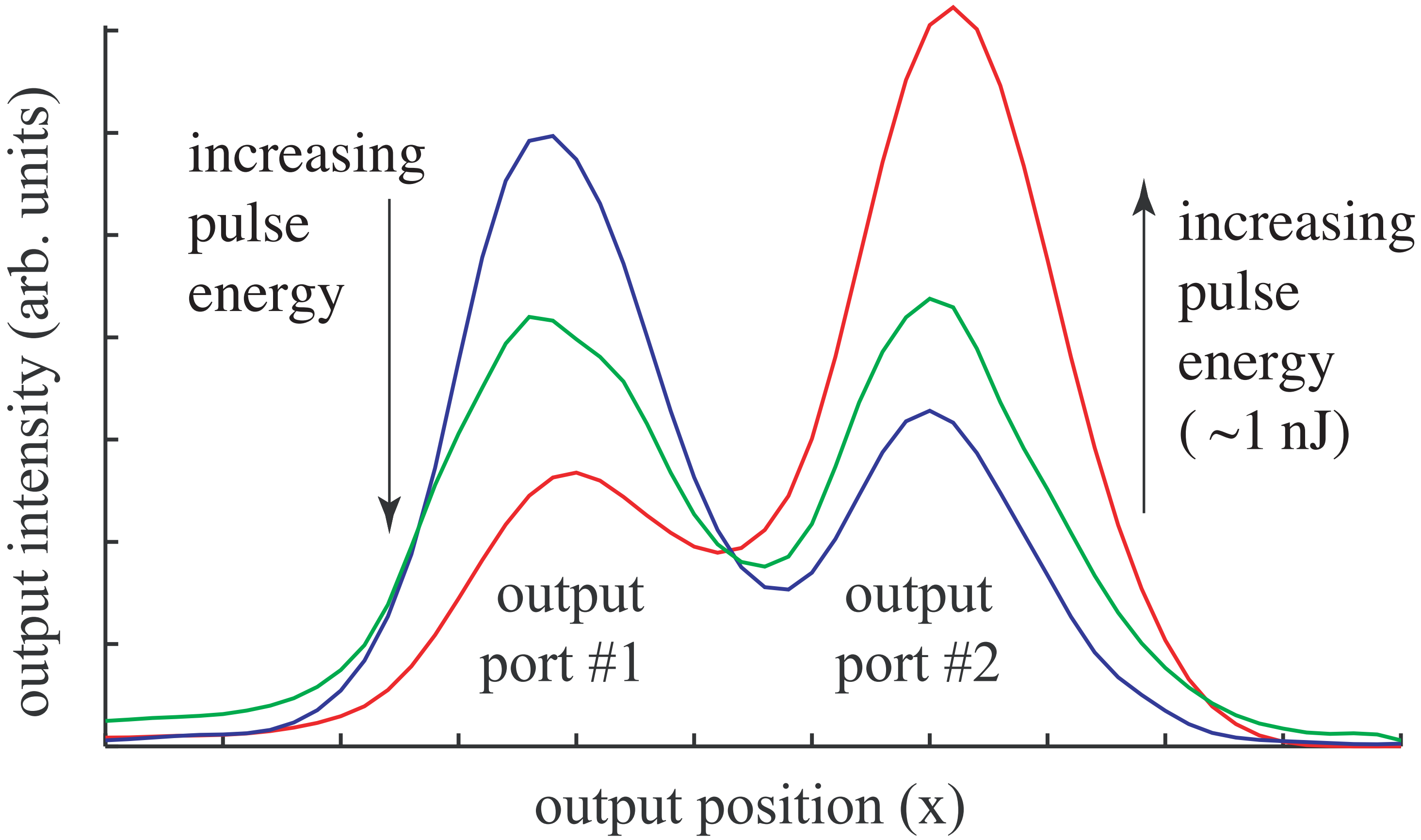




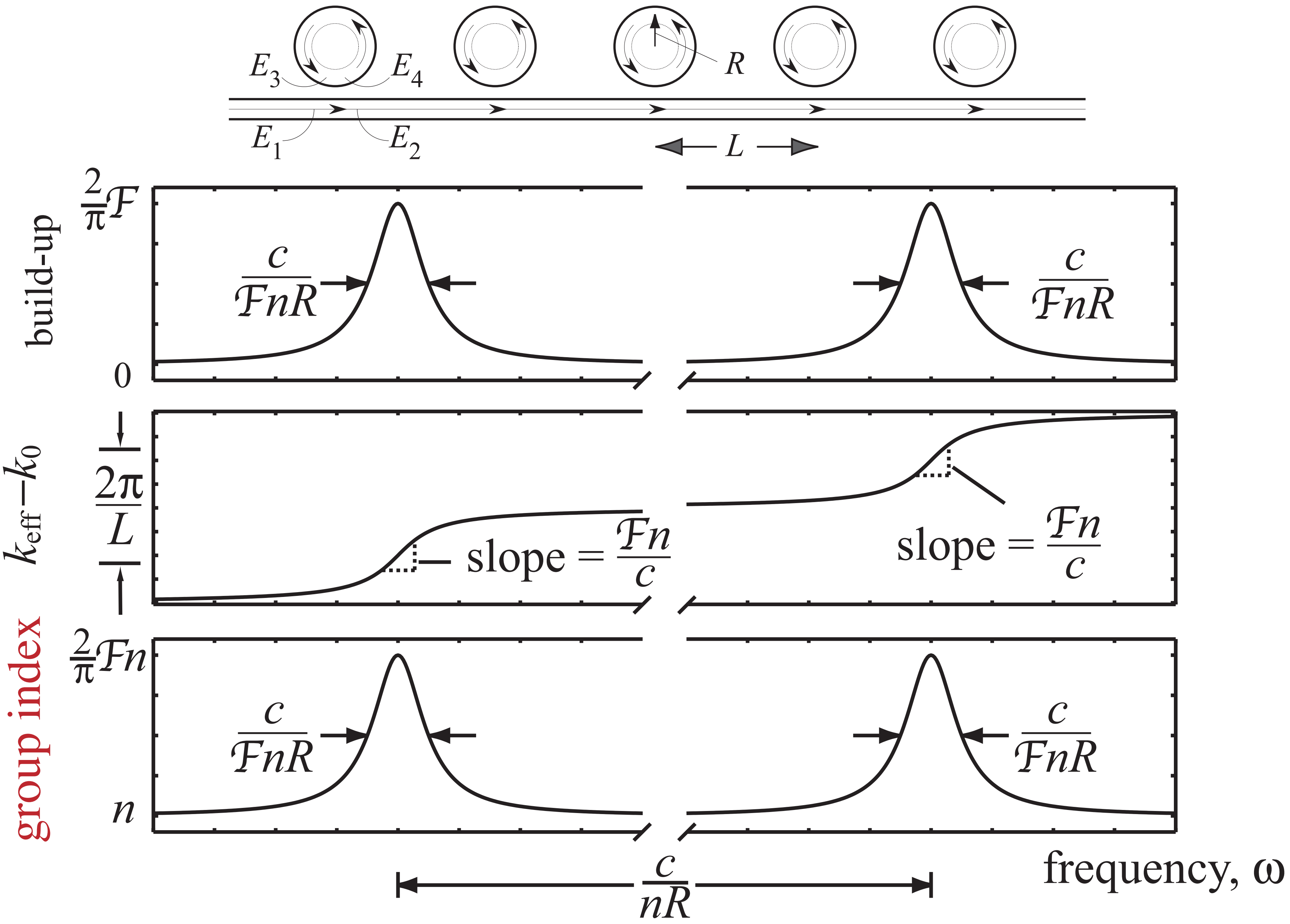
All-Optical Switching in a Microresonator-Enhanced Mach-Zehnder Interferometer



