Tapped Delay Line Filters Using Photonic Crystal Devices

DARPA Analog Optical Signal Processing

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Tapped Delay Line Filters Using Photonic Crystal Devices

- Applications of fiber optics to signal processing
  - tapped delay line architecture
- Comparison of micro-optics to fiber optics for delay lines
  - reduction of loss in micro-optics is essential to practical implementation of compact filters
- Photonic crystal implementation of delay line filters
  - principles and advantages
  - tunable tap implementation
  - fabrication

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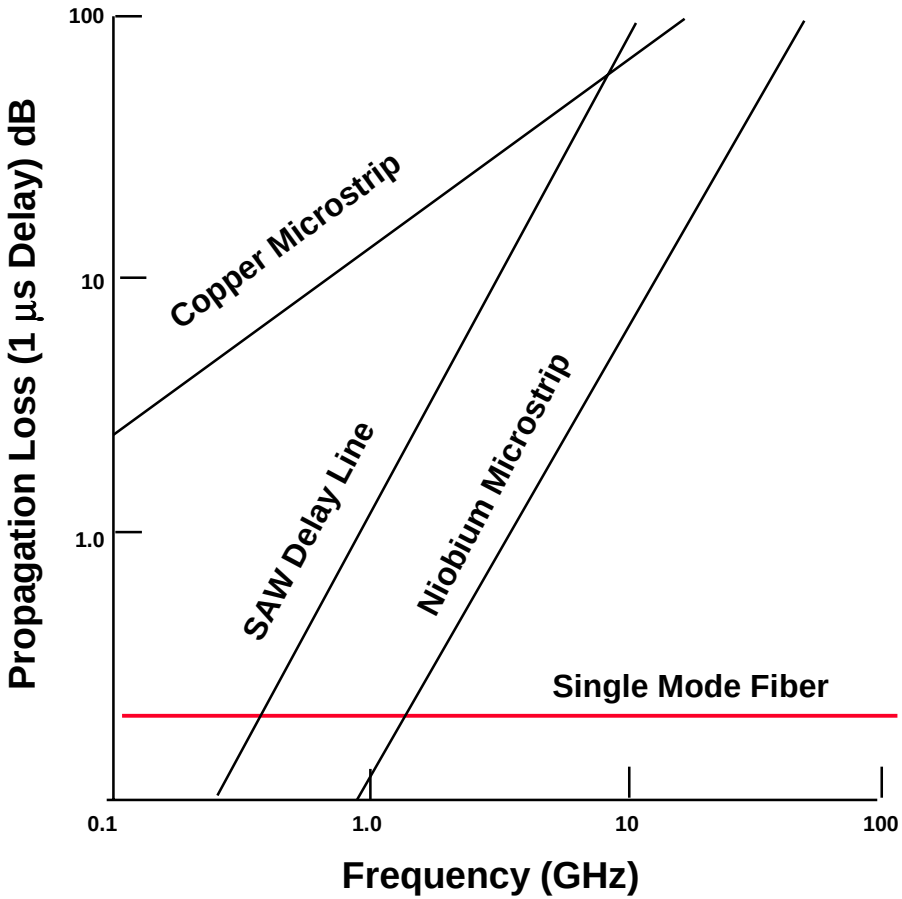
Delay Line Propagation Loss



Jackson, Newton, Moslehi, Tur, Cutler, Goodman, Shaw
IEEE Trans. Microwave Theory and Techniques,
Vol MIT-33, No. 3, March 1985

Photonic Implementation

- **Dispersion**
  - **Very low, controllable**
  - **ps pulses propagate many km**
- **Transmission loss**
  - **Small (~ 0.1 dB/km in fiber)**
  - **Independent of bandwidth**
- **Fractional bandwidth is negligible**

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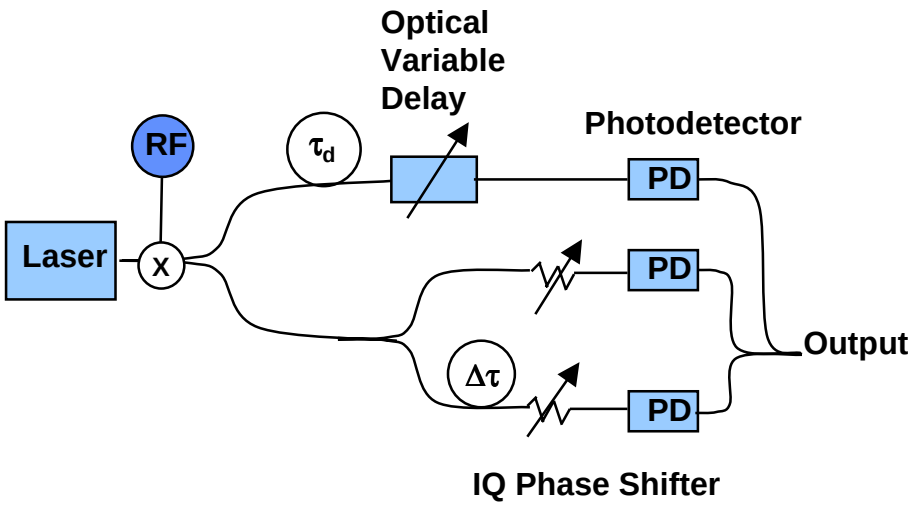
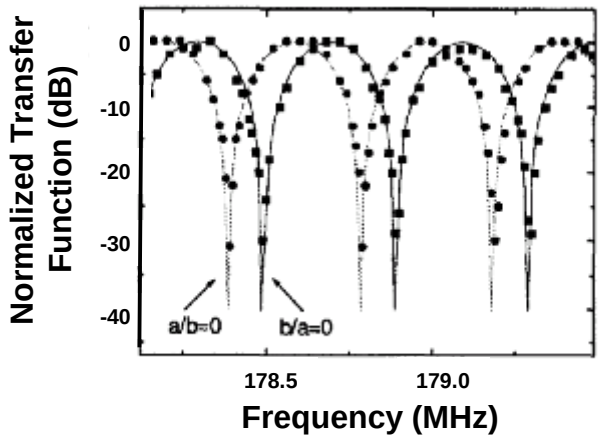
Tunable Notch Filter





