Very Low NF, High DR Heterodyne RF Lightwave Links Using a Simple, Versatile Photonic Integration Technology

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Princeton University

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Agent: Army Research Office

Presentation by: Vinod M. Menon

Program Objectives

- Demonstration of ultra-low noise RF (0.5 - 5 GHz) optical FM link
- Demonstration of high performance transmitter and receiver PICs using twin-guide photonic integration technology

Outline

PROGRAM DESCRIPTION

FM Heterodyne detection for low NF RF links

- WIRNA receiver and PNC circuit
- Low NF, high DR FM link

Photonic Integrated Circuits: RFLICs

- Asymmetric Twin-Guide technology
- Receiver and transmitter design
- Recent results

RFLICs Team

P.I. : Stephen Forrest

Team Leader : Vinod Menon

Students : Fengnian Xia
Shubo Datta

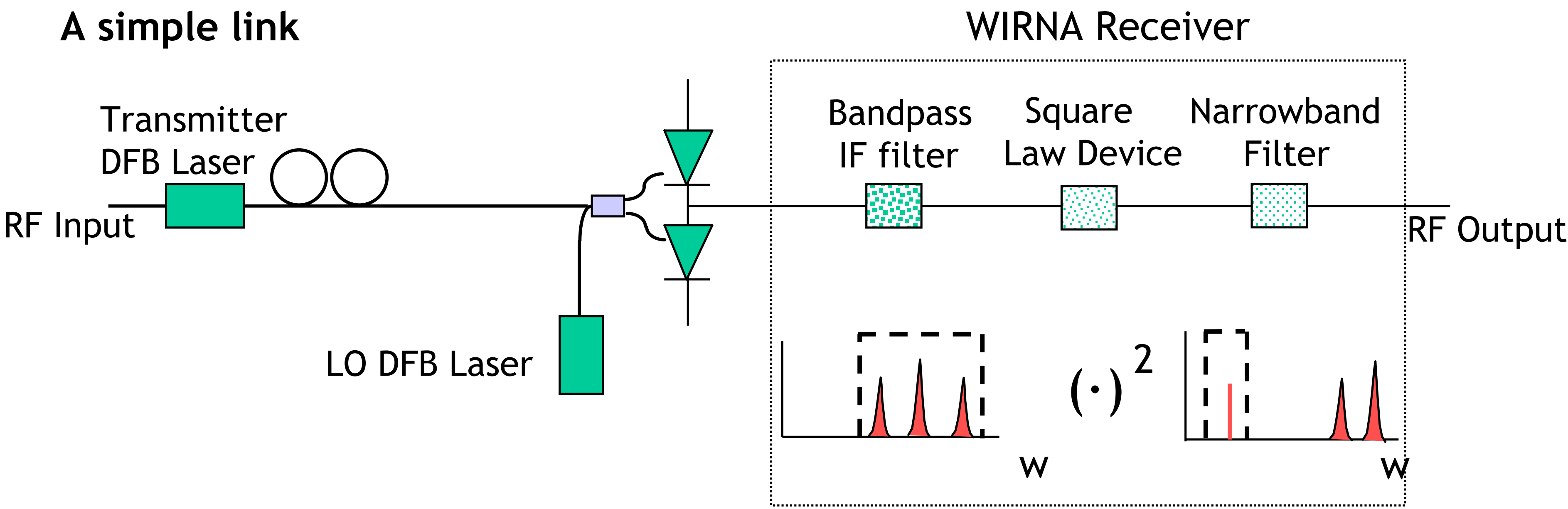
Industrial Collaborators

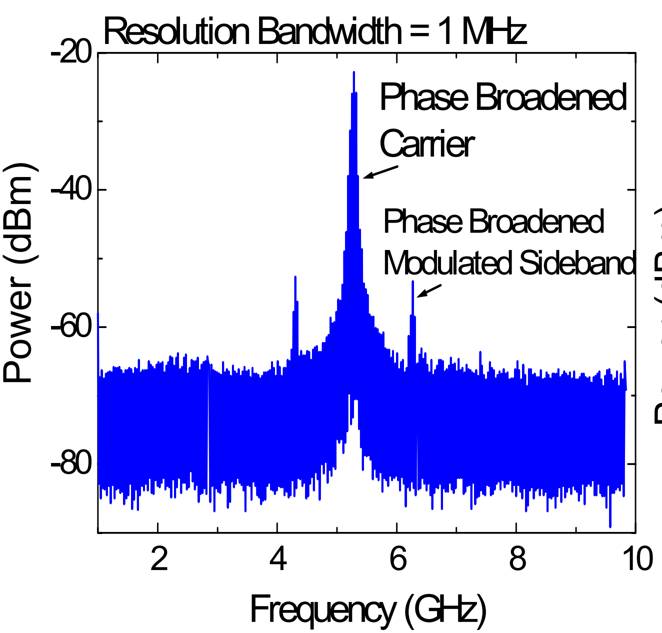
Twin Waveguide Components (*ASIP Inc.*):
Milind Gokhale, Pavel Studenkov, John Thomson

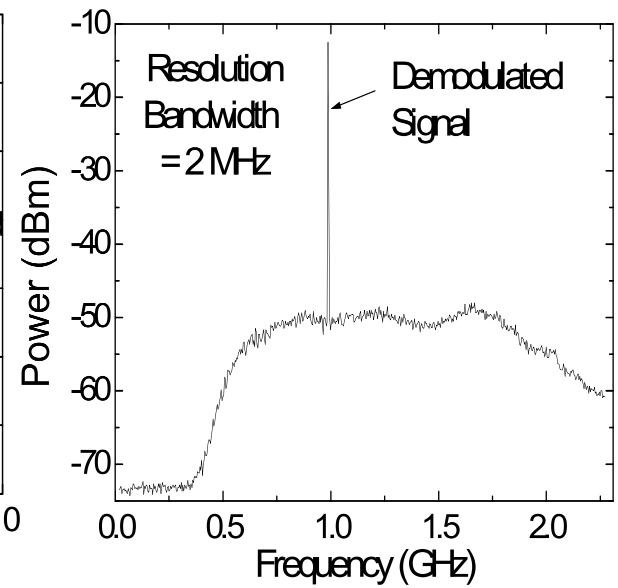
Receivers (*Sensors Unlimited Inc.*):
Marshall Cohen, Chris Dries

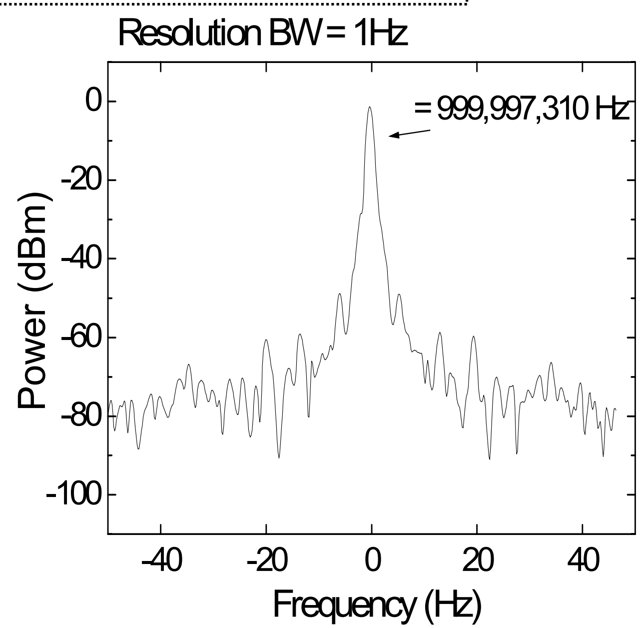
Links: *Not yet identified*

RF Optical Heterodyne Detection









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Princeton University

RFLICs: Photonic Integrated Circuits

Requirements

- Integrated heterodyne receiver: single-frequency lasers, passive waveguide, combiners, balanced detectors. Transmitter is a FM modulated single frequency laser (chirp ~1 GHz/mA)

- Tunability and polarization diversity

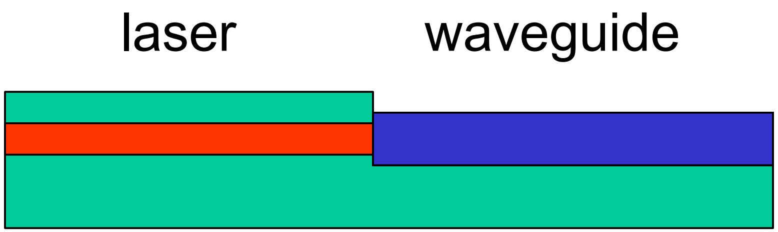
Integration Technology

- Photonic integration using a low-cost, flexible, platform technology based on asymmetric twin-guide with tapers

- Simple fabrication: no re-growth needed, passive devices are fabricated by patterning areas where the top active guide has been etched away

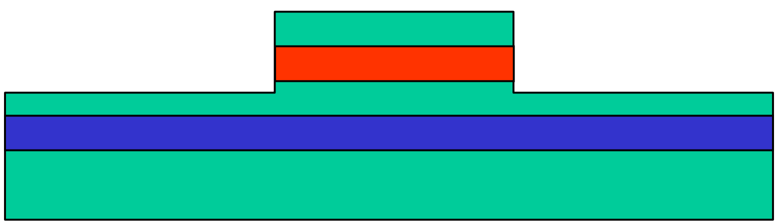
- Integration of active devices such as SOAs and single frequency DBR lasers via low-loss tapers to passive devices such as Y-branches, splitters, EA and Mach-Zehnder modulators

Photonic Integration Technologies



Selective regrowth - *butt coupling*

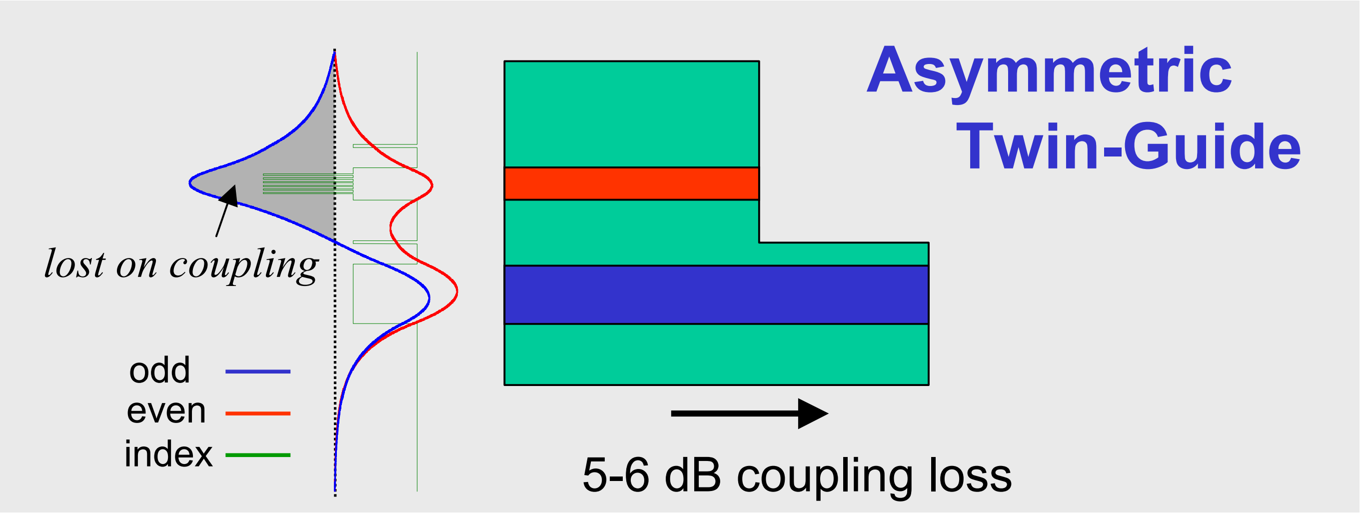
Conventional Integration Method
- Requires multiple growth steps
- Each device custom designed

