

Nanophotonics for On-Chip Integration of WDM Systems

DARPA WDM Workshop
April 18–19, 2000



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Motivation

Microprocessors

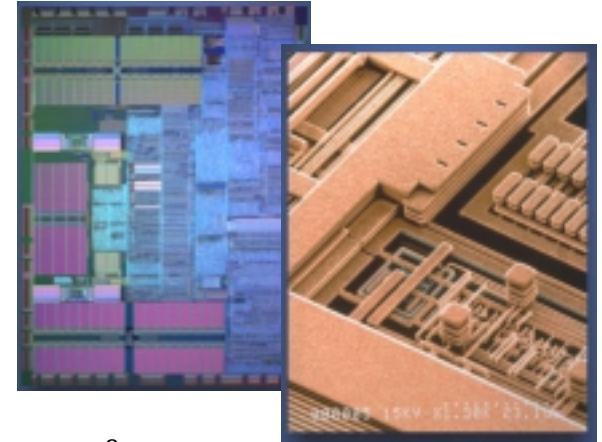
IBM Mark I (1944)



~1000 instructions/sec



PowerPC 750™ Chip (1999)



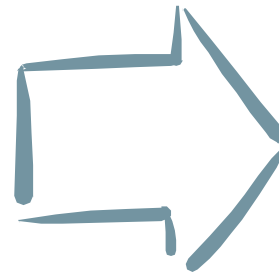
~10⁹ instructions/sec

Optical Networks

Monterey 20000 Series
Wavelength Router (1999)



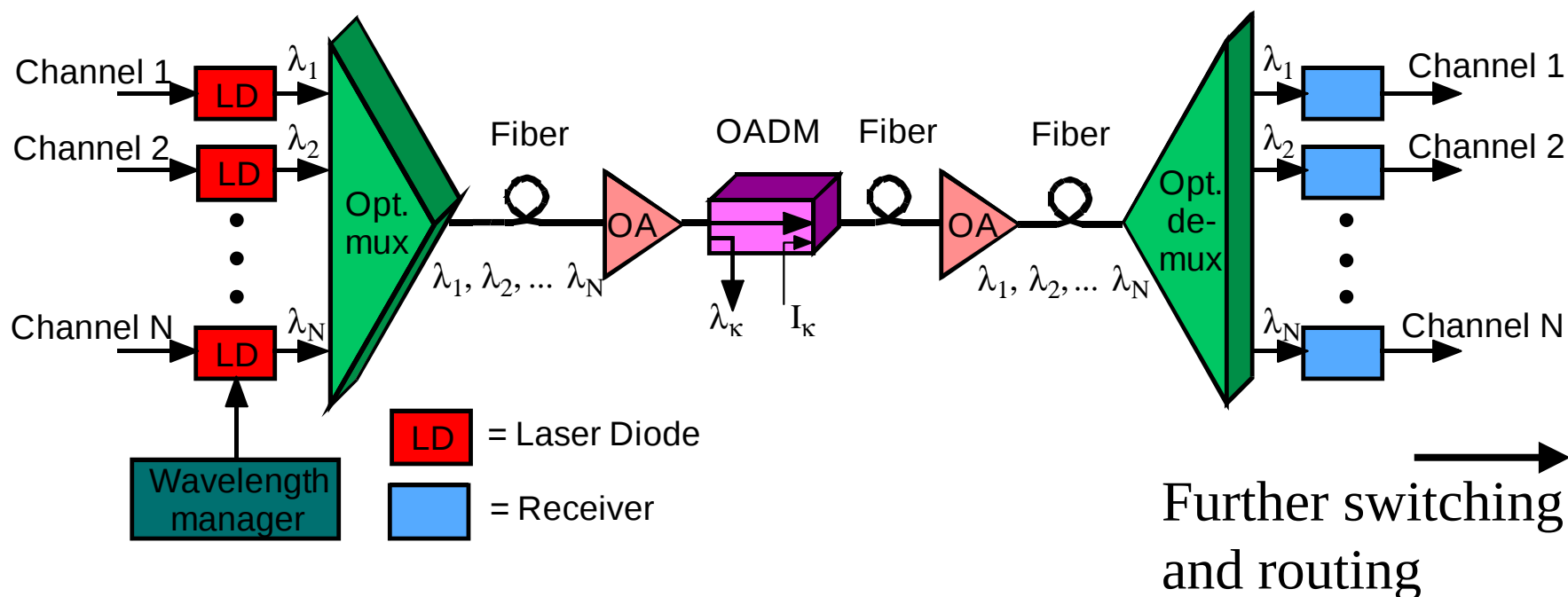
256x256 OC-48 (2.5 Gb/sec)



?