τ_d = 2.5 μs, 500 m of fiber

F. Coppinger, S. Yegnanarayanan, P.D. Trinh, and Jalali
IEEE Photonics Techn. Lett. Vol. 9, No. 3, March 1997

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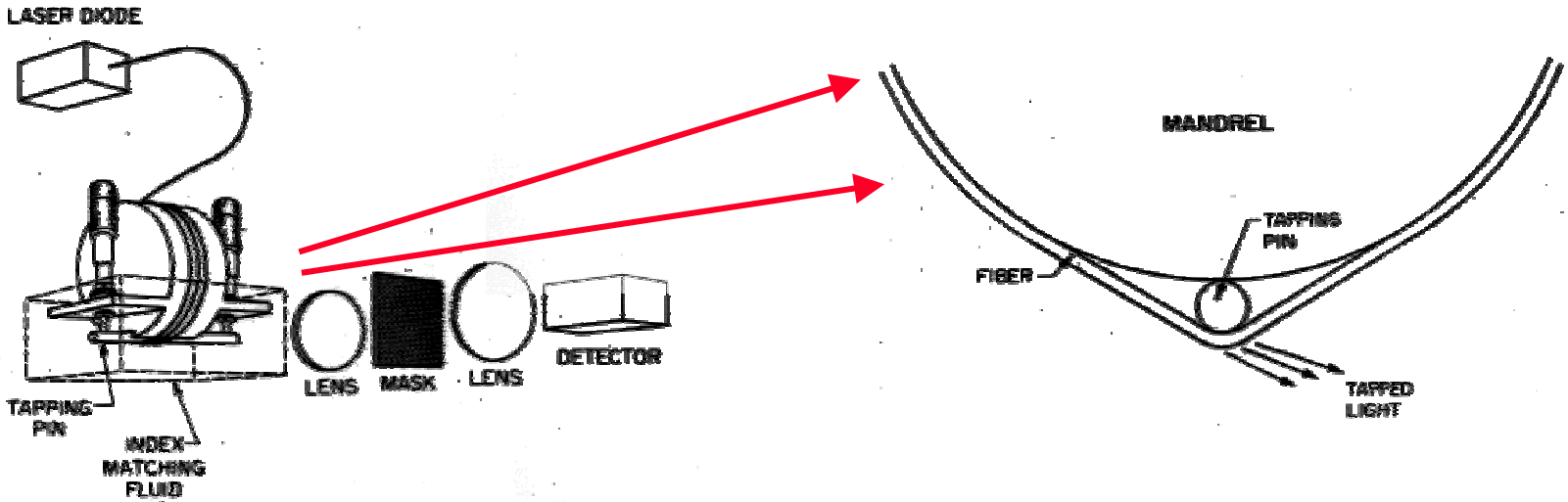
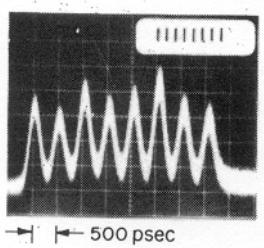
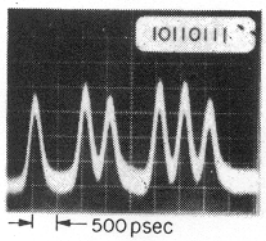
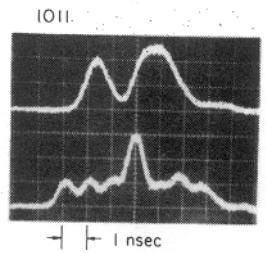
Macrobend Tapped Delay Line Filter

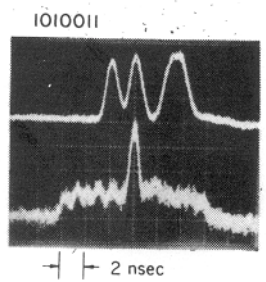






Code Generator





Matched Filter

Jackson, Newton, Moslehi, Tur, Cutler, Goodman, Shaw
IEEE Trans. Microwave Theory and Techniques,
Vol MIT-33, No. 3, March 1985

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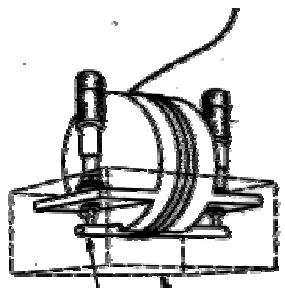
Delay Line Implementation Techniques

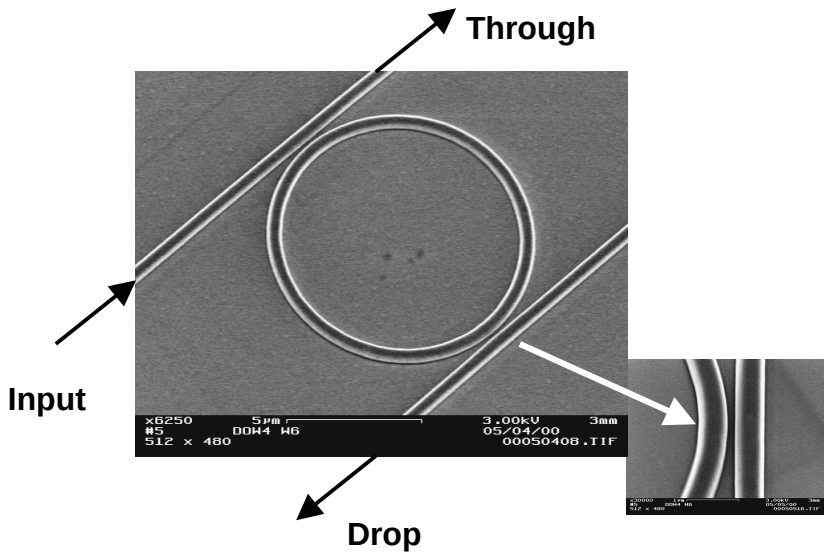
Fiber optic

- glass fiber
- broadband
- large and heavy
- complex assembly
- low loss, 0.1 dB/km

Micro-optic

- silicon, silica, polymers
- broadband
- small and lightweight
- mass production
- higher loss, 0.1 dB/cm





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The Case for Microphotonics

- **Size and weight**
  - **scale feature size using state-of-the-art lithography**
  - **monolithic integration of waveguides and silicon digital logic**
  - **hybrid integration of laser sources**
- **Speed and power**
- **Cost**
  - **economies of scale in IC fabrication**
  - **reduction in size and weight**

- **Problems**
  - **loss in waveguides**
  - **bending loss limits compact implementation**
- **Proposed solution**
  - **photonic crystal implementation**
  - **silicon substrate, IC fabrication techniques**

