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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Program Dates: July, 2000 – October, 2003
Agent: Army Research Office

Presentation by: Milind Gokhale, asip inc.

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

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

Photonic Integrated Circuits: RFLICs

- **Asymmetric Twin-Guide technology**
- **Previous Results**
- **Receiver and transmitter design**

PROGRAM MANAGEMENT

- **Timeline/Milestones**
- **Budget**

RFLICs Team

P.I. : Stephen Forrest

Team Leader : Wilson Lin

Students : Fengnian Xia
Shubo Datta

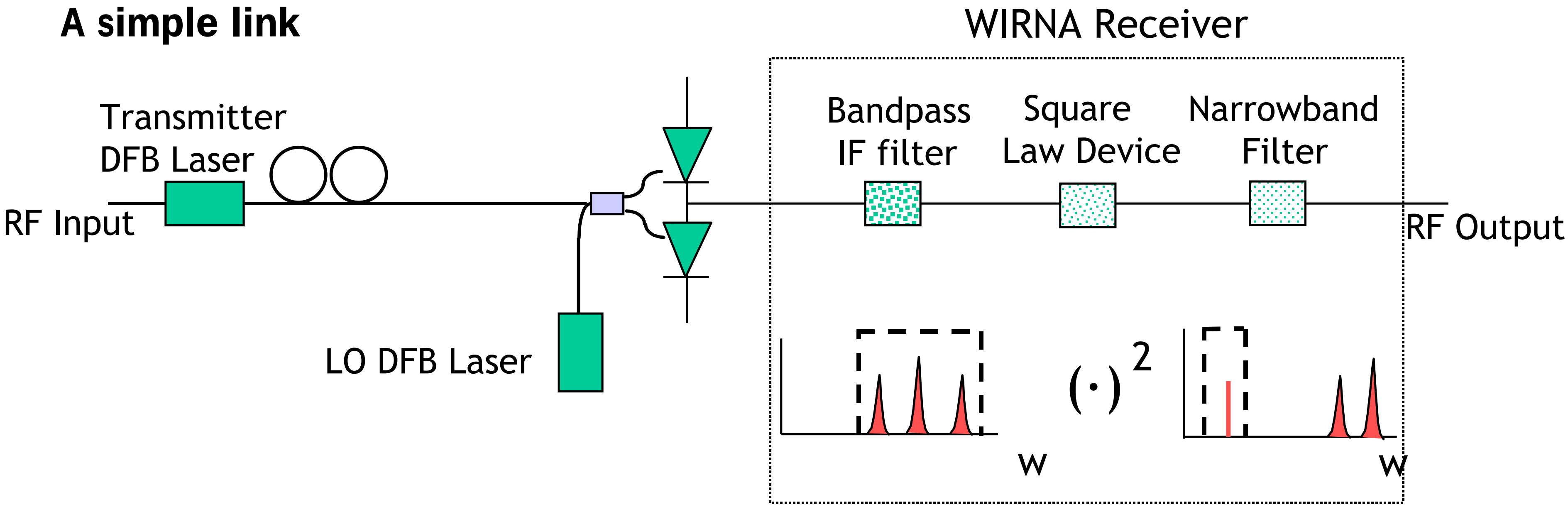
Industrial Collaborators

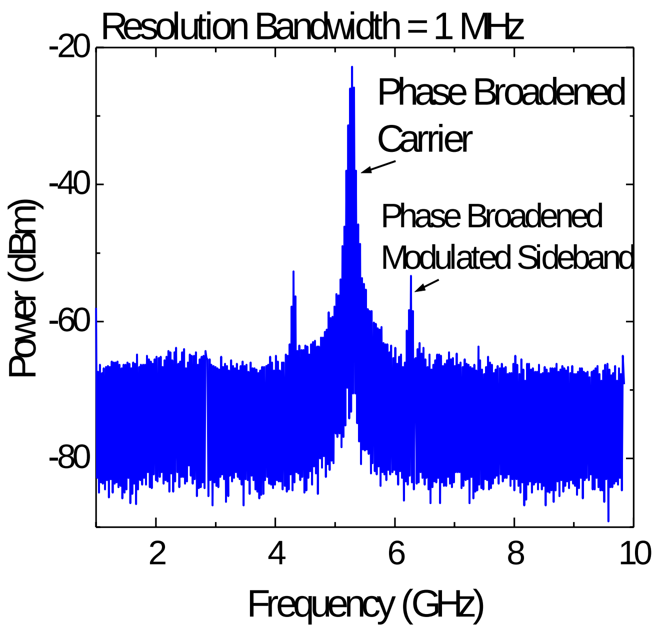
Twin Waveguide Components (*ASIP Inc.*):
Milind Gokhale, Pavel Studenkov

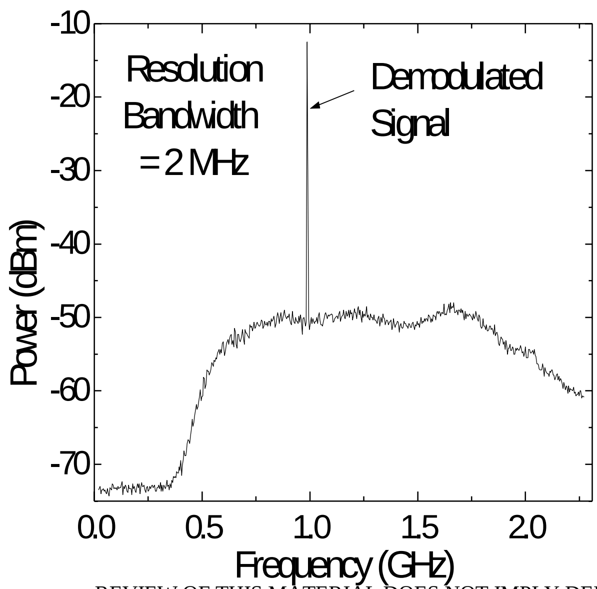
Receivers (*Sensors Unlimited Inc.*):
Marshall Cohen, Chris Dries