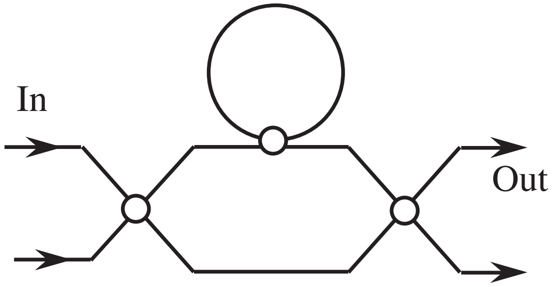


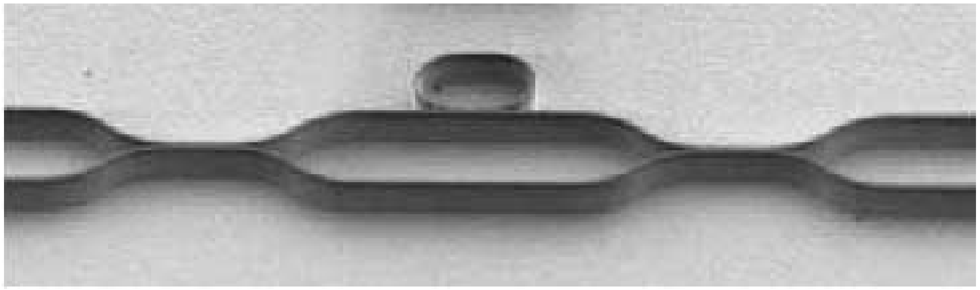


Slow Light and SCISSOR Structures

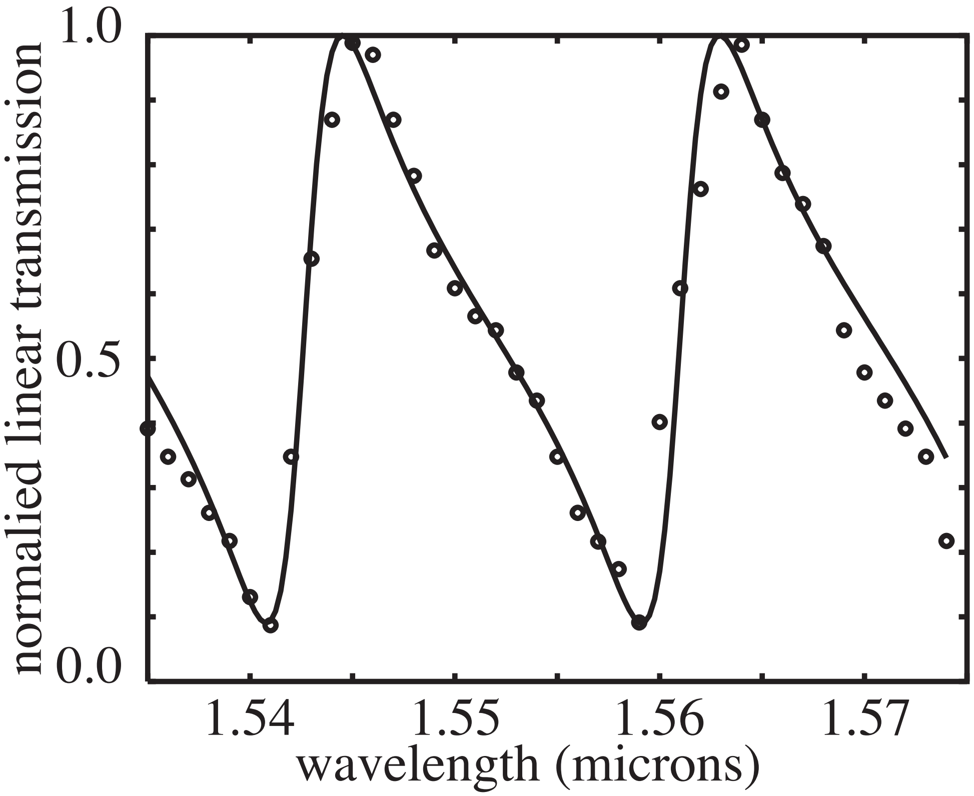


Phase Characteristics of Micro-Ring Resonator

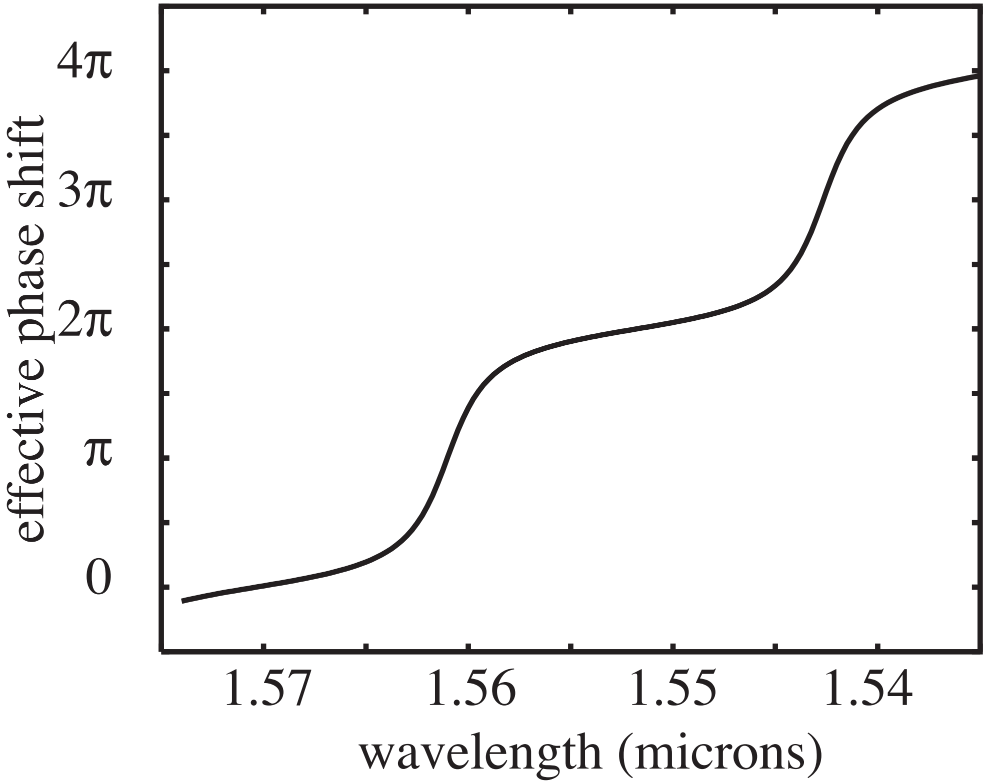




transmission



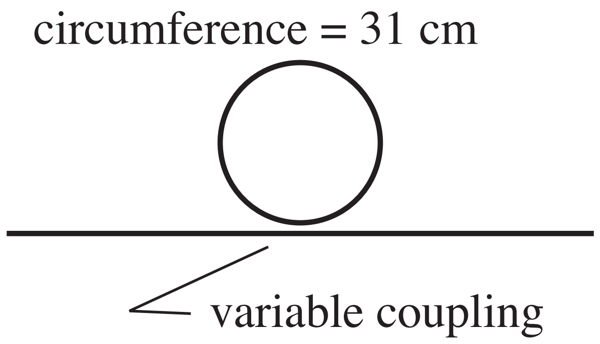
induced phase shift



Studies of Fiber Ring Resonators

Using fiber connectors and variable couplers, it is straightforward to investigate a wide variety of configurations and to vary the resonator finesse.