Typical DWDM Point-to-Point Link with Add/Drop Capability

Even simple functionality requires complex hardware realization

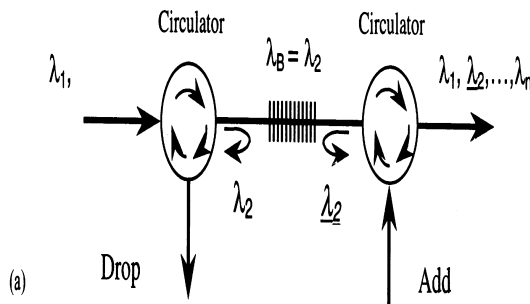


Challenges:

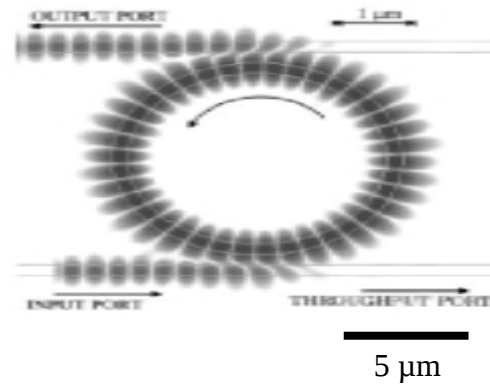
- Integration
- Manufacturability
- Size
- Weight
- Cost

Add/Drop Filter

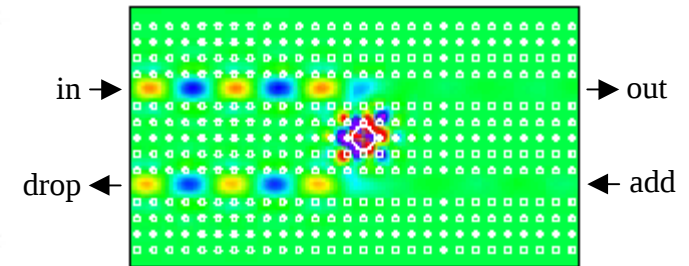
Fiber grating/free space



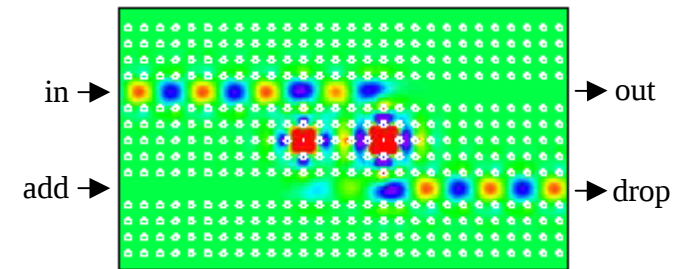
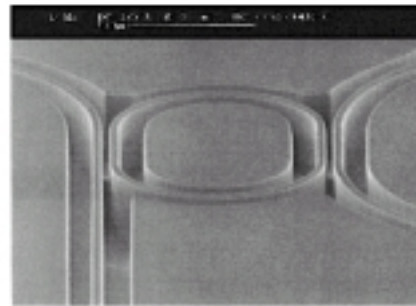
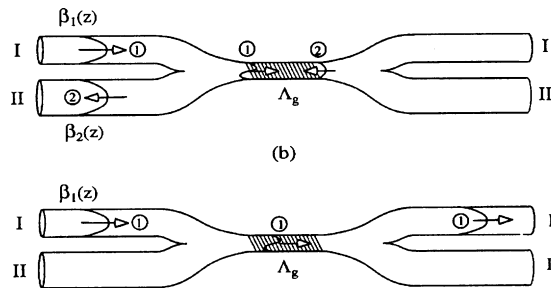
Waveguide^{2,3}



Photonic crystal⁴



All fiber¹



1. A. S. Kewitsch, *et al.*, "All-fiber zero-insertion-loss add-drop filter for wavelength-division multiplexing," *Opt. Lett.* **23**, 106–108 (1998).
2. B. E. Little, *et al.*, "Ultra-compact Si-SiO₂ microring resonator optical channel dropping filters," *IEEE Photonics Technology Letters* **10**, 549–551 (1998).
3. M. K. Chin, *et al.*, "GaAs microcavity channel-dropping filter based on a race-track resonator," *IEEE Photonics Technology Letters* **11**, 1620–1622 (1999).
4. Shanhui Fan, *et al.*, "Channel drop tunneling through localized states," *Phys. Rev. Lett.* **80**, 960–963 (1998).

Nanotechnology for Scalability and System Integration

Microprocessors

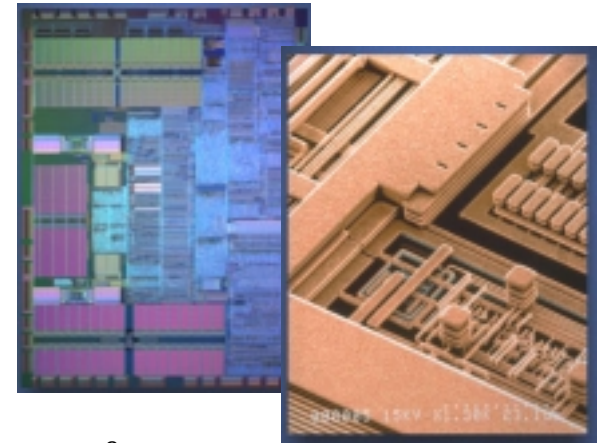
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~1000 instructions/sec