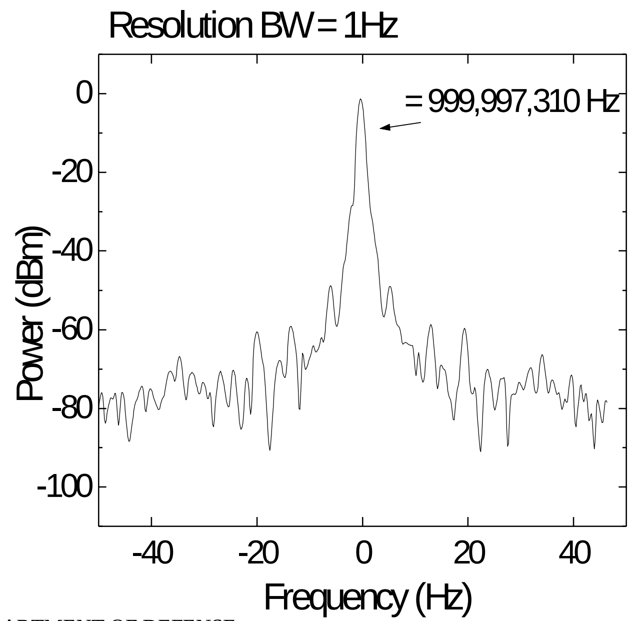
Links: *Not yet identified*

RF Optical Heterodyne Detection

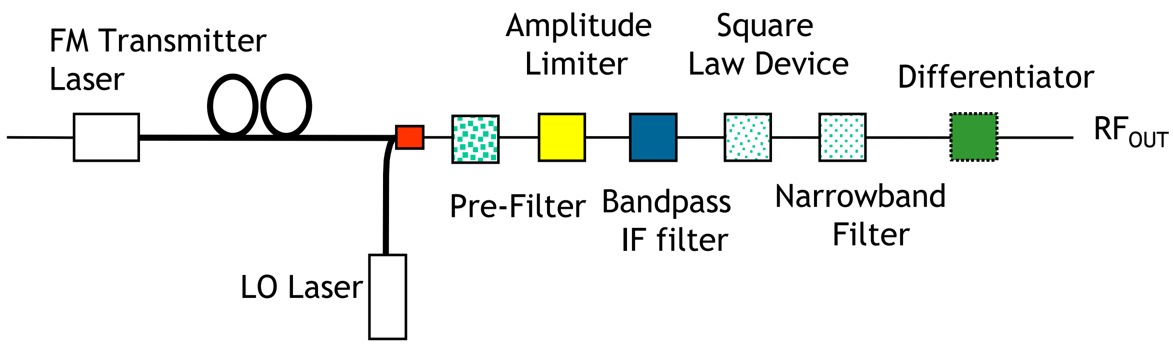


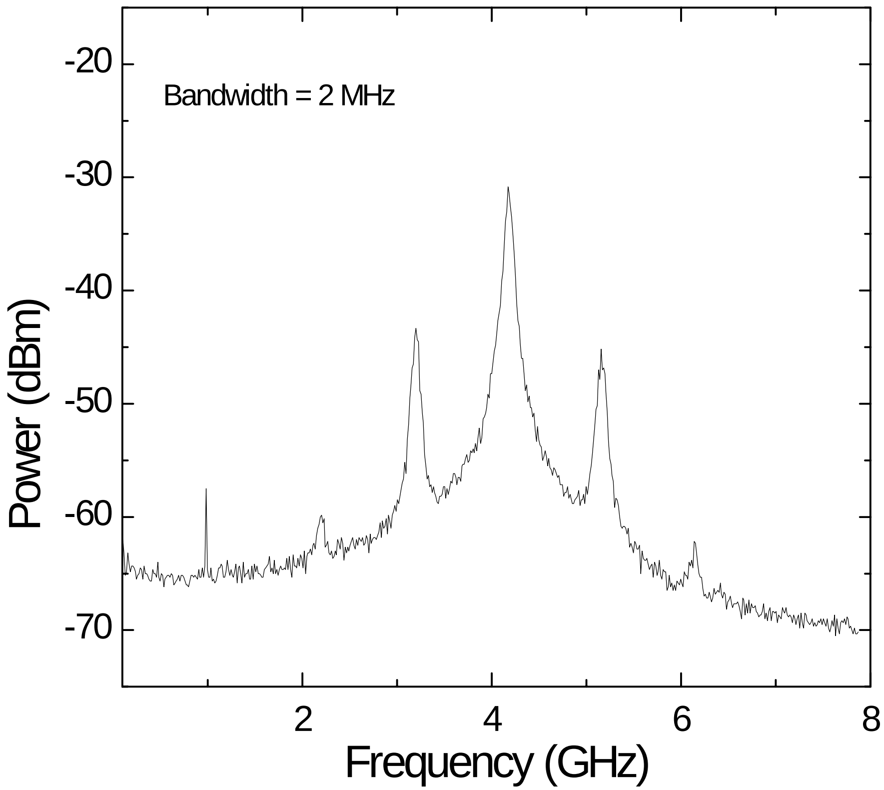


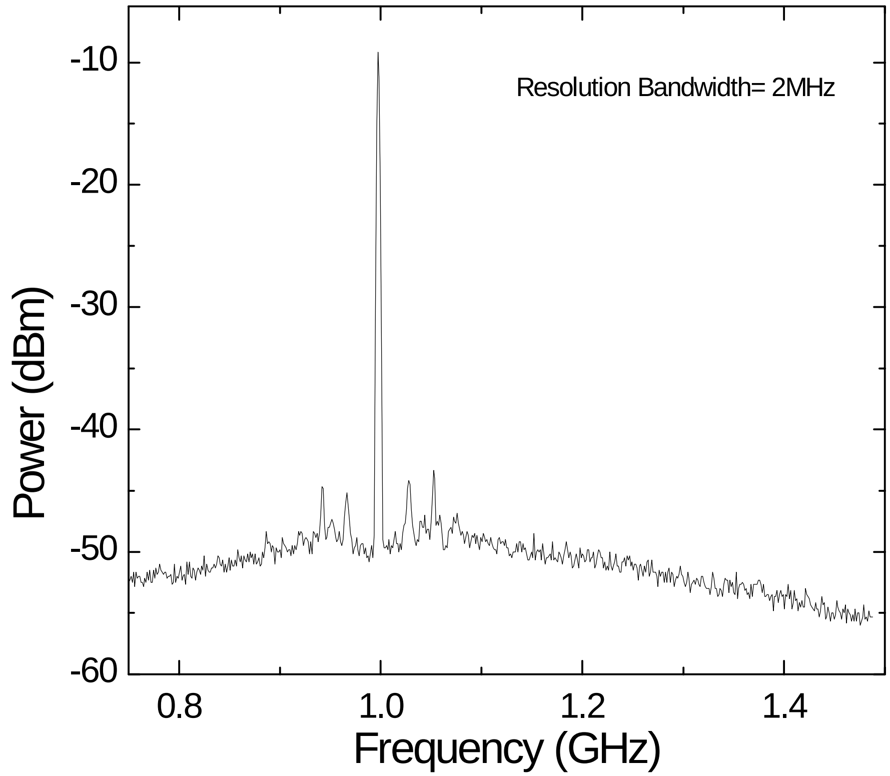




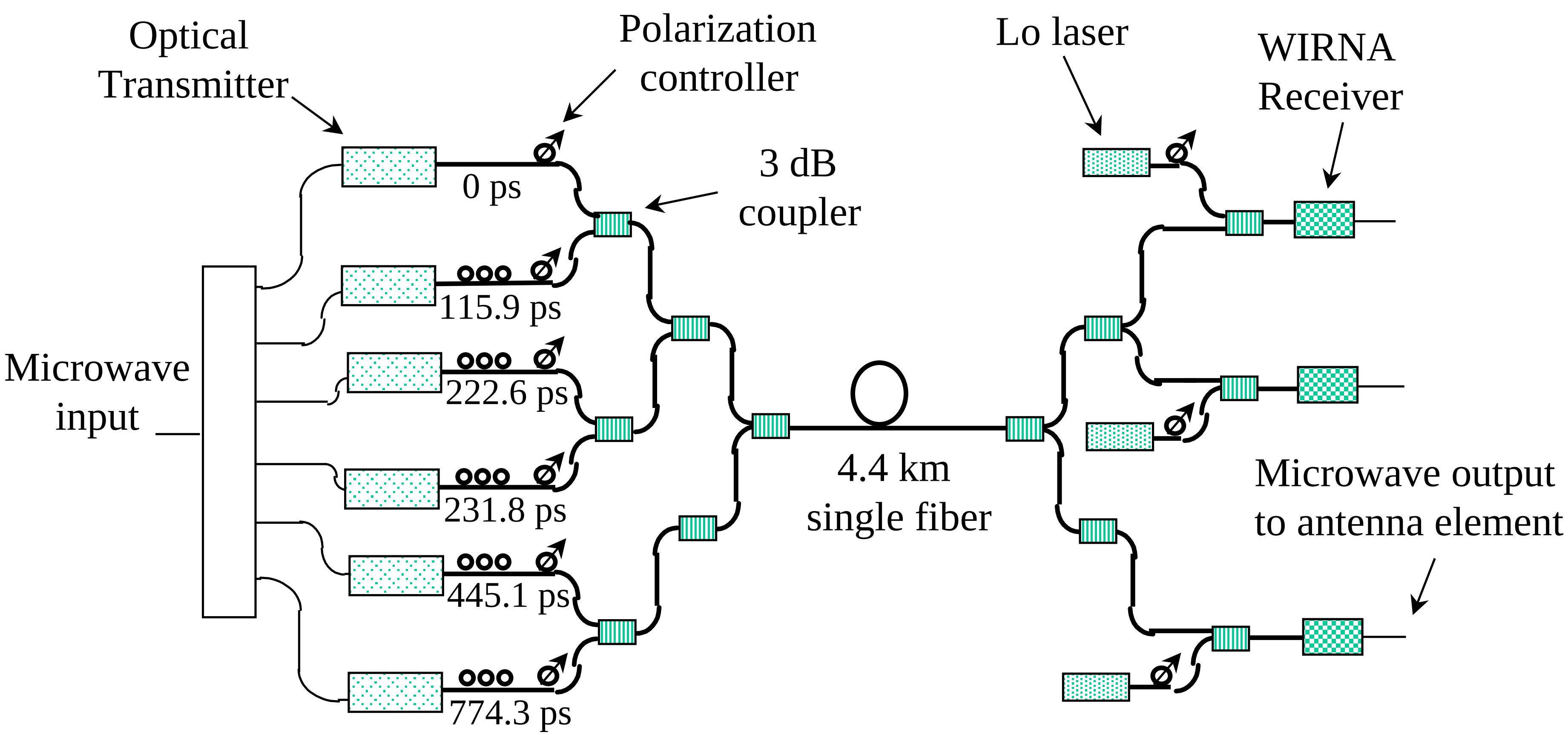
Phase Noise Cancellation Circuit: Results



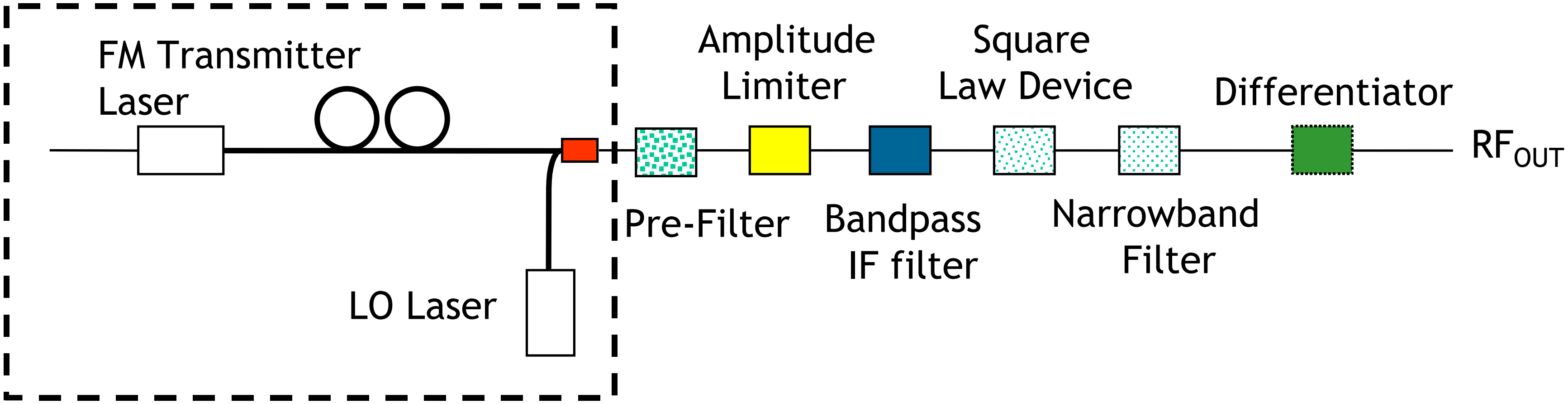


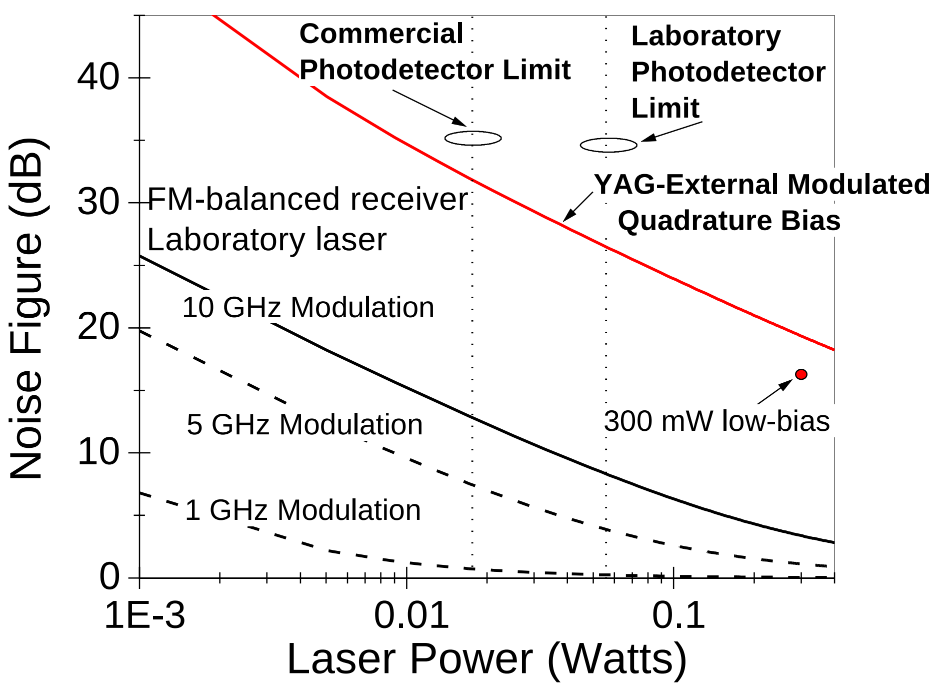


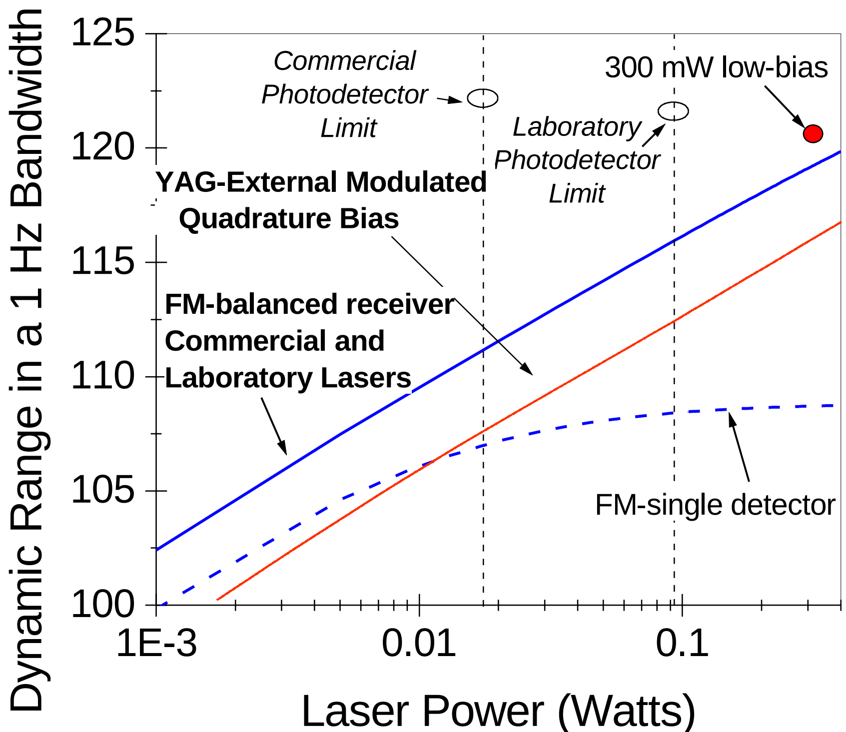
Heterodyne-link: Previous Results



RFLICs: FM-link Demonstration







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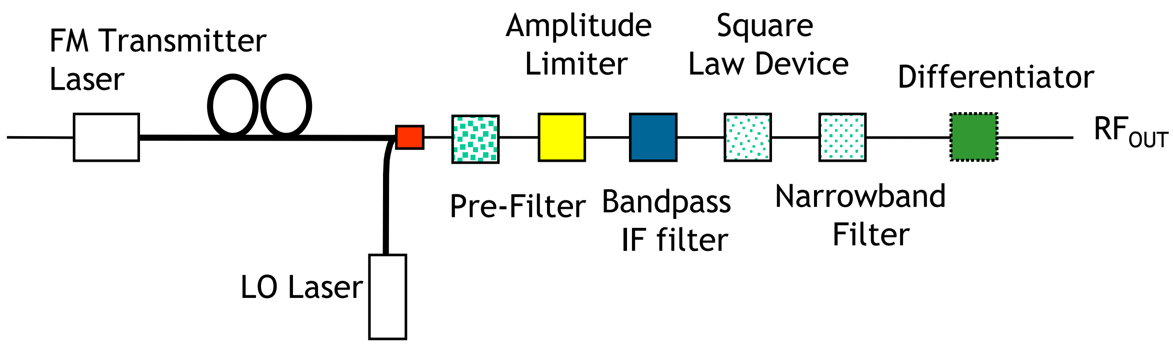
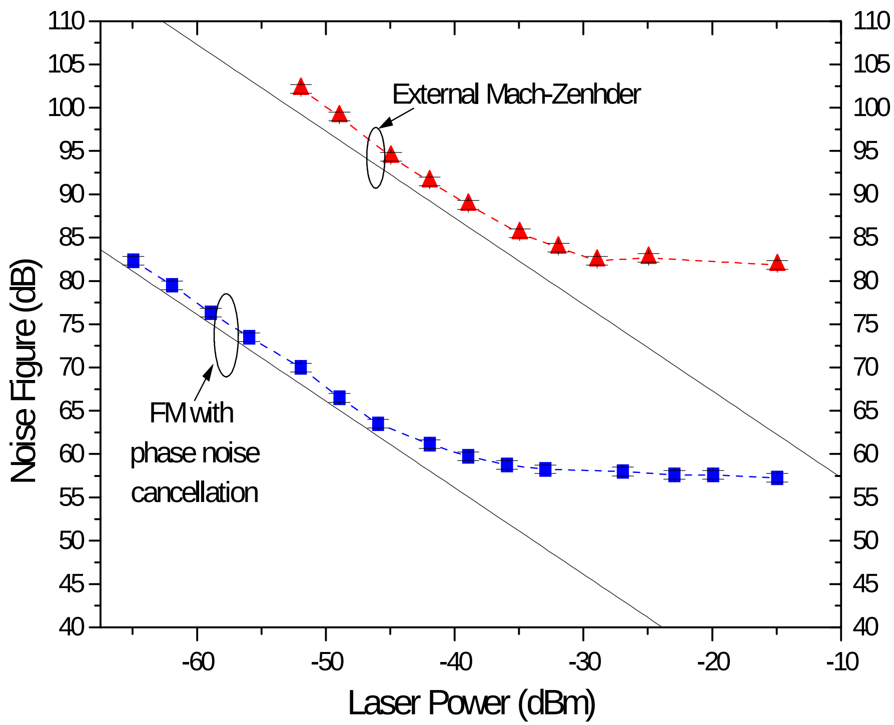
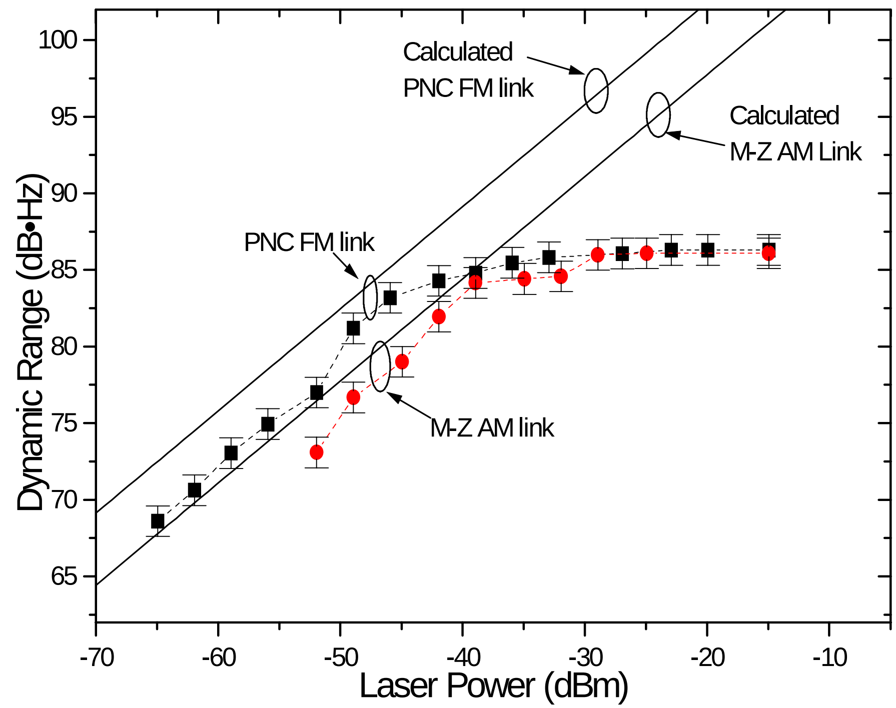
Previous Link Results