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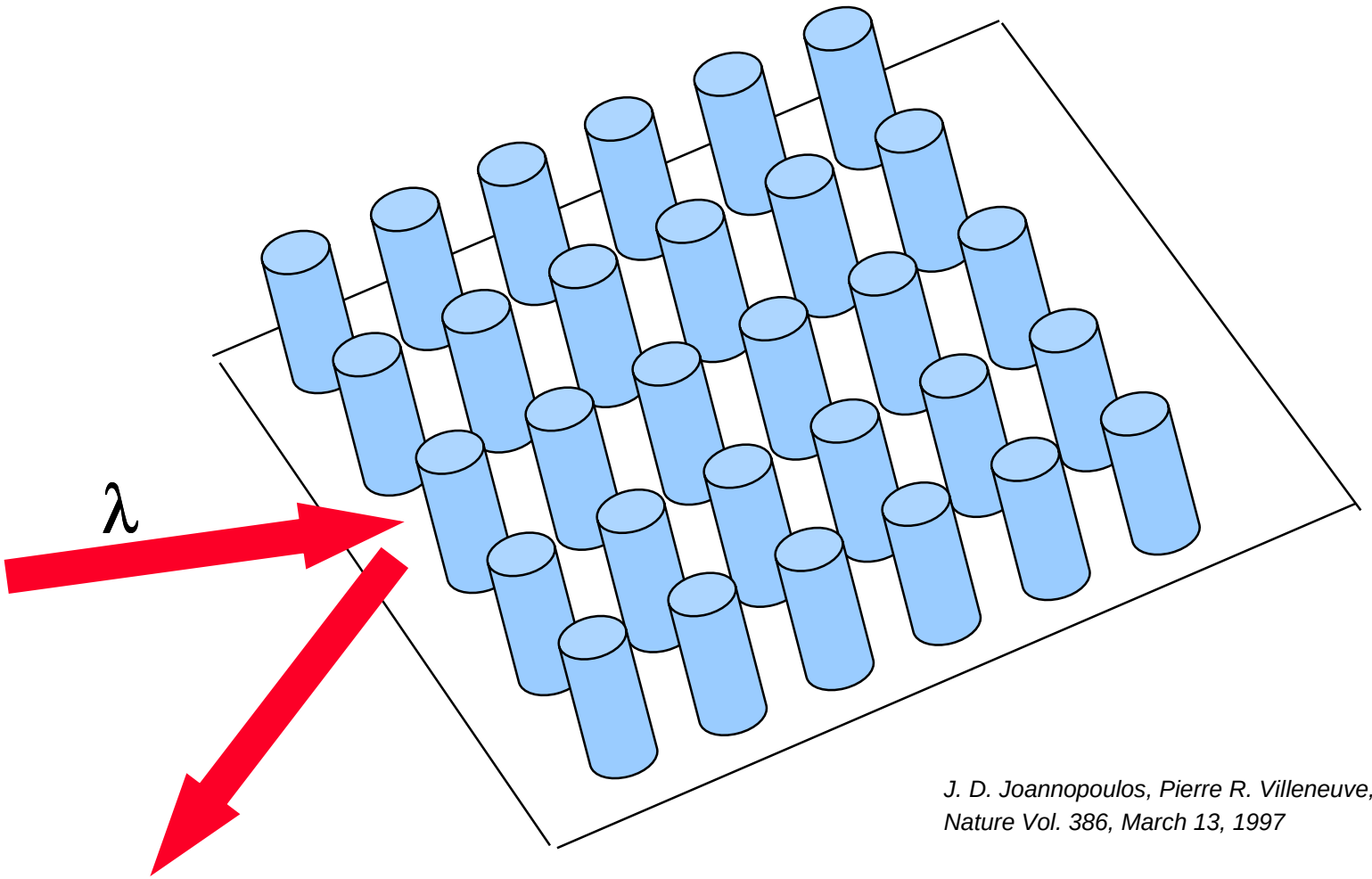
Photonic Crystal

Periodic Dielectric - Photonic Bandgap



J. D. Joannopoulos, Pierre R. Villeneuve, and Shanhui Fan
Nature Vol. 386, March 13, 1997

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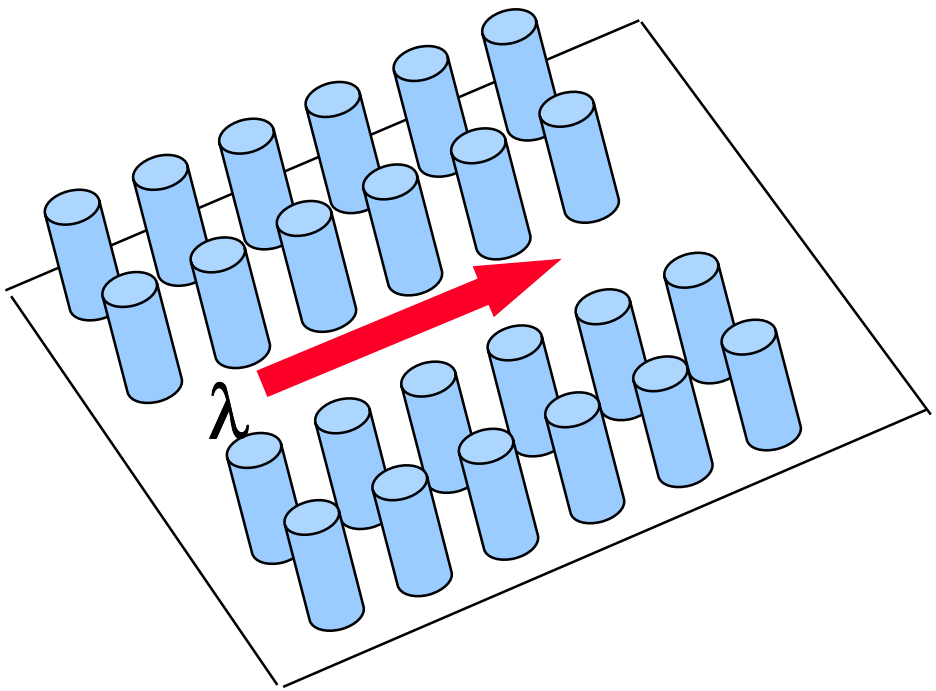
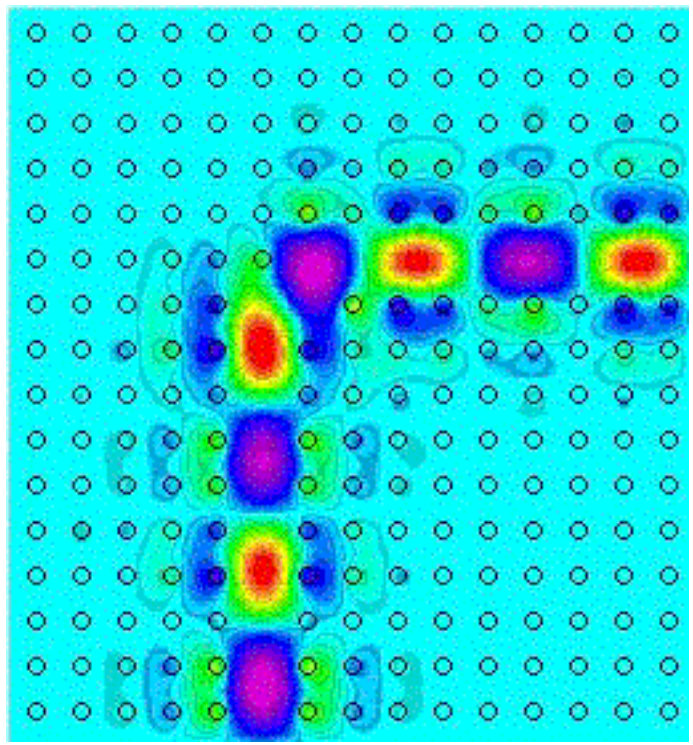
Photonic Crystal Waveguide