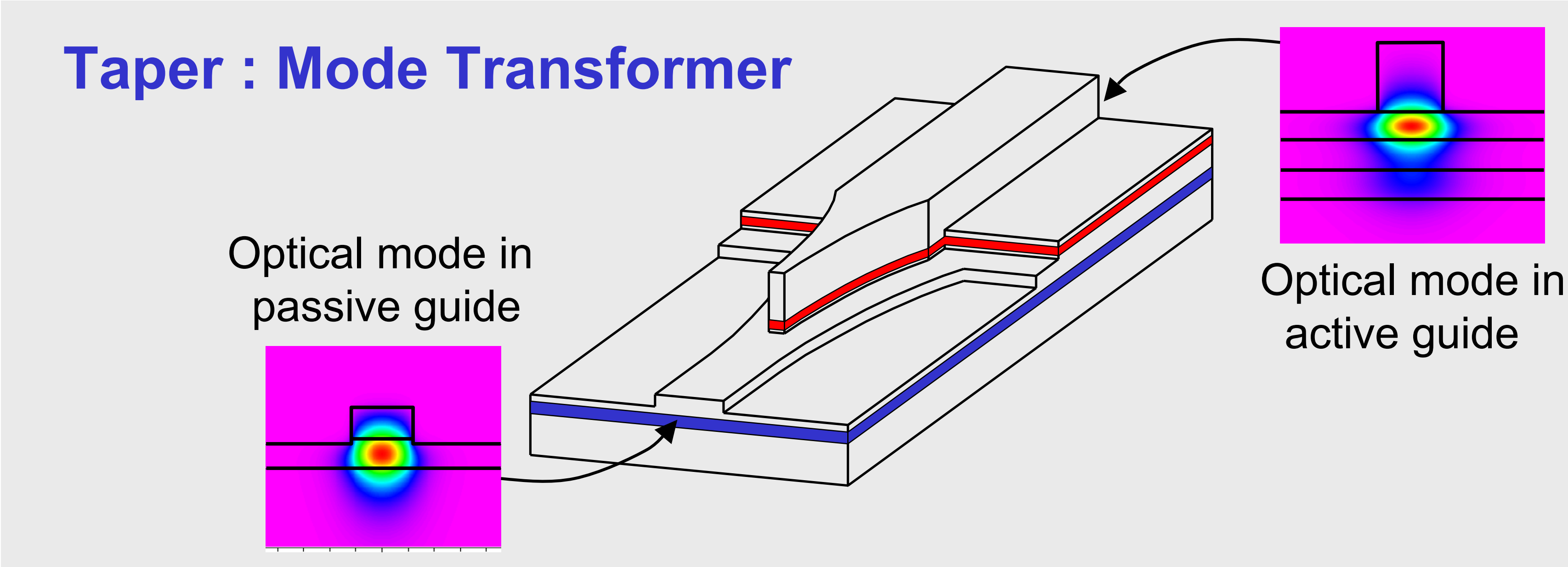


Asymmetric Twin-Guide (ATG) -
separate active and passive waveguides with vertical coupling of light via lateral tapers

Princeton's Integration Method
- Requires a single growth step
- All devices defined by processing
- Separate device optimization not required

Asymmetric Twin Guide with Tapers





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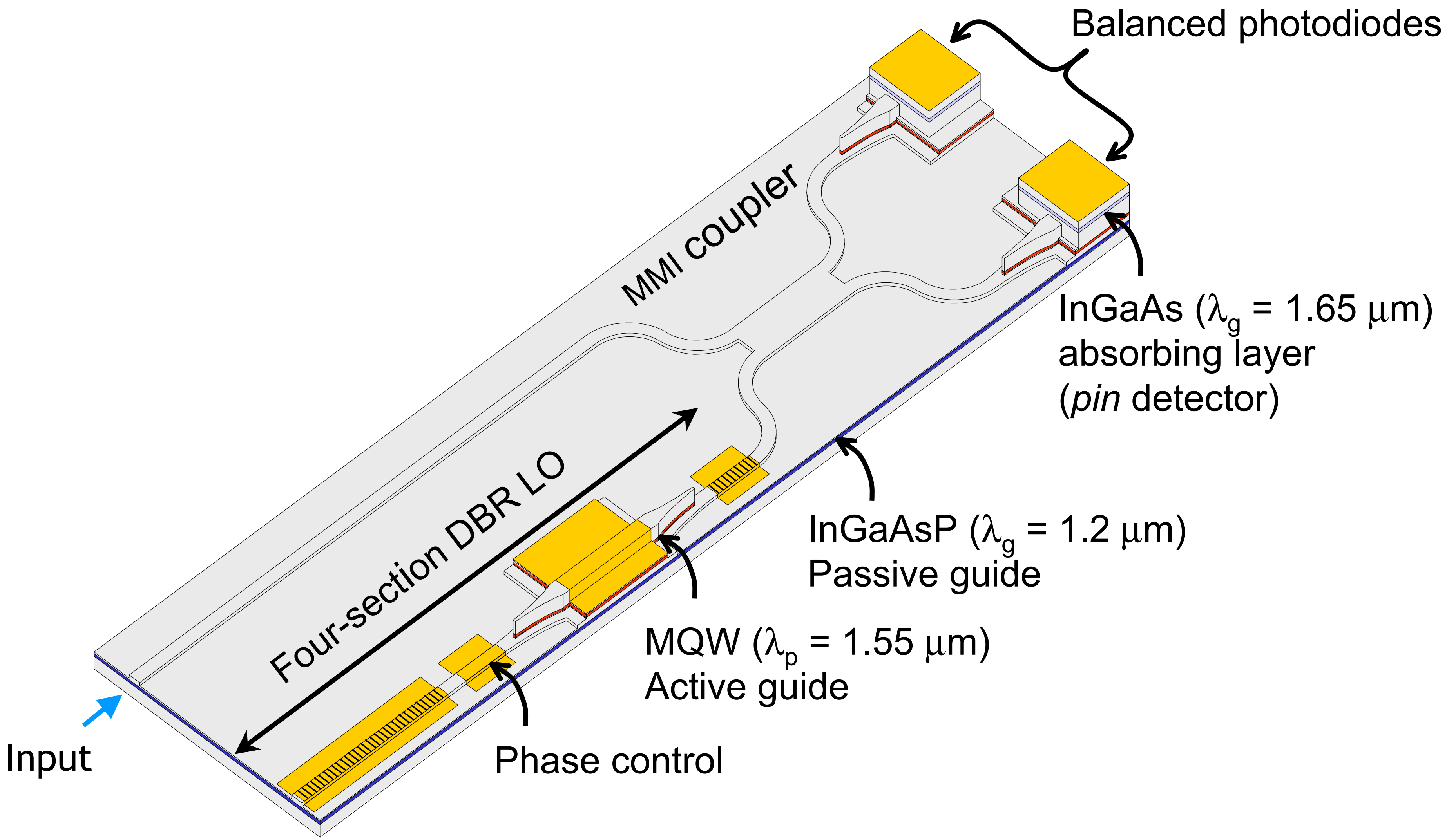
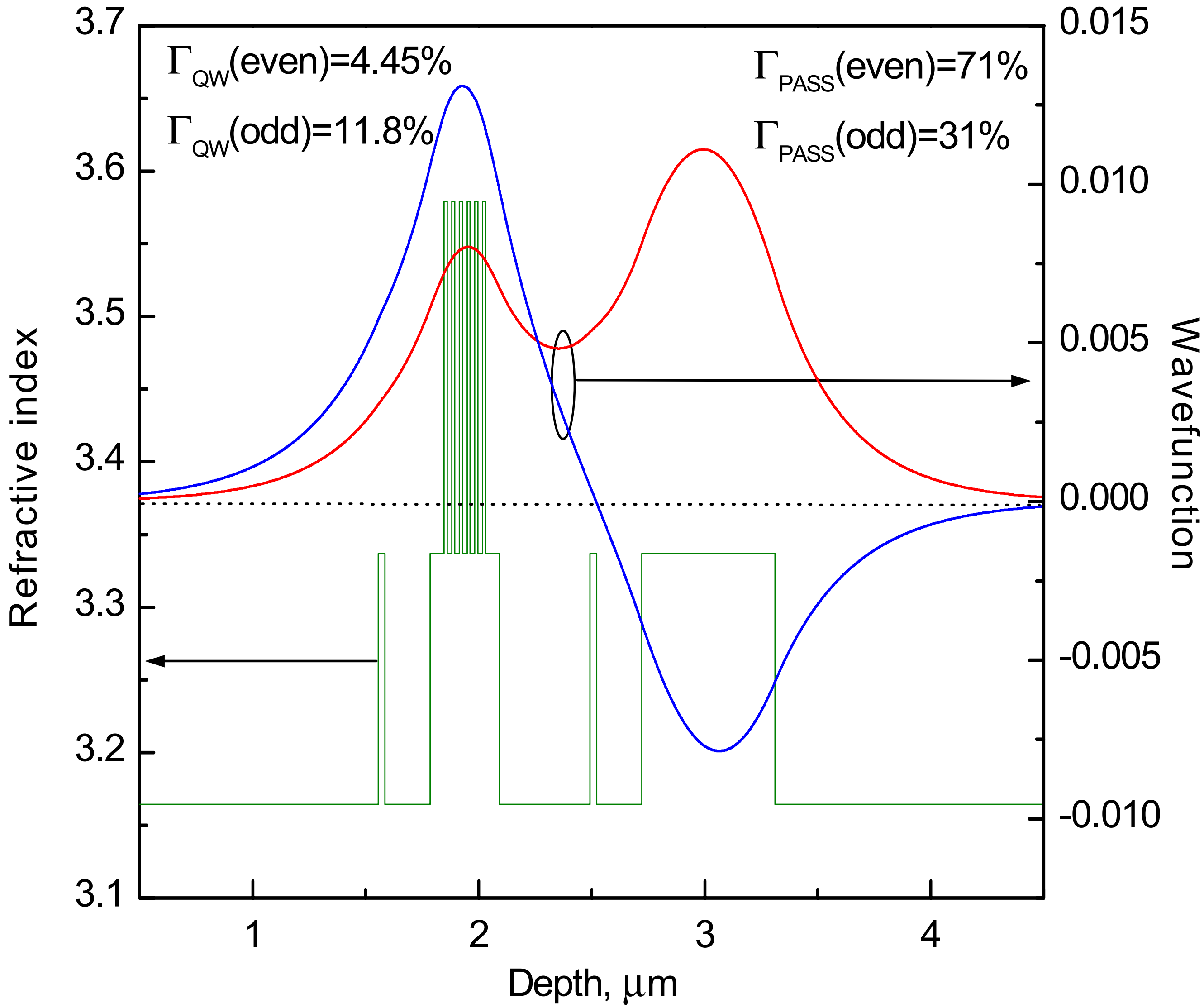
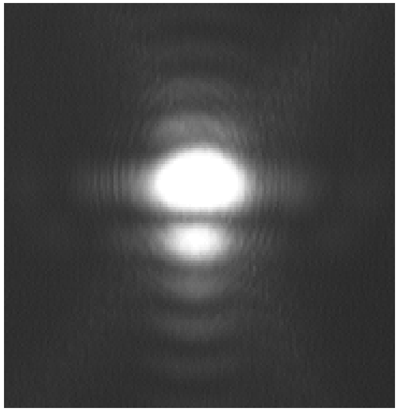
TG-Based Heterodyne Receiver



Asymmetric Twin Guide



NEAR FIELD



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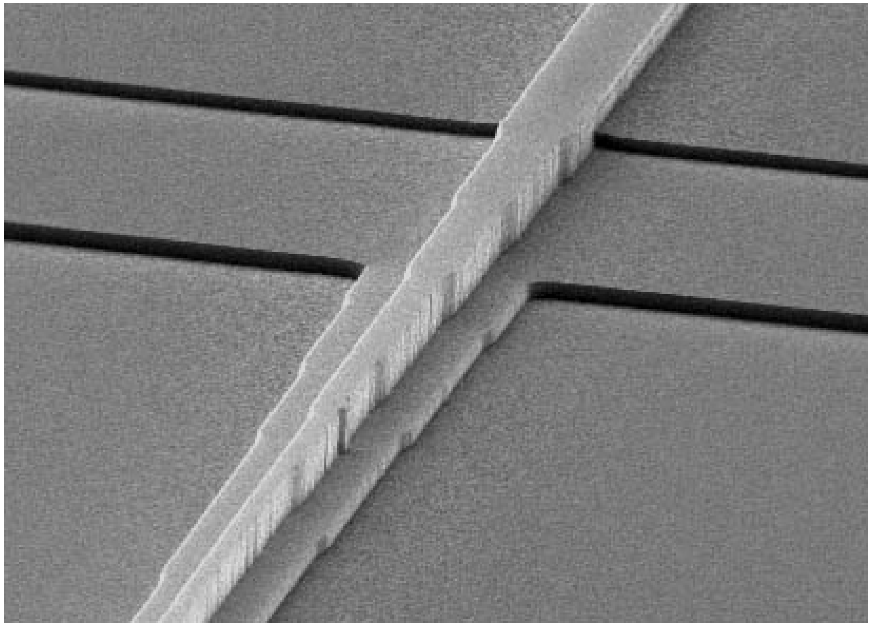
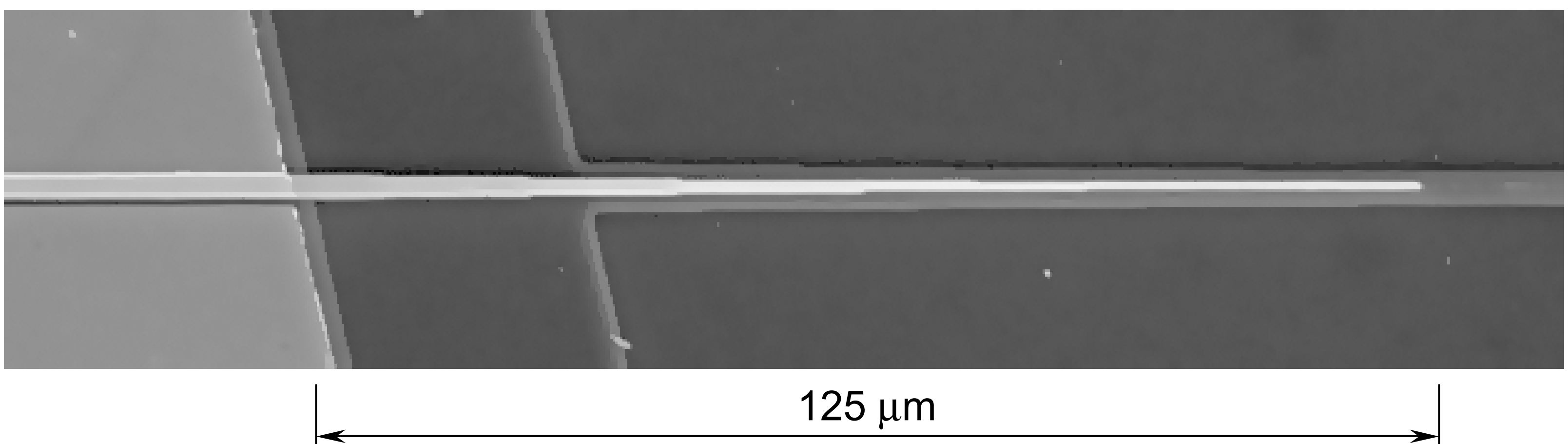
Dry-etched Waveguide Taper

