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RFLIC Technical Proposal

DARPA

Photonic Integrated Transmitter and Receiver Components for RF Links with Gain

Lead organization : University of California Santa Barbara

Prof. John E. Bowers and group member

Prof. Larry A. Coldren and group member

Team members : Agility Communication, Inc.

HRL.

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Outline

(1) introduction :

(2) technical rationale, previous results and approach

-DBR-laser, amplifier and modulator.

-Electroabsorption modulator.

-TAP traveling-wave photodetector

(3) technology transition

-Agility

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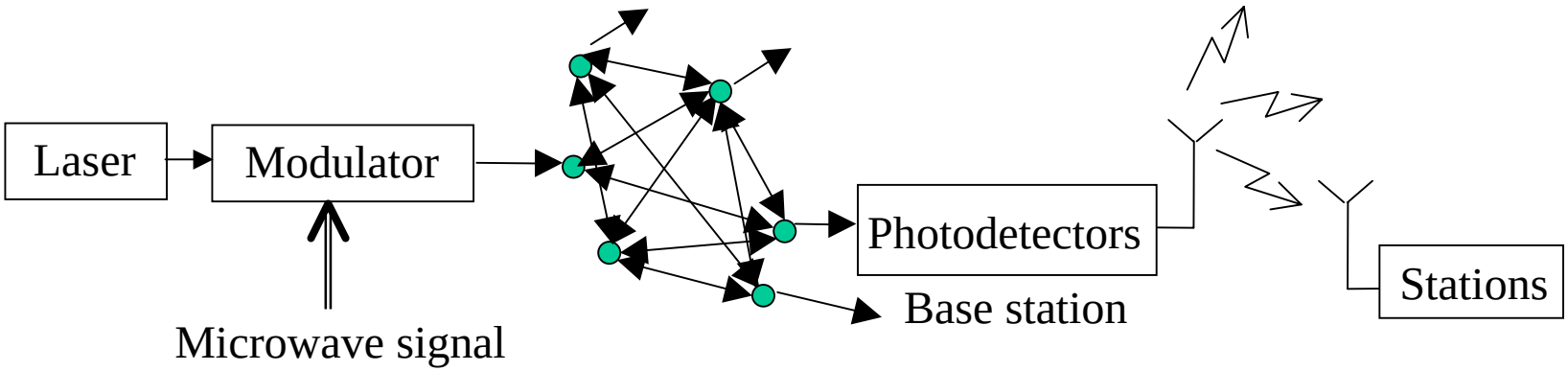
Introduction

Optical Fiber Link



$$G = \frac{S_{out}}{S_{in}} = \frac{i_{out}^2 \cdot R_{out}}{i_{in}^2 \cdot R_{in}} = \frac{R_{out}}{R_{in}} \cdot [\eta_t \eta_r \eta_{ct} \eta_{cr} T_{fiber}]^2$$

Net efficiency between transmitter and receiver components greater than unity :

(1) High-efficiency Distributed Bragg Reflector (DBR) Laser.

(2) High-speed electroabsorption modulator.

(3) High-efficiency and high-speed photodetectors.

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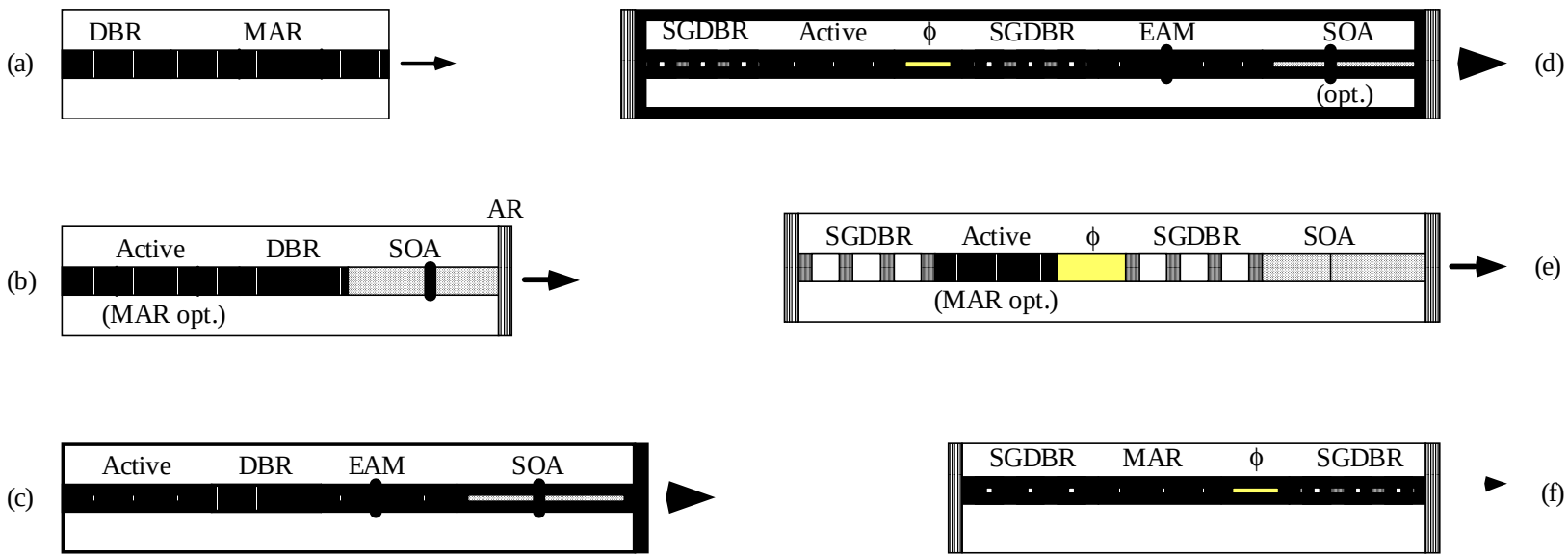
Proposed Single-Frequency Edge-Emitting Tunable DBR Lasers with $\eta_d > 1$



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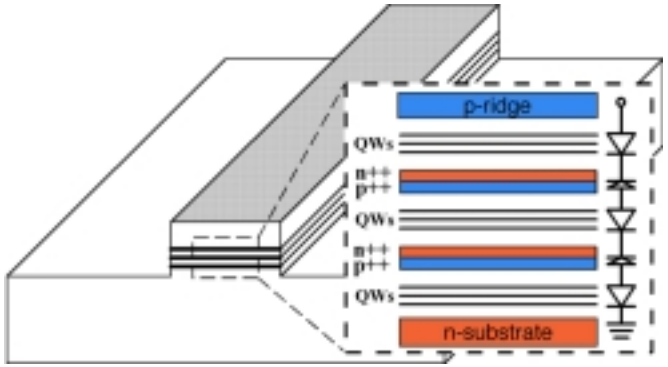
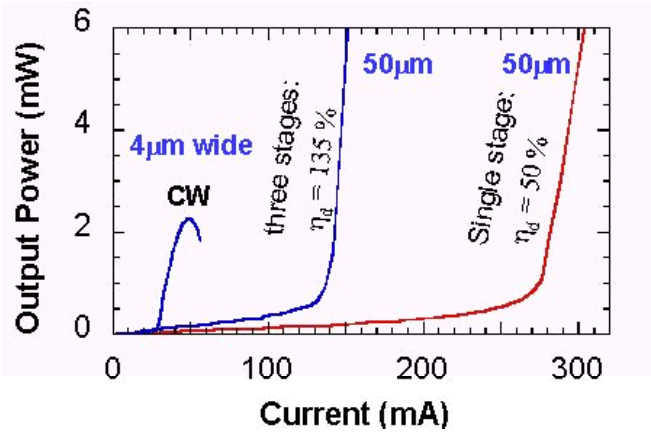
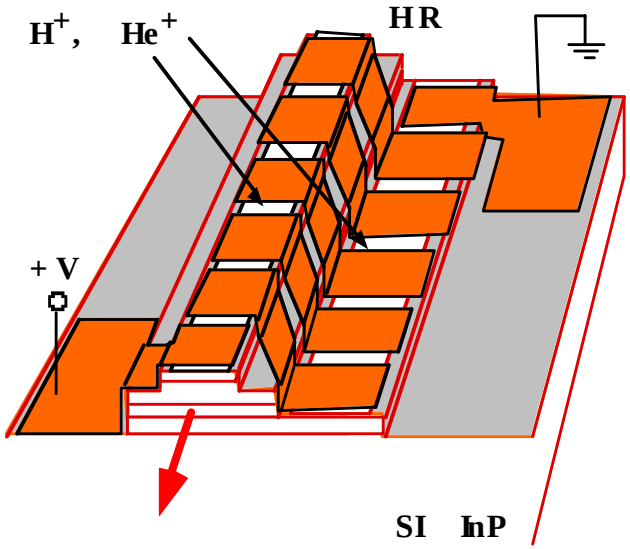
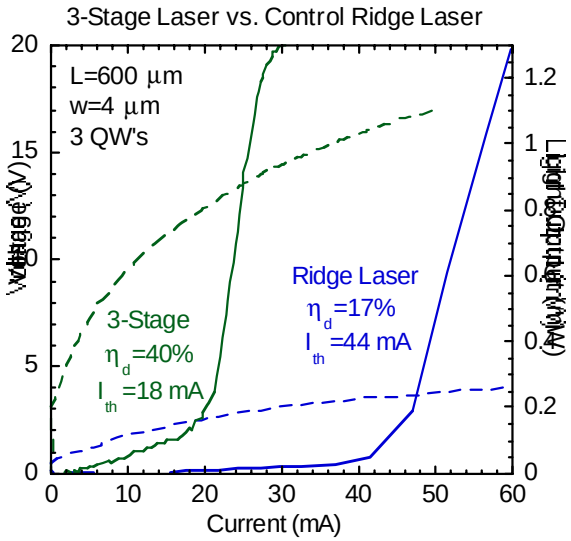
1.55µm MAR-edge-emitters and results with one and three actives connected in series.