Attila Mekis, J. C. Chen, I. Kurland, Shanhui Fan, Pierre R. Villeneuve, and J. D. Joannopoulos
Phys. Rev. Lett. Vol 77, No. 18, October 28, 1996

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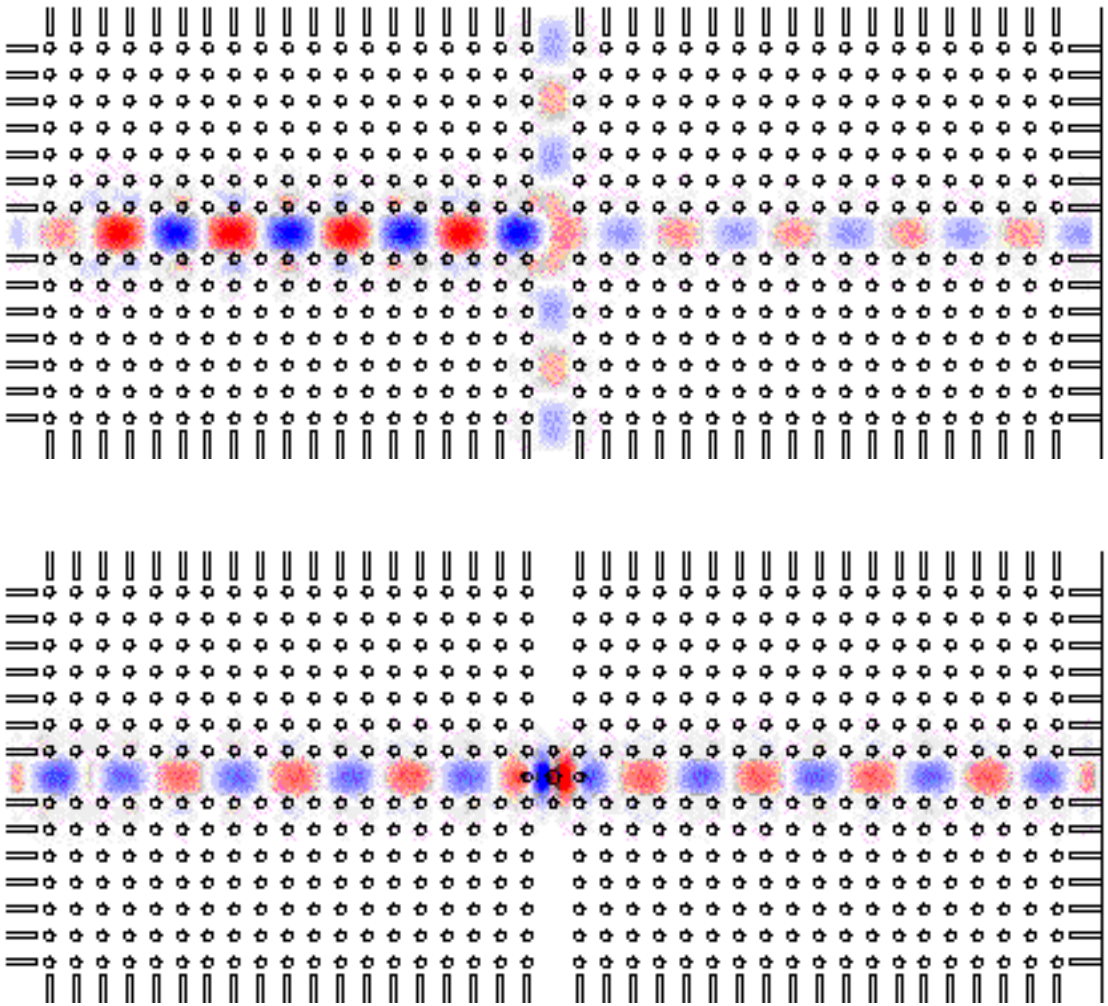
Crosstalk Reduction Using Photonic Crystal Resonators