Problem: *Rolloff at high optical powers is due to Phase-To-Intensity (PTI) noise*
Solution: *DFB lasers with linewidth < 100KHz (demonstrated in AM link)*

RFLICs: Photonic Integrated Circuits

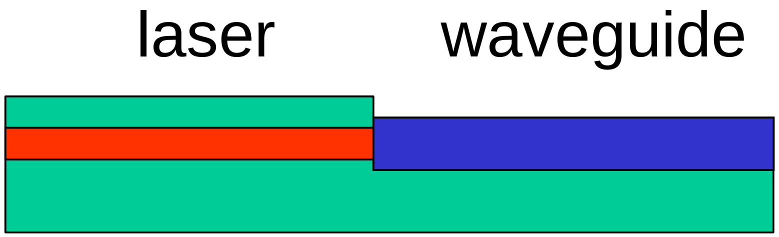
Requirements

- 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

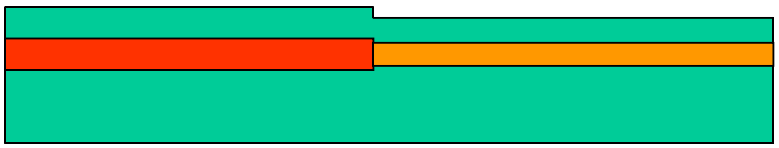
Integration Technology

- 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 a low-loss tapers to passive devices such as Y-branches, splitters, EA and Mach-Zehnder modulators

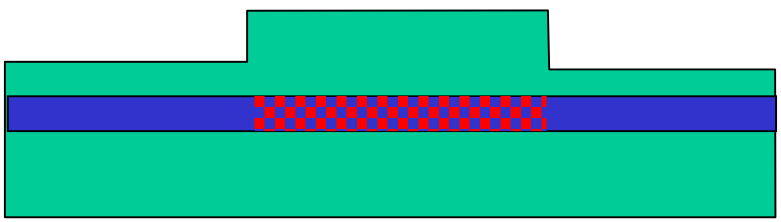
Technologies for monolithic integration



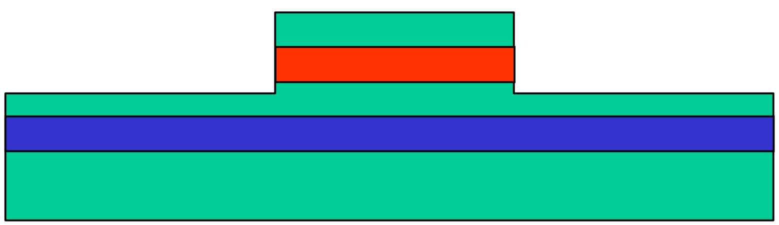
Selective regrowth - *butt coupling*



Selective-area growth - *vary mask widths to define active and passive regions*

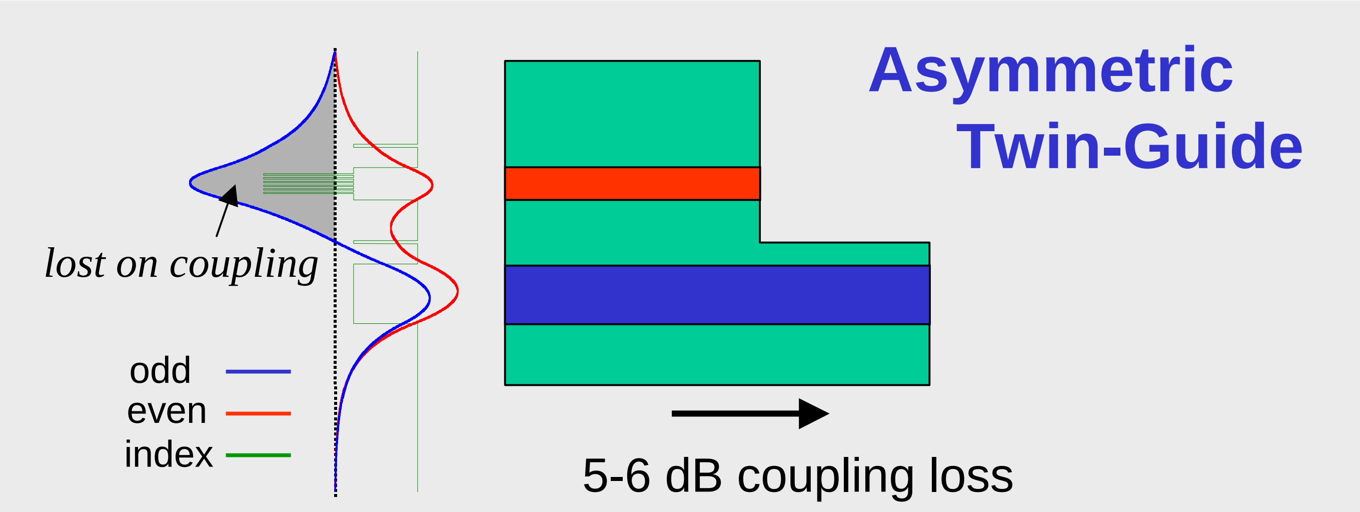


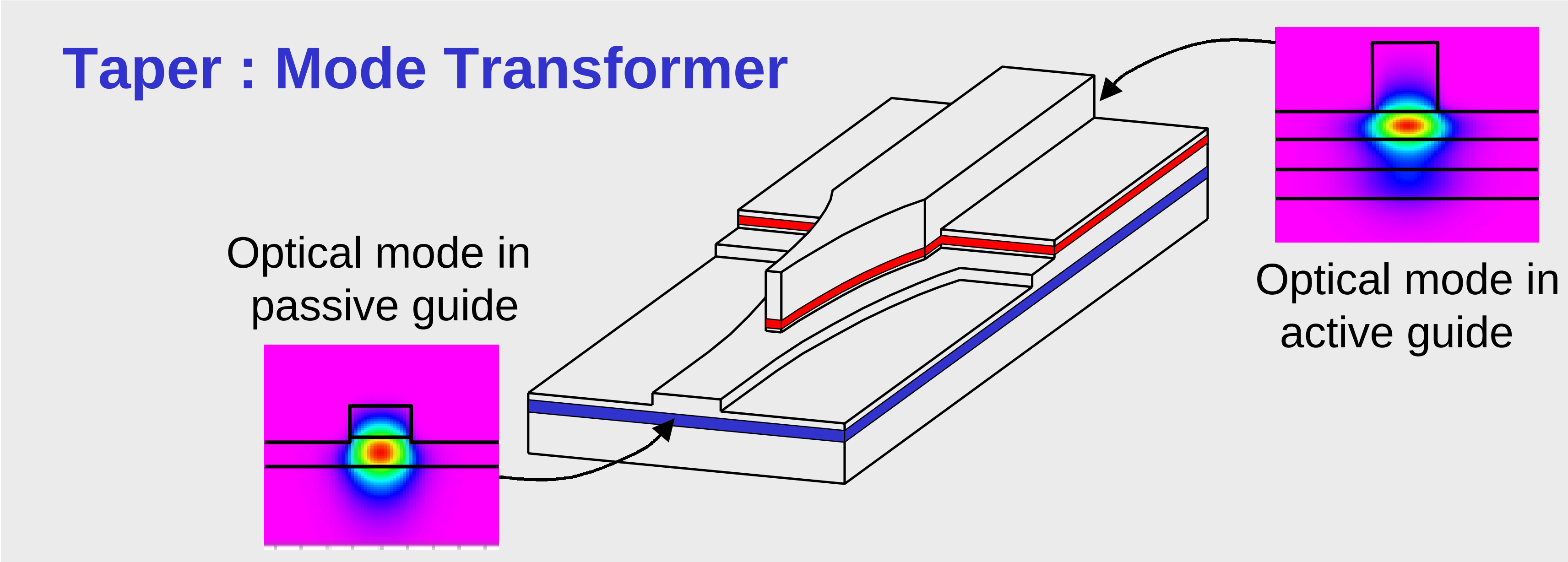
MQW disordering - *blue shift absorption edge of MQW in passive regions*



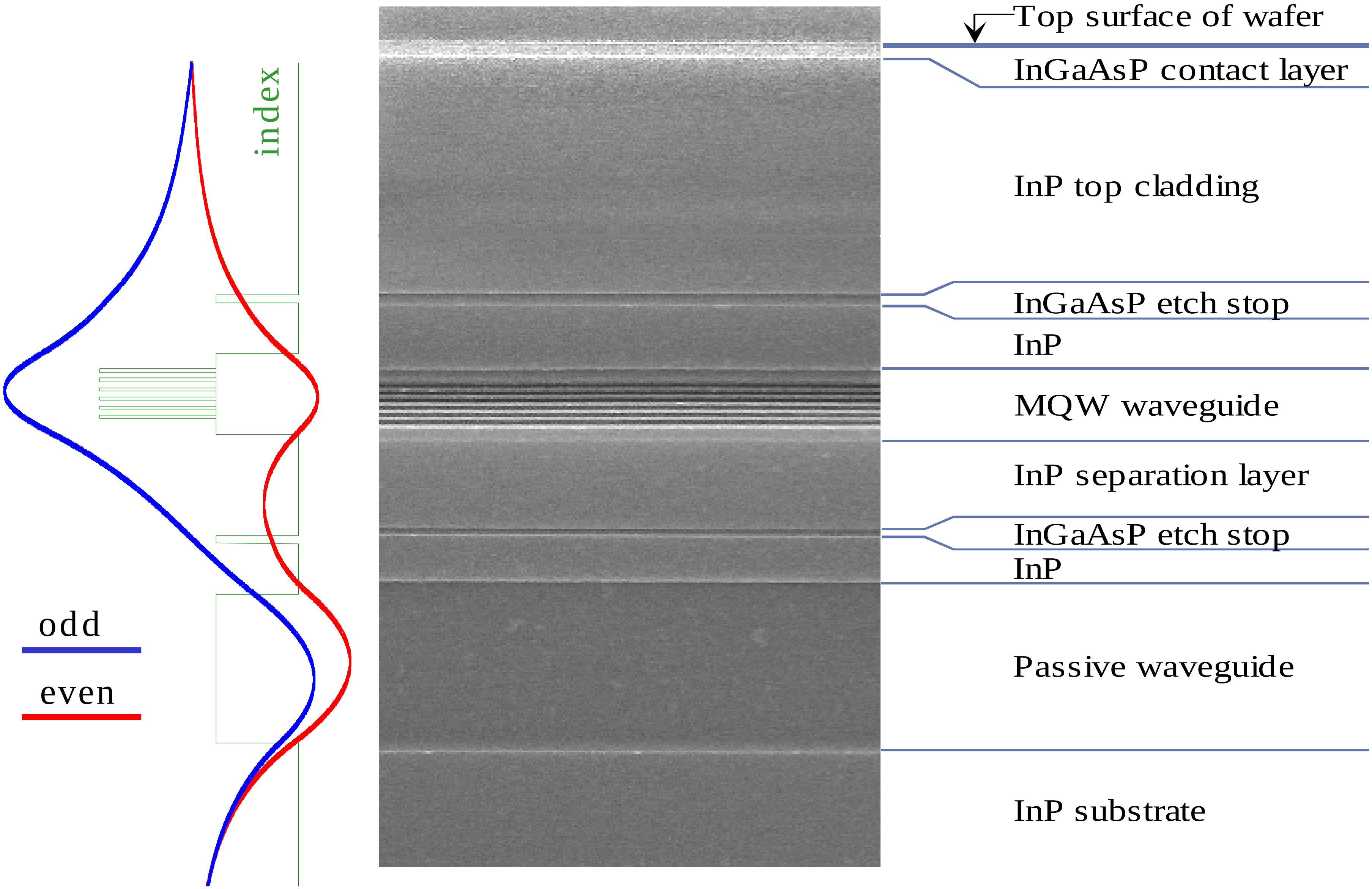
Twin-Guide (TG) - *separate active and passive waveguides with vertical coupling*