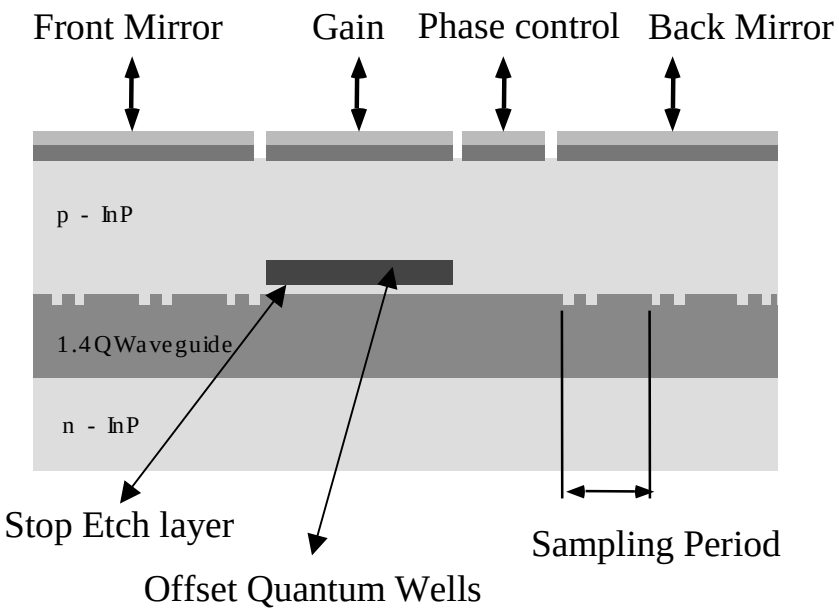


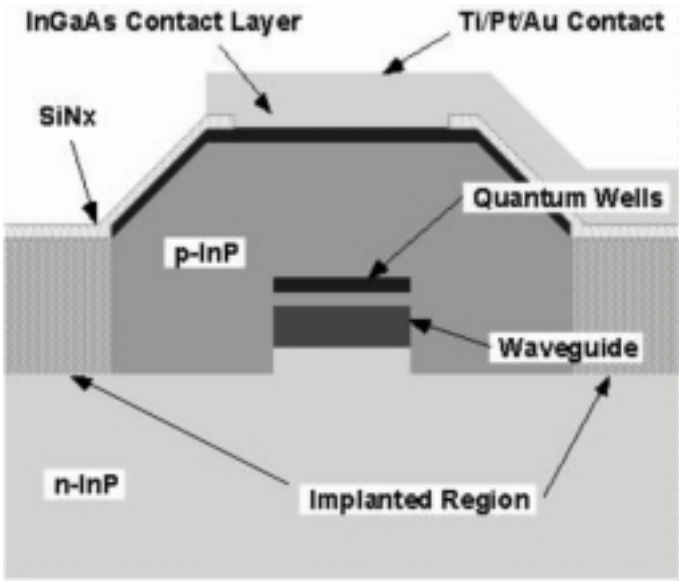






Axial and lateral cross sections of DBR (or SGDBR) lasers





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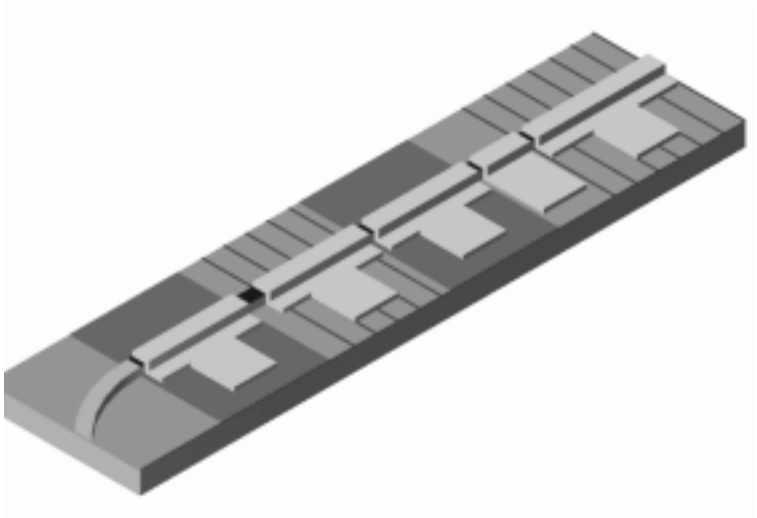
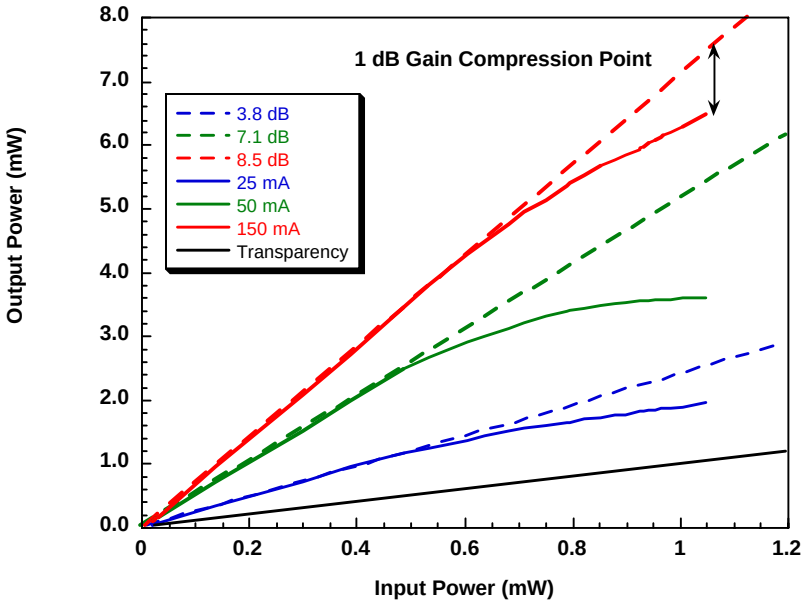
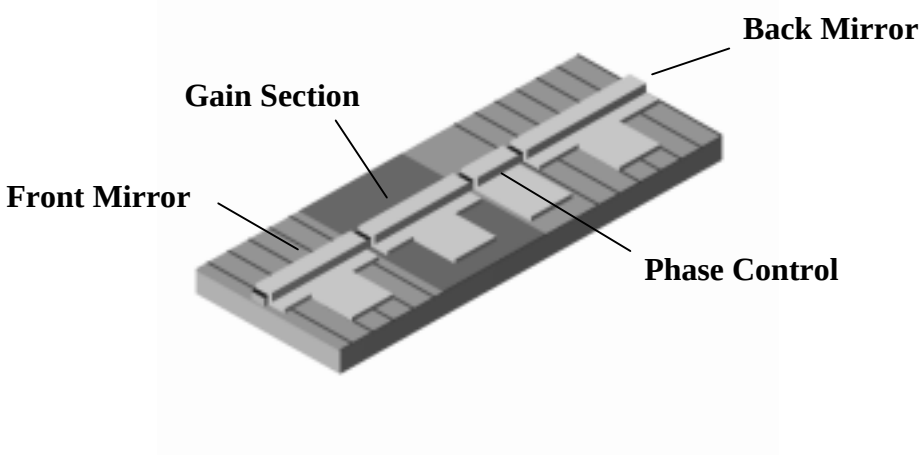
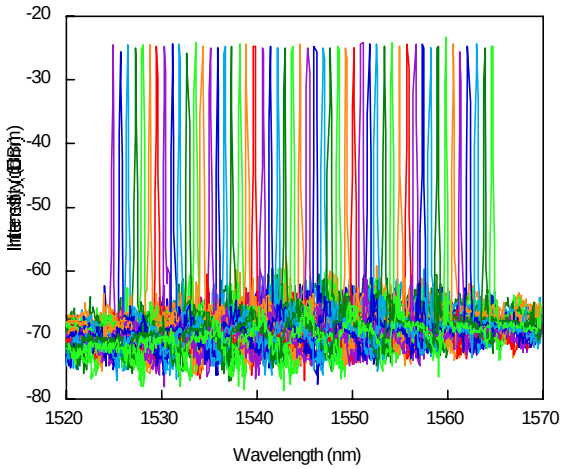
SGDBR laser integrated with SOA