Transmission Characteristics of Fiber Ring Resonator

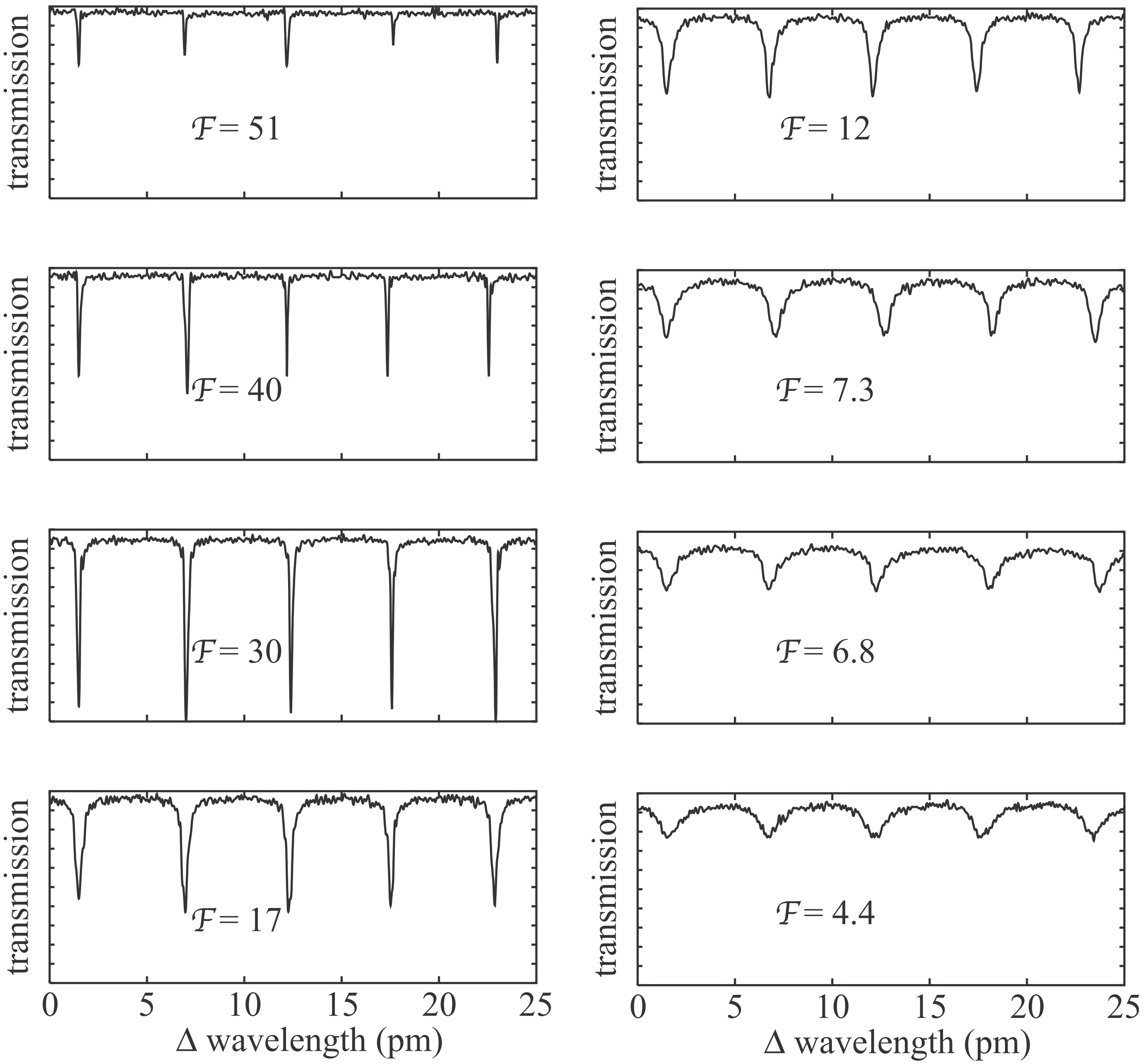


Measure transmission vs. λ for various values of the finesse

undercoupled

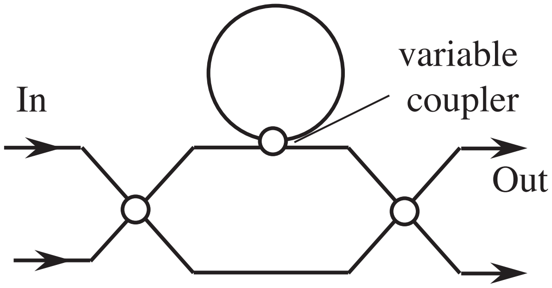
critically coupled

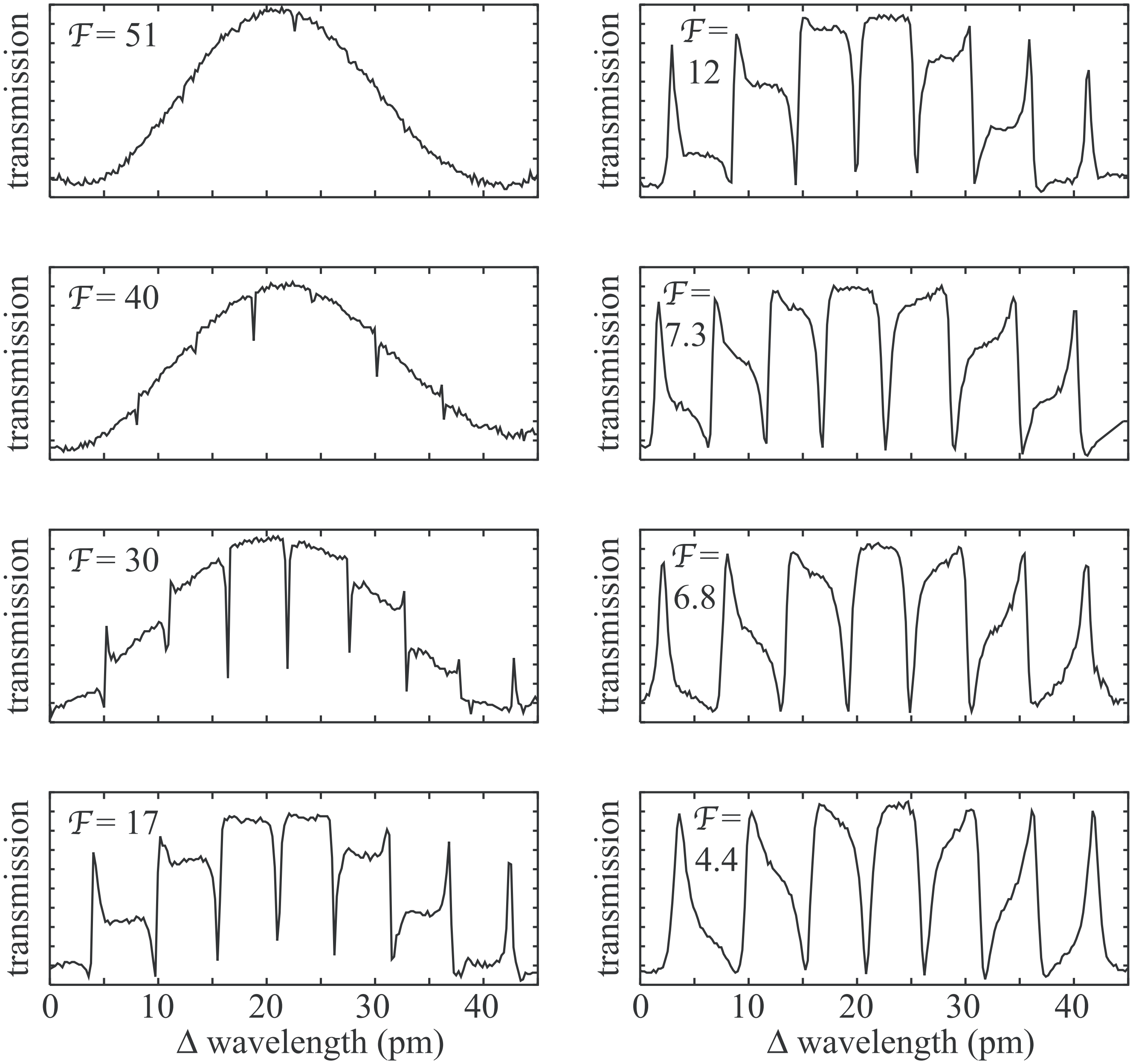
overcoupled



Phase Characteristics of Fiber Ring Resonator

Place ring resonator inside Mach-Zhender interferometer and measure transmission versus wavelength.