Asymmetric Twin Guide with Tapers

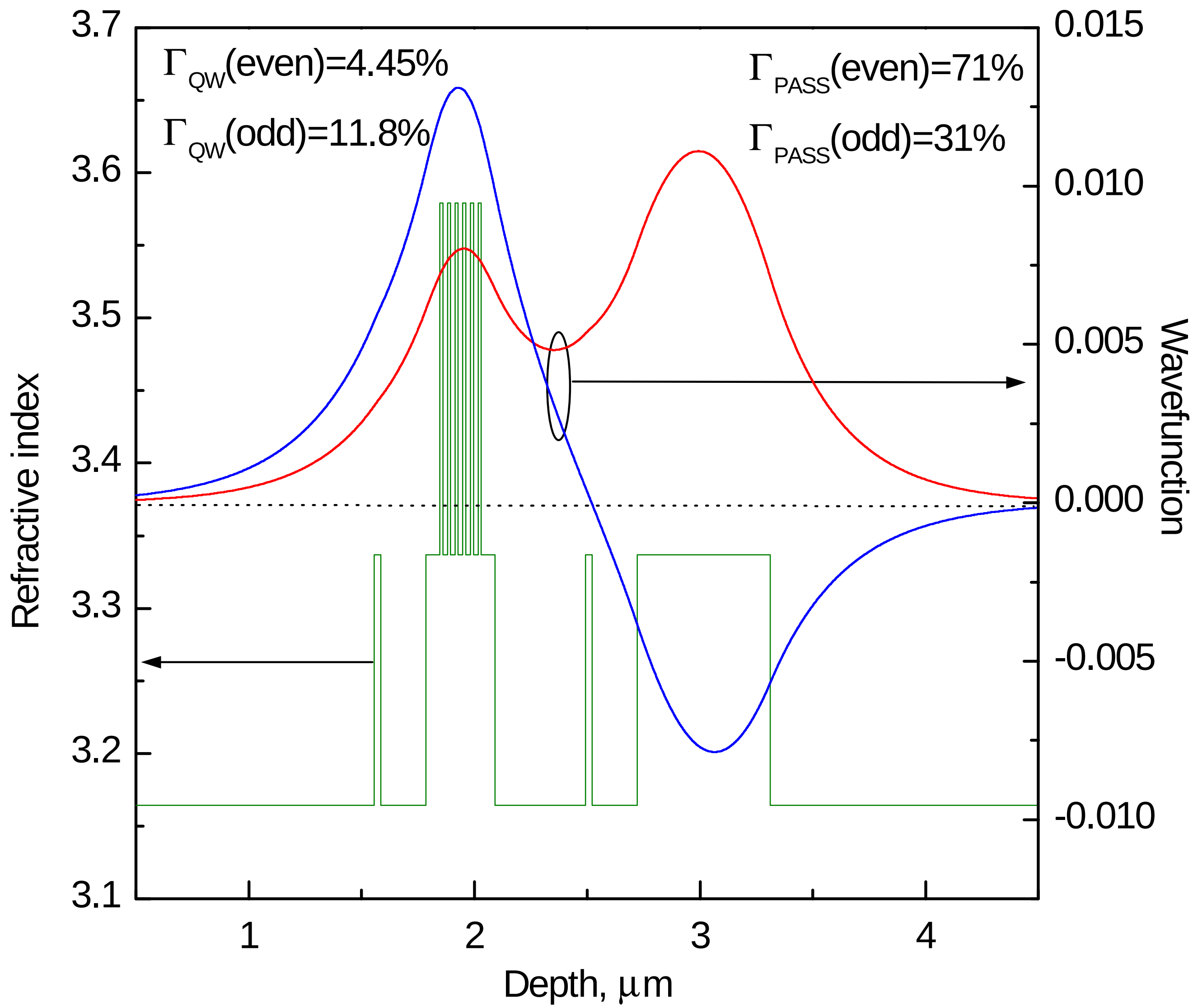




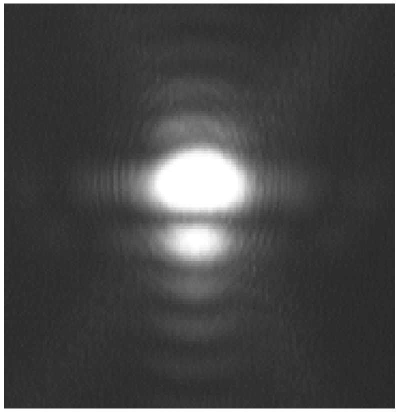
The TG structure and its two optical modes



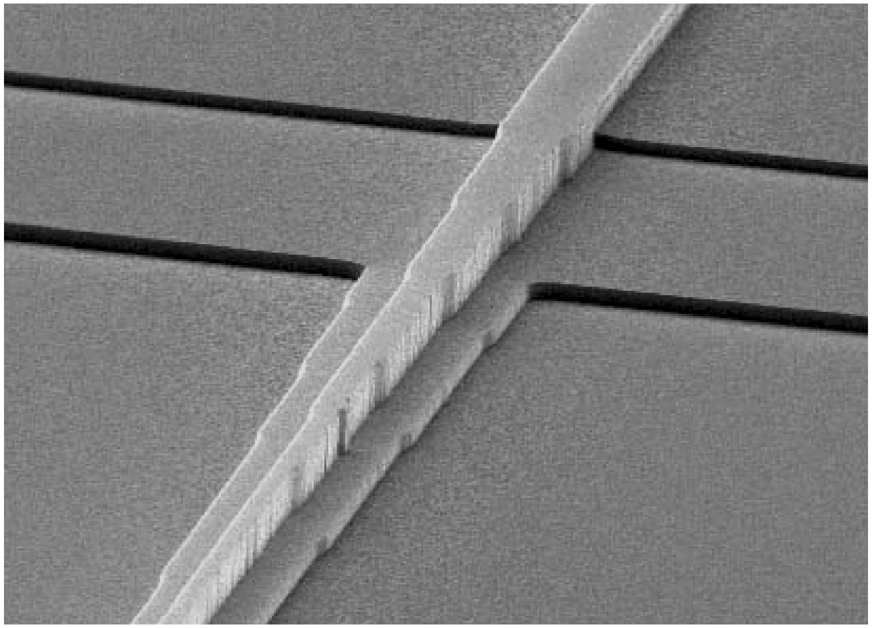
Asymmetric twin guide



NEAR FIELD

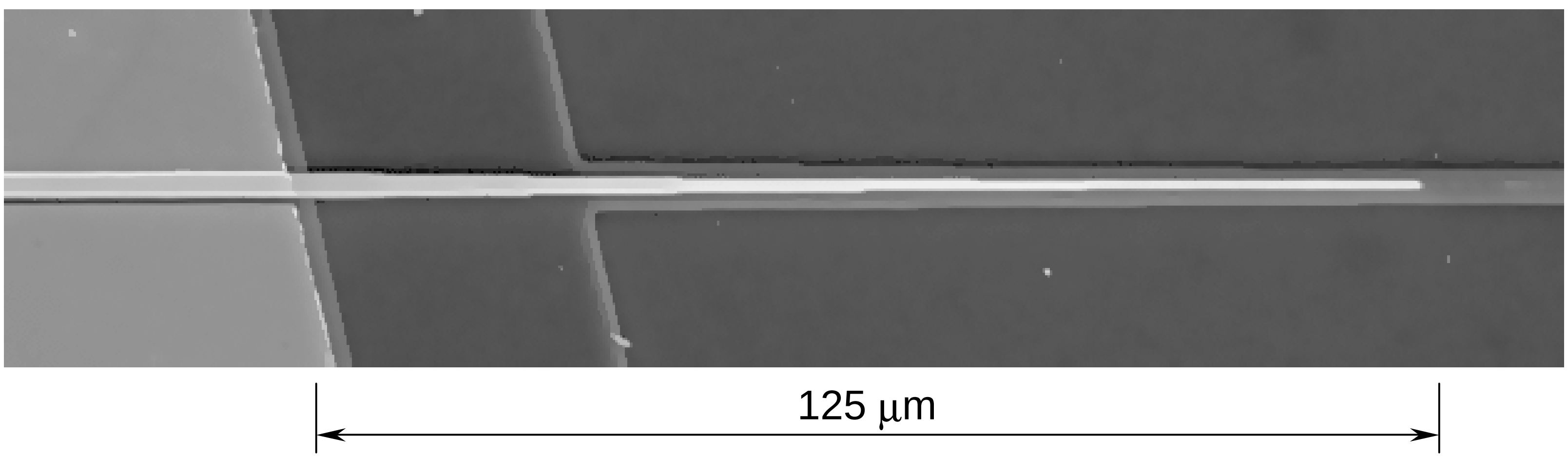


Dry-etched waveguide taper

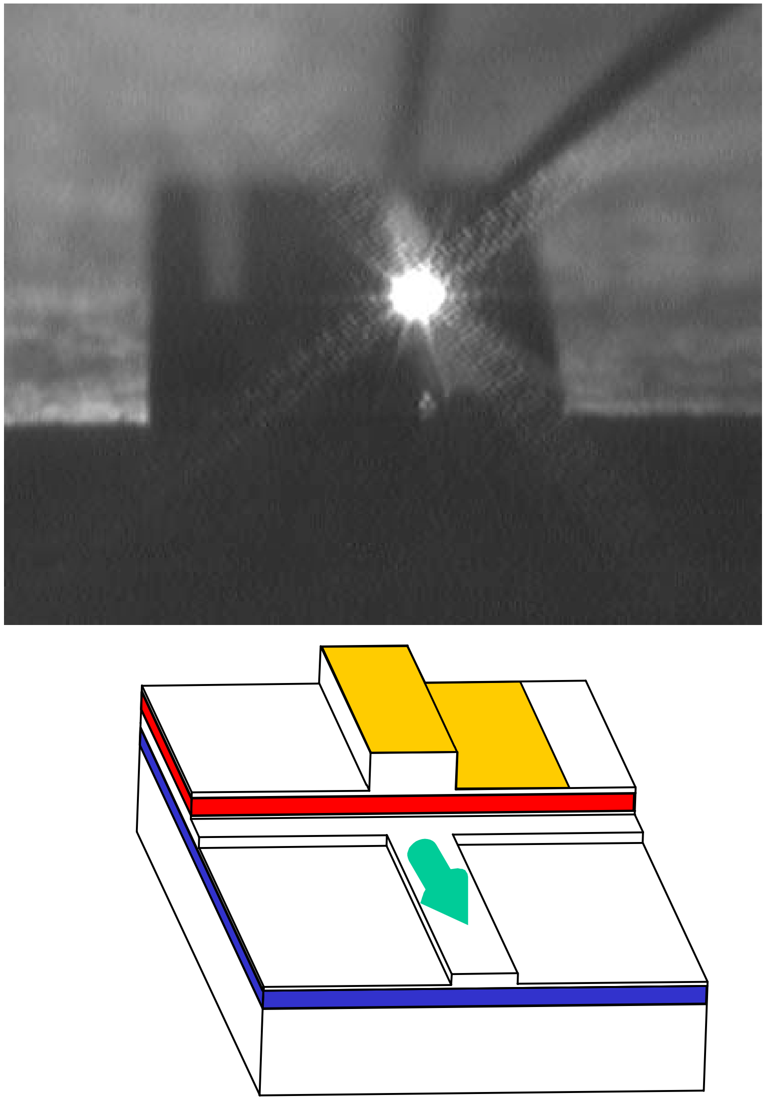


- Optical lithography
- Reactive ion etching in CH_4/H_2
- Three mask steps
- Taper width 3 μm ➔ 0.6 μm