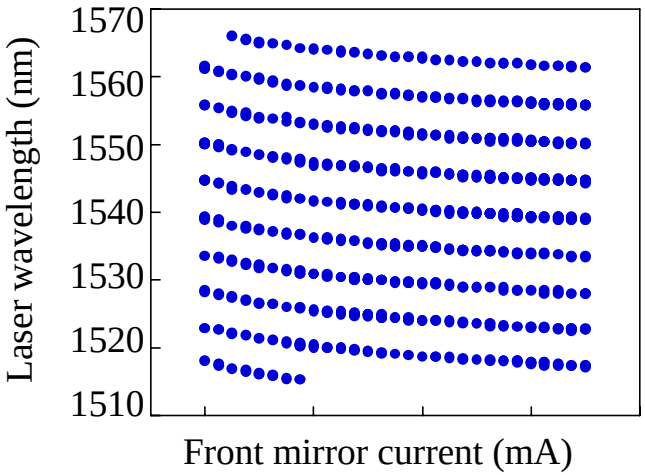


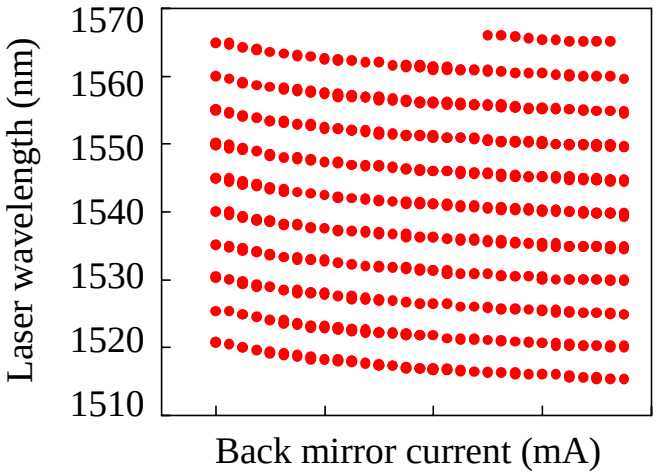


Sampled-grating DBR laser and illustrative results









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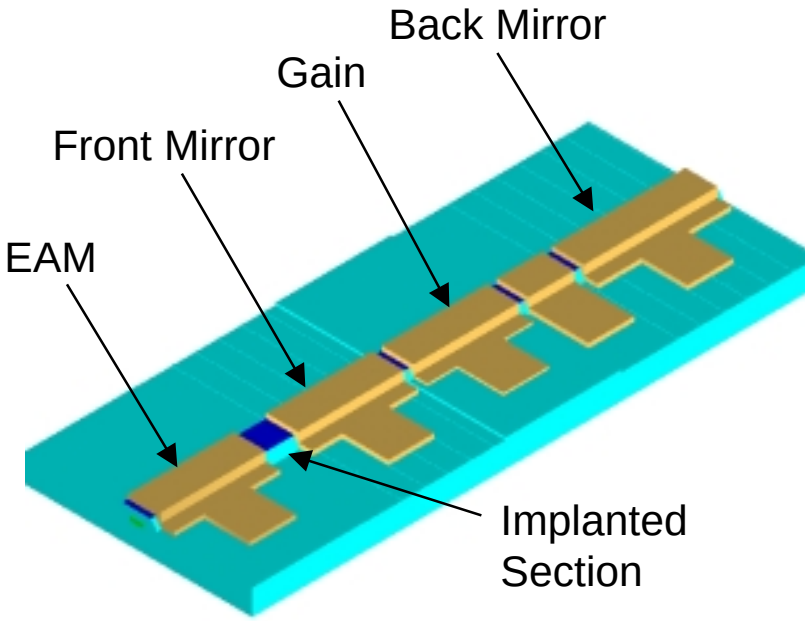
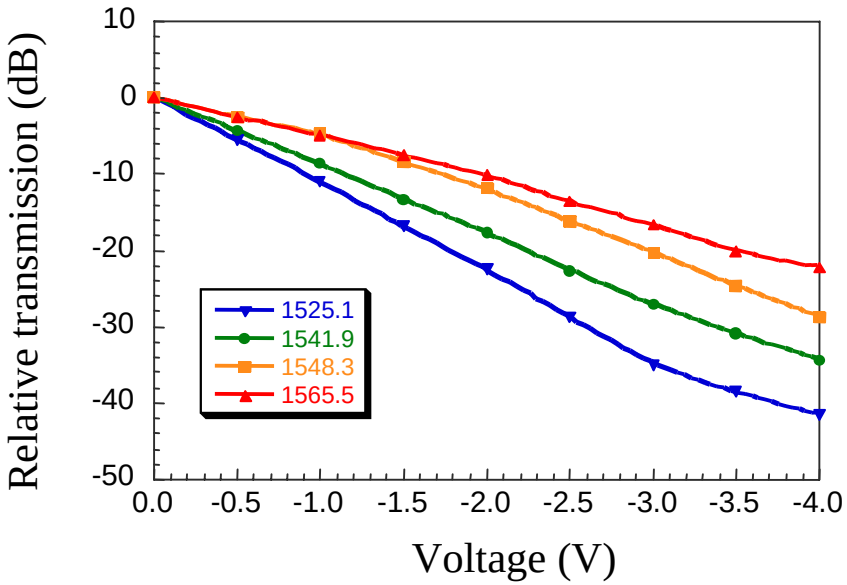
Integrated SGDBR-EAM and extinction ratio vs. voltage for several different wavelenths





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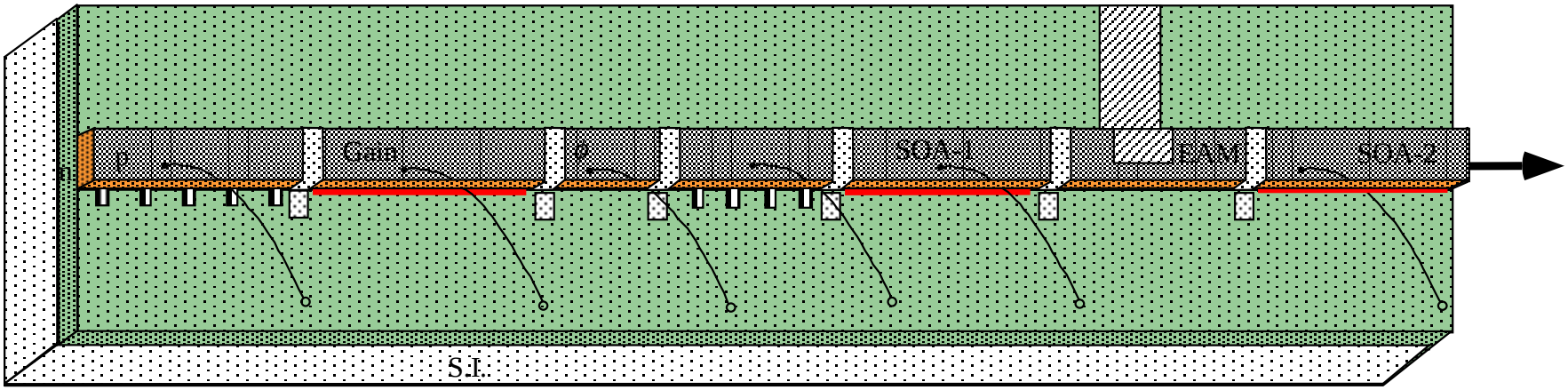
Schematic of SGDBR laser with optional integrated SOAs and EAMs



SGDBR Tune-1 Active Bias Phase SGDBR Tune-2 SOA Bias-1 SOA Bias-2

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Electroabsorption modulator by using Quantum Confined Stark Effect

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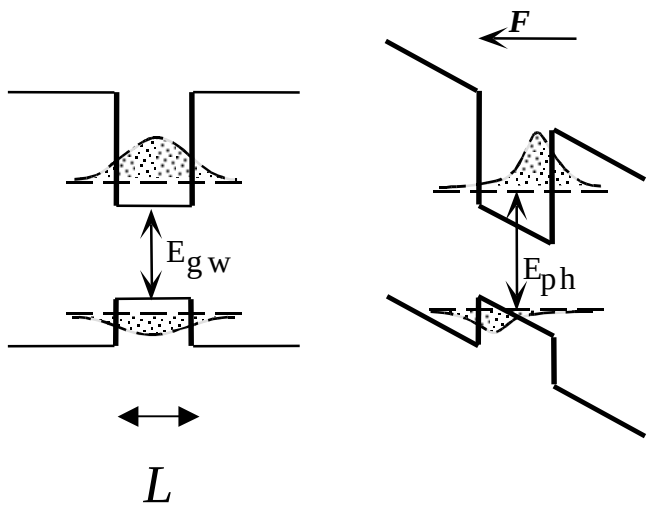

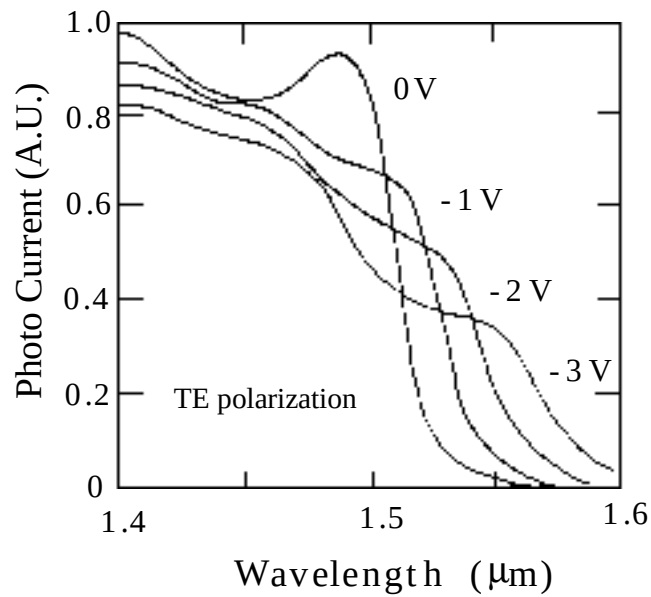

(1) $\Delta E \infty \frac{m^* e^2 F^2 L^4}{\hbar^2}$ Field induced eneryy shift

(2) charge pile-up effects in the heterointerfaces causes the power saturation problem

Reverse bias results in:
1. red shift of absorption spectrum
2. broadening of absorption spectra

Low voltage and high saturation
1. Increase the well thickness *L*.
2. Bandgap engineering to lower the band offset .

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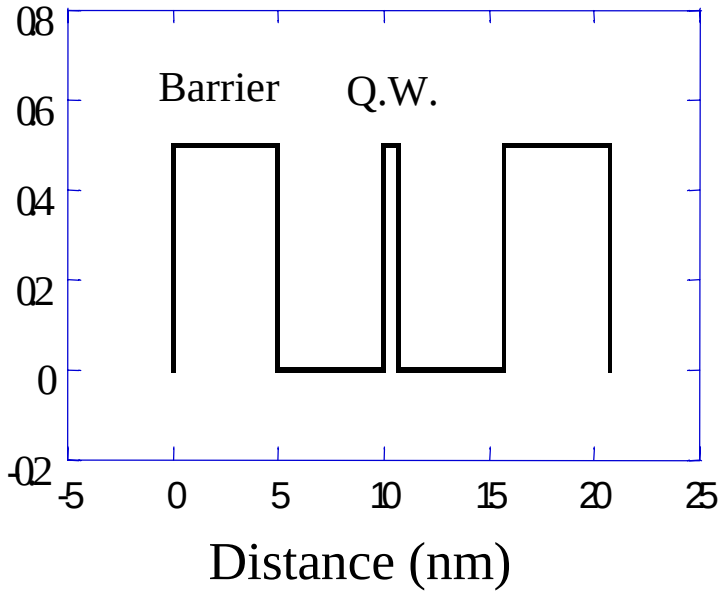