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Optical Networks

Monterey 20000 Series
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256x256 OC-48 (2.5 Gb/sec)



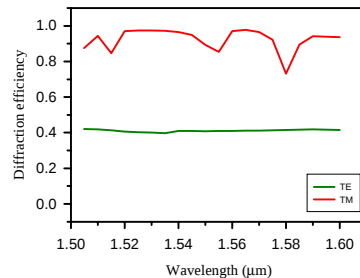
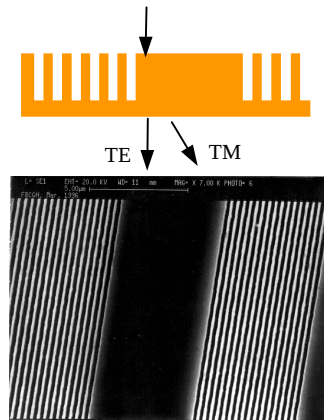
Next-Generation Photonic Chips

- Higher performance
- Greater functionality
- Better reliability
- Improved manufacturability
- Smaller size
- Lower cost

Artificial Dielectric Optical Nanostructures: Materials and Devices

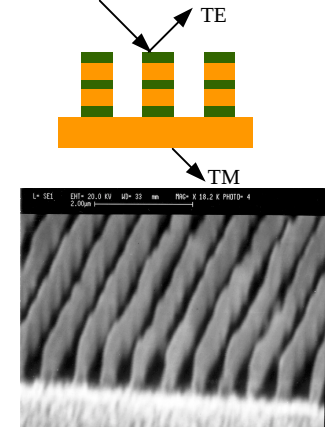
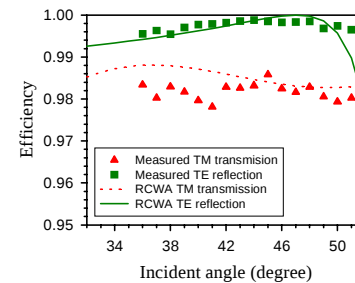
Form Birefringent Computer Generated Hologram :

Multi-functionality and arbitrary phase profile

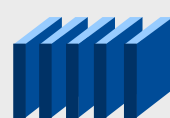
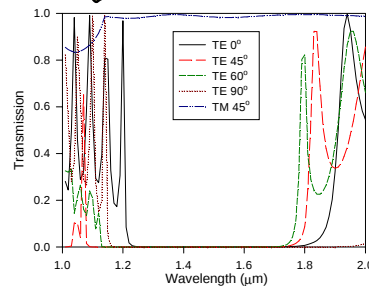
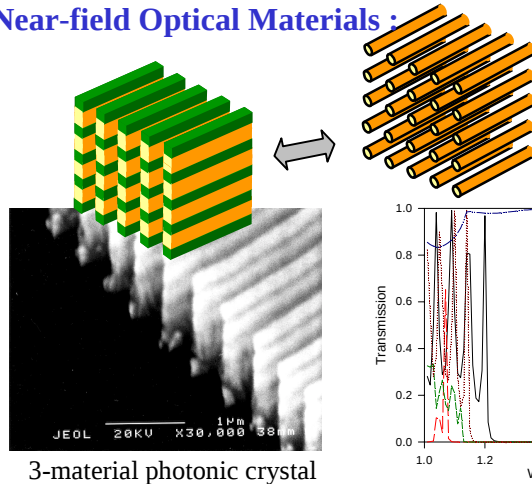


Anisotropic Spectral Reflectivity Polarization Optics :

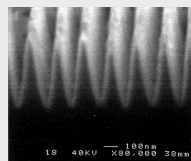
Large spectral and angular bandwidth, compact size, and normal incident operation



Near-field Optical Materials :



Near-field interactions modify bulk material properties

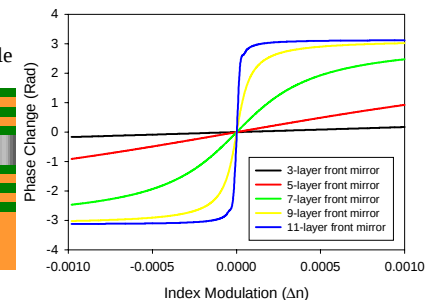
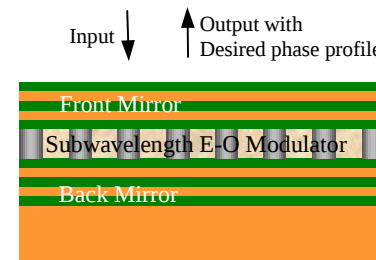


Experimental example* :

Material : GaAs
Incident wavelength = 920 nm
Grating period = 200 nm
Grating depth = 490 nm
Phase difference $\Delta\phi = 162.5^\circ$
 $\Rightarrow \Delta n/n = 0.47$