Johnson, Manolatou, Fan, Villeneuve, Joannopoulos Optics Letters, Dec 1998

http://ab-initio.mit.edu/photons/cross.html

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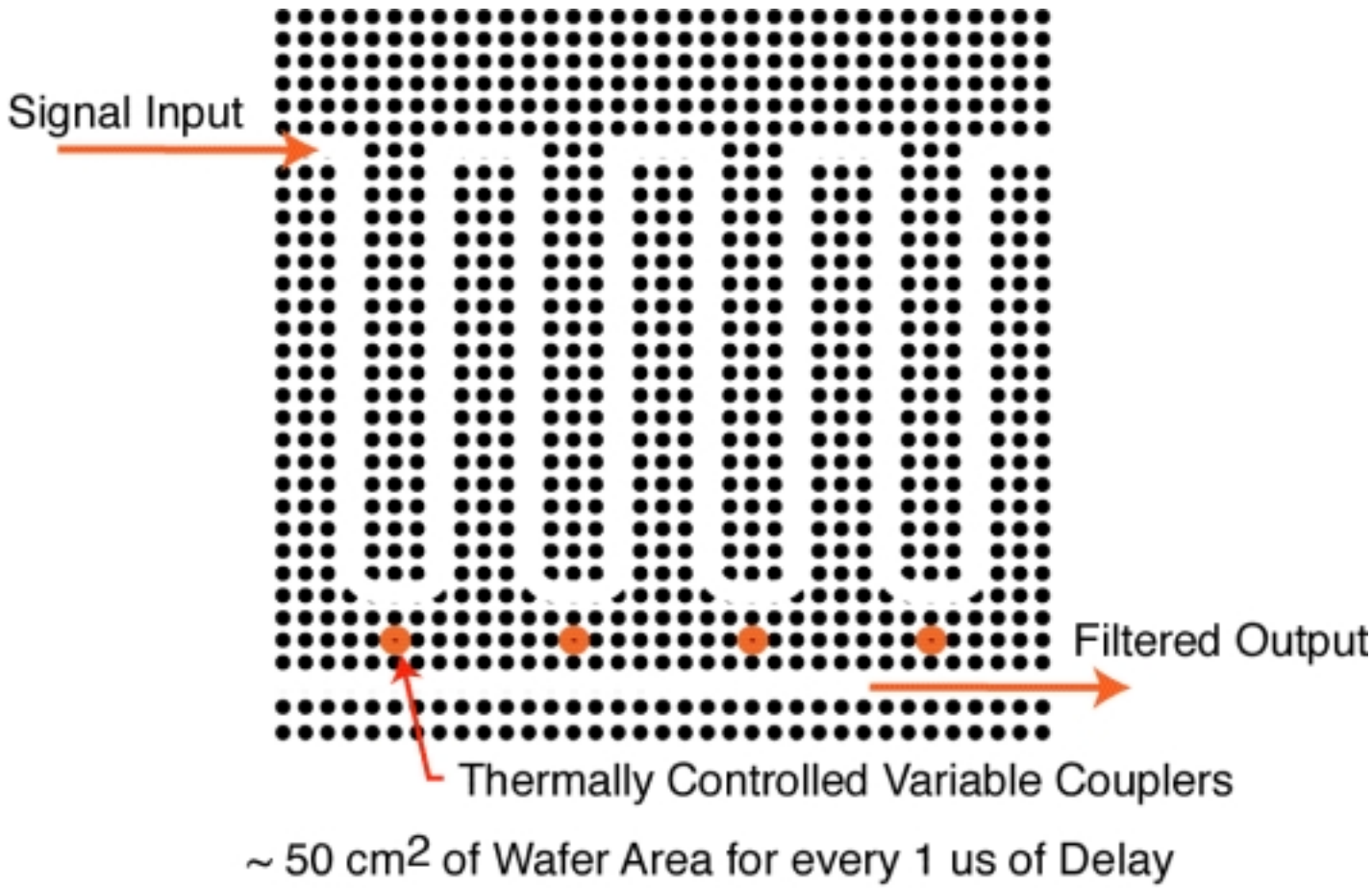
Tapped Delay Line Filter
RF Signal Modulated on Optical Carrier



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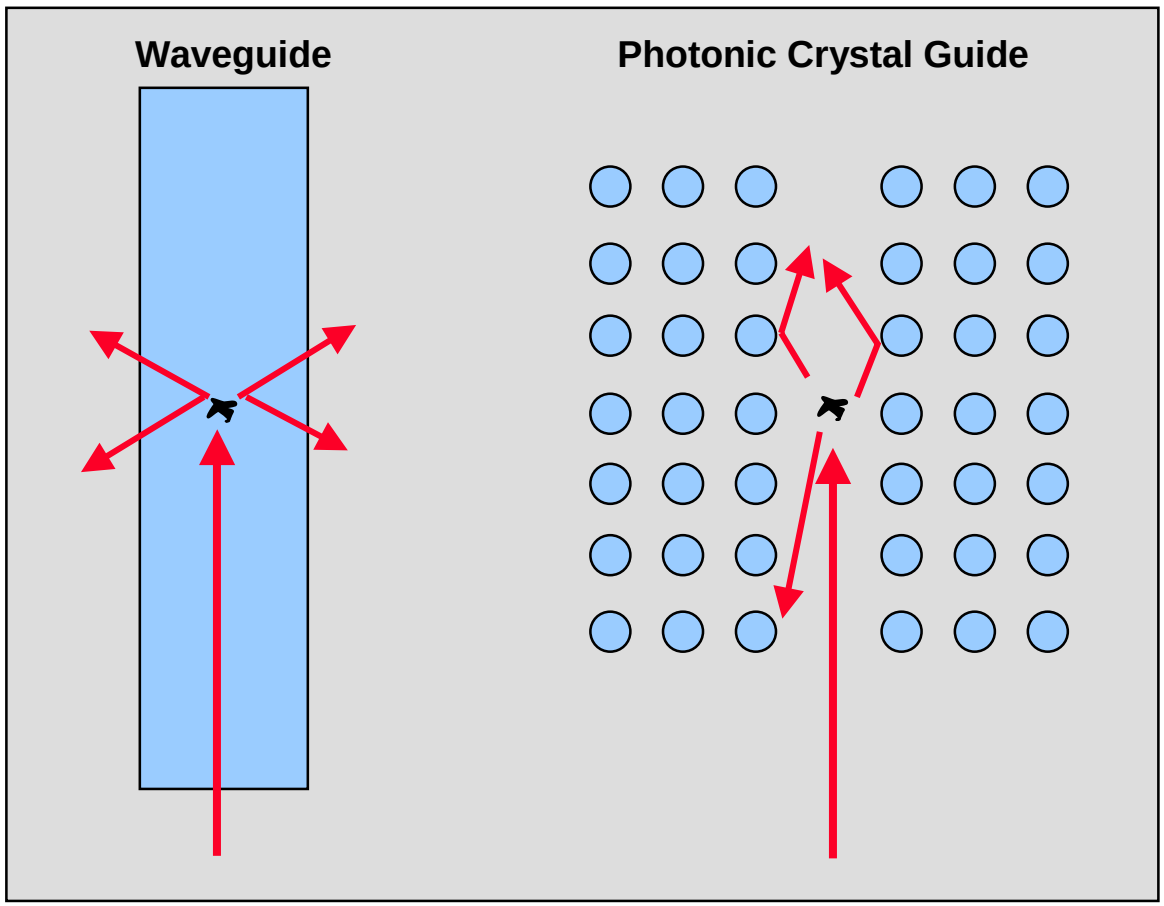
Optical Losses
Waveguide vs Photonic Crystal