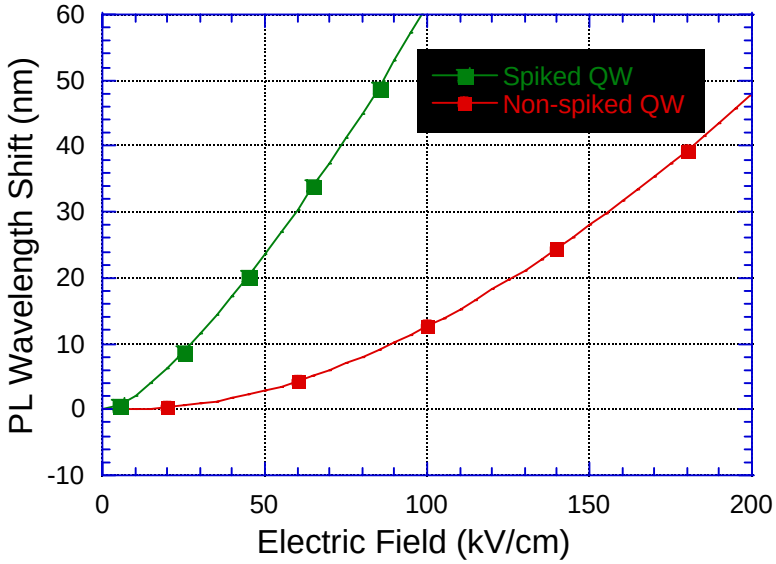

Adding a very thin layer barrier allows wider well thickness

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InGaAs/InAlAs vs. InGaAsP/InGaAsP QWs

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	InGaAs/InAlAs non-strained	InGaAs/InAlAs strained	InGaAs/InP non-strained	InGaAsP/InGaAsP strained
Well	InGaAs, ε=0	InGaAs, ε=-0.35%	InGaAs, ε=0	InGaAsP,ε=-.3%
Barrier	InAlAs, ε=0	InAlAs, ε=0	InP, ε=0	InGaAsP,ε=+.5%
Cladding	InAlAs	InAlAs	InP	InP
$\Delta E_c/\Delta E_g$	~70%		~40%	
$\Delta E_c/\Delta E_{hh}/\Delta E_{lh}$	500/200/200 meV	452/199/226 meV	220/390/390meV	130/164/240meV
Well thickness	~7.2 nm	~12 nm	~11 nm	~6.5 nm
Growth	MBE		MOCVD	
Growth quality	Good uniformity, hard to grow strain free thick p-cladding (~1.8μm)		Bad uniformity, cladding strain free	
p-cladding hole mobility	25 $cm^2/v.s$		130 $cm^2/v.s$	
Absorption	strong excitonic peak, sharp edge		weak excitonic peak, broad edge	
Processing	Cl_2 RIE, angled sidewall, 67°		CH_4:H_2:Ar RIE, 90° sidewall	
Saturation power	High	High	Low	Very high

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Traveling wave electroabsorption modulator

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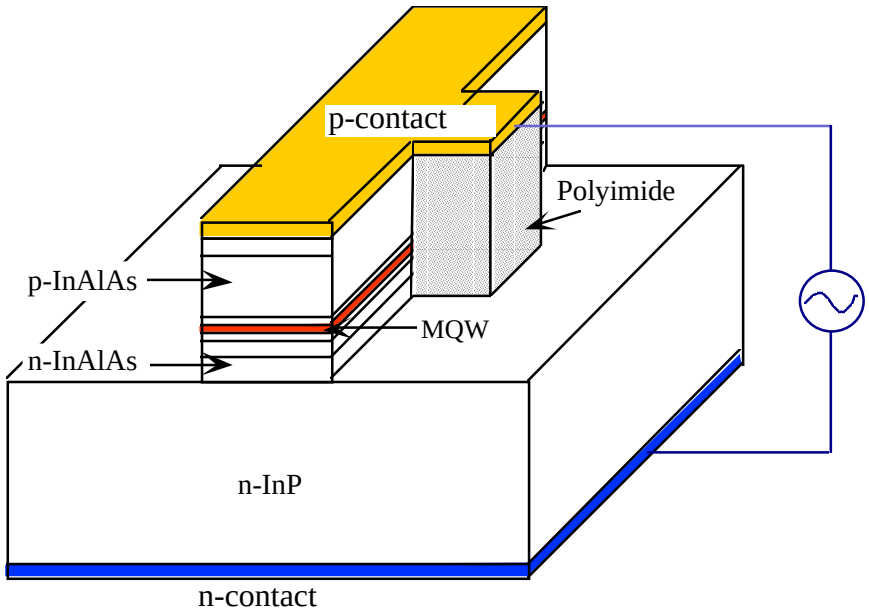

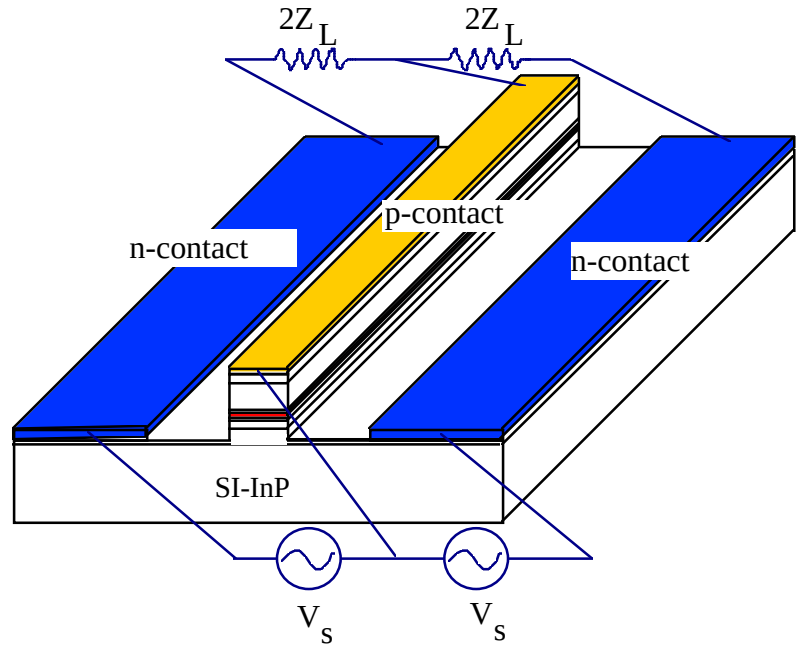

Lumped EA modulators

RC limited

Very short device length(< 100 mm)

Hard to handle

Potentially higher driving voltage

& lower saturation power

Traveling-Wave EA Modulators

Overcome RC limitations

Higher speed with the same size

Bigger device size for easier handling

Long device to make Lower driving voltage

Higher optical saturation power

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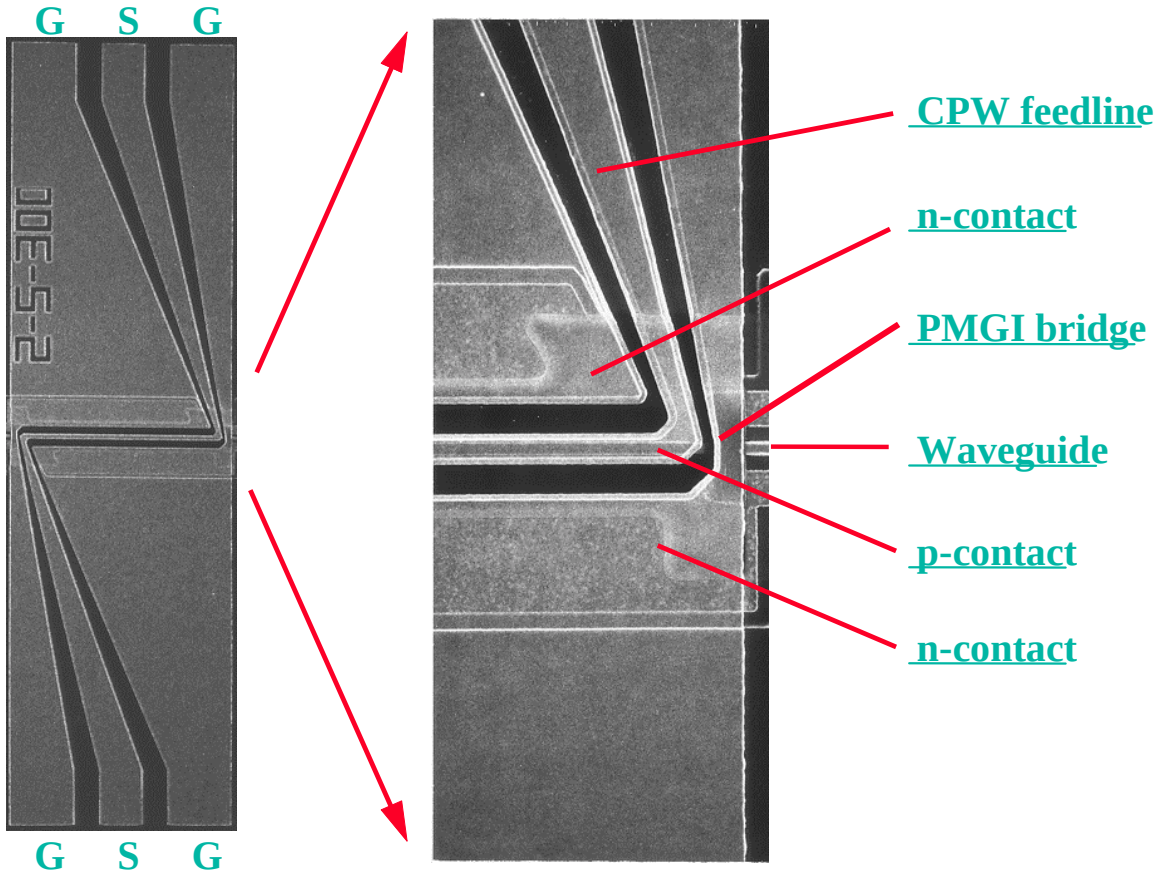
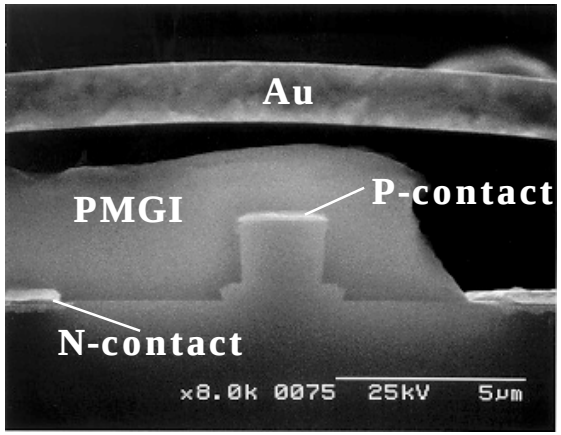
Traveling-Wave Electroabsorption modulator