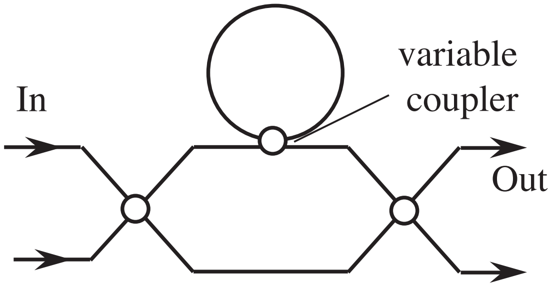
undercoupled

critically coupled

overcoupled

Phase Characteristics of Fiber Ring Resonator

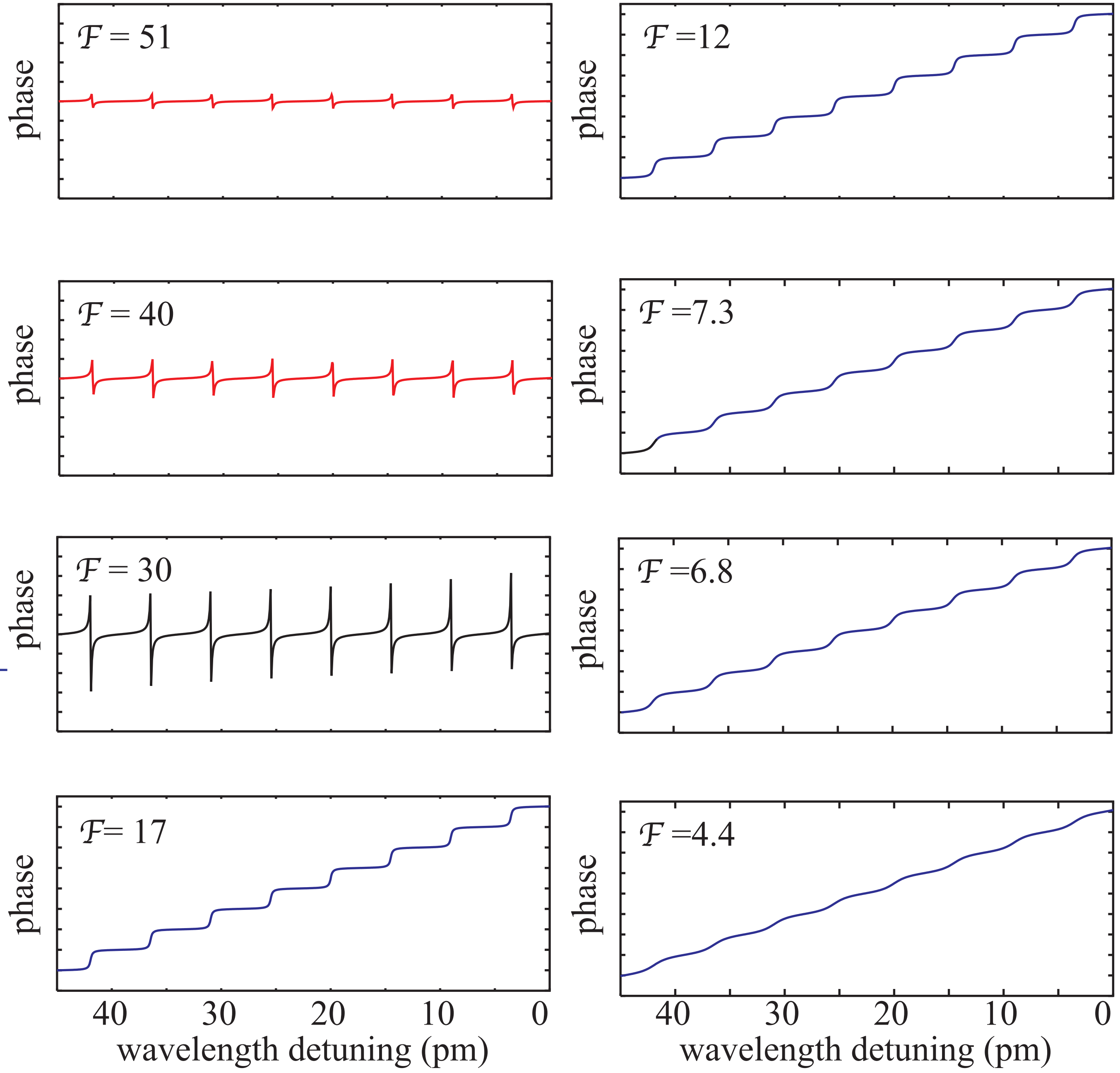
Extracted phase strcuture



undercoupled

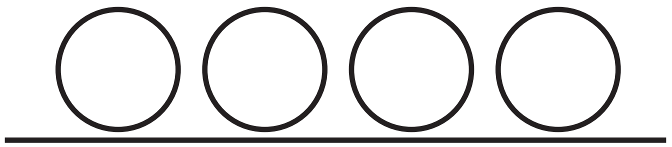
critically coupled

overcoupled

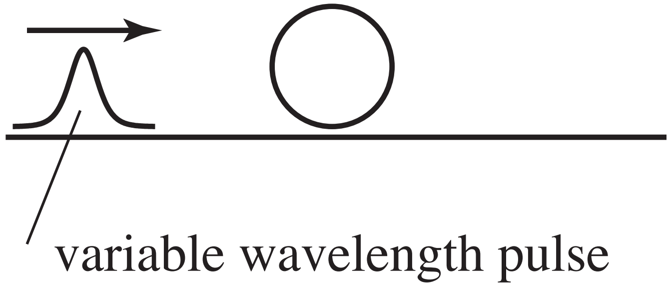