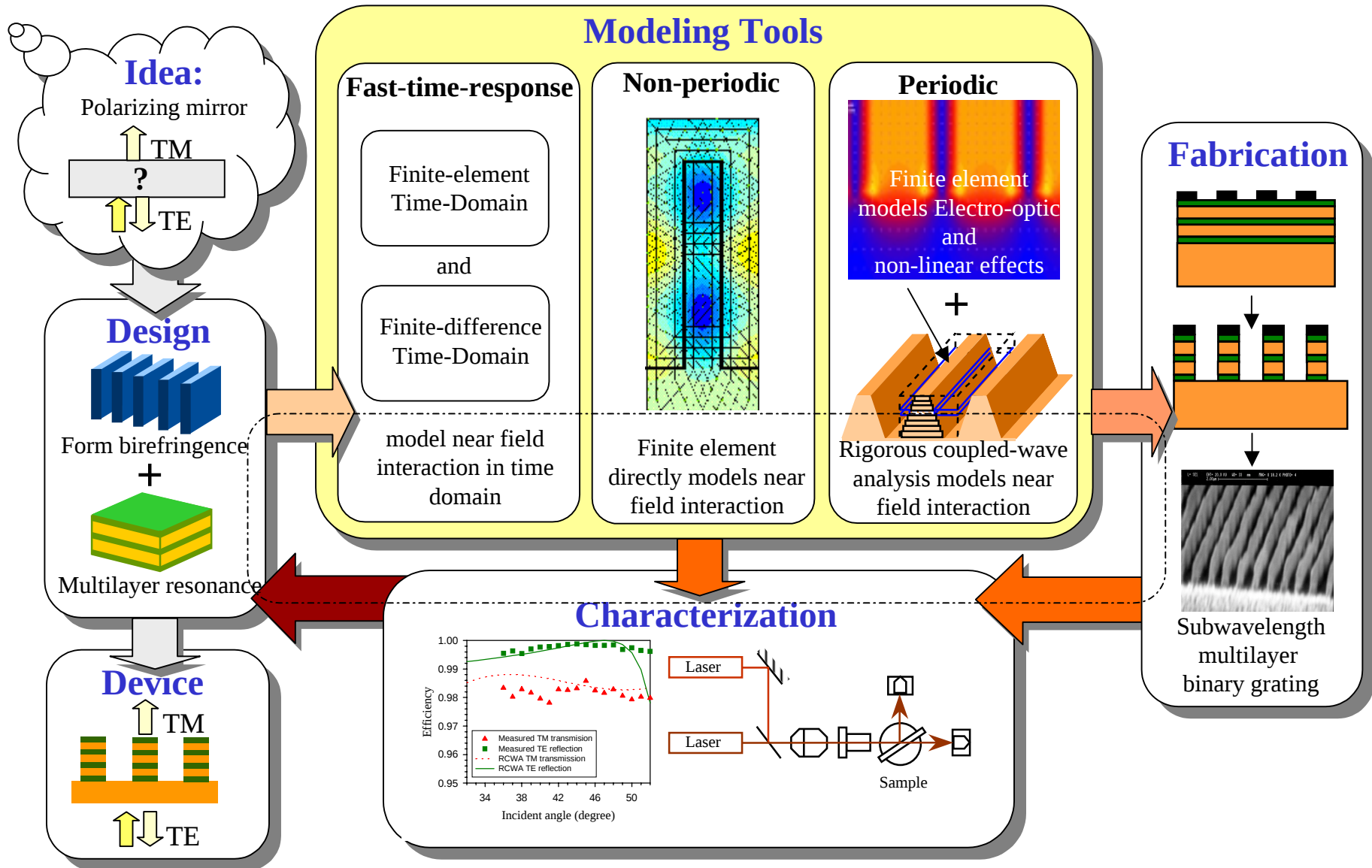
Near Field Programmable Diffractive Optical Element :