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D.C. and A.C. characteristics of TWEAM

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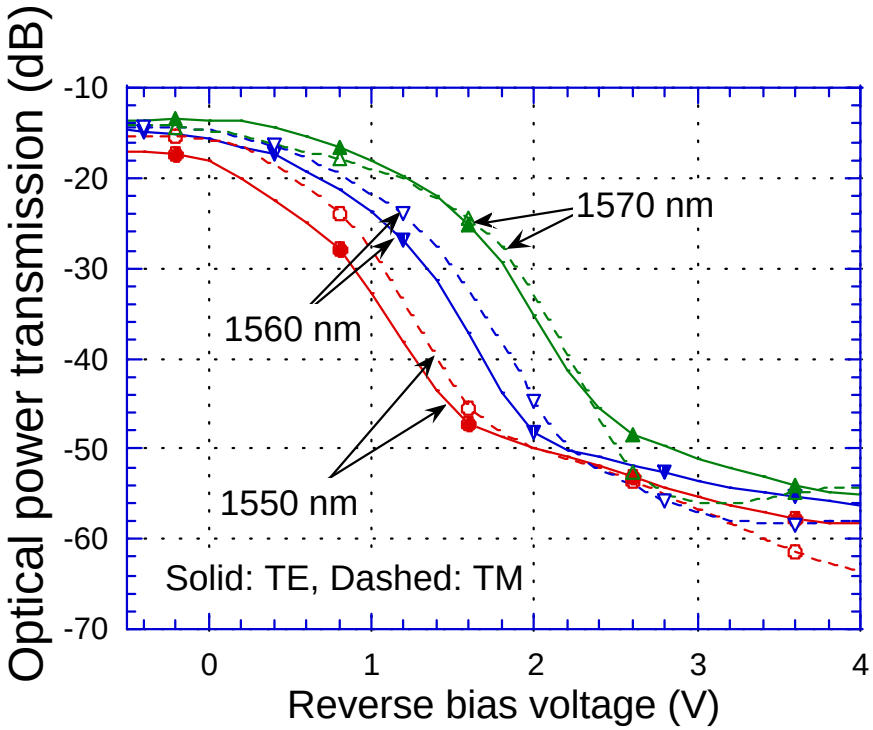

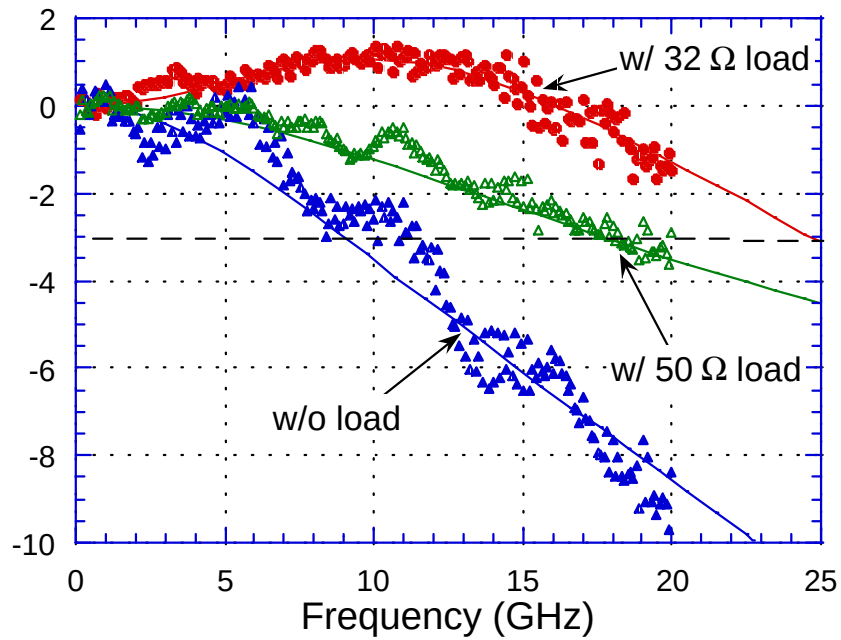

V_{10dB} = 0.8 V
V_{20dB} = 1.2 V
@ 1550nm, TE

Device size:
L = 300 μm, w = 2.0 μm

$f_{3dBe} \cong$ 25 GHz (w/ 32 Ω load)
f_{3dBe} = 10.7 GHz (w/o load)

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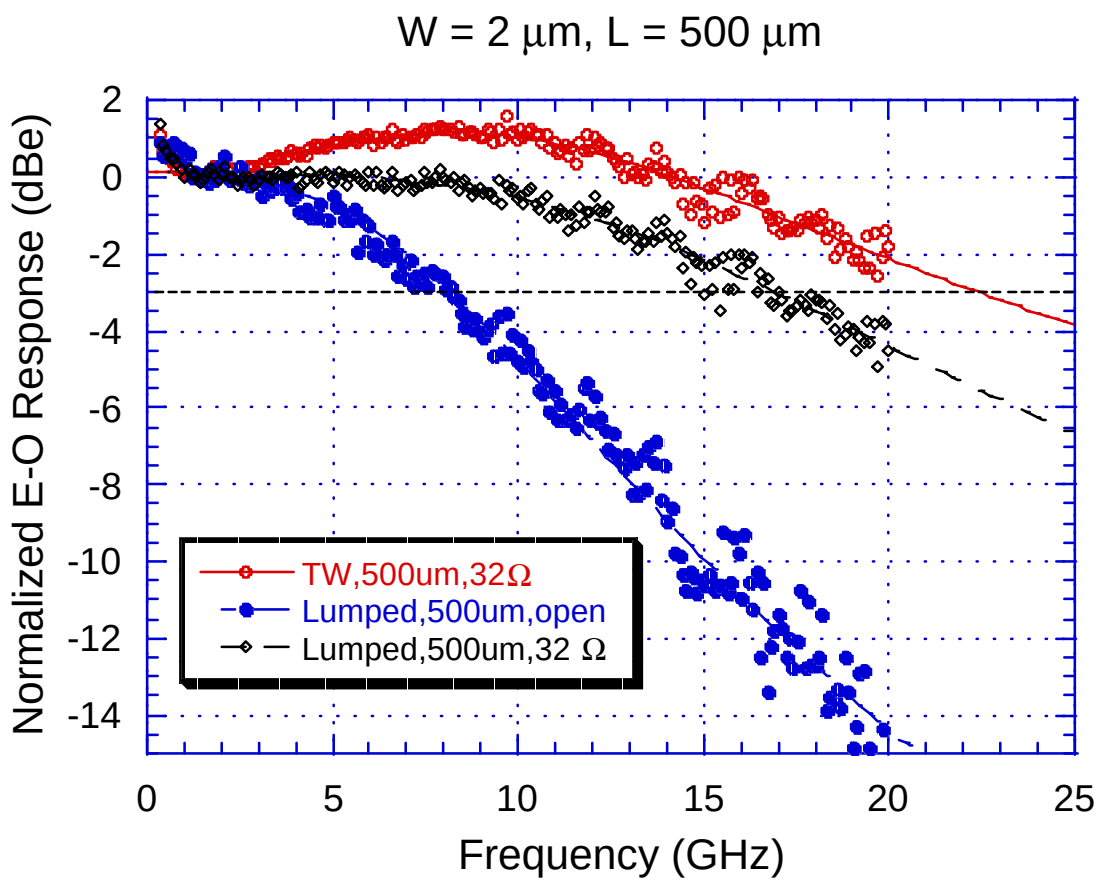
Long TWEAM



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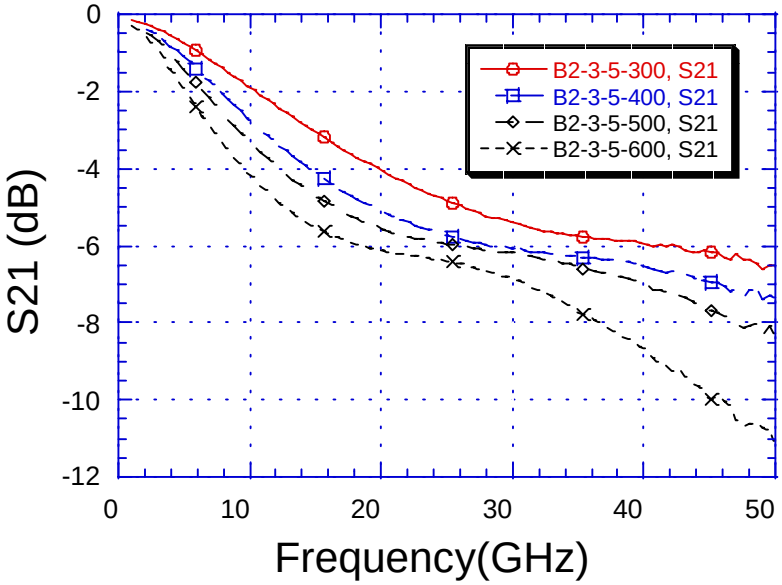
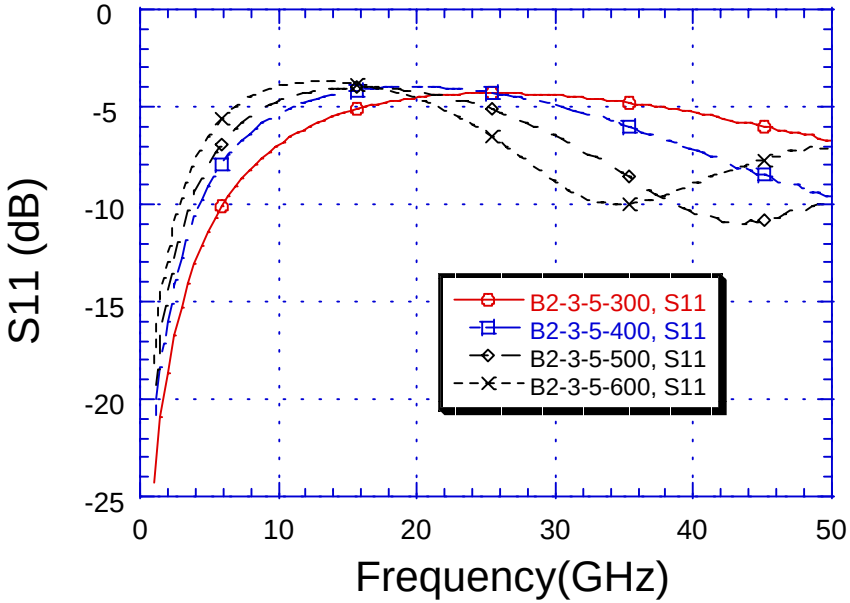
Measured S Parameters