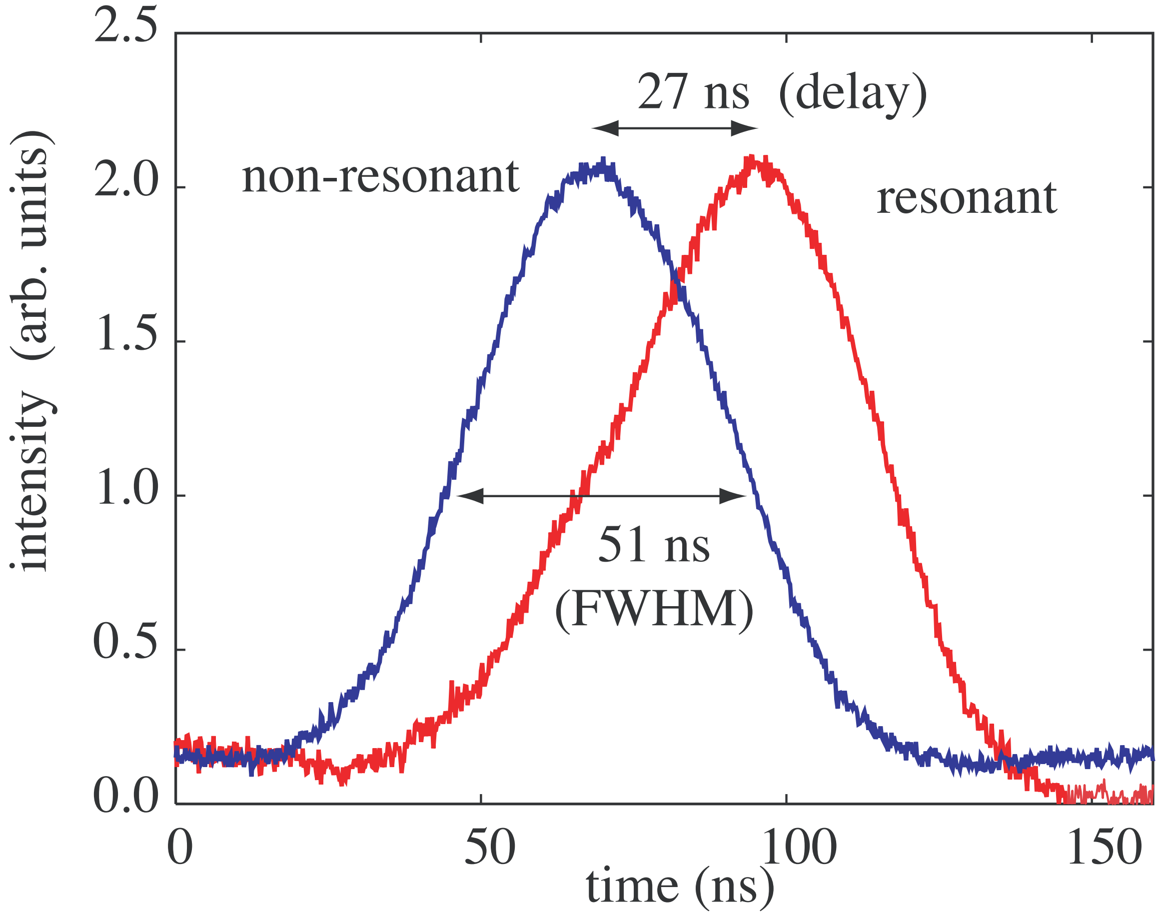
Fiber-Resonator Optical Delay Line

Fiber optical delay line:



First study one element of optical delay line:





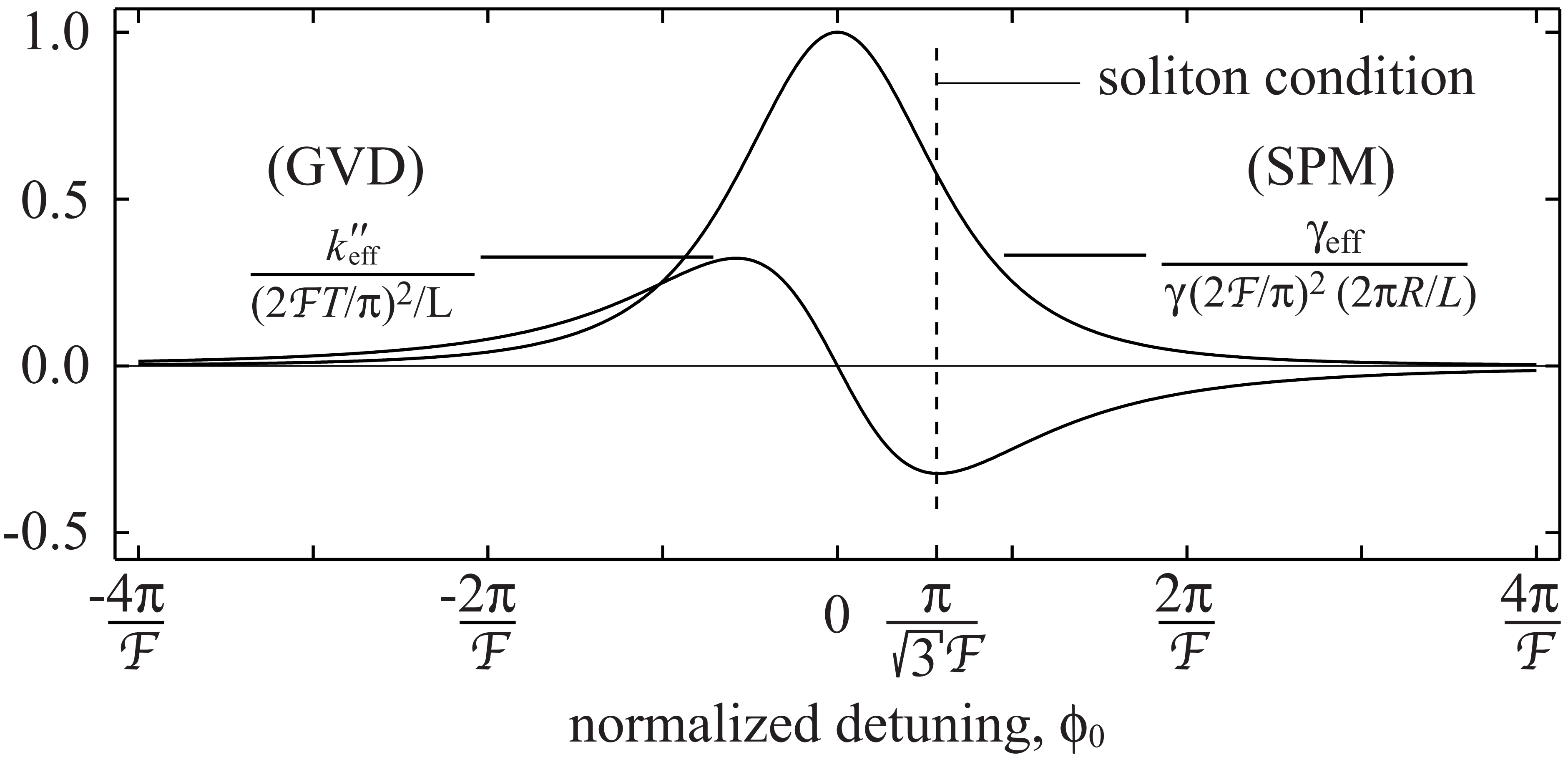
with Deborah Jackson, JPL

Ring Resonators Have Highly Controllable Optical Properties

Both slow and superluminal propagation can occur.