Low voltage, compact size
and programmability



fabricated in collaboration with Prof. Axel Scherer, CalTech

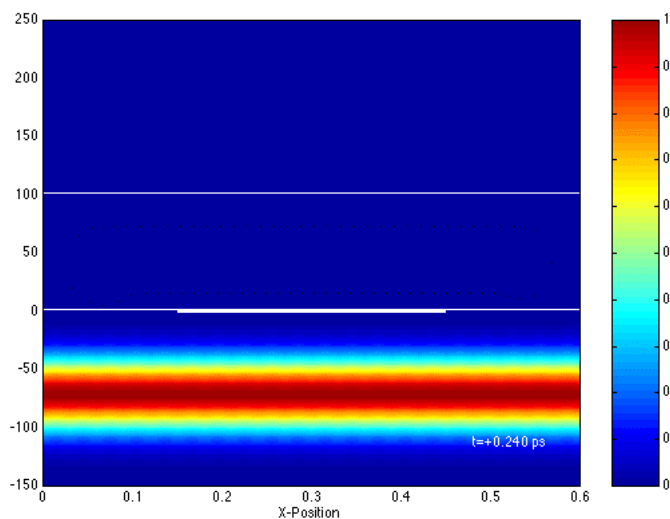
Near-field Nanophotonics: Methodology



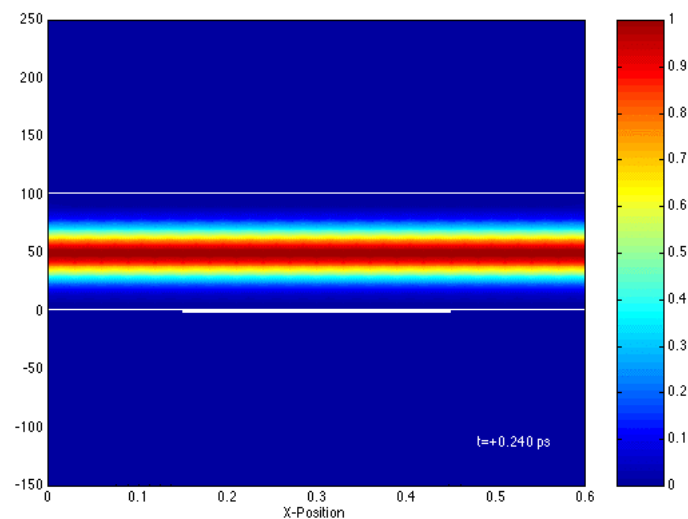
Visualization of Modeling Results

TE Polarization

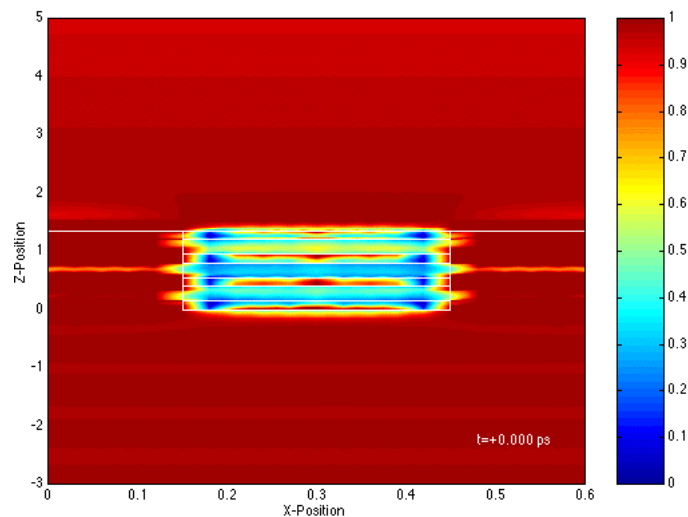
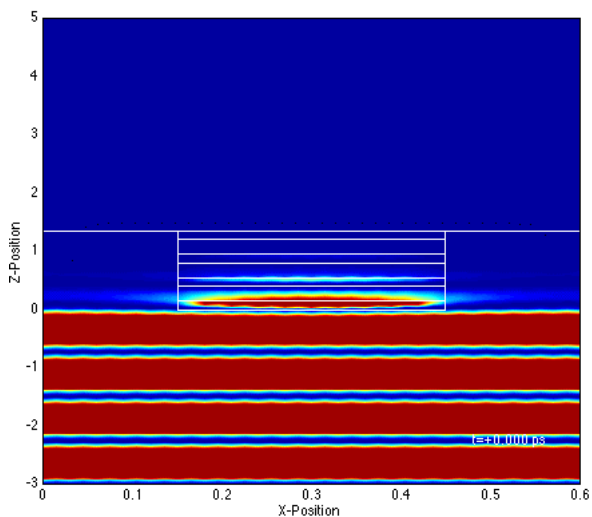
Wide
view



TM Polarization

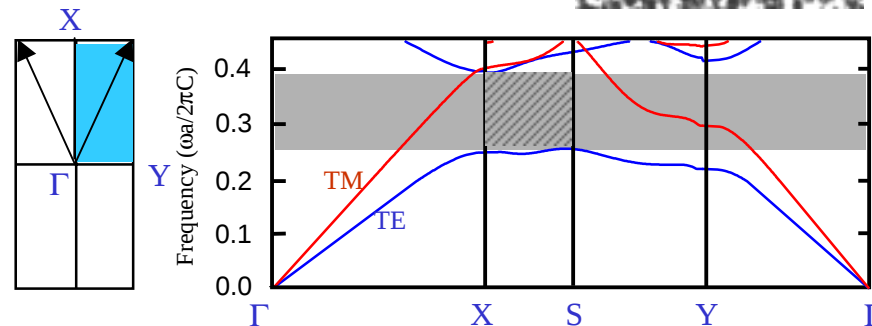
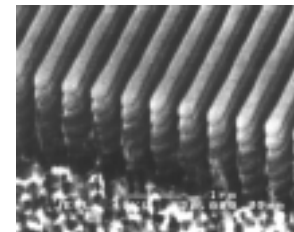