The bandwidth is mainly domainated by the microwave loss

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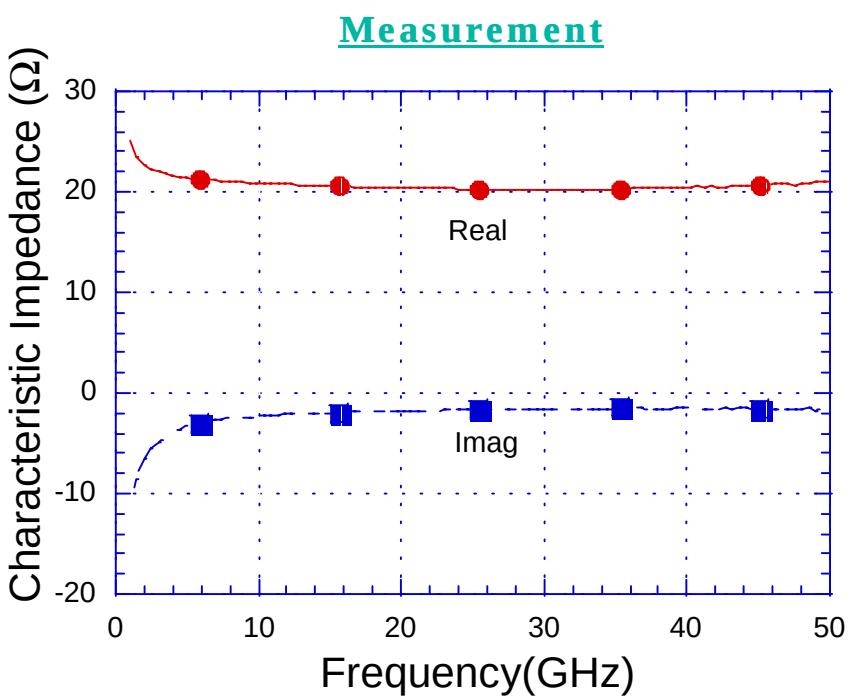
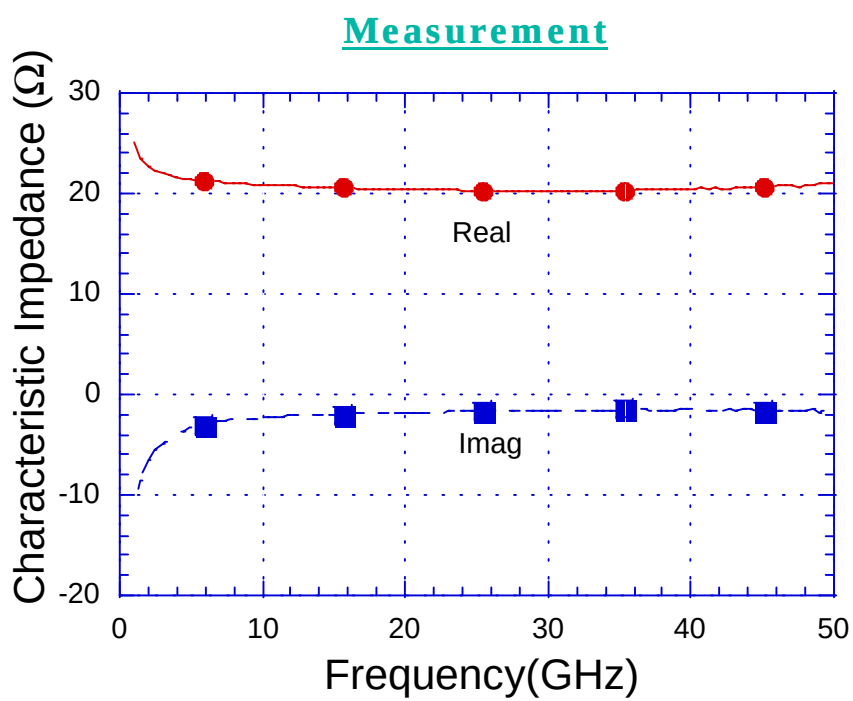
Simulated and Measured Characteristic Impedance





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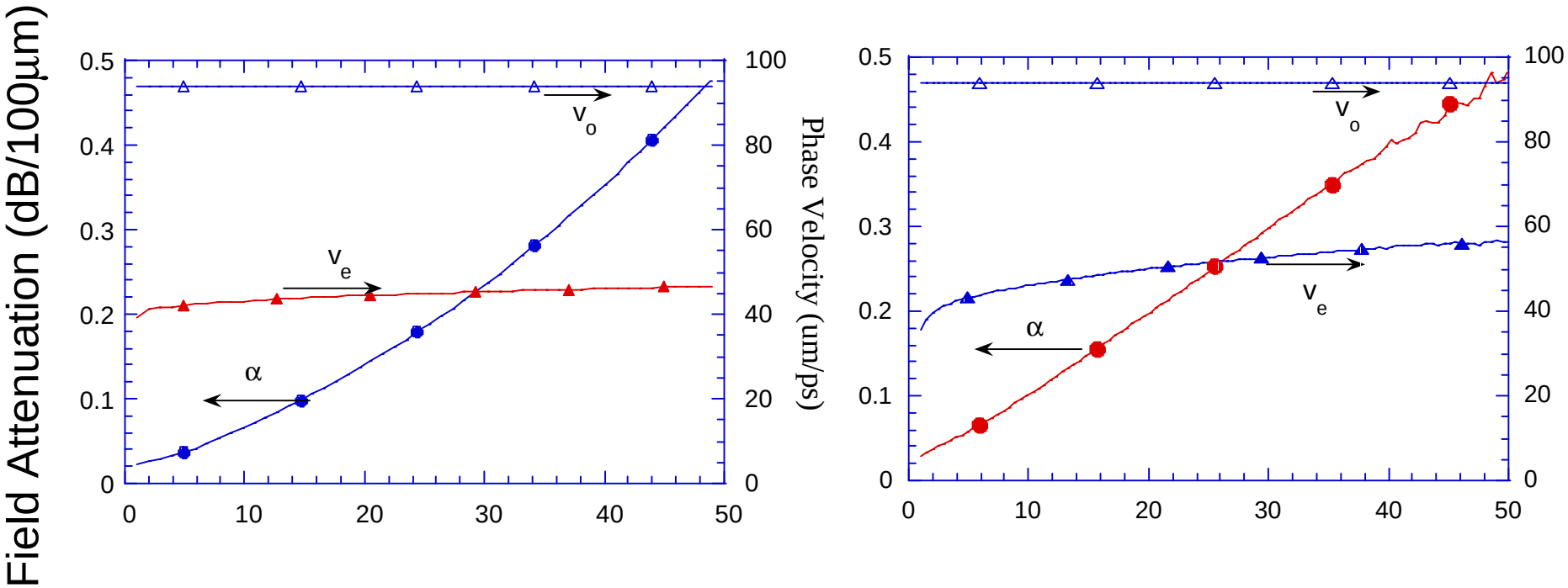
Simulation vs. Measurement
Field Attenuation and Phase Velocity



Straight CPW line, w = 2 μm

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30 Gbit/s TDM Transmission

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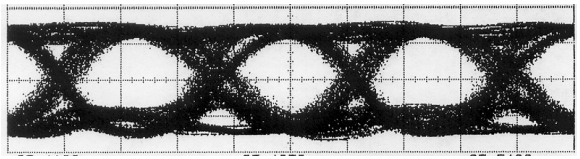
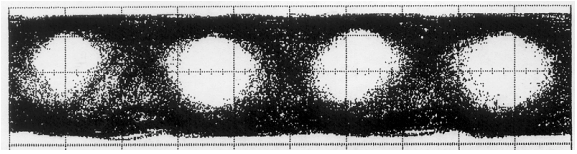


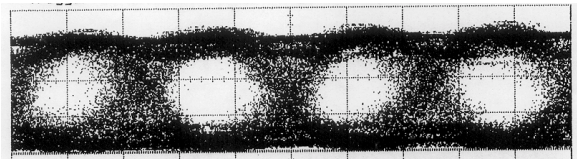
30 Gbit/s
H: 13ps/div

30 Gbit/s signal after MUX



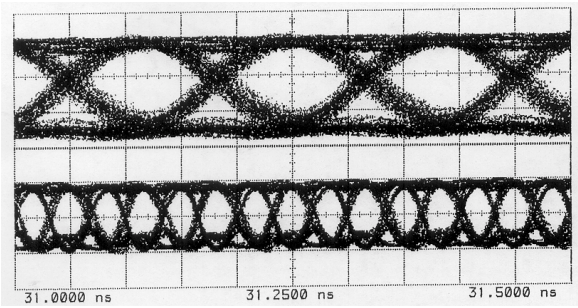
30 Gbit/s

0km, before DMUX



30 Gbit/s

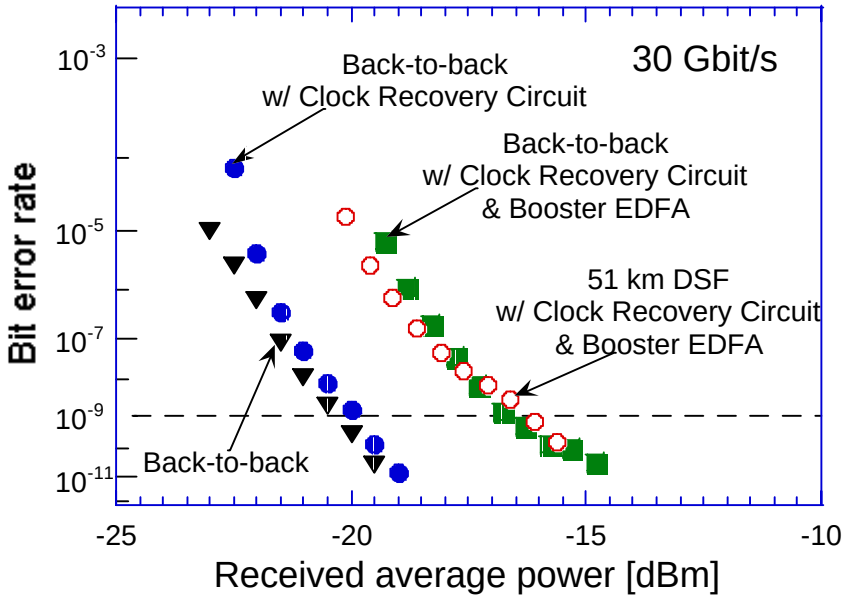
51 km, before DMUX



7.5 Gbit/s

30 Gbit/s
MUX output

51 km, after DMUX (top)