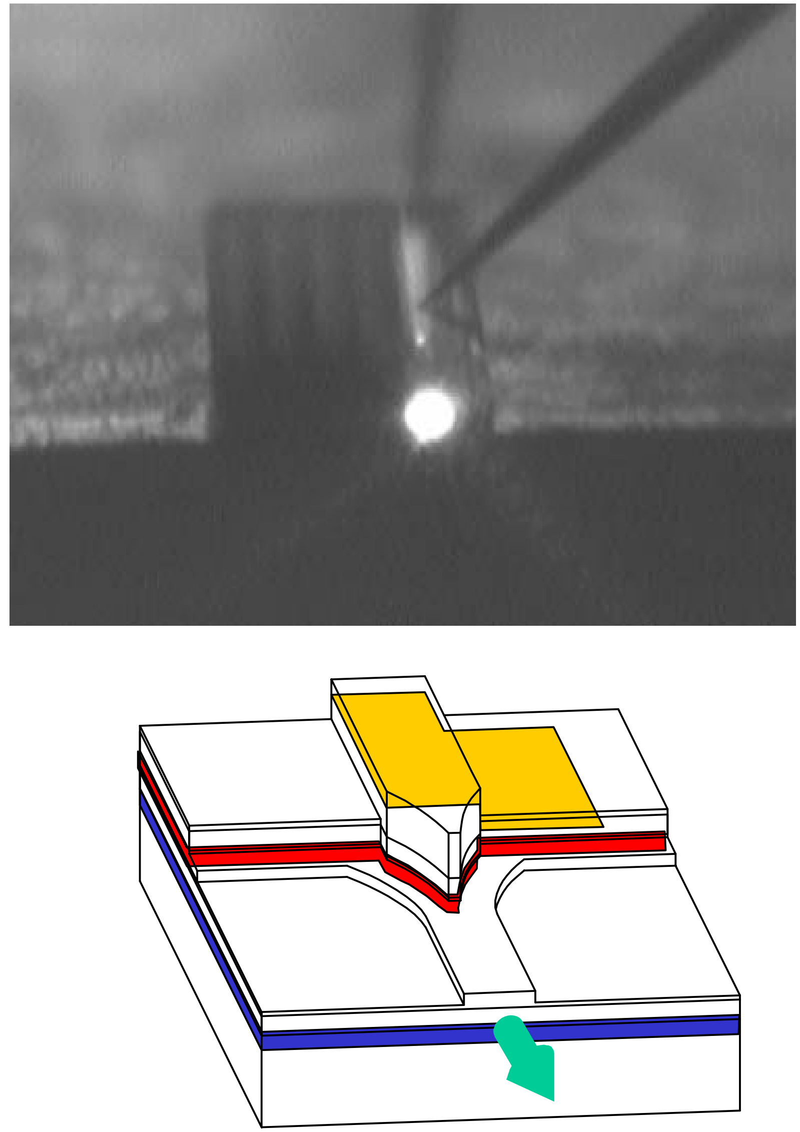
top view



Infrared camera images

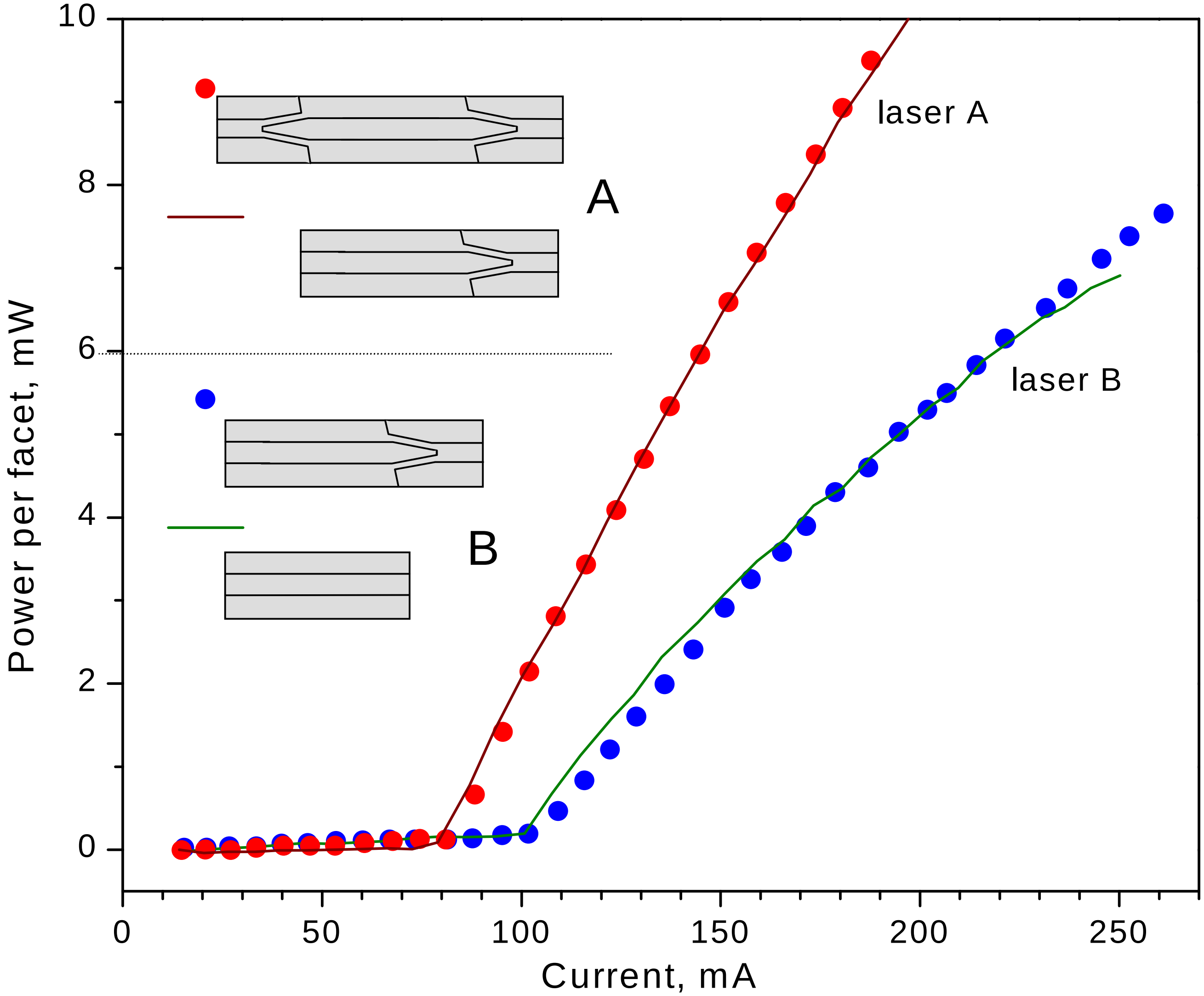


Facet coupler



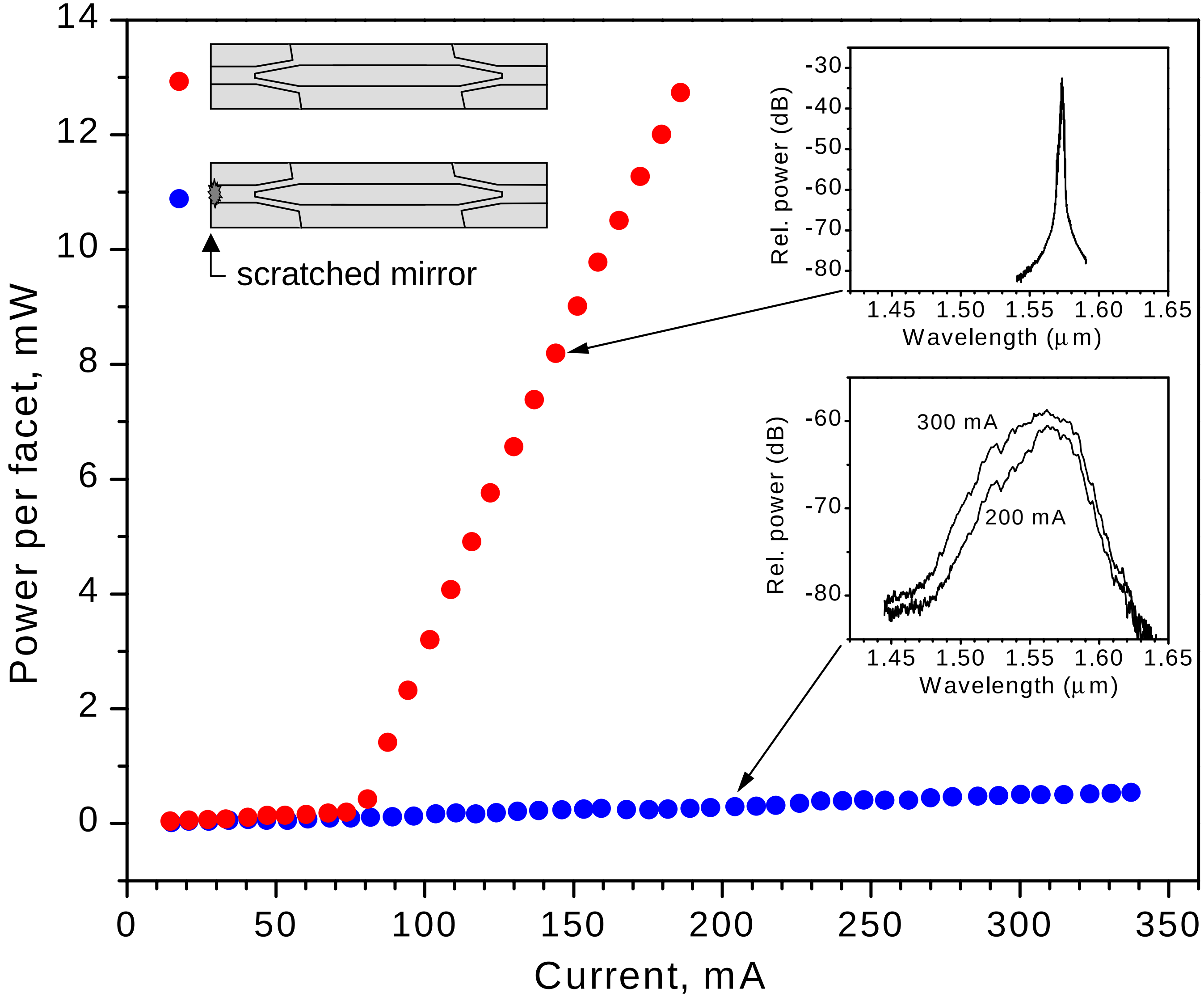
Taper coupler

"Lossless" coupling



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

Low reflection at active-passive interface



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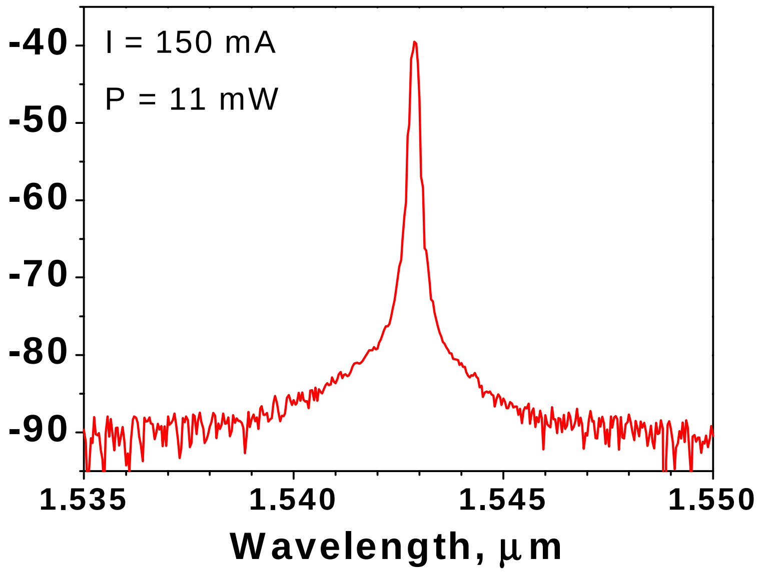
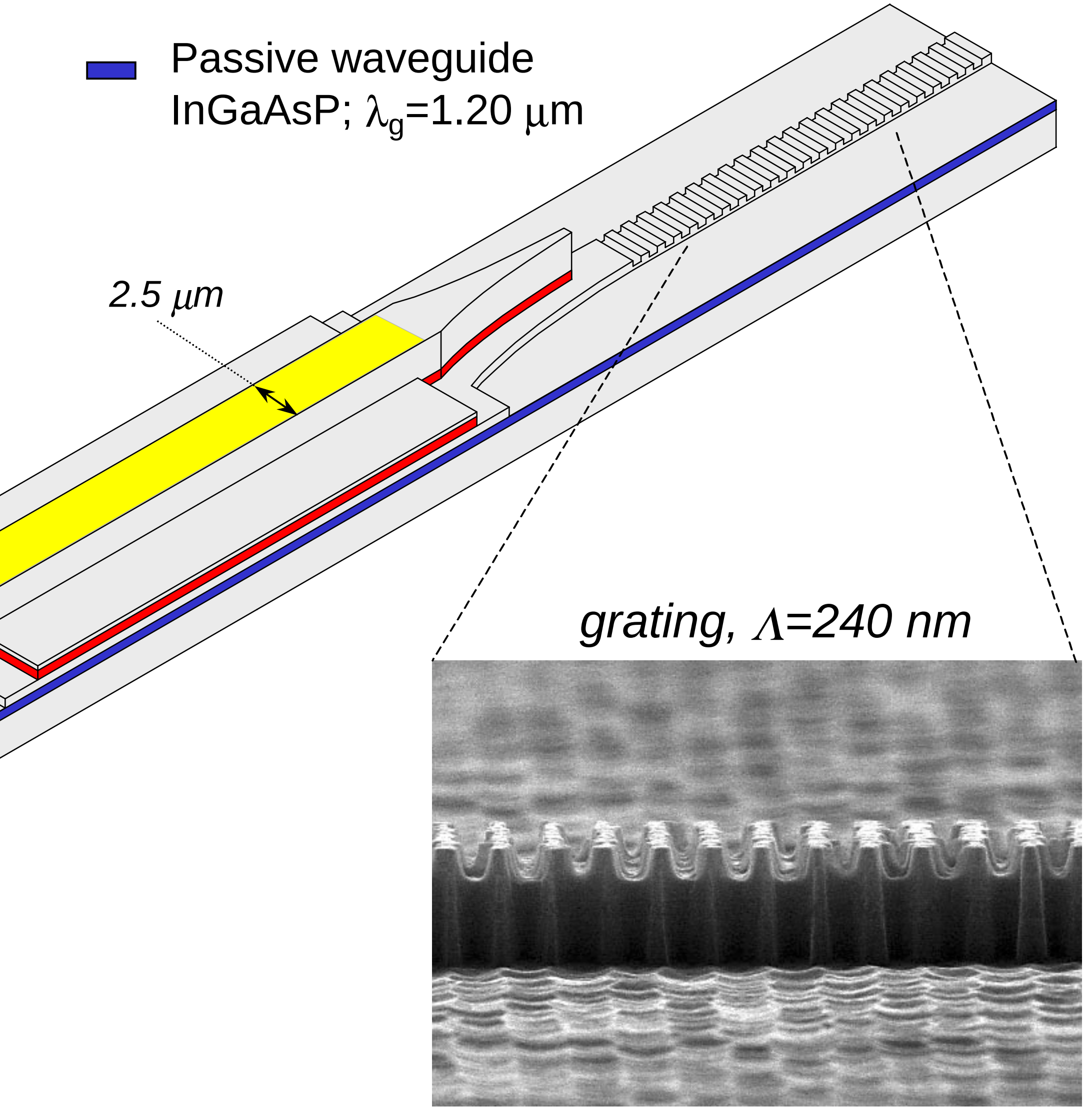
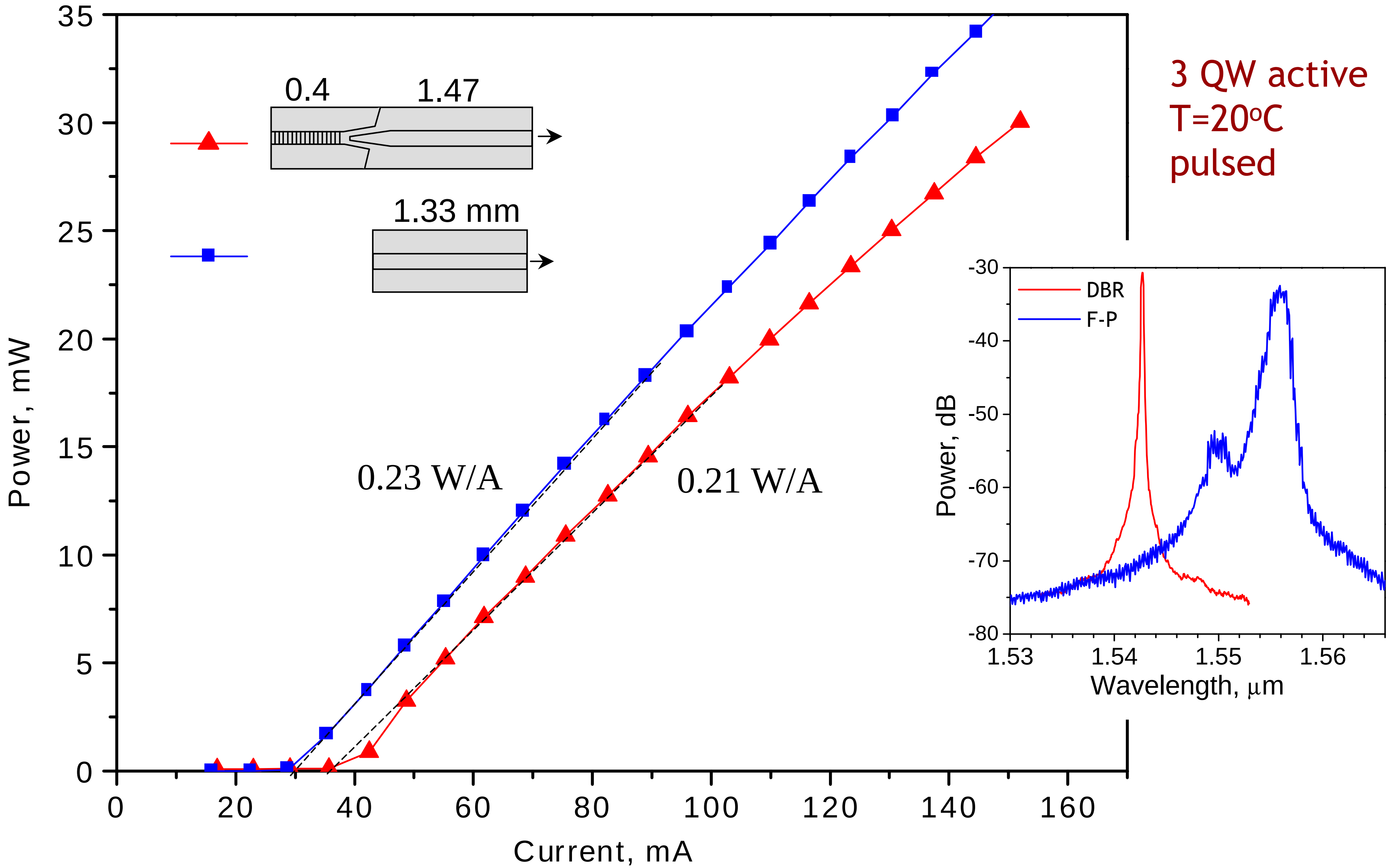
Twin-Waveguide DBR laser