Zoom
view

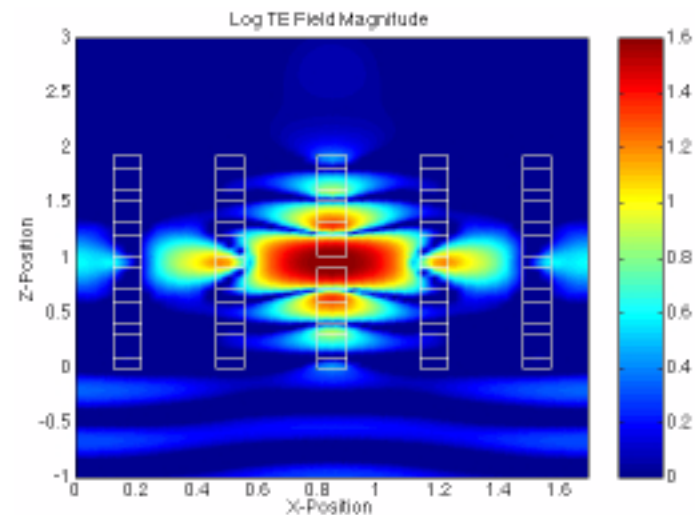
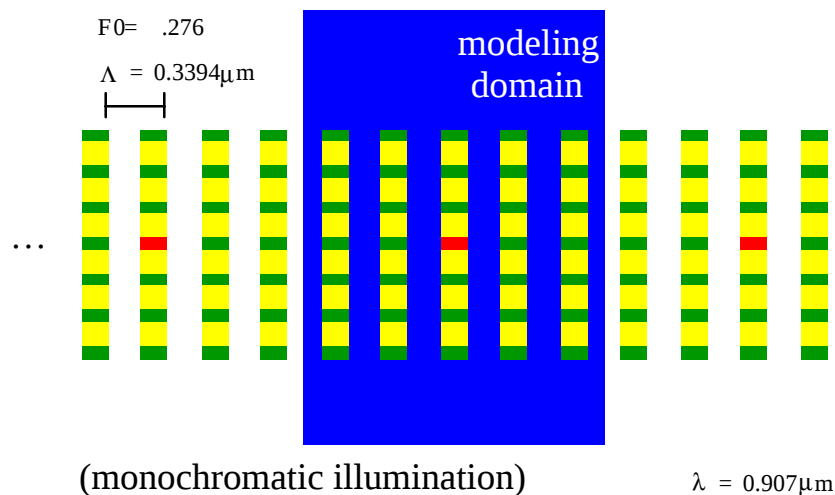


2-D Photonic Crystals using Artificial Dielectric Nanostructures

Implement 2-D PC using multilayer AD:



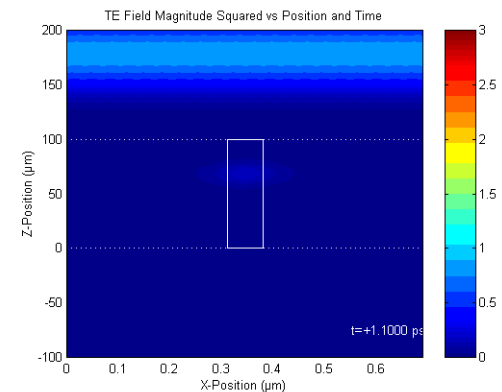
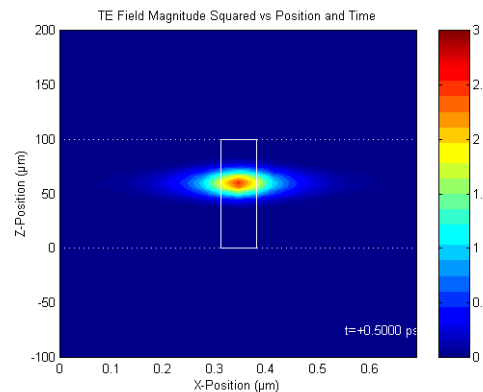
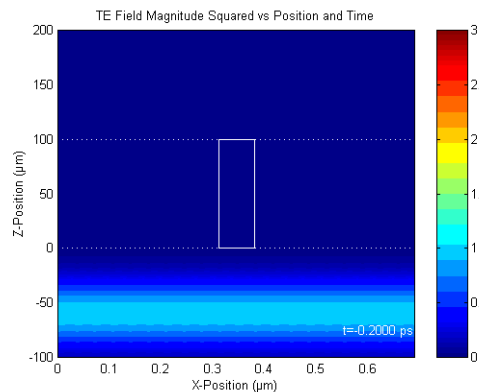
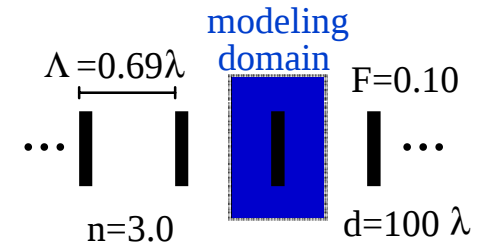
Defects in PC structure:



Transverse Field Localization for Optical Nonlinearity Enhancement

Enhancement of nonlinear processes:

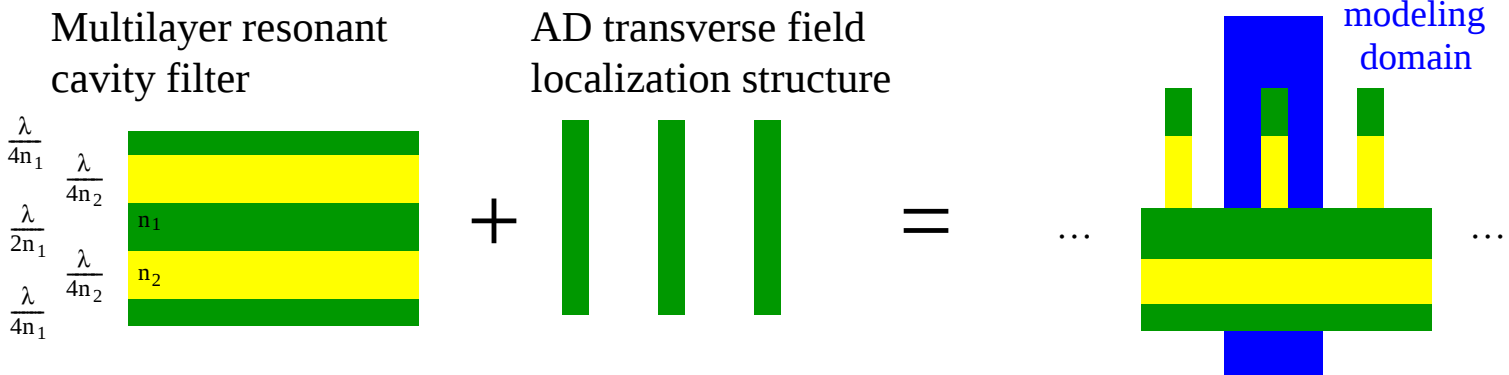
- temporal field localization (ultrashort pulse)
- transverse spatial field localization
- large nonlinear coefficients are typically found in high refractive index materials



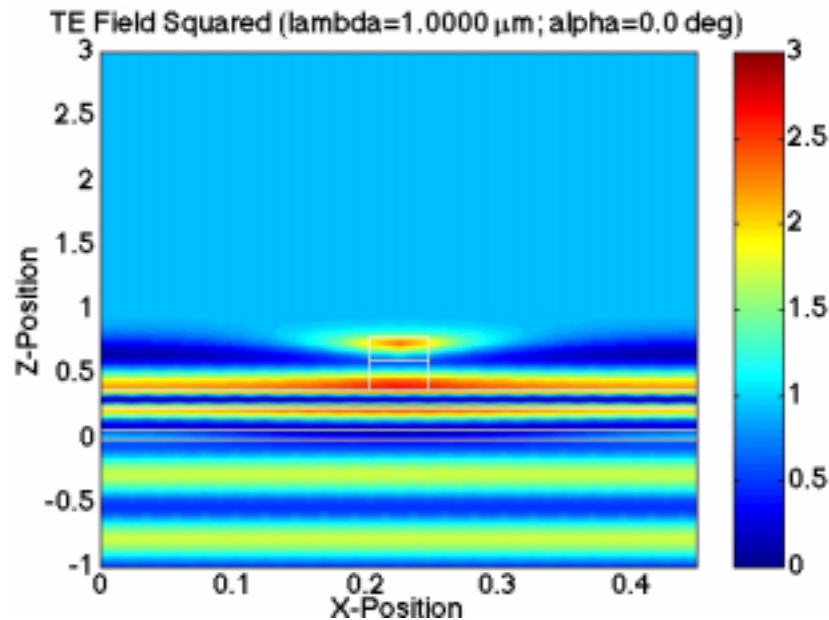
Approach:

- Array of coupled waveguides with single allowed mode result in transverse field localization in high index region
- Peak intensity is ~ 10 times that of bulk material

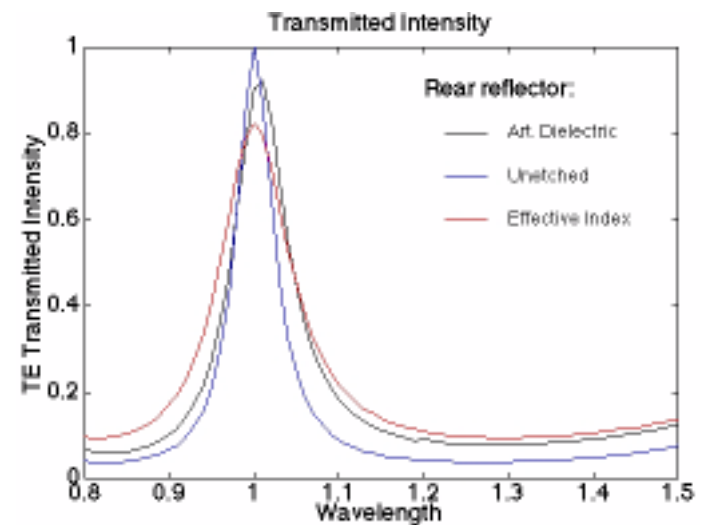
Multifunctional Artificial Dielectric Nanostructure Device