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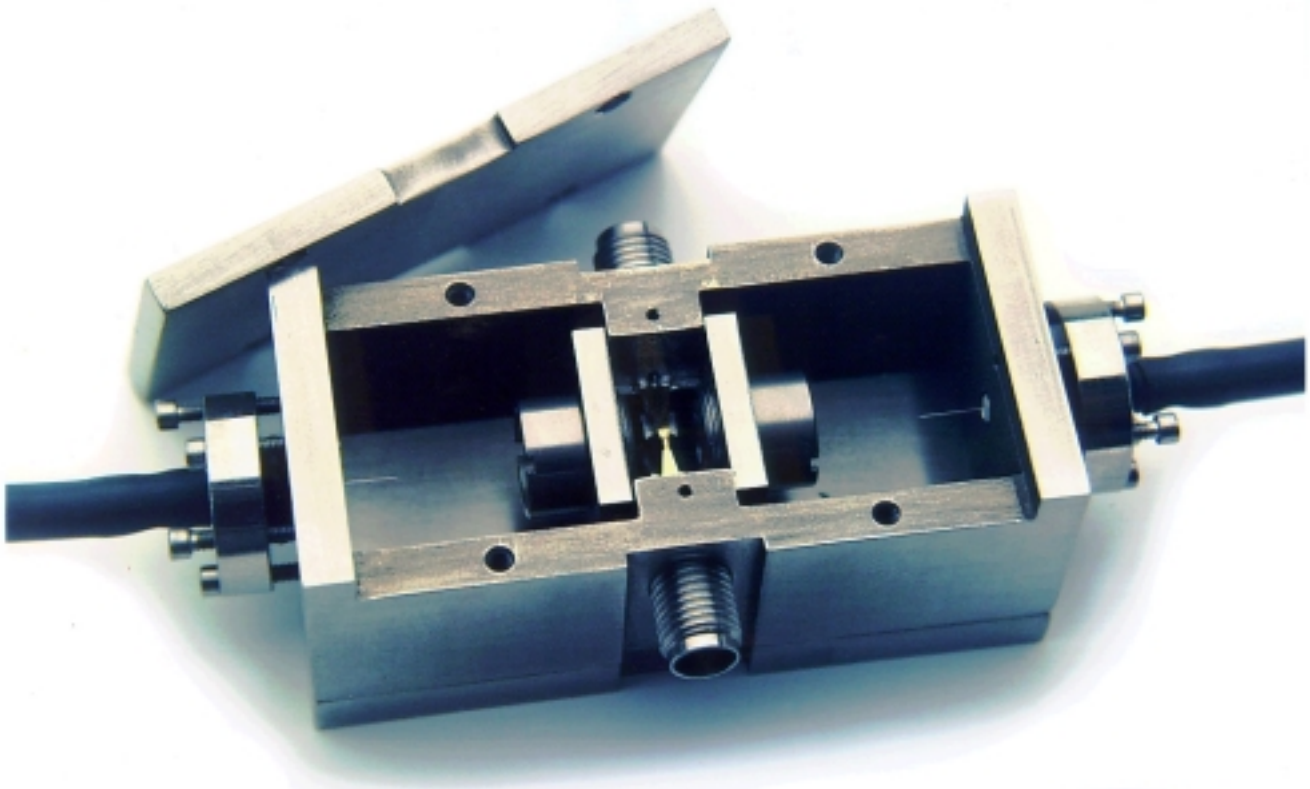
Modulator Package



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Ion Implantation

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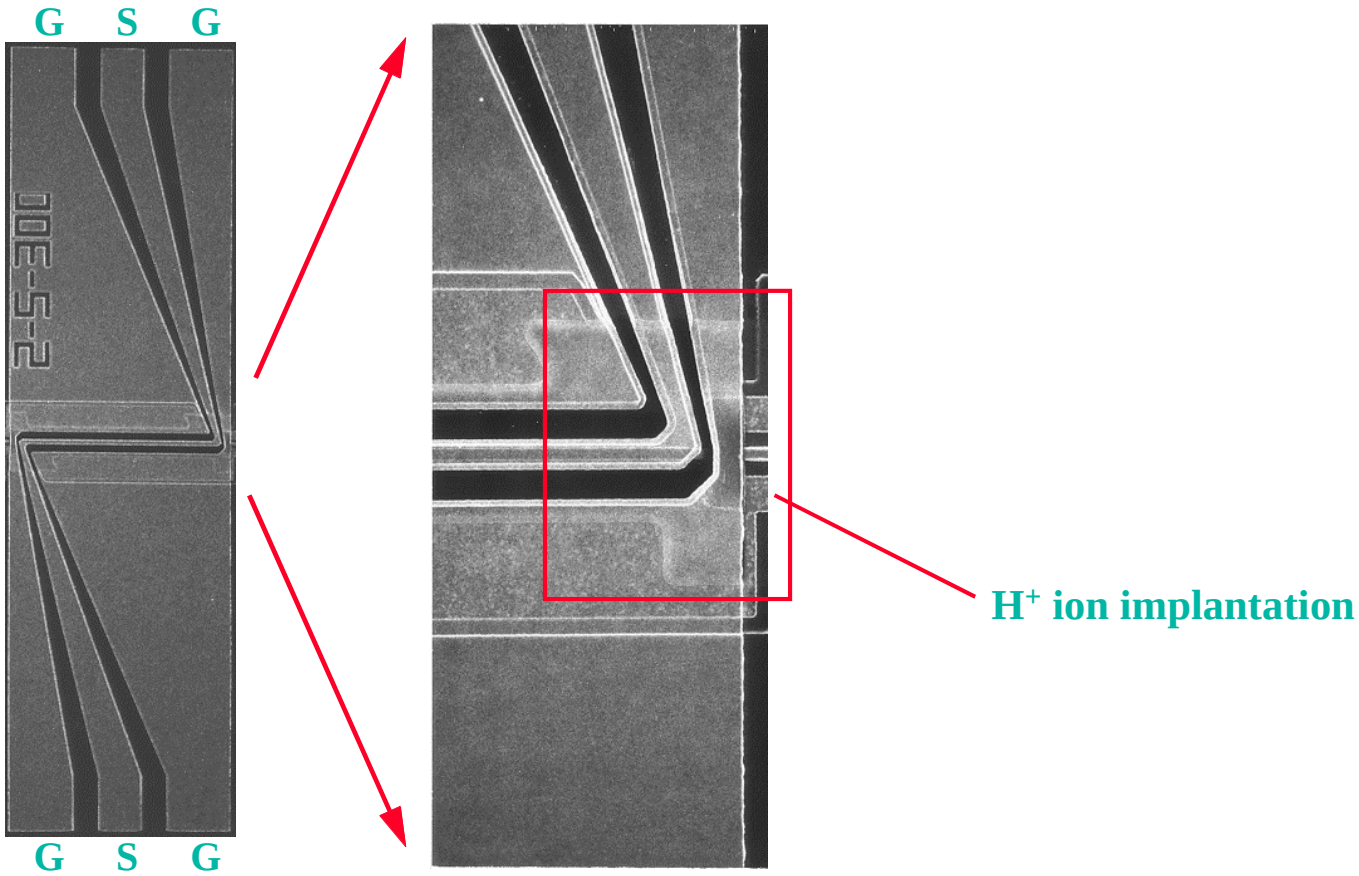

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Tandem TWEAM

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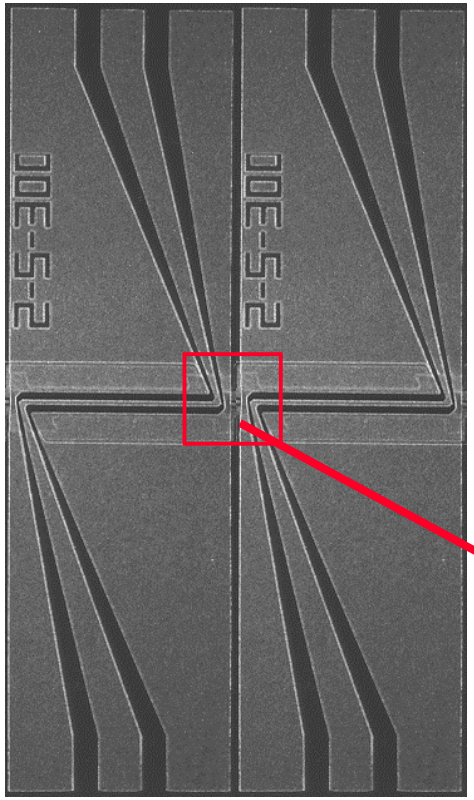