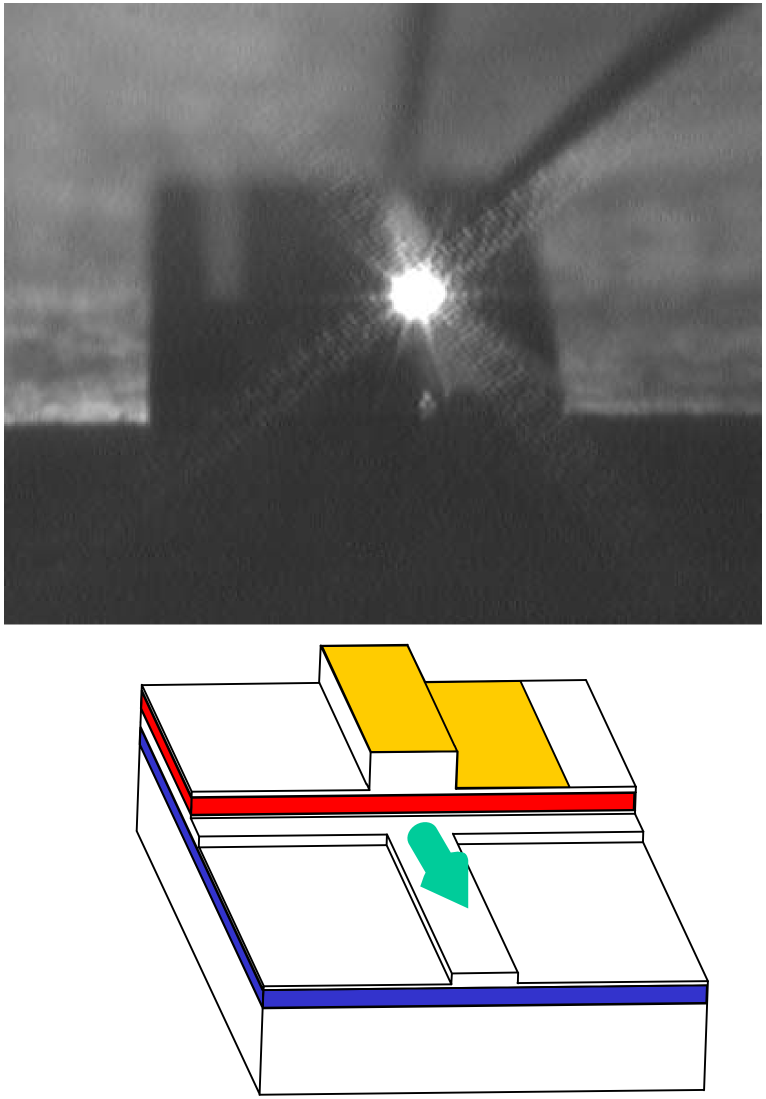


- Optical lithography
- Reactive ion etching in CH_4/H_2
- Three mask steps
- Taper width 3 μm ➔ 0.6 μm