Comparison of DBR and Fabry-Perot lasers

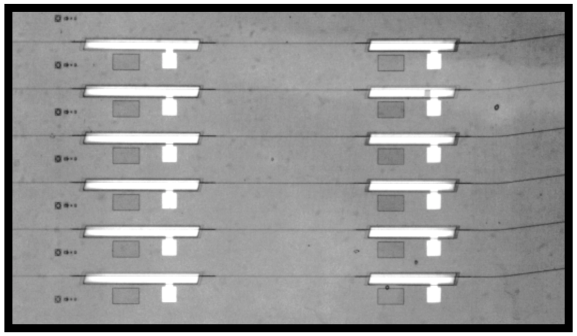


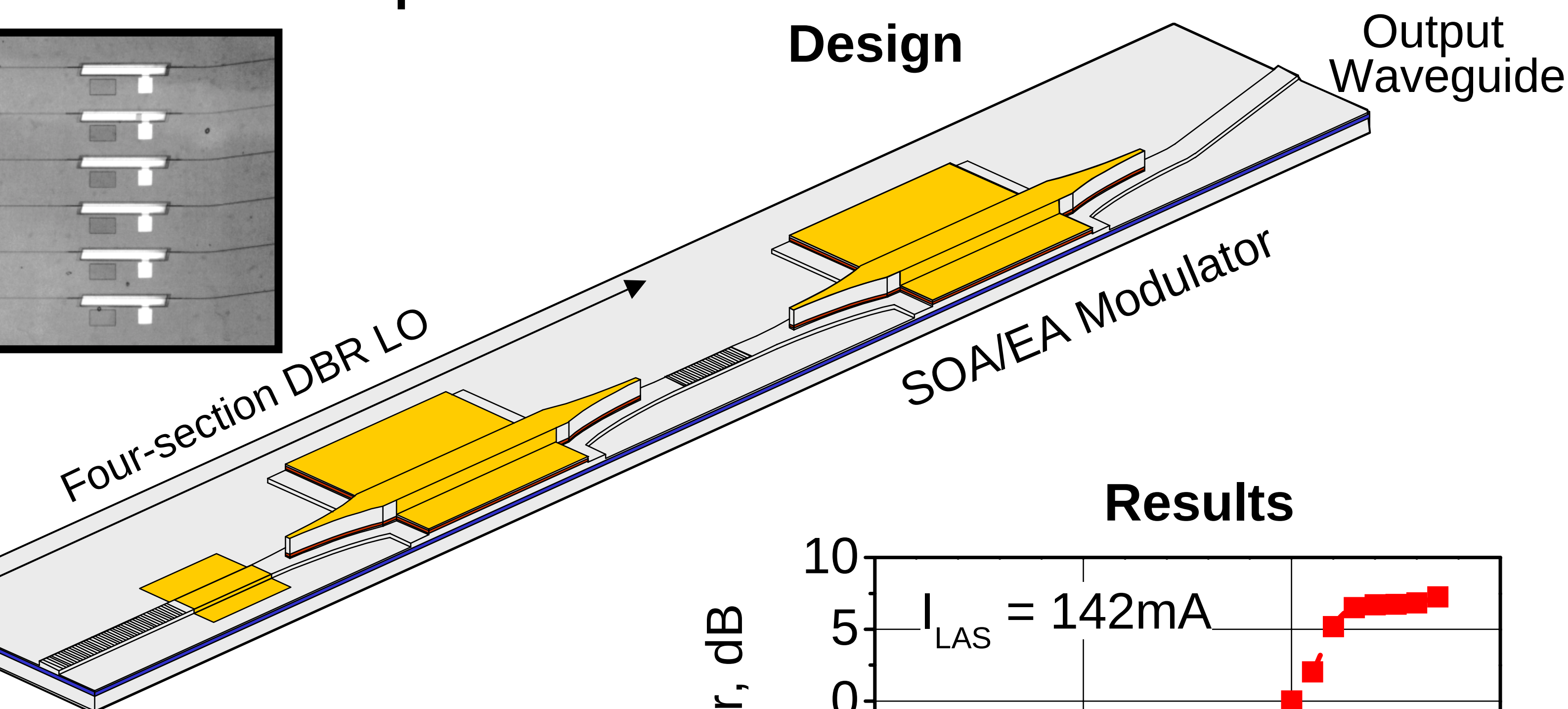
3 QW active
T=20°C
pulsed

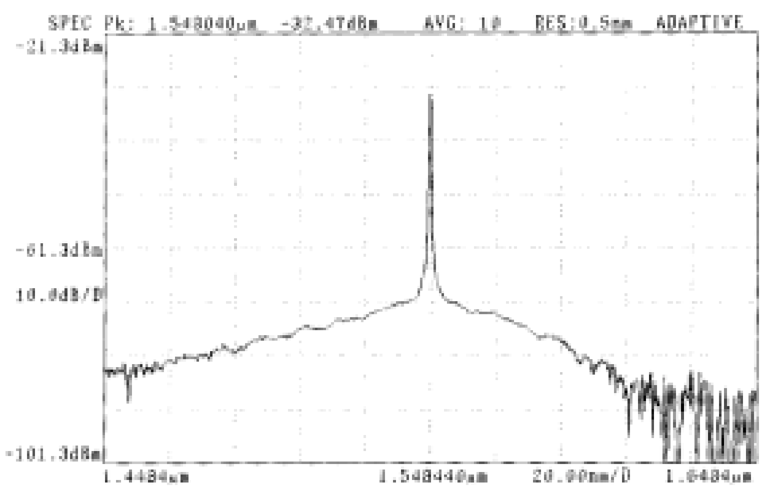
DBR wavelength is blue-shifted from gain peak by 15 nm