Even the sign of the GVD parameter can be controlled.

Frequency Dependence of GVD and SPM Coefficients



Soliton Propagation

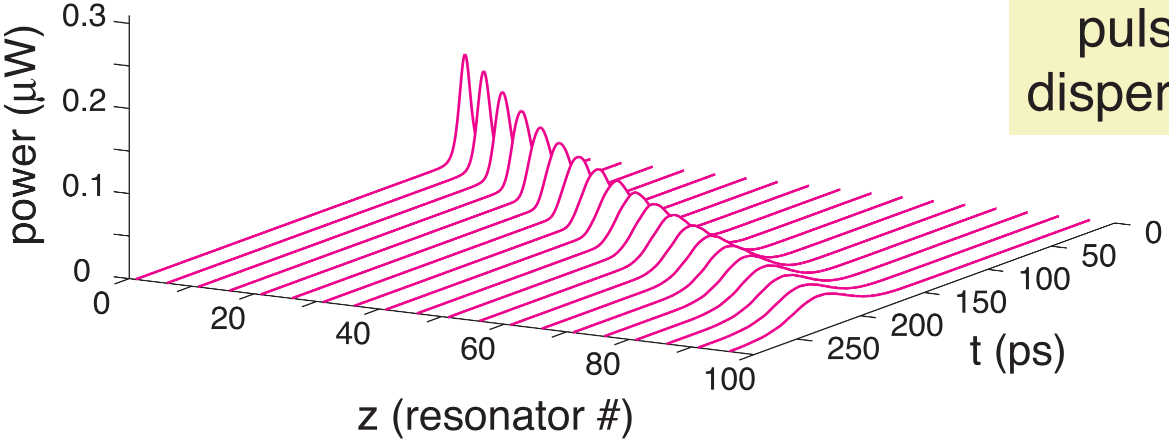
5 μm diameter resonators with a finesse of 30

SCISSOR may be constructed from 100 resonators spaced by 10 μm for a total length of 1 mm

soliton may be excited via a 10 ps, 125mW pulse

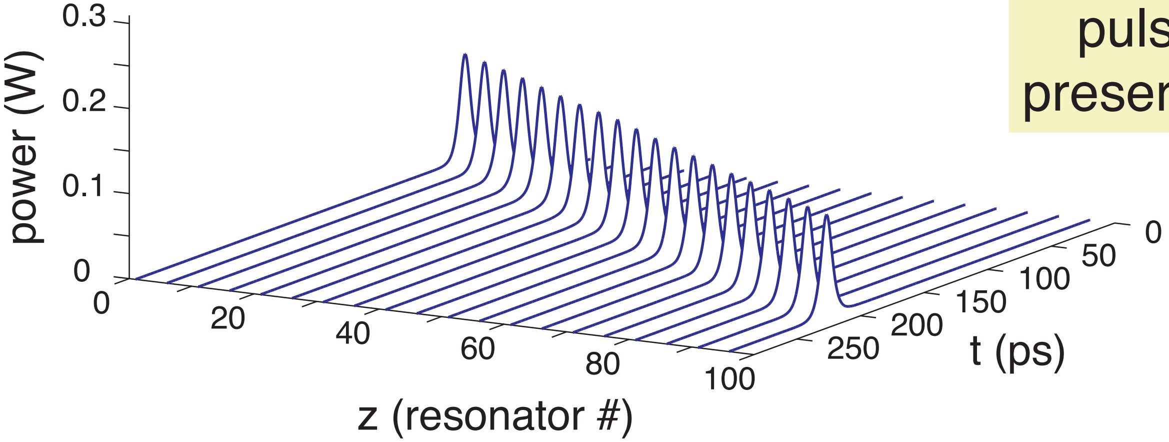
simulation assumes a chalcogenide/GaAs-like nonlinearity