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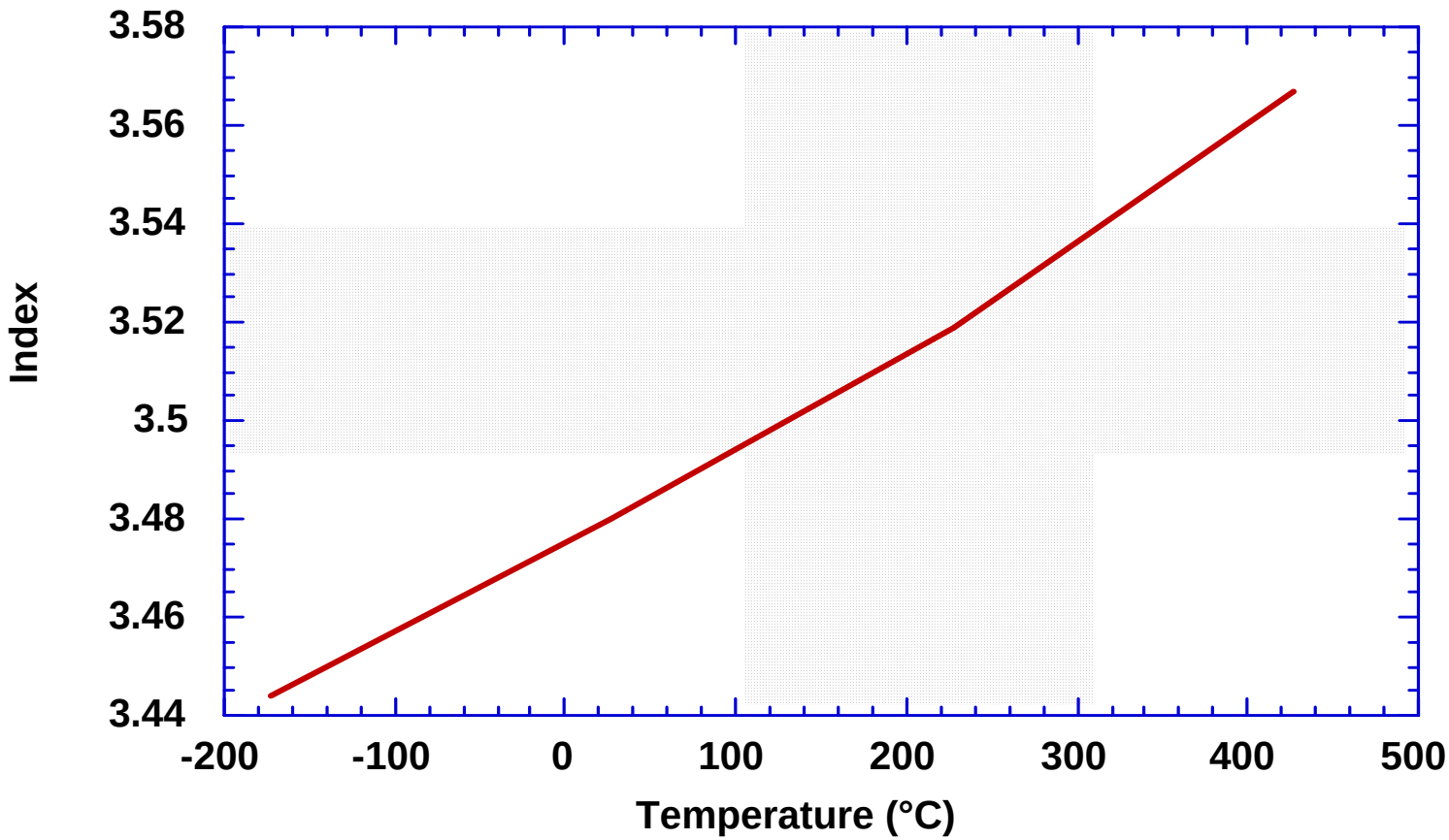
Optical Index of Silicon at 1.55 µm
Feasibility of Thermally Tuned Devices



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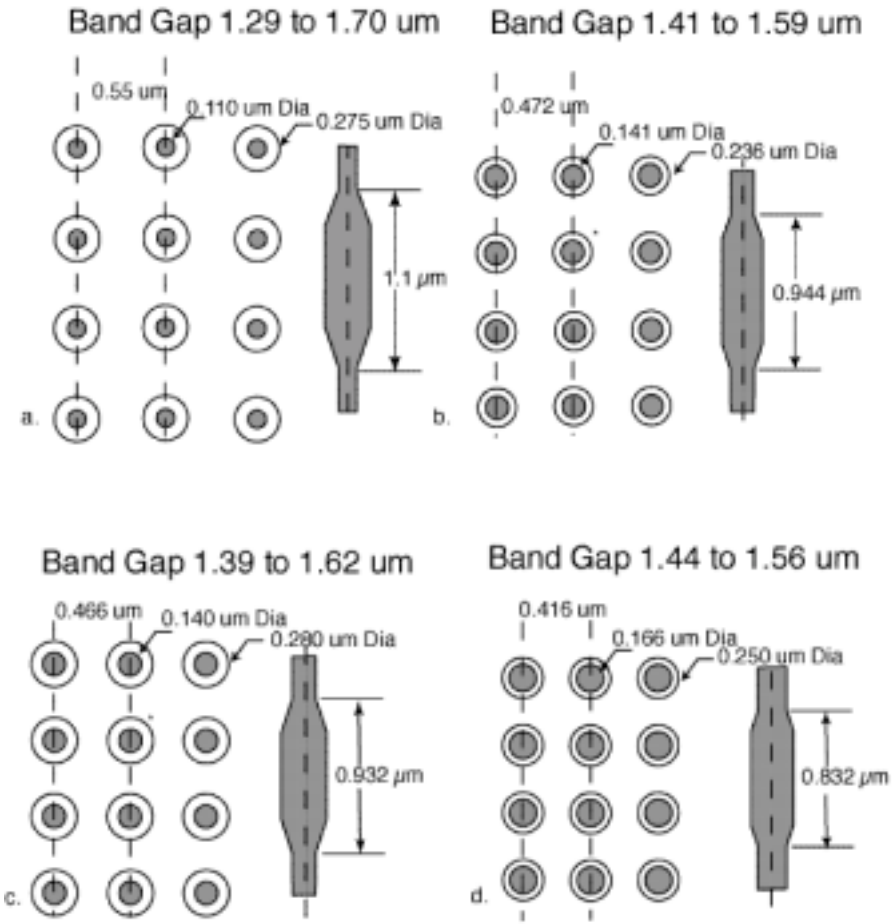
Photonic Crystals and Band Gap Calculations for Silicon Substrates