Integrated Laser-Modulator : Results

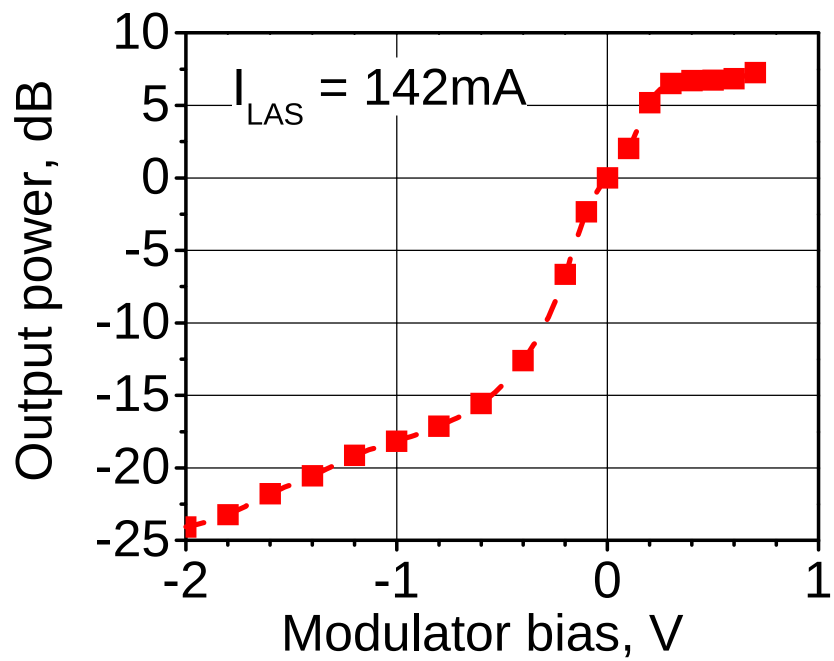
Fabricated Laser - SOA Chip



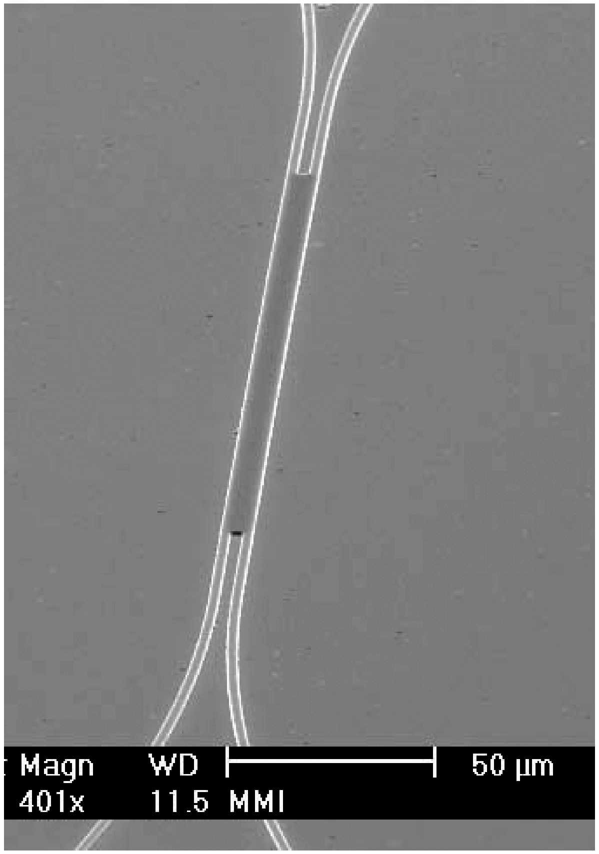


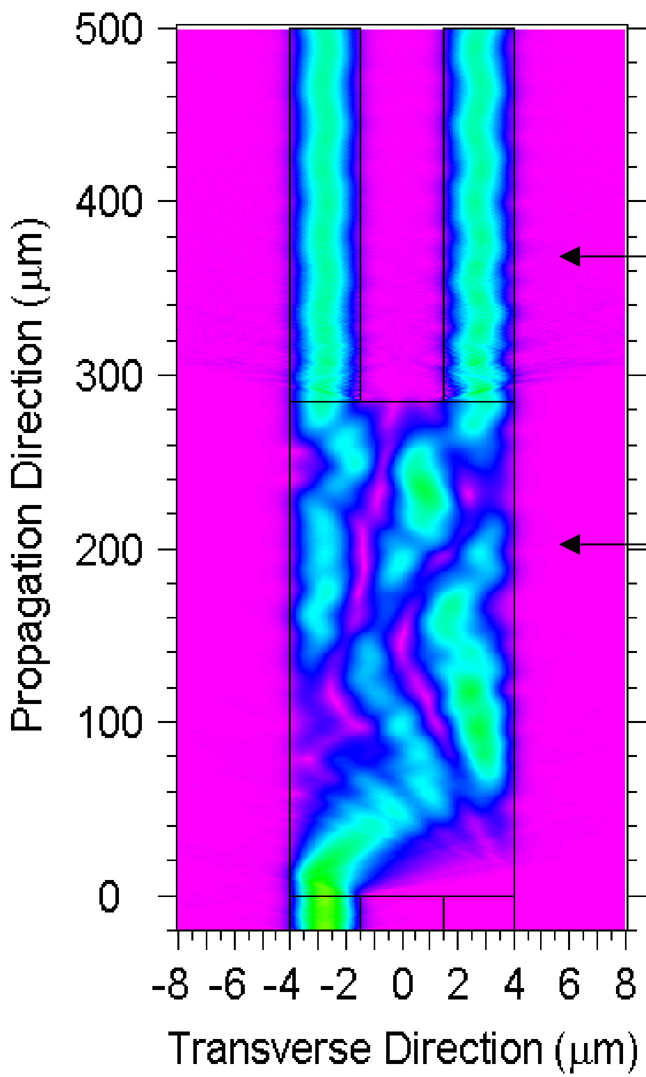


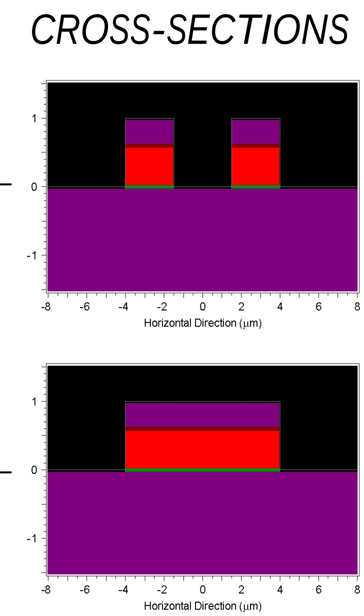
Results



2x2 multimode interference (MMI) coupler

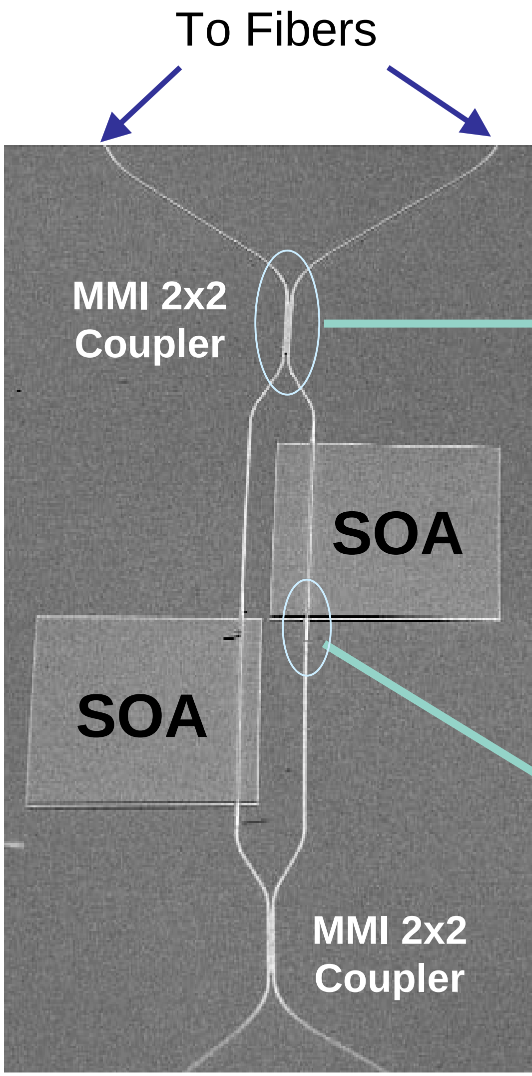


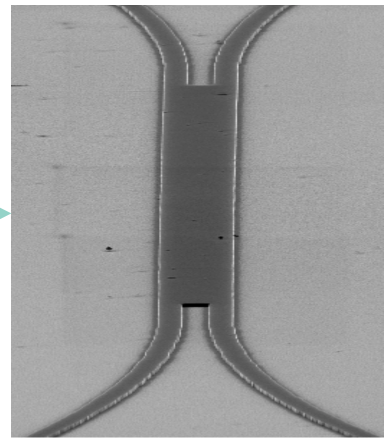




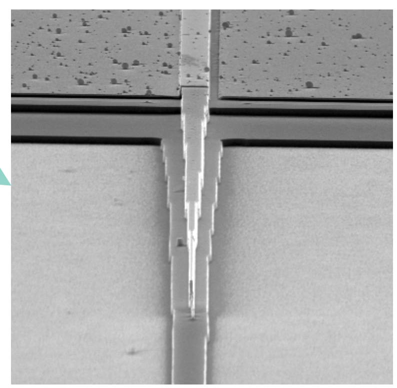
W_{MMI}=8 µm
W_{guide}=2.5 µm
L_{MMI}=280 µm

Integrated Mach-Zehnder TOAD

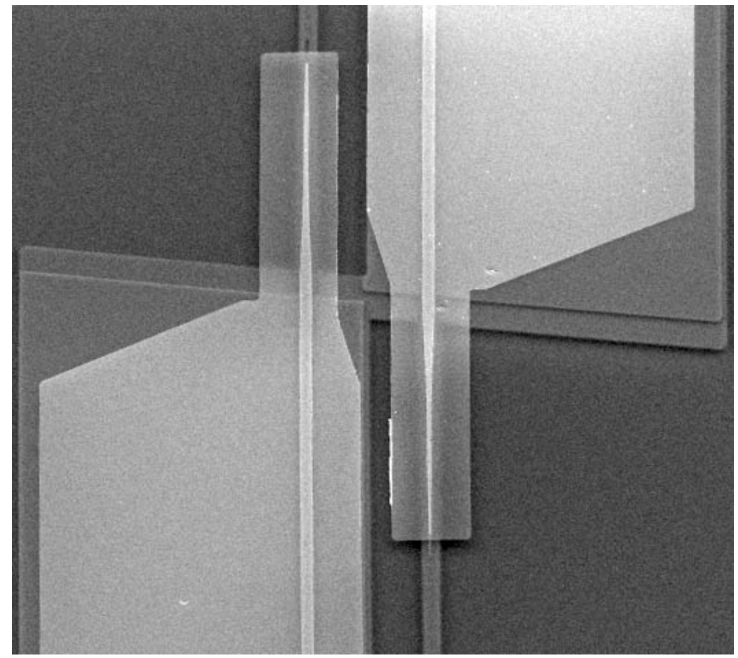




3 dB MMI couplers

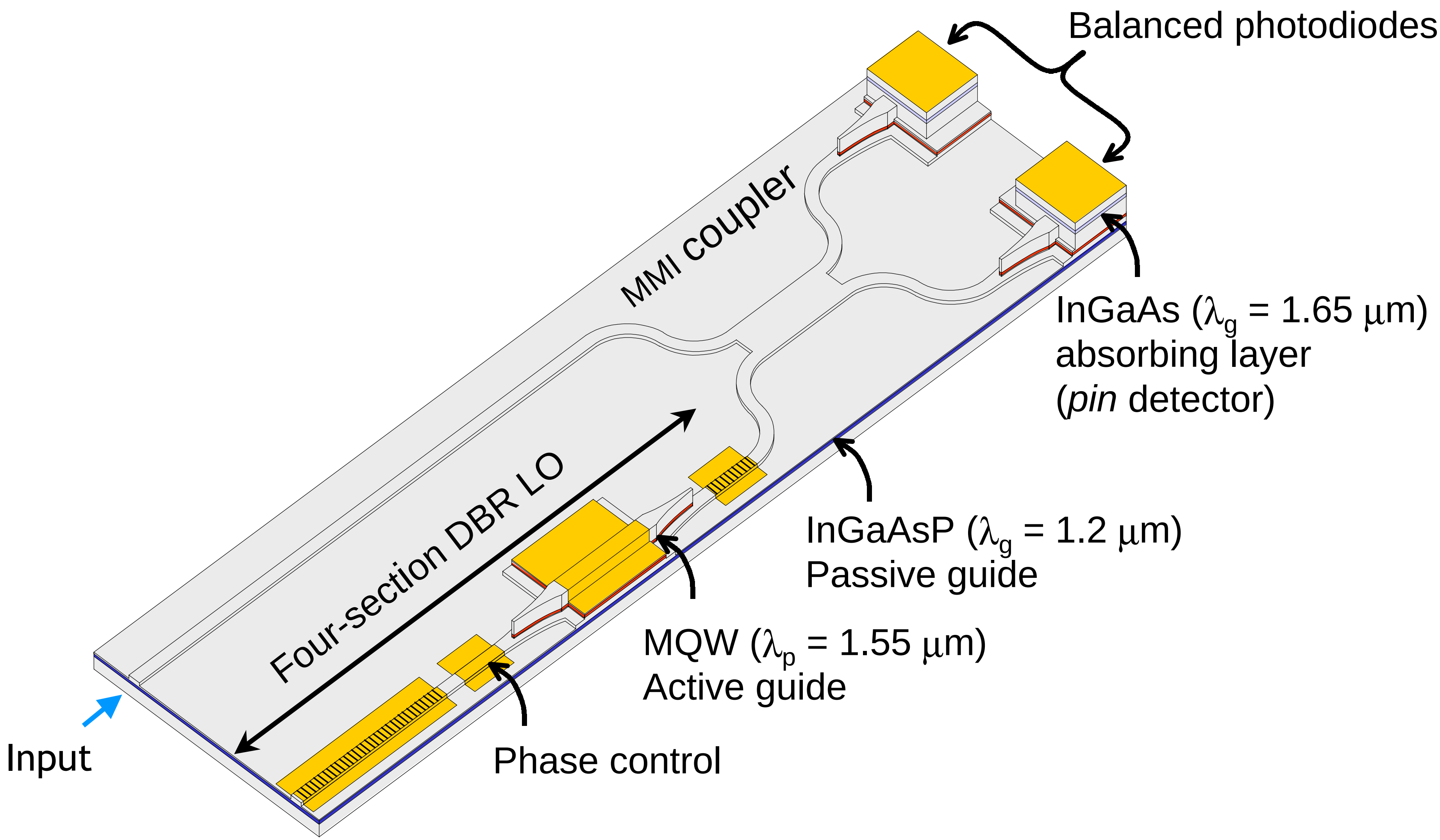


Tapers



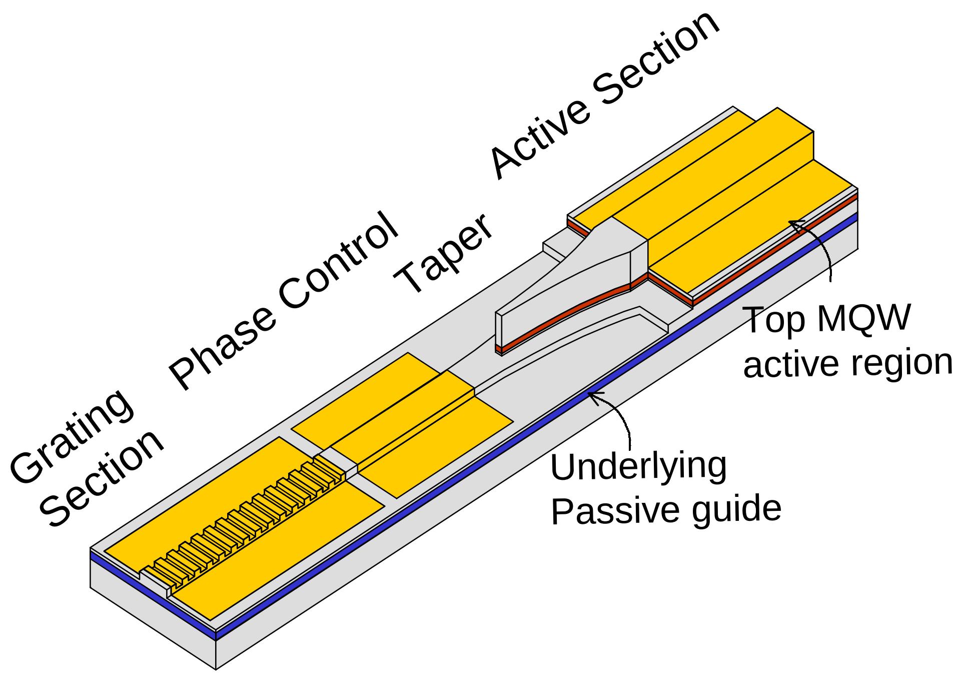
Close-up of the middle part of a MZ TOAD device. The tapers are planarized and metal contacts extend over tapers