Weak Pulse



pulse disperses

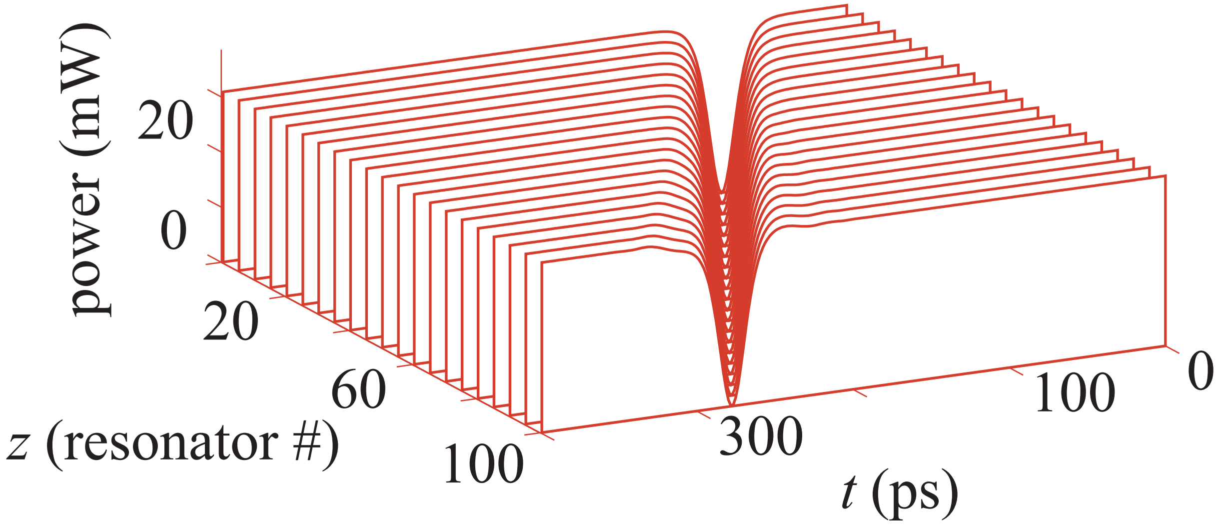
Fundamental Soliton



pulse preserved

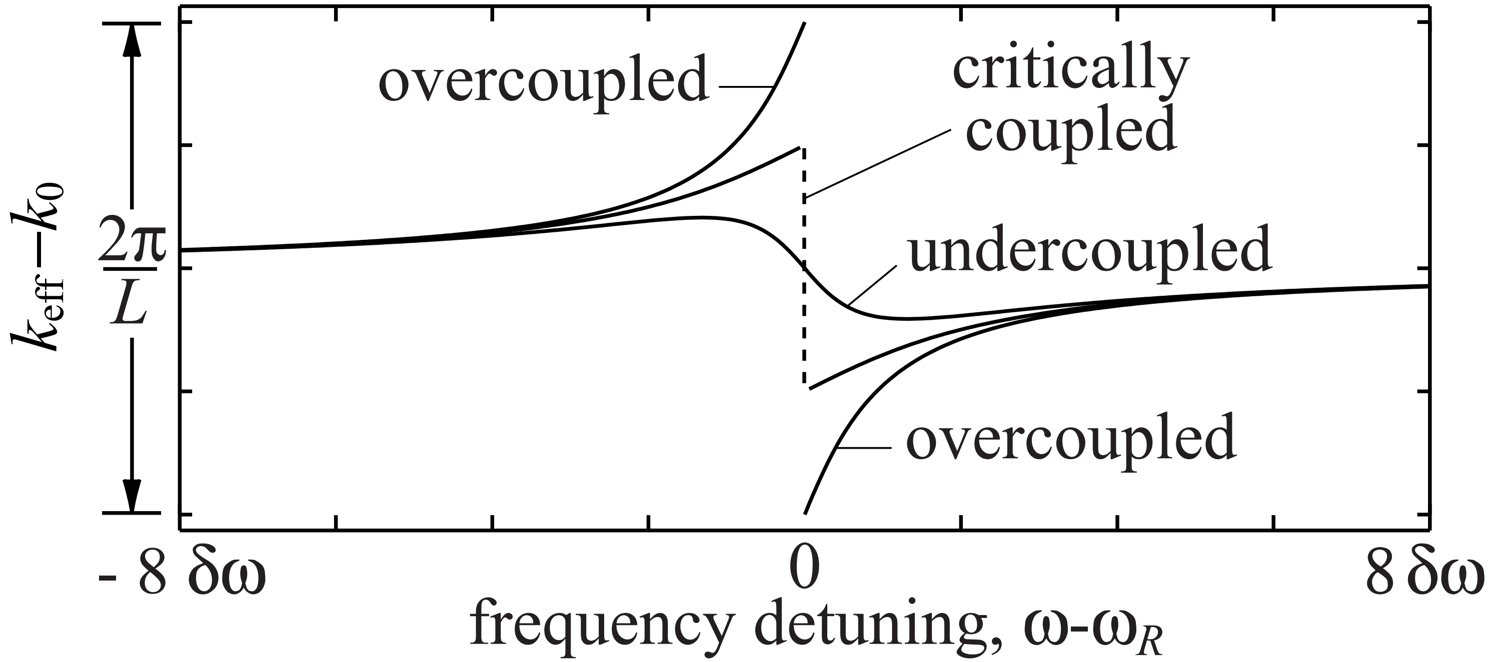
Dark Solitons

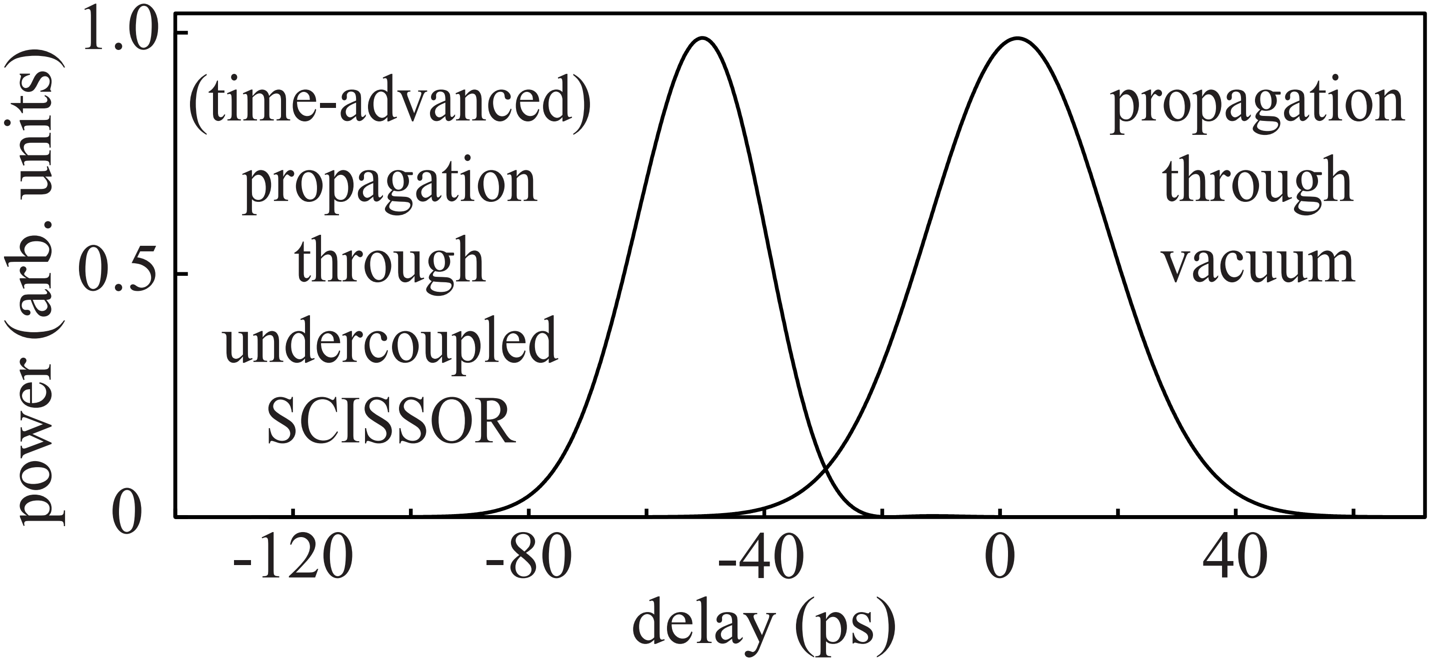
SCISSOR system also supports the propagation of dark solitons.



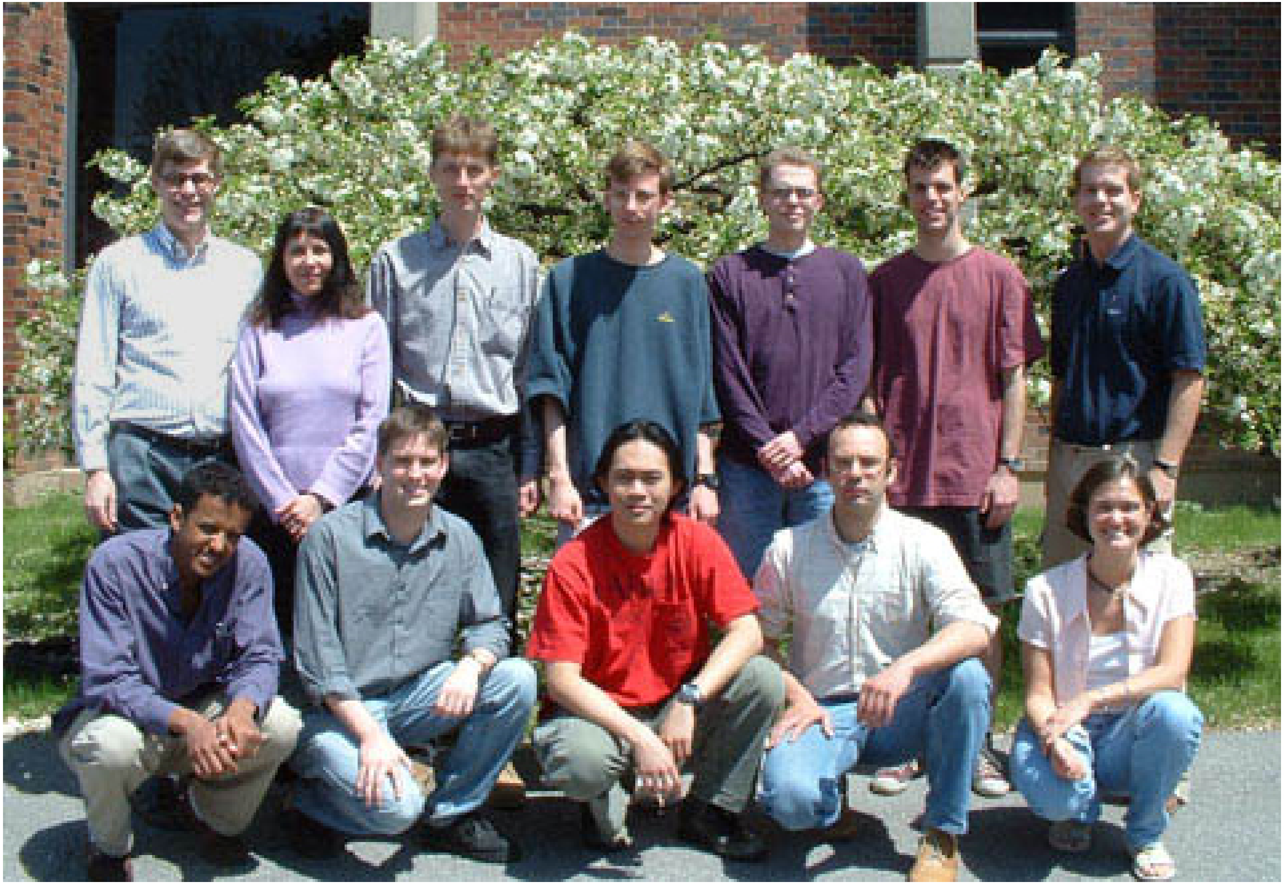
"Fast" (Superluminal) Light in SCISSOR Structures