Result of J. Joannopoulos' MIT Group and Lincoln

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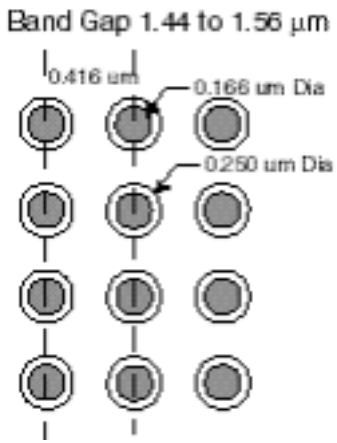
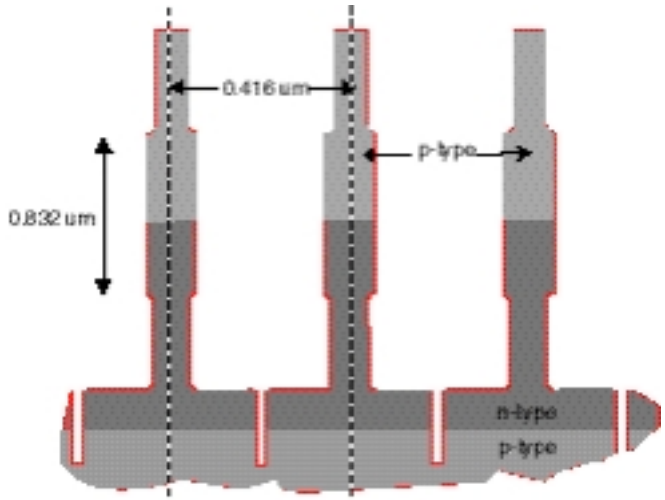
Silicon Photonic Crystal Array



2-D array specifications



Array cross section
- **3-D confinement**
- **resistive heating**
- **diode isolation**

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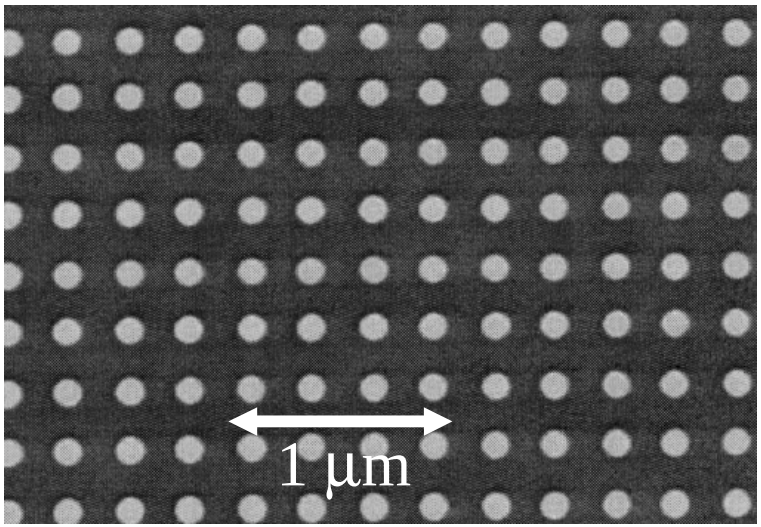
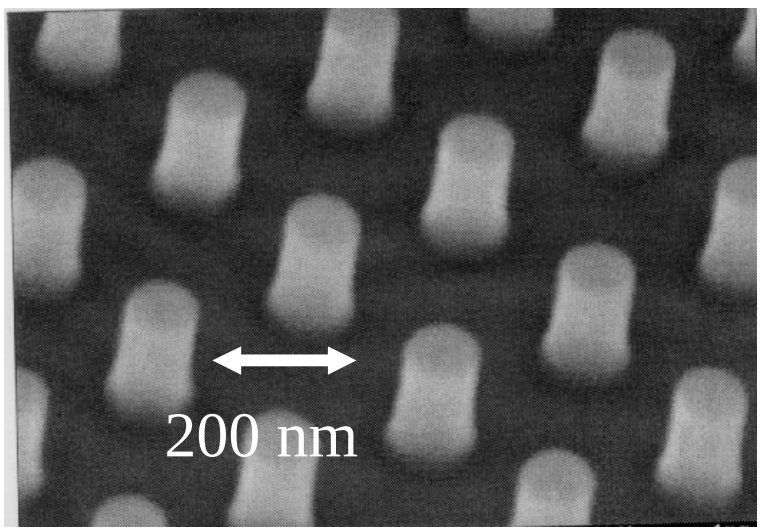
Nano-Pillar Structures: 248 nm phase-shift lithography capabilities





Method:

Crossed double exposure of phase-shift gratings

High density plasma etch into amorphous-silicon

CD = 100 nm
Pitch = 300 nm
Density: 11 pillars/μm^2

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Summary

- Photonics offer wideband signal processing opportunities
- Tapped delay line flexible architecture for RF filters
- Photonic crystal implementation
  - potential for low loss, compact realization
  - adjustable tap weights using localized heating
  - fabrication using commercial IC technology, low cost

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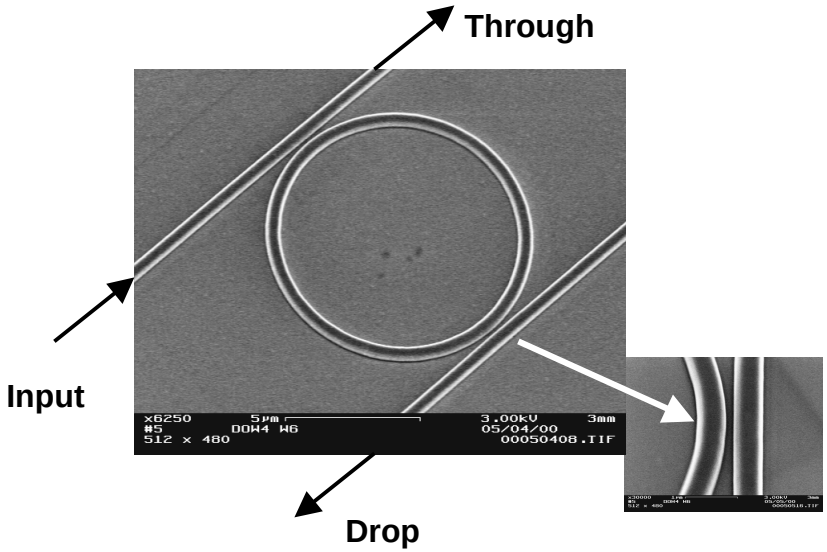
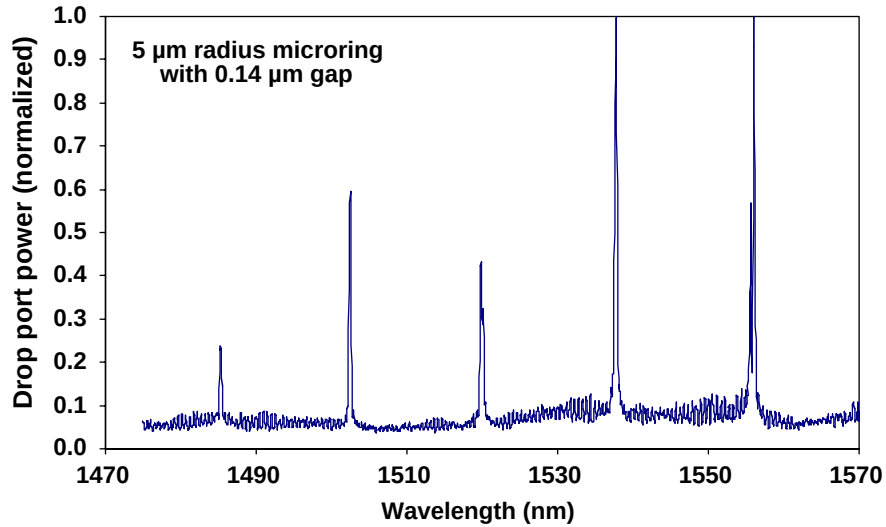
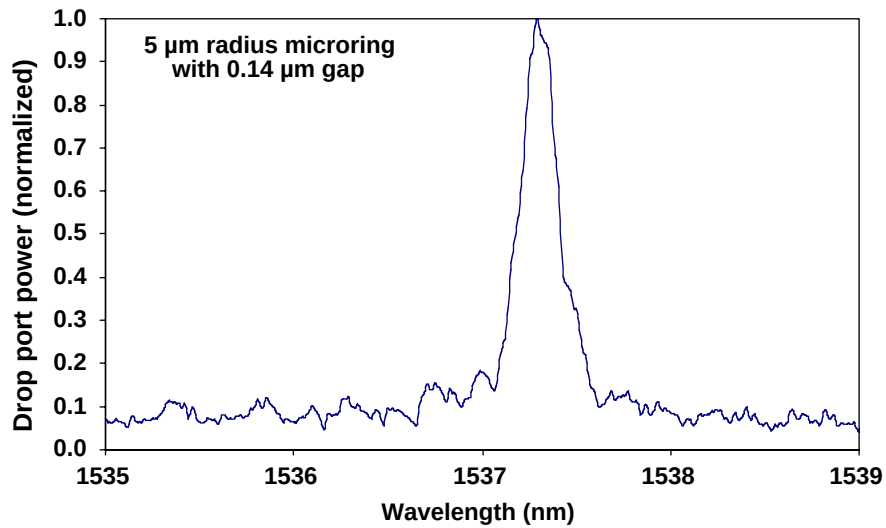
10 µm Diameter PolySi Microring Resonator