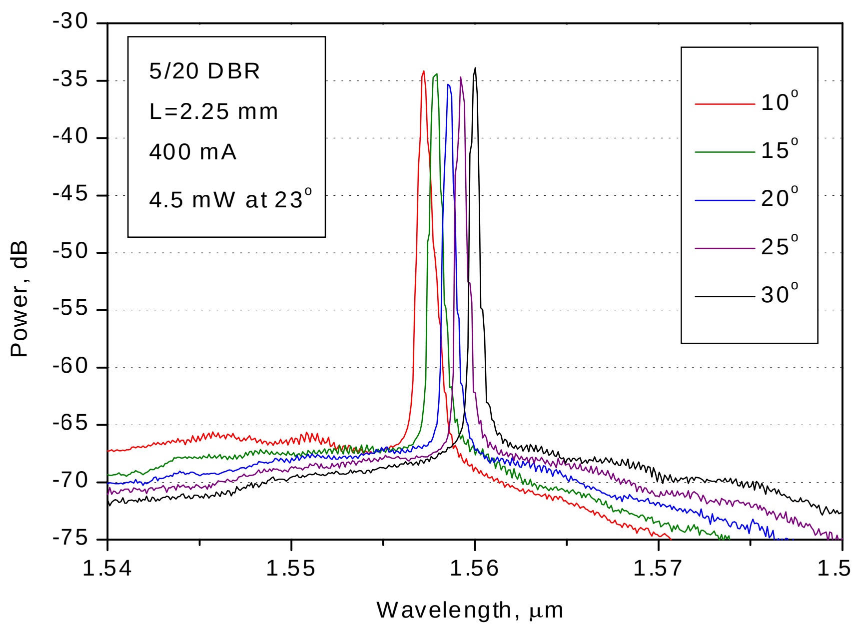
TG-Based Heterodyne Receiver



FM Transmitter: Commercial and TG based

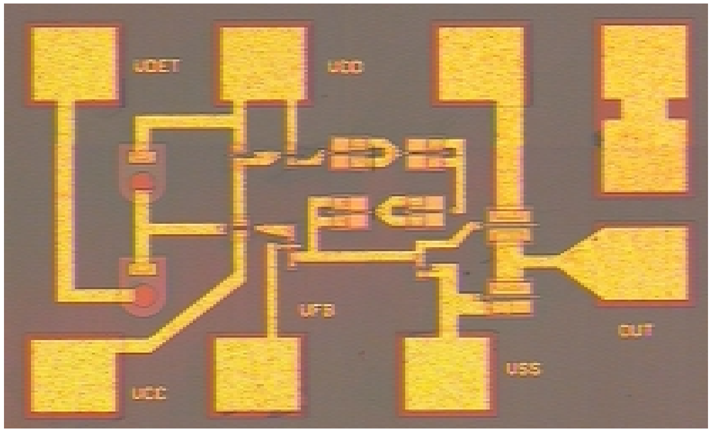
- Commercial DFB lasers: δ_{FM} = 0.4 – 1 GHz/mA
- TG based DBR laser with FM provided by chirping the grating section
  - Chirp parameter is estimated at 1 GHz/mA
- Temperature tuning of wavelength



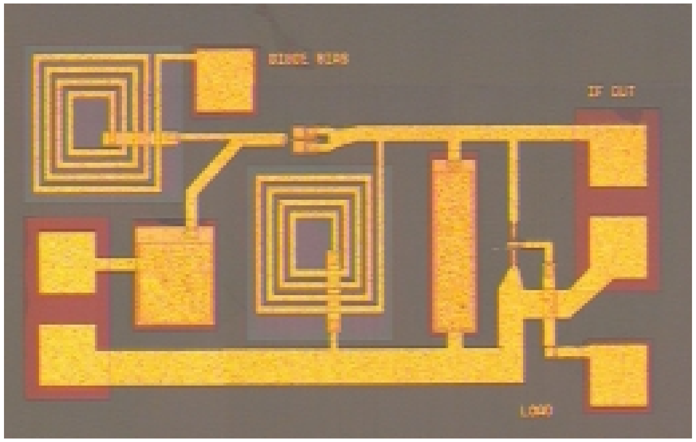


WIRNA Receiver Electronics

- Receiver front-end will be fabricated using InGaAs/InAlAs HEMT technology
- Our current technology uses optical lithographically defined gates that limit f_T ~ 40 GHz, BW ~ 8GHz . E-beam gates will be used to extend bandwidth



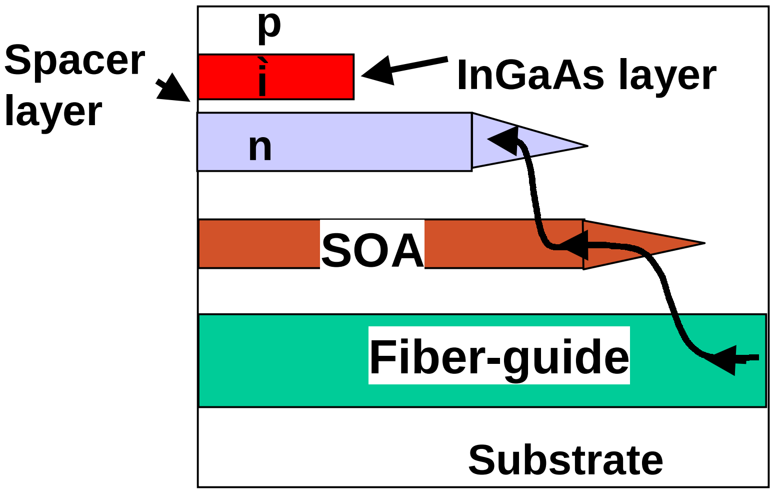
Balanced p-i-n/HEMT receiver



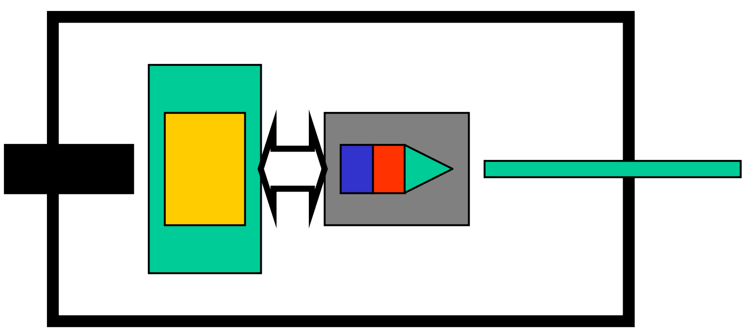
Mixer to remove 6GHz IF

- With the balanced detectors integrated on the PIC, receiver electronics may be designed separately using commercial foundry services.

Integration of laser and detector

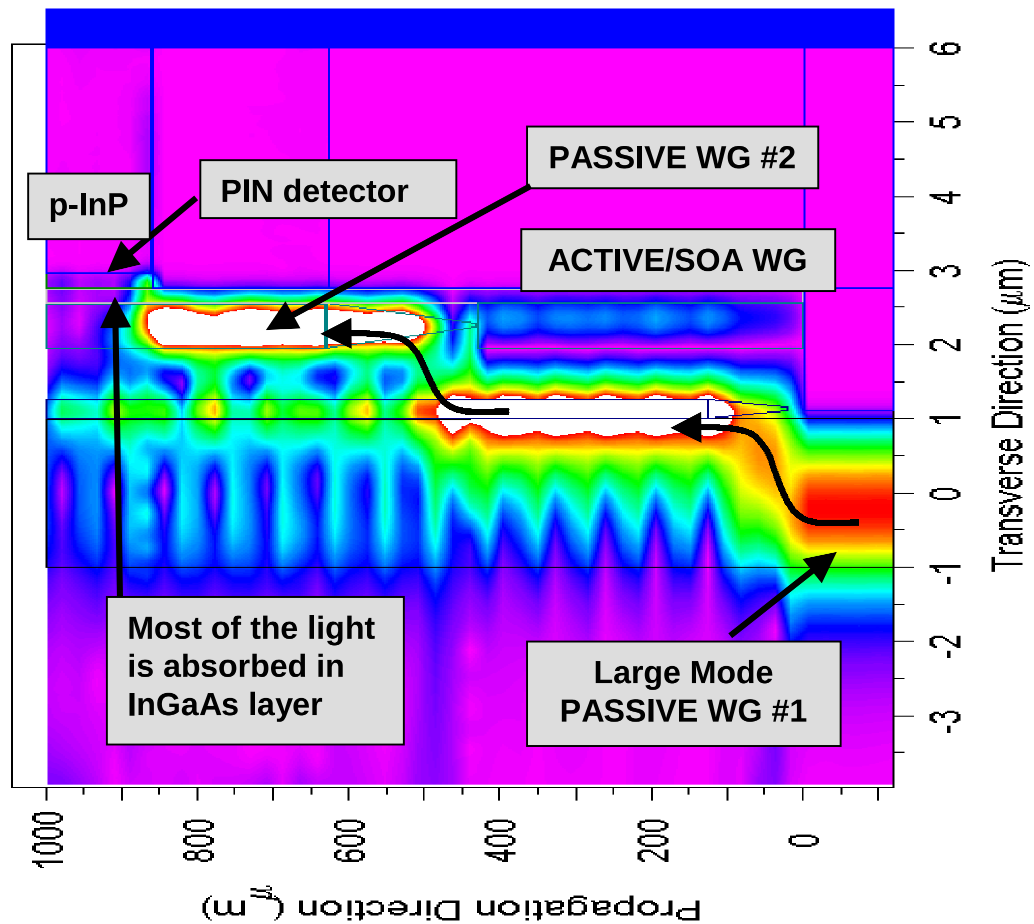


Integration of PIN detector with active devices



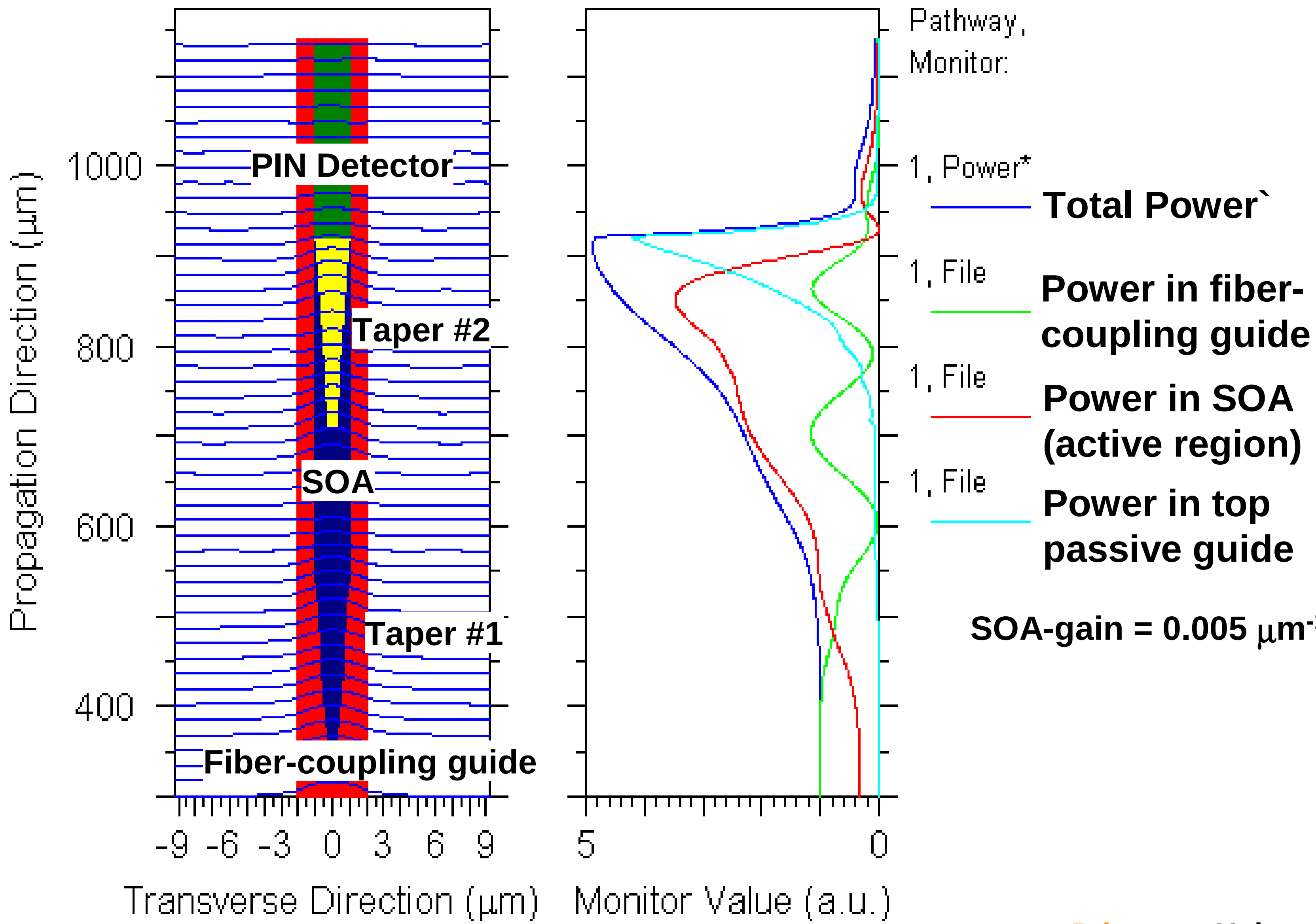
Laser-PIN module

2-D simulation of laser-PIN



3D Simulation: Power transfer via tapers

Total loss < 1 dB



SOA-gain = 0.005 μm^{-1}

Project Milestones

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