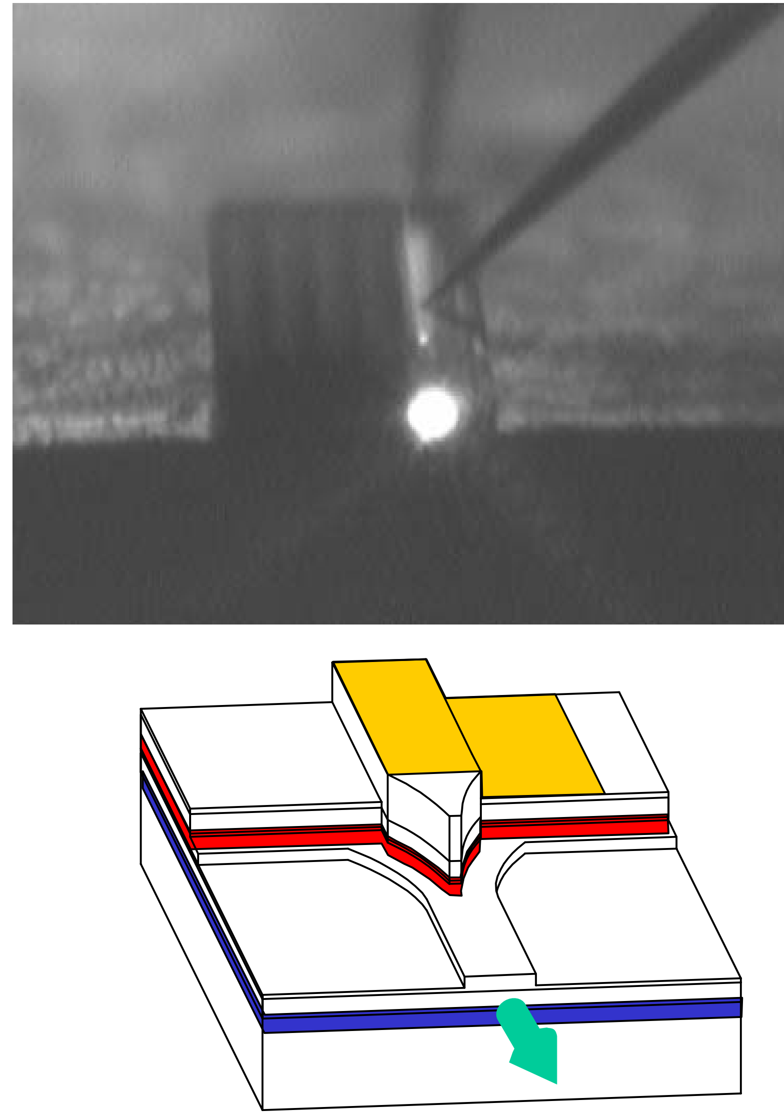
top view



Infrared Camera Images

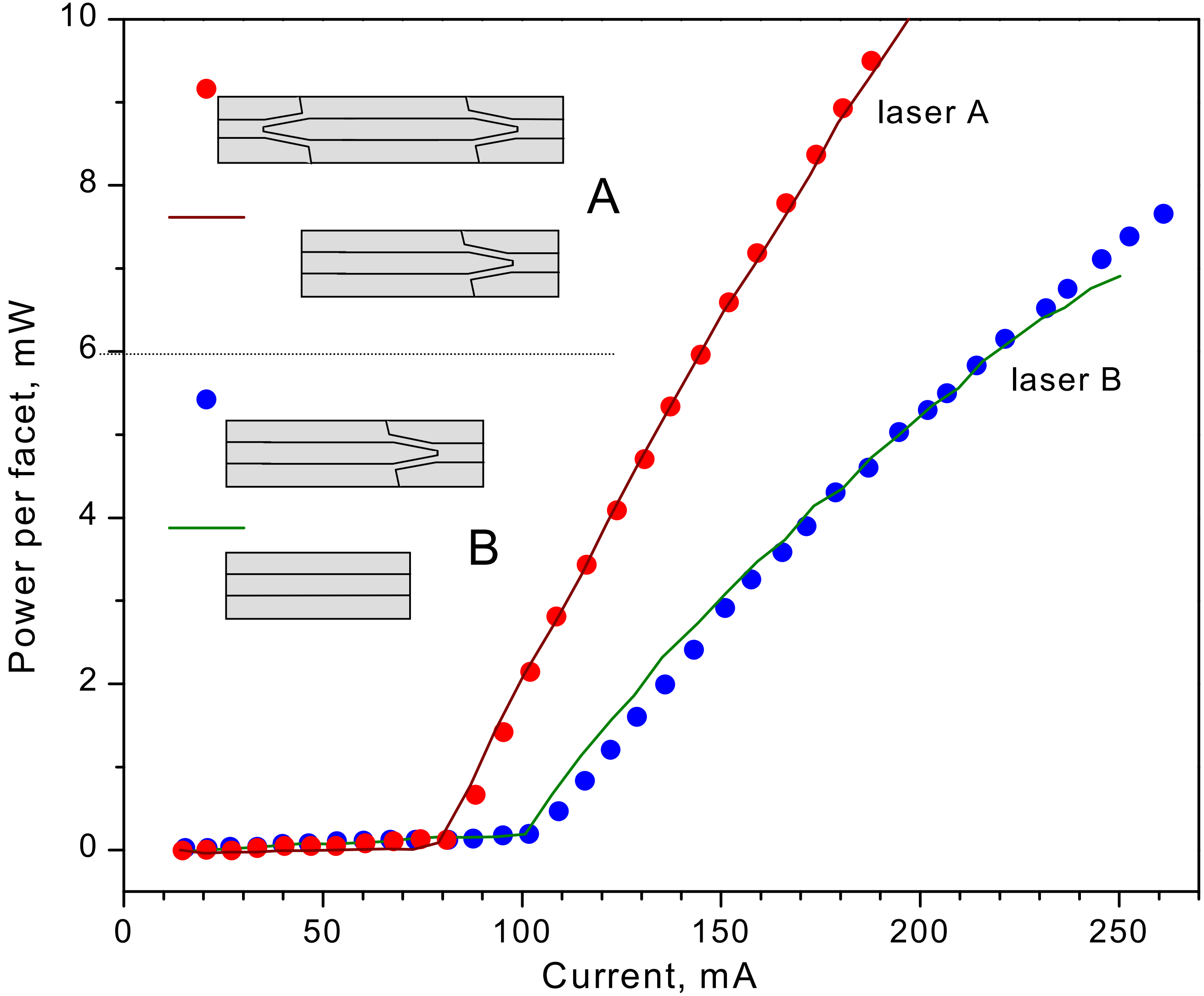


Facet coupler



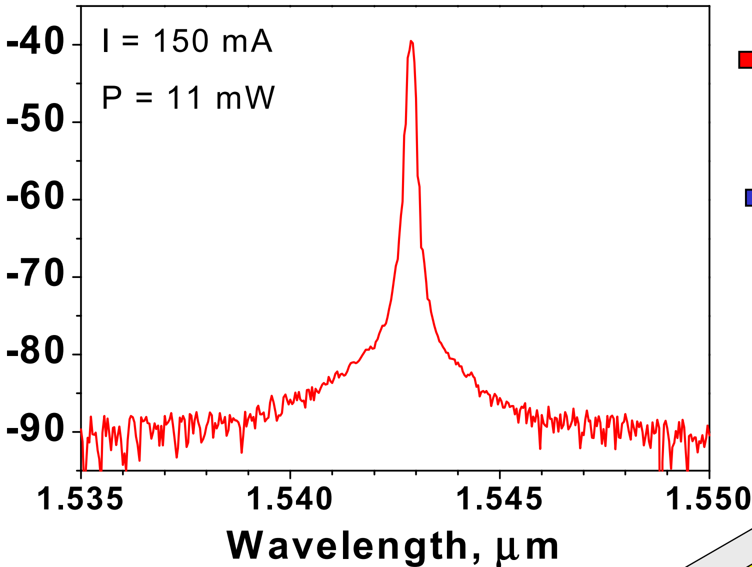
Taper coupler

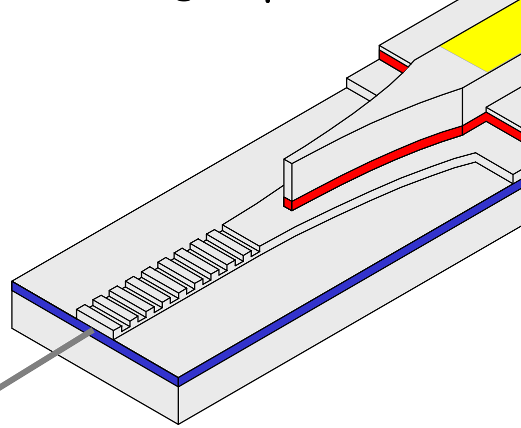
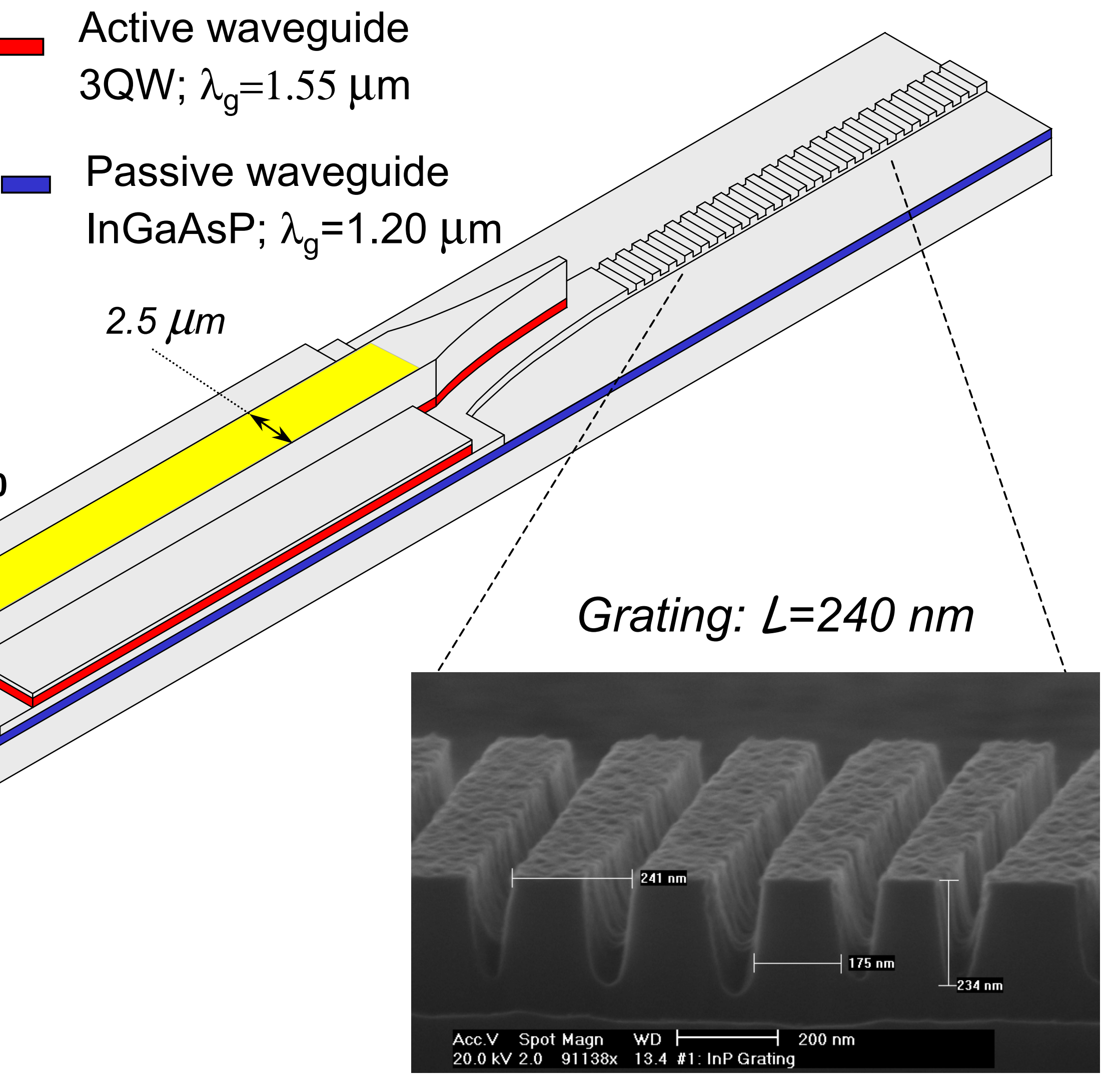
“Lossless” Coupling



Replacing a taper/waveguide with a cleaved facet does not change the laser’s I_{th} or η_d

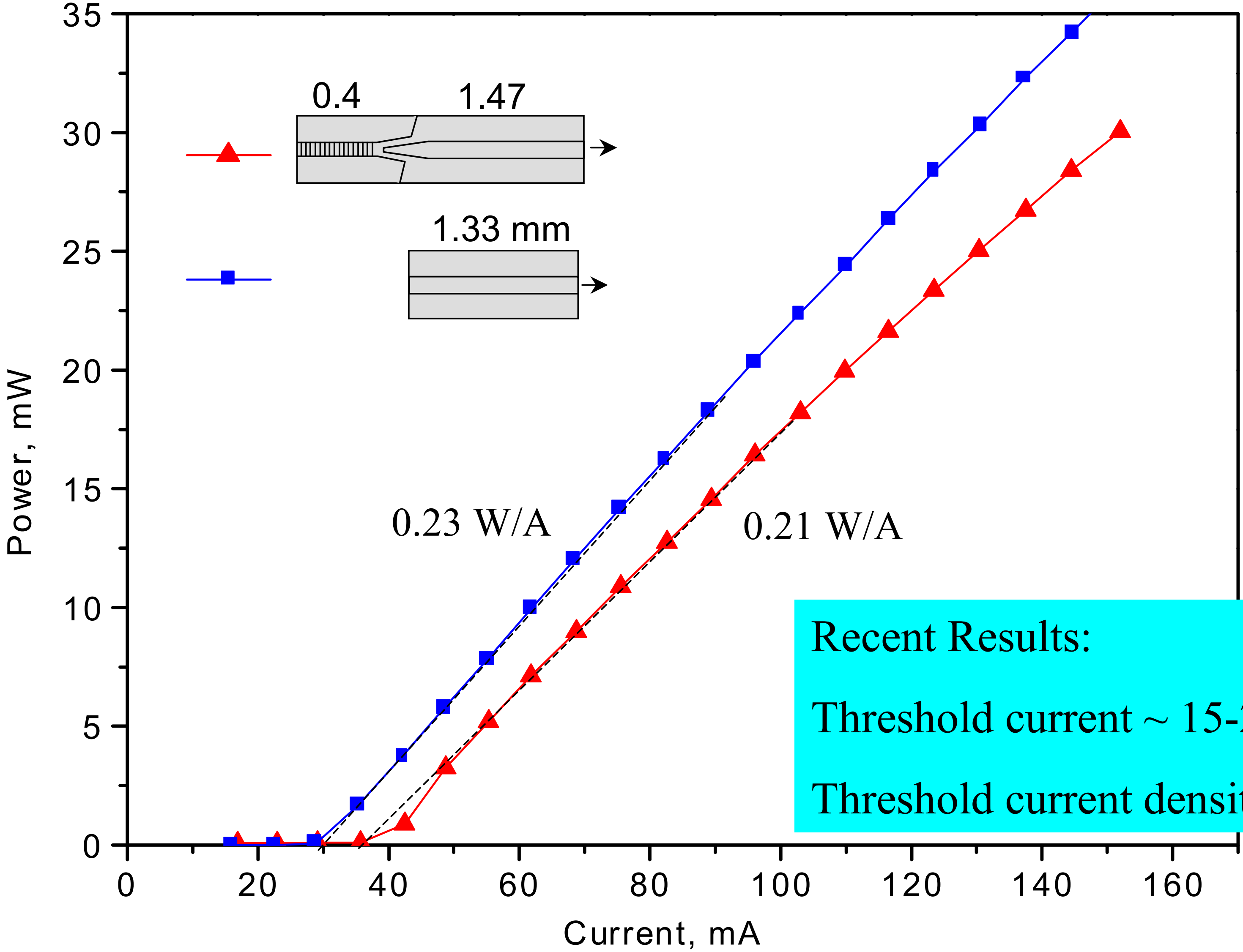
Single Frequency DBR Laser



Output ridge waveguide –
to other integrated devices

Comparison of DBR and Fabry-Perot Lasers



3 QW active
T=20^{o}C
pulsed

Recent Results:

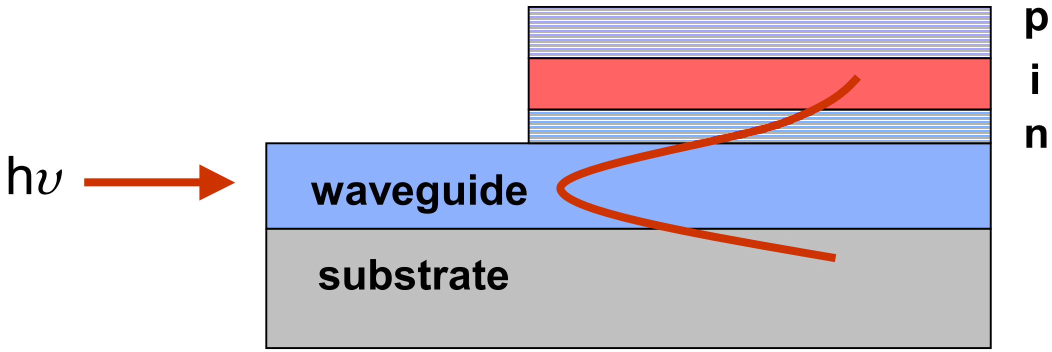
Threshold current ~ 15-20 mA

Threshold current density ~ 600 A/cm^2

DBR wavelength is blue-shifted from gain peak by 15 nm

High Speed p-i-n Photodiode Structures

Evanescently coupled waveguide p-i-n:

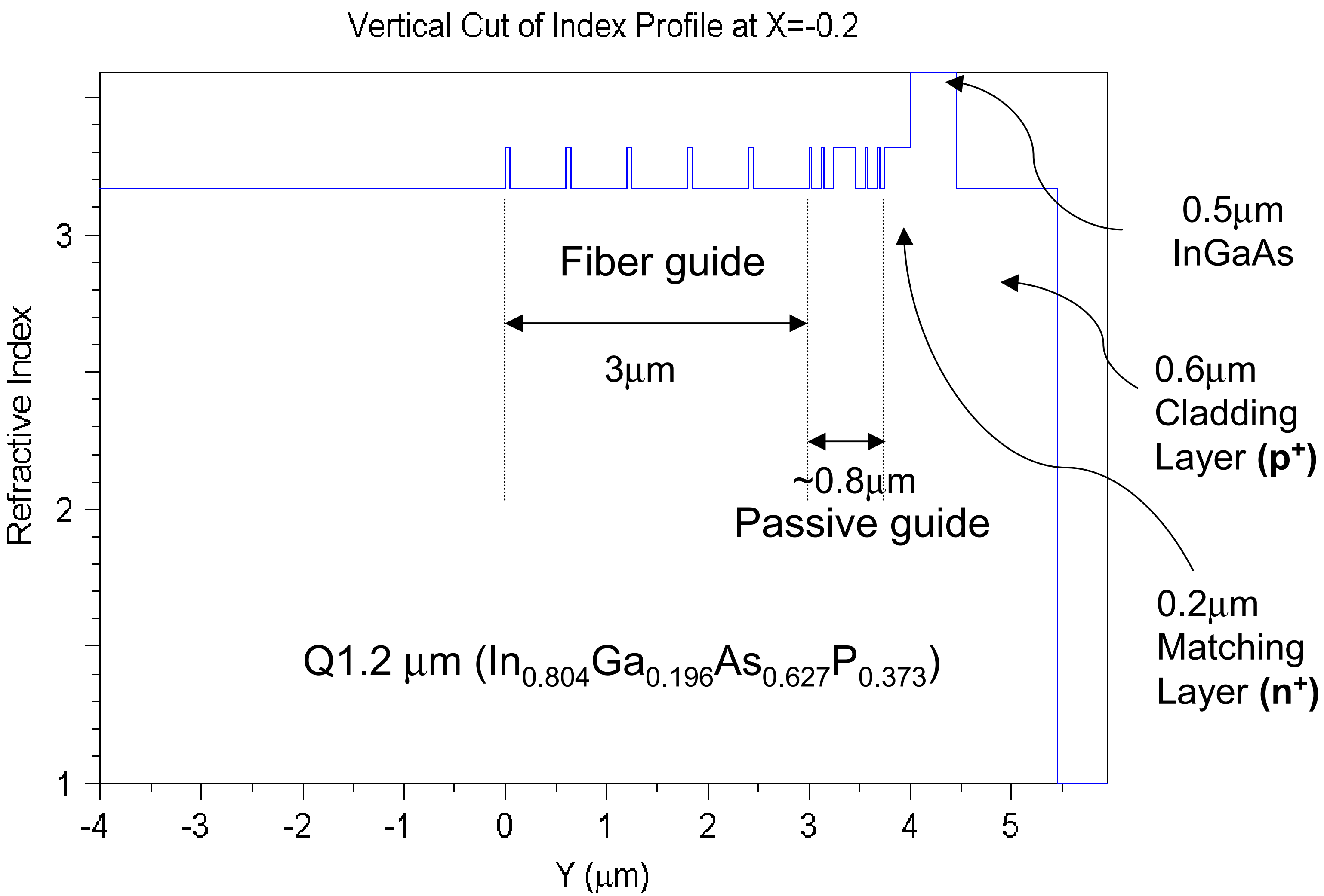


- optical integration easier

    semiconductor optical amplifiers, waveguide filters

- efficient evanescent coupling demands small waveguide mode

Index Profile Design for Waveguide Photodiode



DC Device Performance

- Lensed fiber far field FWHM: 18º

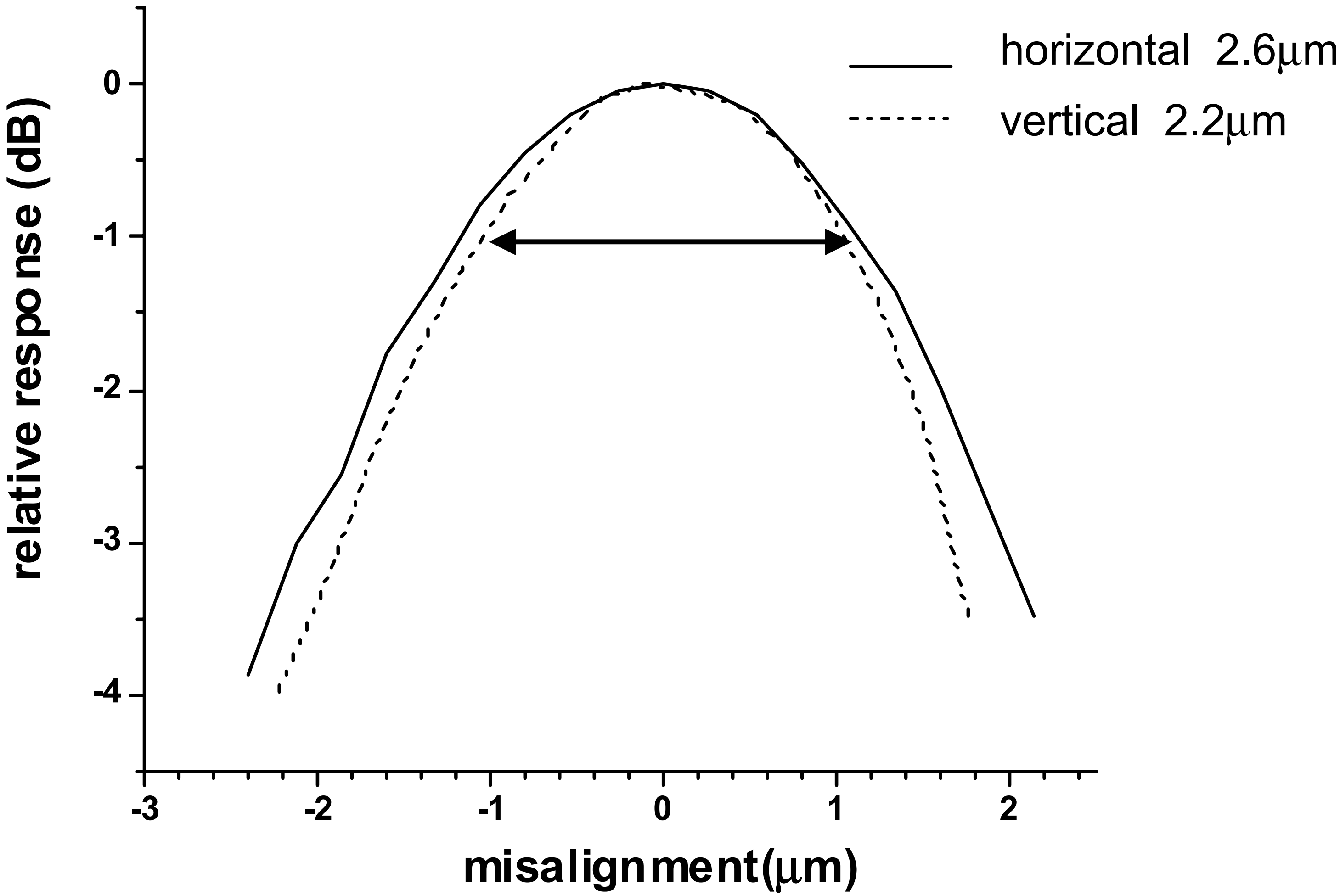
taper length		absorption length: 30 μm	absorption length: 60 μm / 90 μm
	250 μm	0.75	0.84
	400 μm	0.71	0.80

responsivity (A/W)

- Reflections due to imperfect AR coating and cleaving
- Losses from scattering in waveguides

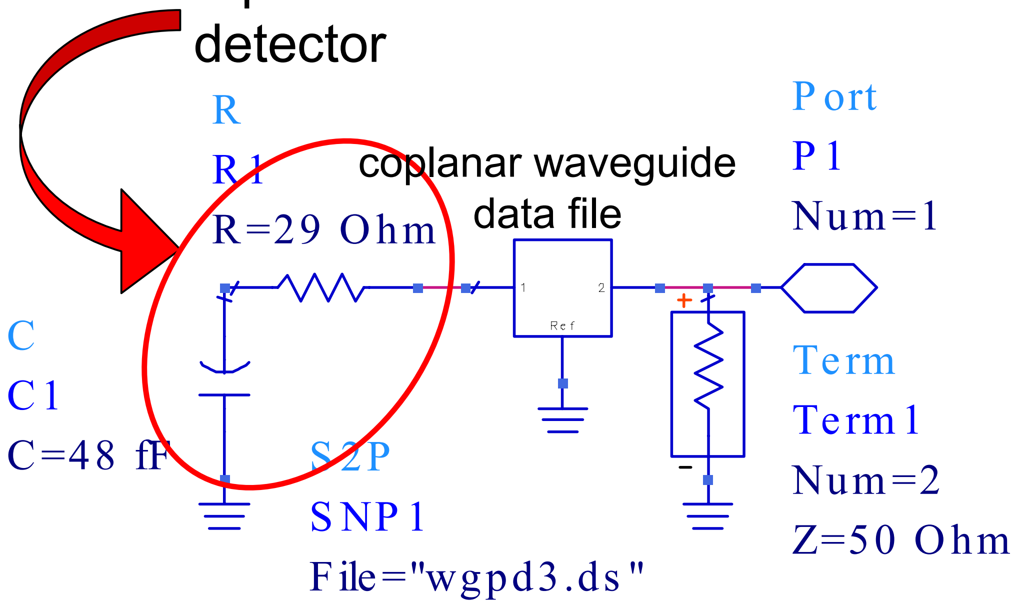
- Devices show a polarization sensitivity from 0.3db to 0.5dB

Alignment Tolerance

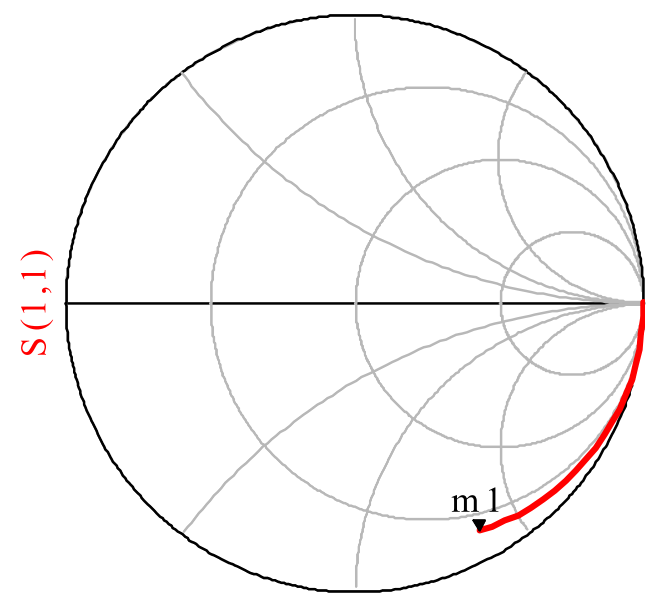


Detector Model

equivalent circuit of detector



input impedance of detector and waveguide

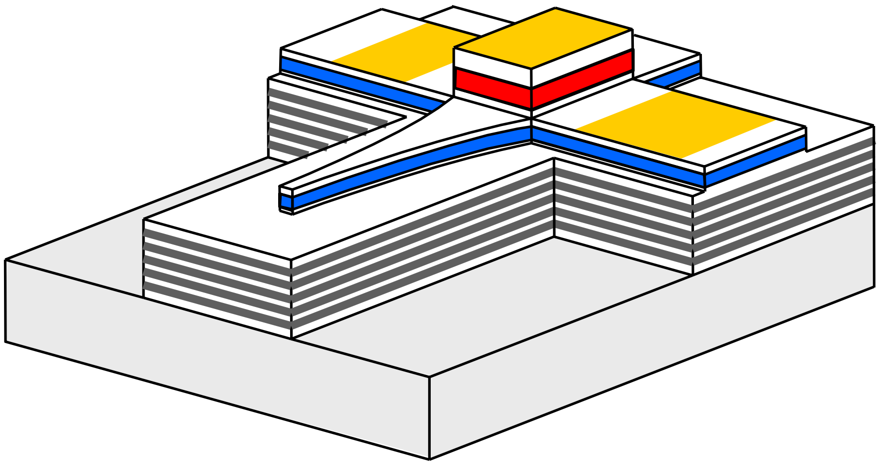


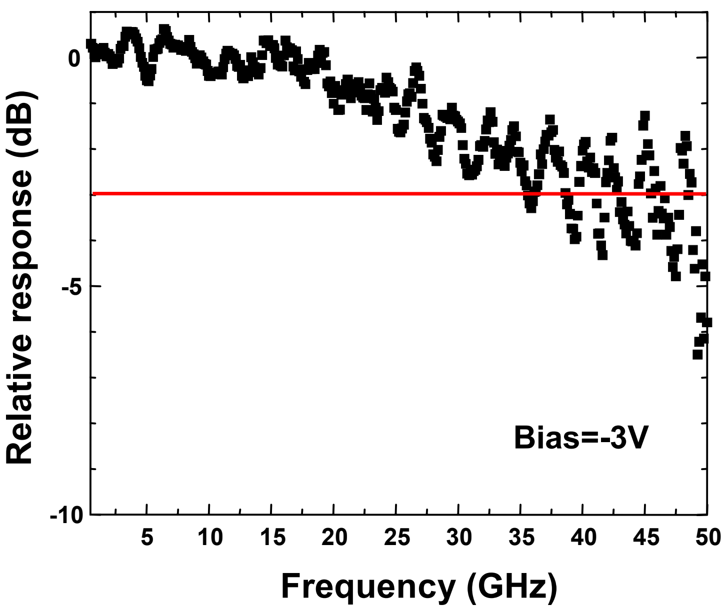
freq (0.0000 Hz to 20.00GHz)
m1
freq=20.0GHz
S(1,1)=0.90 / -61.40
impedance = Z0 * (0.199 - j1.667)

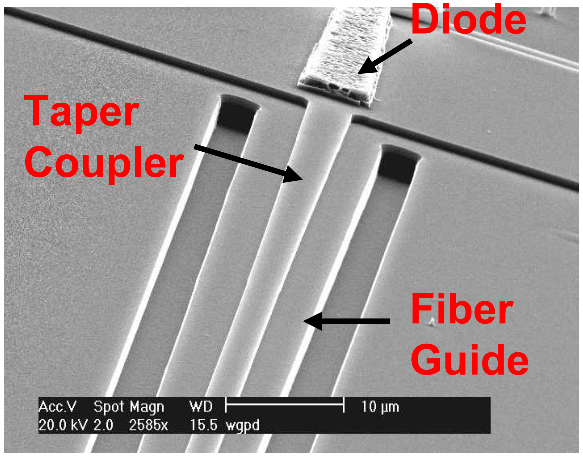
R 29Ω
C 48fF (Diode: 38fF; parasitic: 10fF)
RC bandwidth limit 43GHz