Transverse field localization



Transmitted Intensity



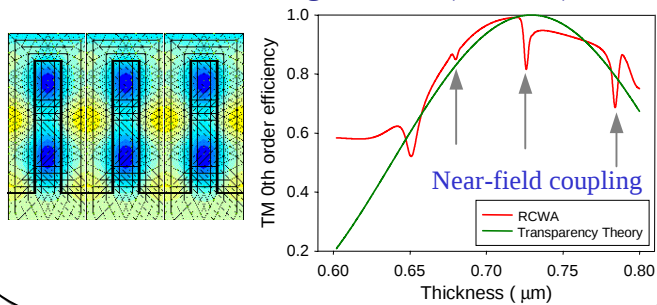


Artificial Dielectric Nanostructures

- Compatible with VLSI Technology
materials and fabrication techniques
- Material Design Flexibility
choice of materials; large, adjustable birefringence, dispersion
- Ease of Integration and Packaging
- Device Multifunctionality
antireflection, phase retardation, polarization, color,
programmable, enhanced nonlinearity

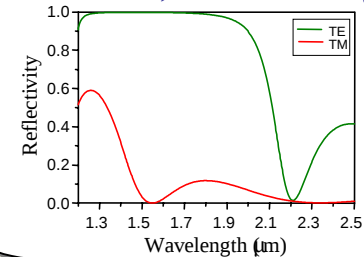
Nano-optics for Photonic Integrated Chips

Near-field coupling between pixels
in Form-birefringent CGH (FBCGH)

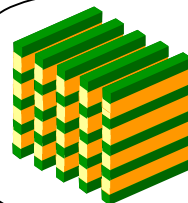
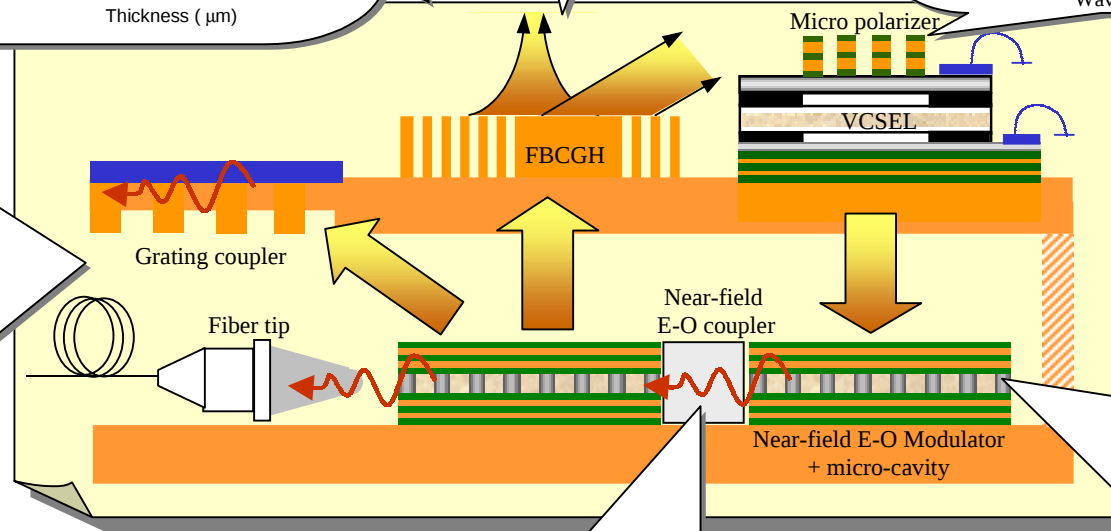
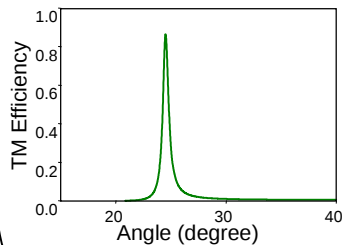


FBCGH possesses
dual-functionality
such as focusing
and beam steering

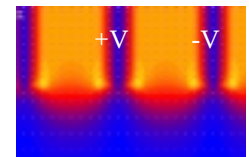
VCSEL + Near-field polarizer :
Efficient polarization control, mode
stabilization, and heat management



Information I/O through
surface wave, guided
wave, and optical fiber
from near-field edge and
surface coupling



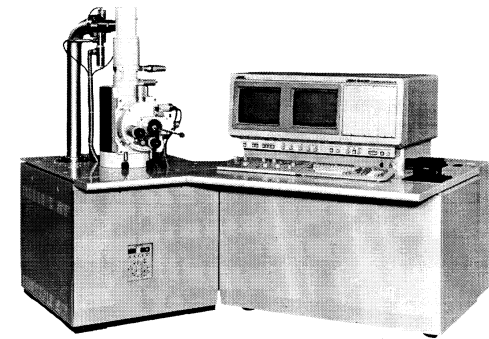
Composite nonlinear,
E-O, and artificial dielectric
materials control and
enhance near-field coupling



Near-field E-O
modulator controls
optical properties
and near-field
micro-cavity
enhances the effect

Enhancement of Fabrication Facilities at UCSD

- Scanning Electron Microscope (SEM) for patterning and characterization



- Chemically-Assisted Ion Beam Etching

- Femtosecond Pulsed Laser Ablation



- DekTak Surface Profilometer
- Other UCSD fabrication facilities:
 - Electron Beam Lithography
 - Reactive Ion Etching