Requires **loss** in resonator structure



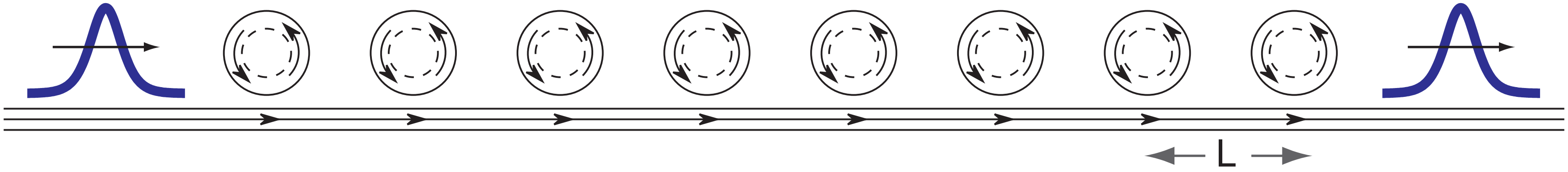


Special Thanks to my Students and Research Associates



Thank you for your attention.

Propagation Equation for a SCISSOR



By arranging a spaced sequence of resonators, side-coupled to an ordinary waveguide, one can create an effective, structured waveguide that supports pulse propagation in the NLSE regime.

Propagation is unidirectional, and there is NO photonic bandgap to produce the enhancement. Feedback is intra-resonator and not inter-resonator.

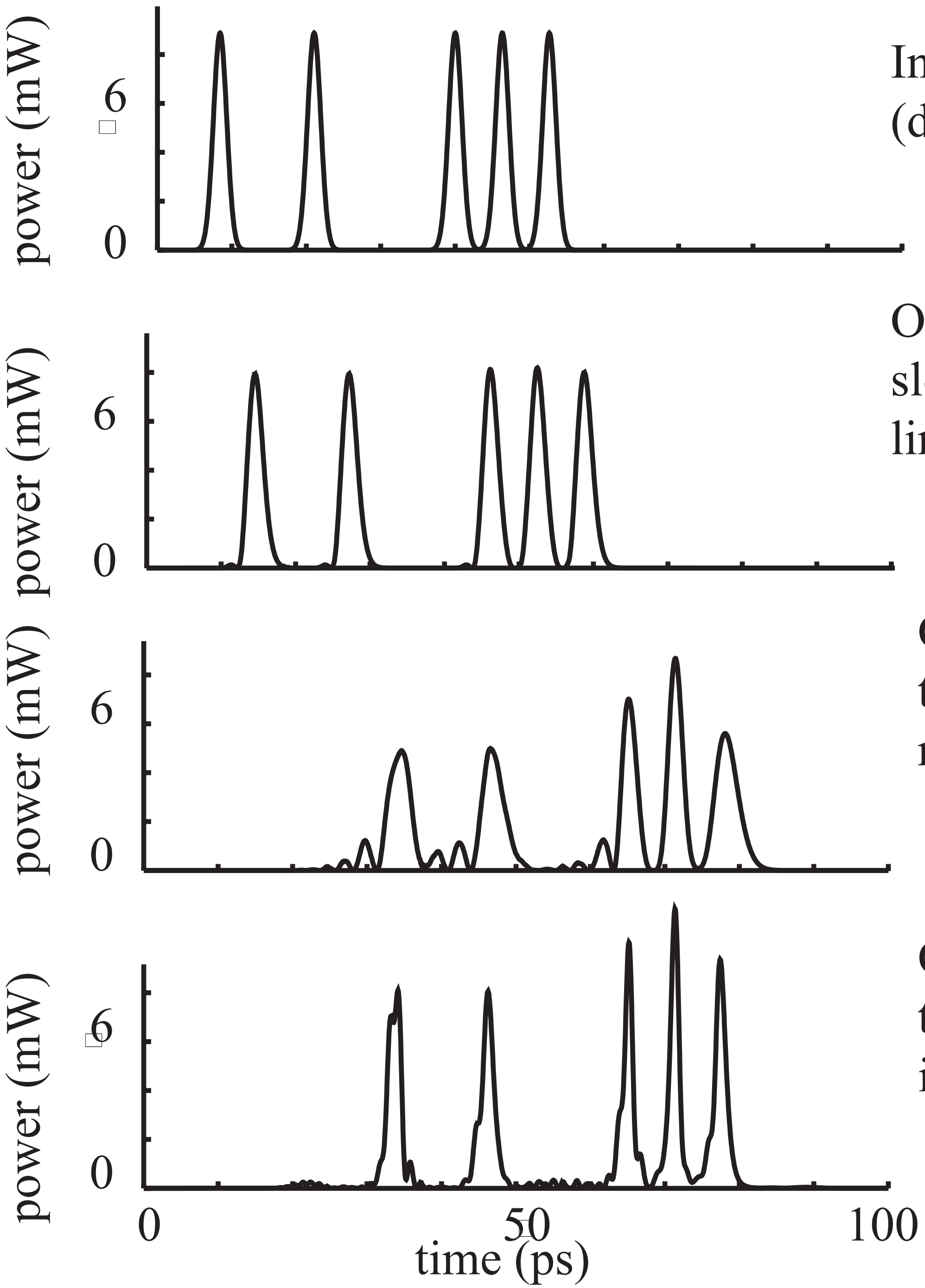
Nonlinear Schrödinger Equation (NLSE)

$$\frac{\partial}{\partial z} A = -i \frac{1}{2} \beta_2 \frac{\partial^2}{\partial t^2} A + i\gamma |A|^2 A$$

Fundamental Soliton Solution

$$A(z,t) = A_0 \operatorname{sech}\left(\frac{t}{T_\mathrm{p}} \right) e^{i \frac{1}{2} \gamma |A_0|^2 z}$$

Performance of SCISSOR as Optical Delay Line



Input
(duty factor = 1/3)

Output --delayed one time slot by six resonators in linear limit

Output --delayed four time slots by 26 resonators in linear limit

Output --delayed four time slots by 26 resonators in nonlinear limit