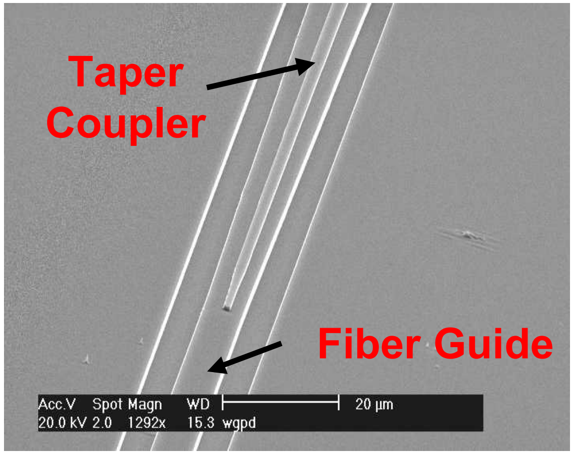
40 Gbps Photodetector

Device Schematic

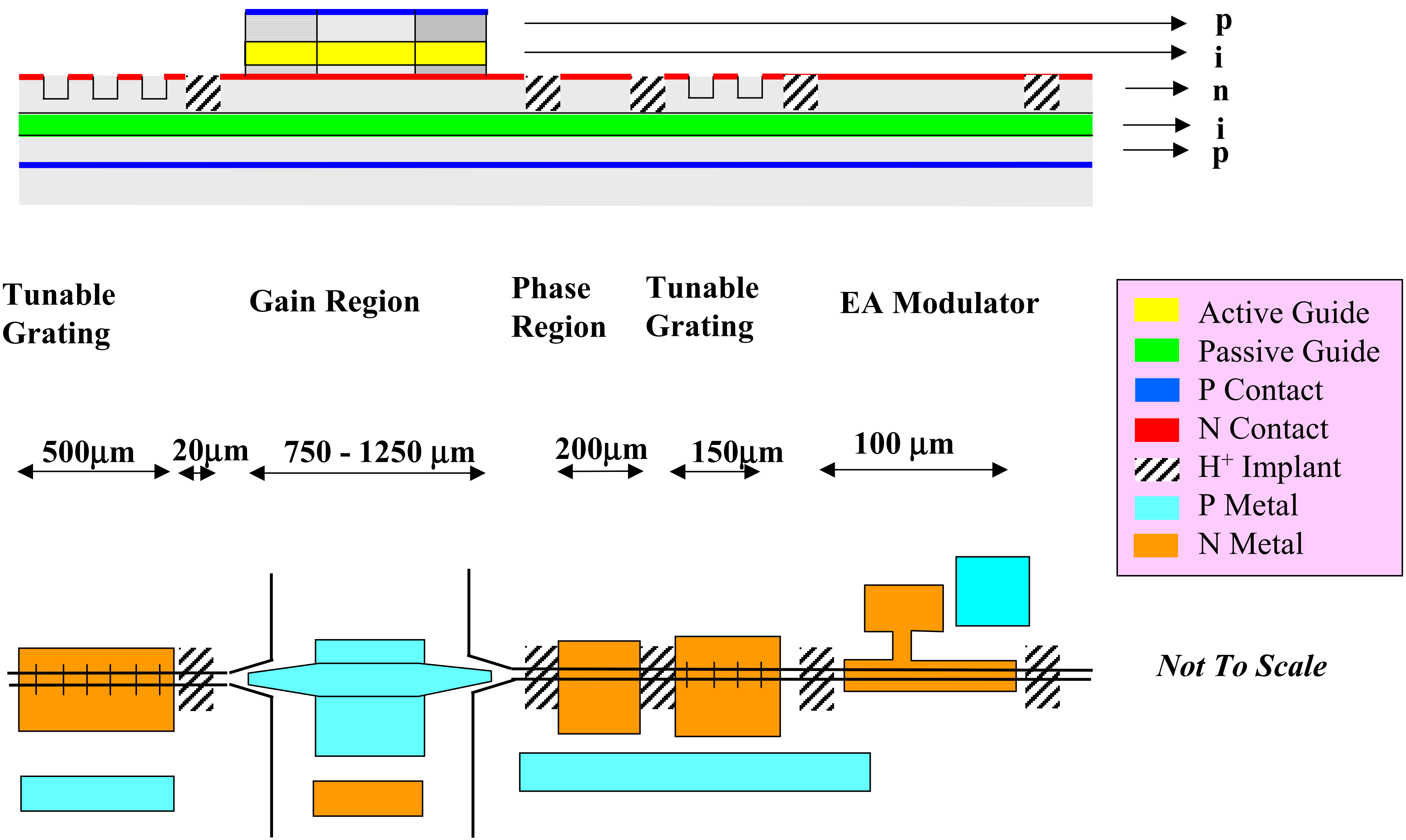








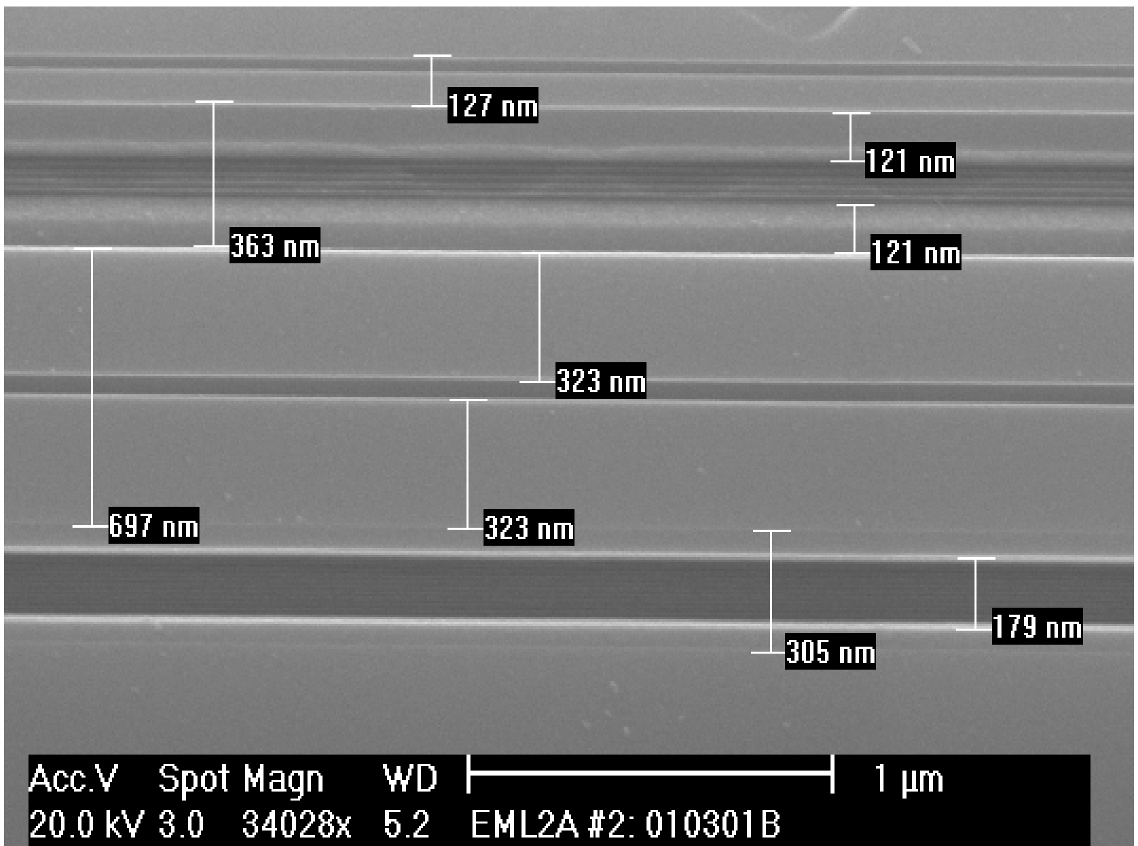
Externally Modulated Tunable DBR Laser

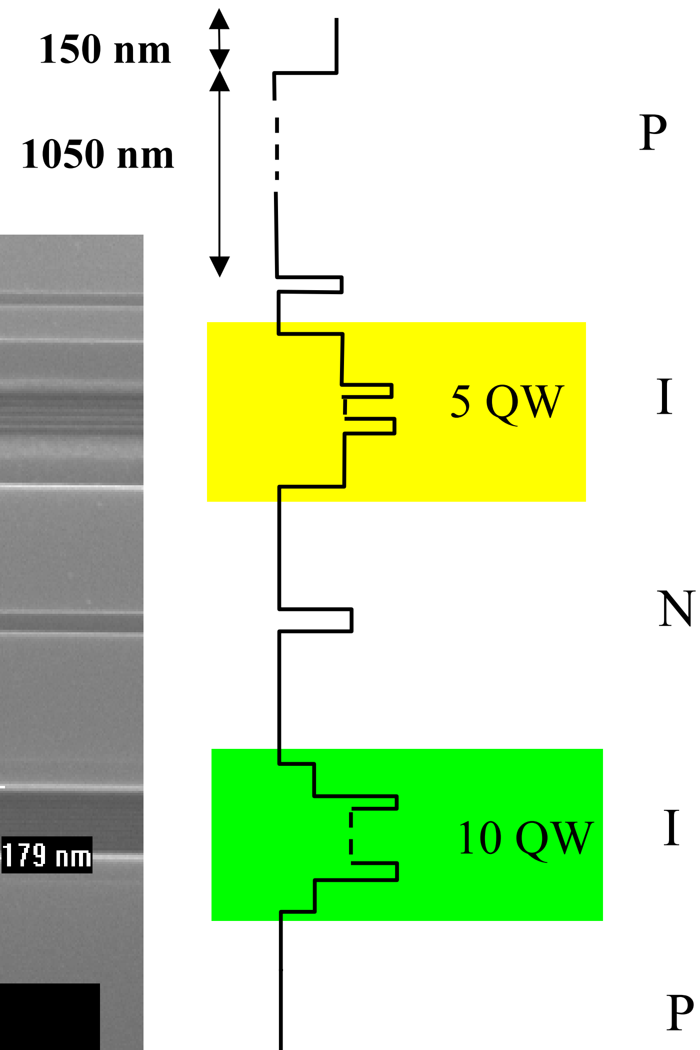


Externally Modulated DBR Laser

Structure:

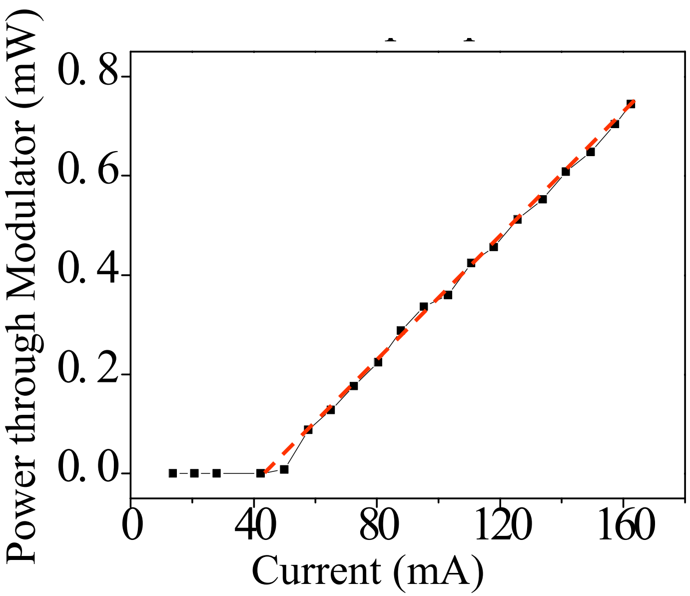
PL Peak: Active 1533nm
Passive 1480nm



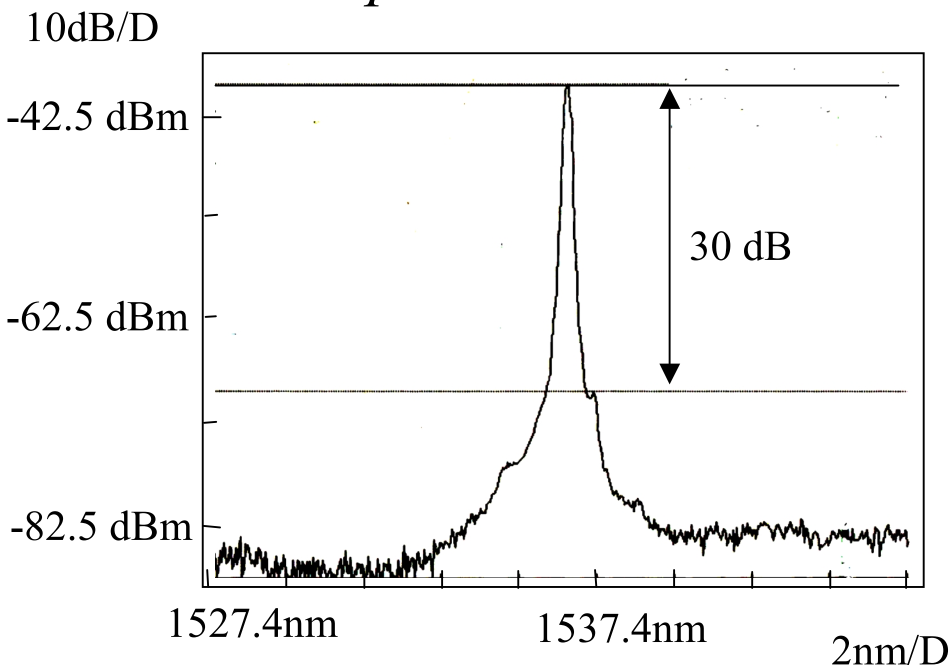


Externally Modulated DBR Laser

L- I Curve:



Spectrum:

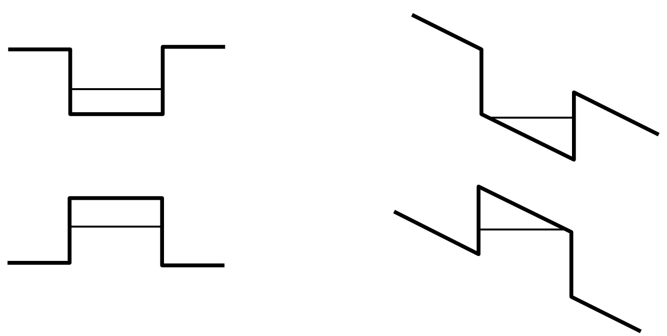


Threshold Current = 47 mA
Threshold Current Density = 1.4 kA/cm^2

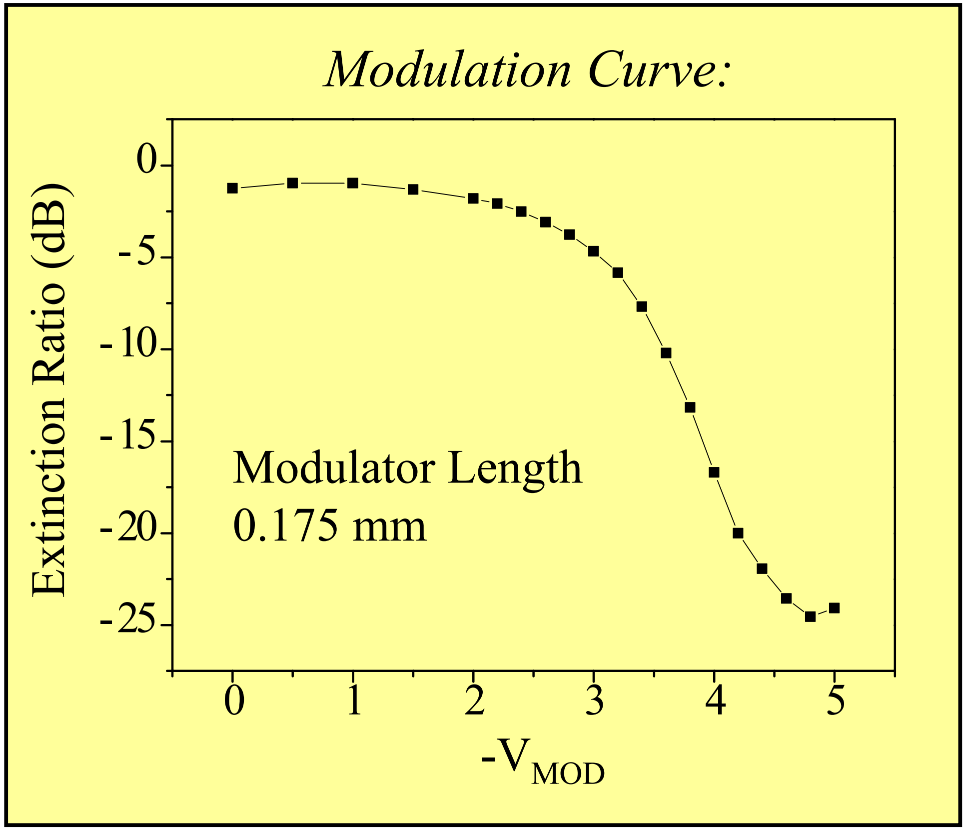
Peak Wavelength = 1536.6 nm
Line Width = 2 nm

Electro-absorption Modulator

Reverse bias shifts the sharp absorption edge of the quantum well material towards higher wavelength

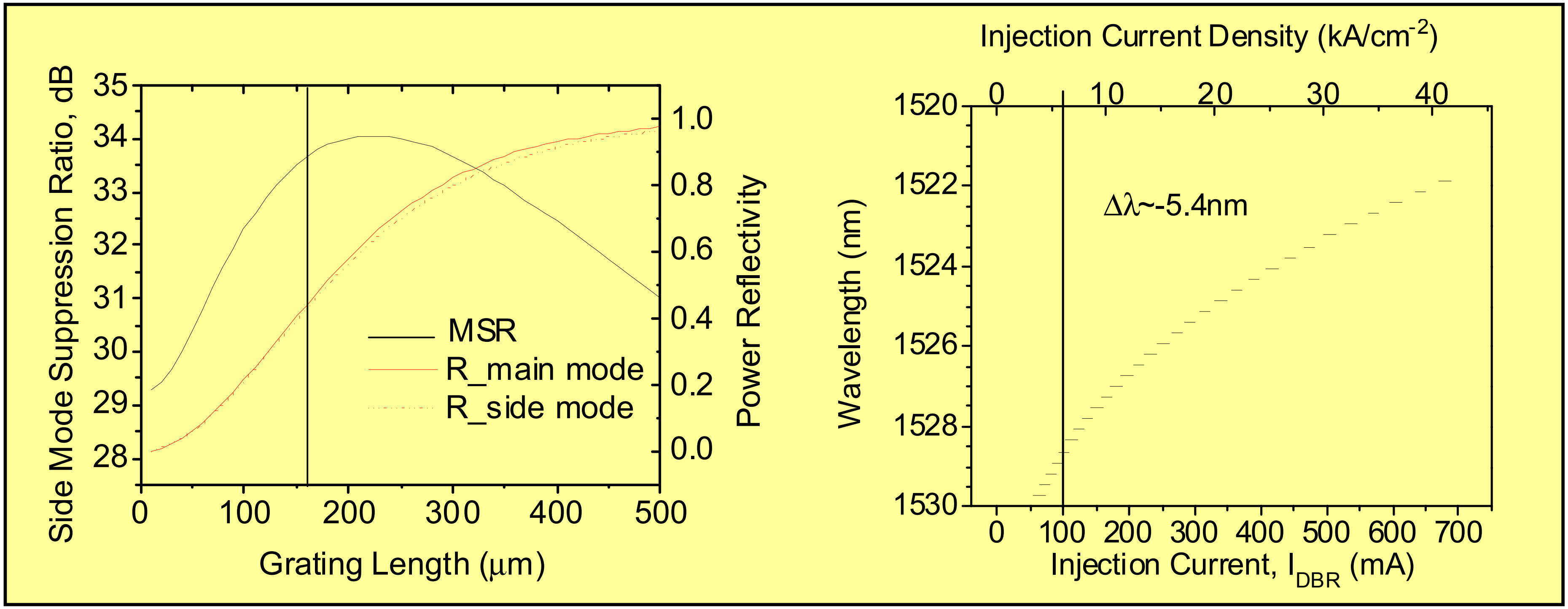


Quantum Confined Stark Effect:
Electron and hole wave function overlap decreases due to reverse bias leading to decrease and broadening of the absorption edge



3dB bandwidth of the device was measured to be between 7 and 8 GHz

Tunable Gratings



Back Grating Length = 0.5 mm
Front Grating Length = 0.16mm
Cavity Length = 1mm
Coupling Constant = 50 cm^{-1}
Phase Section = 0.2mm

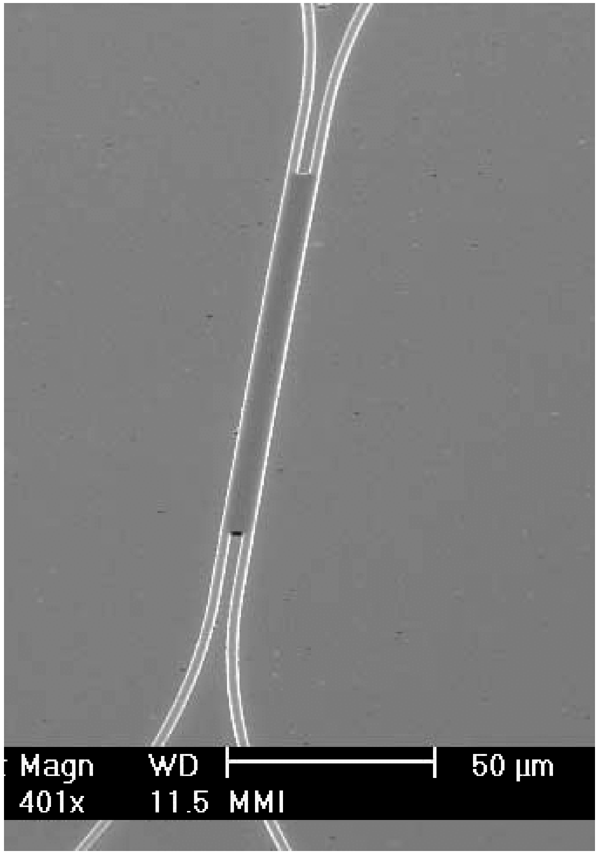
Refractive Index Change

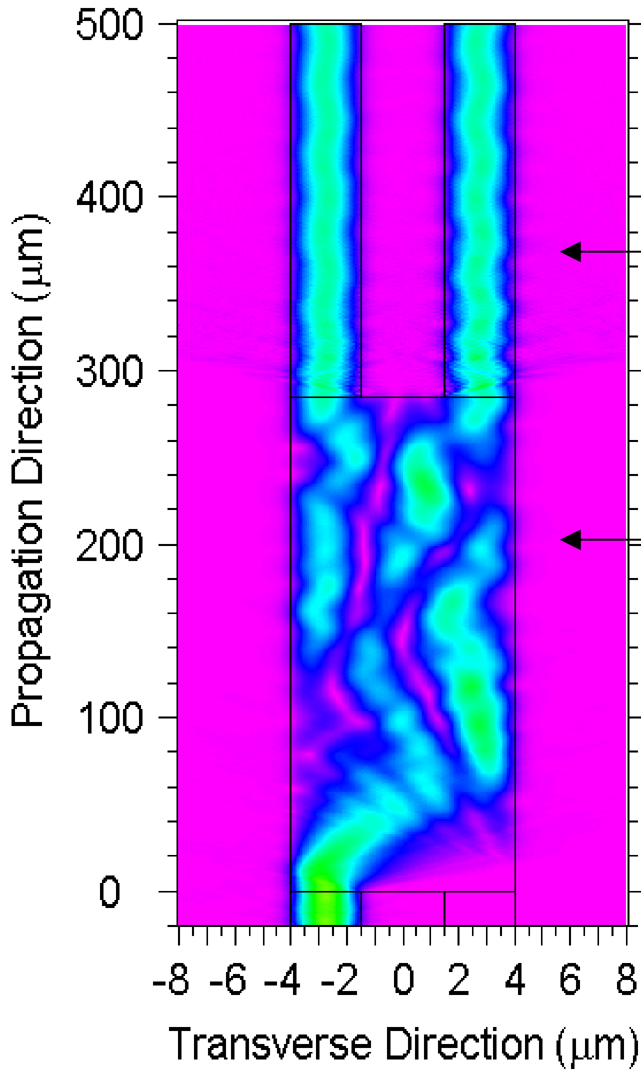
Plasma Loading: Reduction in refractive index with increasing current.

Heating: Increment in refractive index with increasing current.