Channel Dropping Filter







- Q~7000
- Free spectral range = 17.9 nm
- Coupling gap = 144 nm

Maki, et al

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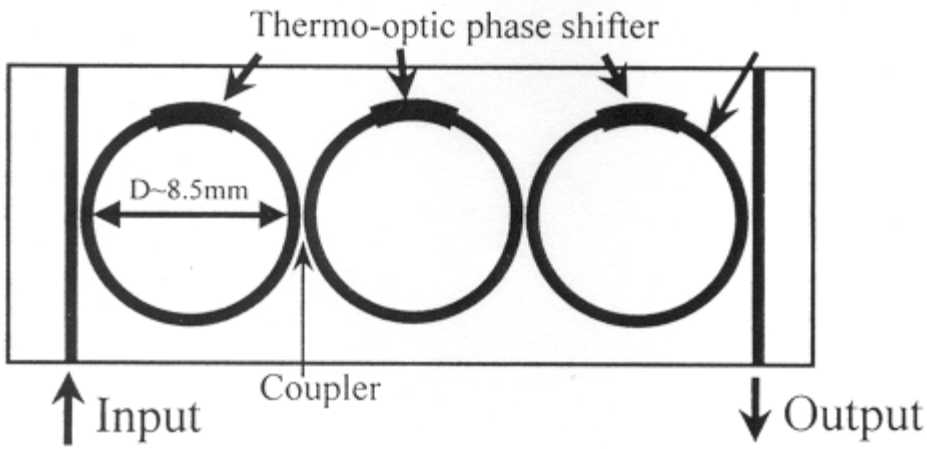
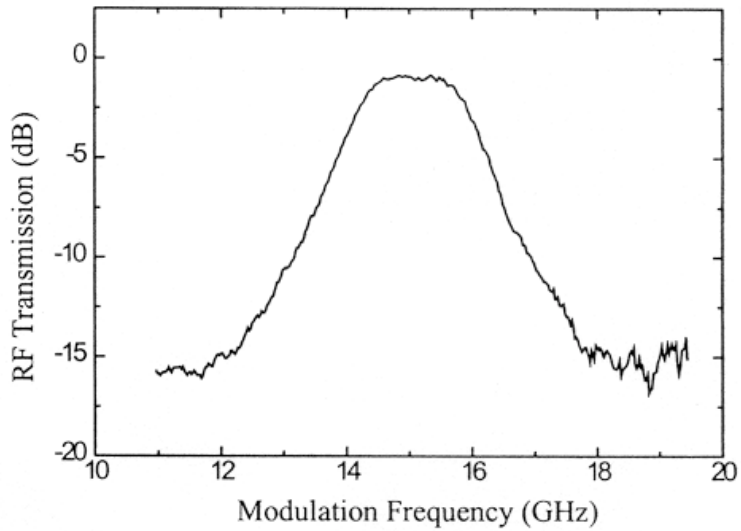
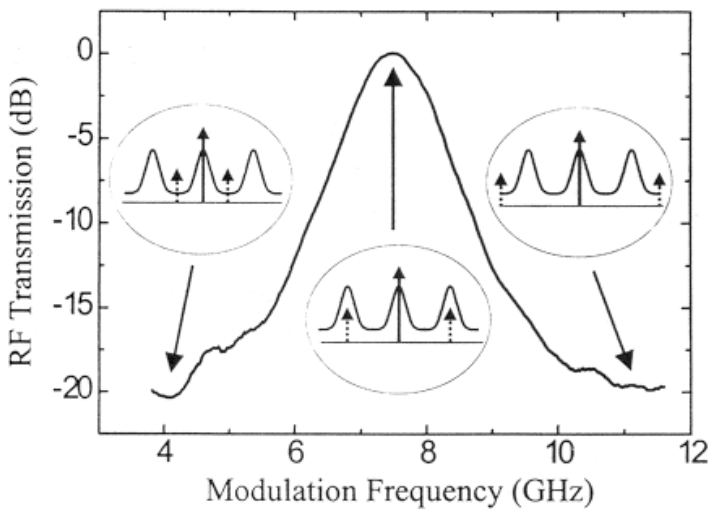
Photonic Microwave Filter

Silica Coupled Ring Resonators







F. Coppinger, C. K. Madsen, and B. Jalali
Microwave and Optical Technology Letters
Vol. 21, No. 2, April 20, 1999

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