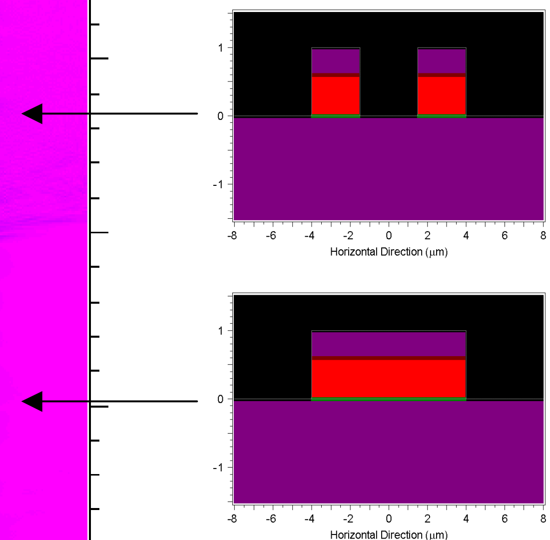
Can obtain refractive index change of -1% at a current density of 1.5kA/cm^2

2x2 Multimode Interference (MMI) Coupler



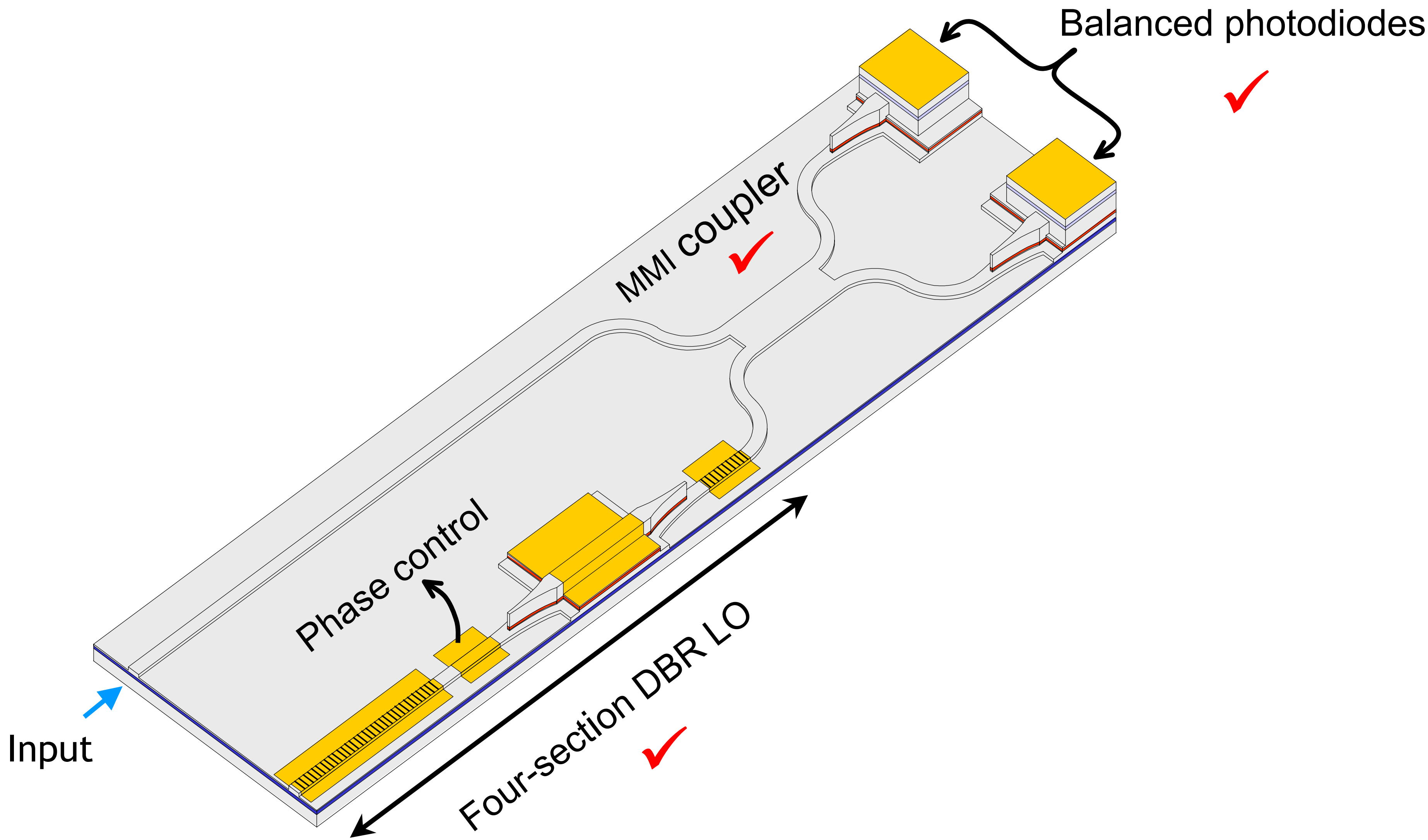


CROSS-SECTIONS

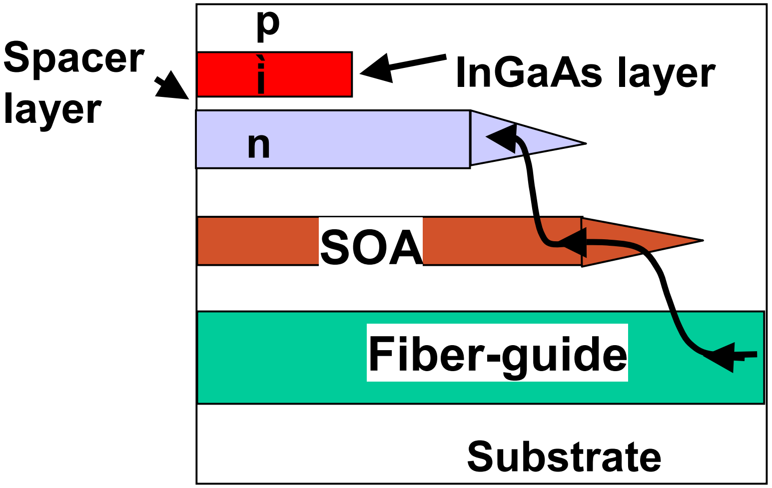


W_{MMI}=8 µm
W_{guide}=2.5 µm
L_{MMI}=280 µm

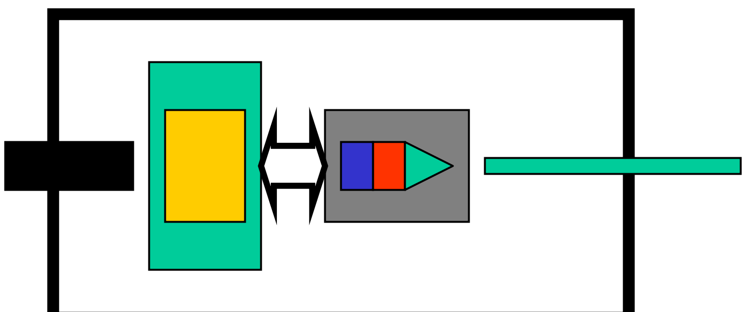
TG-Based Heterodyne Receiver: Present Status



Integration of SOA and Detector

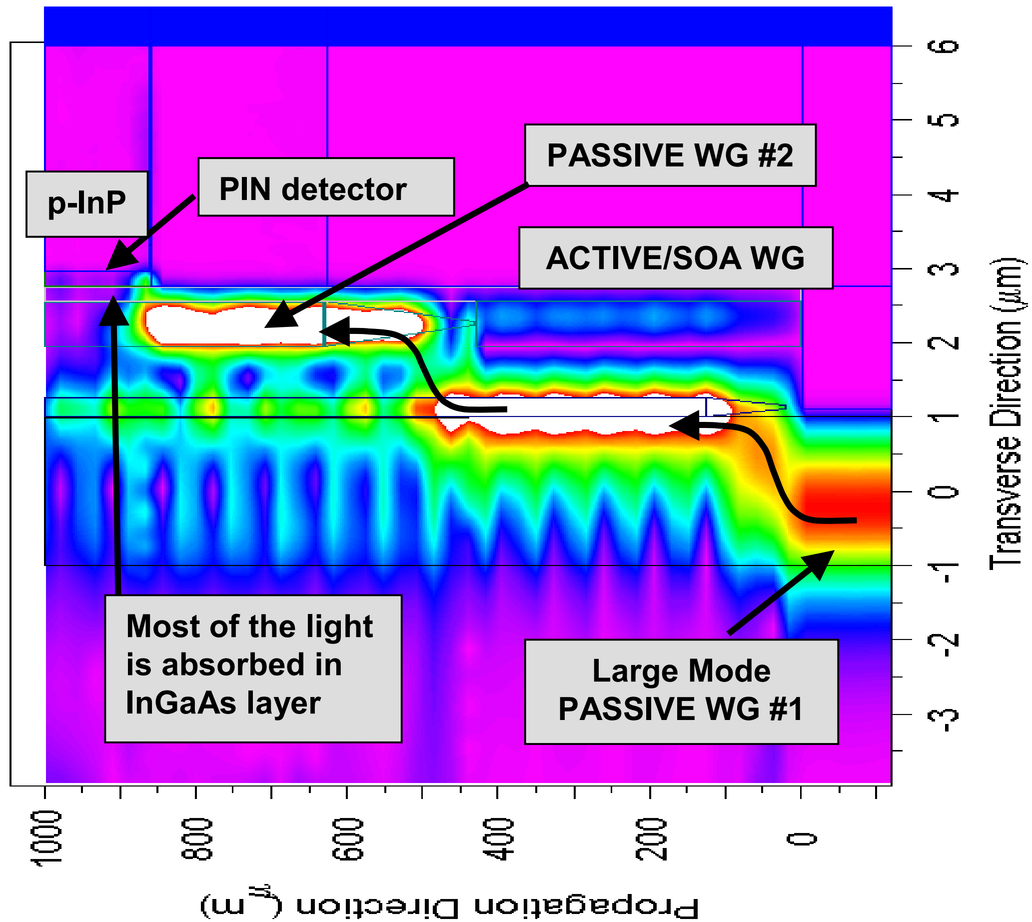


Integration of PIN detector with active devices



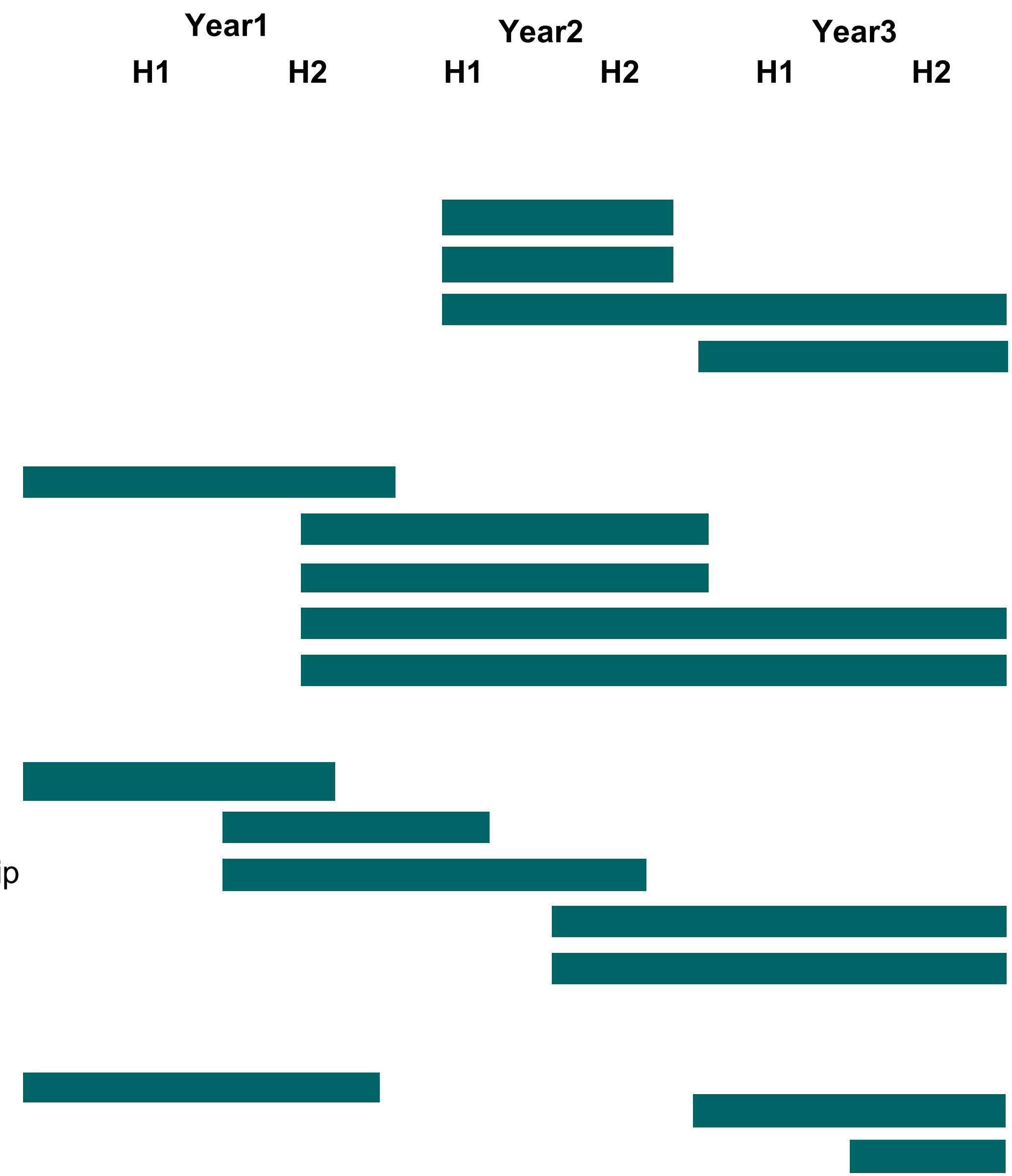
Laser-PIN module

2-D simulation of laser-PIN



Program Roadmap

Project Milestones



FM-link

Set up FM link with commercial components

Test and characterization

Test bed for new PICs

Characterize link parameters (DR, NF)

Photonic Integrated Circuits

Initial design : Mask, grow wafers, process

Develop FM transmitter chip

FM receiver chip: LO and balanced receiver

Develop packaged modules

Iterate design to match link needs

Receiver Electronics

Design WIRNA receivers

Set-up e-beam lithography system

Packaging issues: Bump bond for receiver chip

Receivers with BW>10GHz (e-beam gates)

Finalize and implement designs for FM-link

Project

FM link: commercial components

FM link: Twin-guide based PICs

Report