H^+ ion implantation

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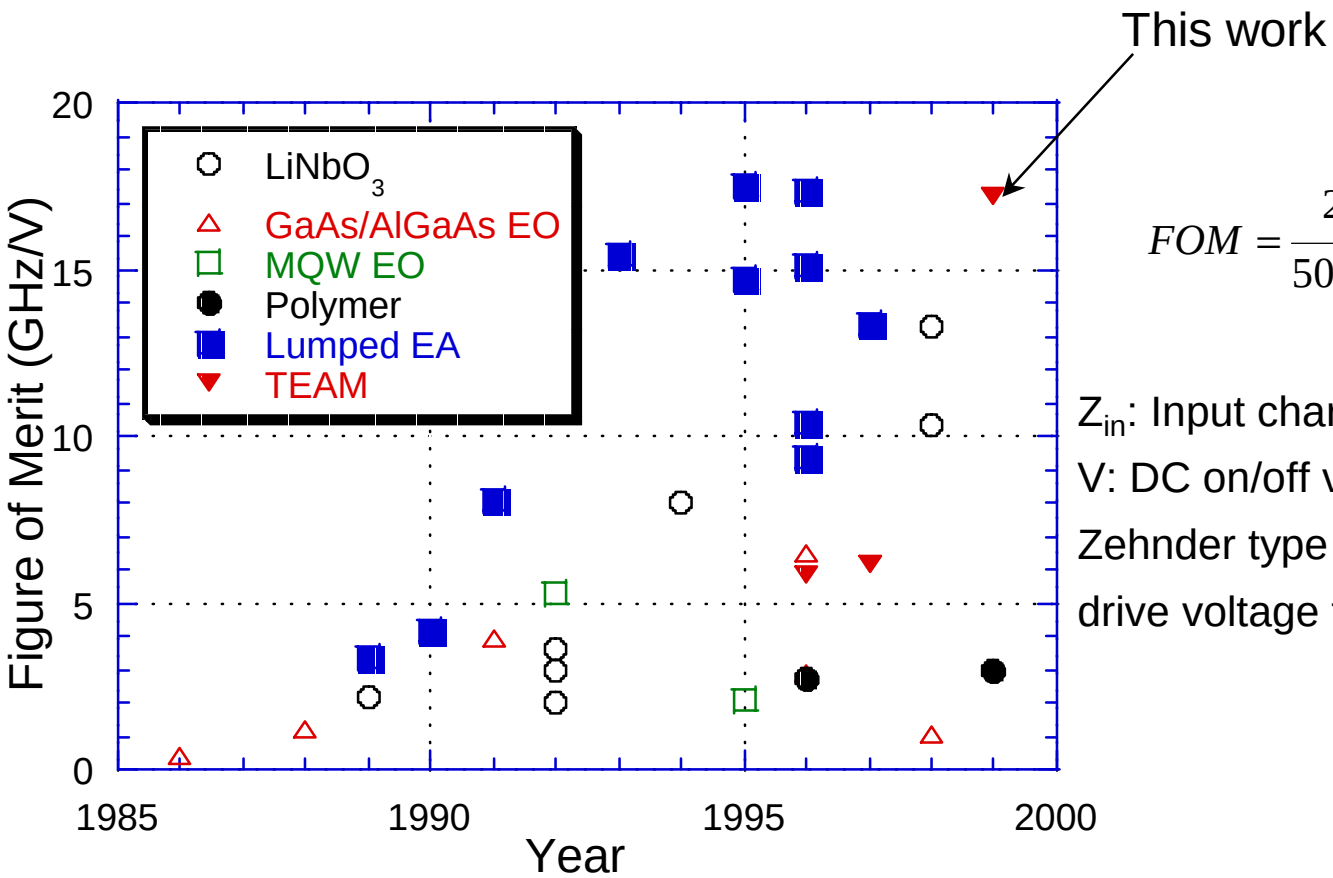

$$FOM = \frac{2Z_{in}}{50 + Z_{in}} \cdot \frac{f_{3dBe}}{V}$$

Z_{in}: Input characteristic impedance

V: DC on/off voltage for Mach-Zehnder type modulators (V_{π}), 20 dB drive voltage for EA modulators

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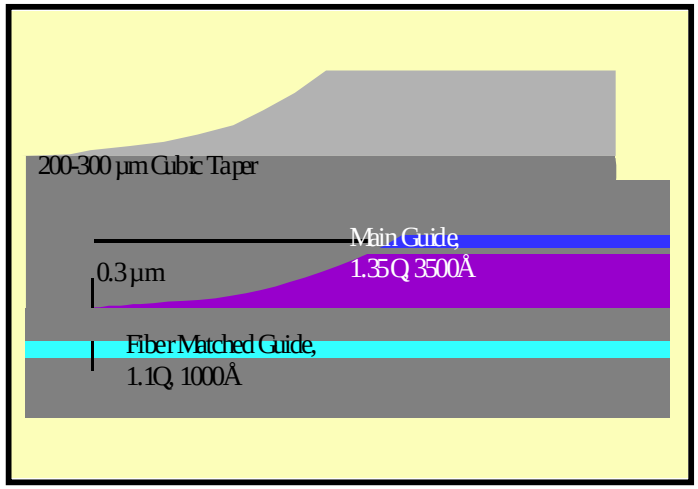
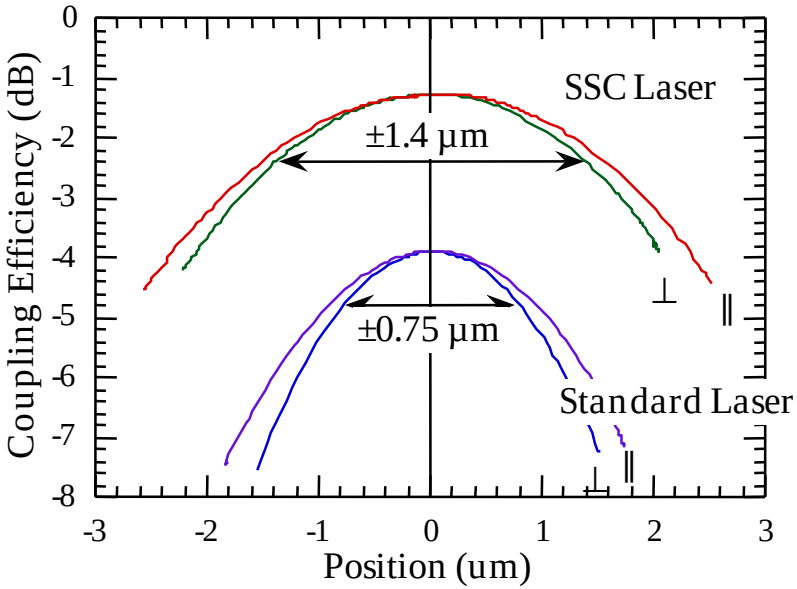
Mode transformer design using selective area etching and an illustration of fiber coupling results





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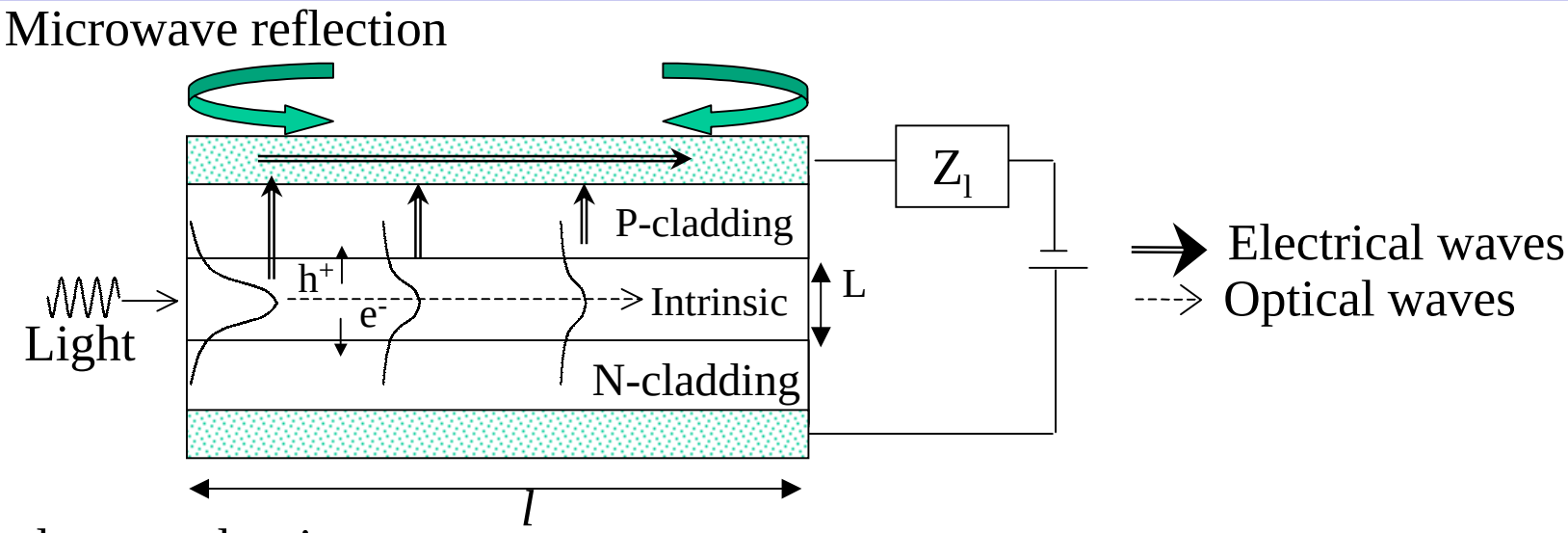
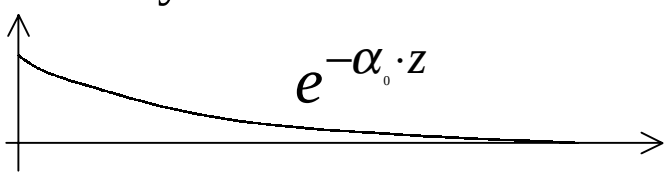
Traveling wave photodetector



Optical power density



(1)Optical absorption length l and carrier transit length L are separated

(2)Speed optimizatoin:

(a)**velocity matching**

(b)**impedance matching**

(c)**low microwave loss**

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TWPD top and side view

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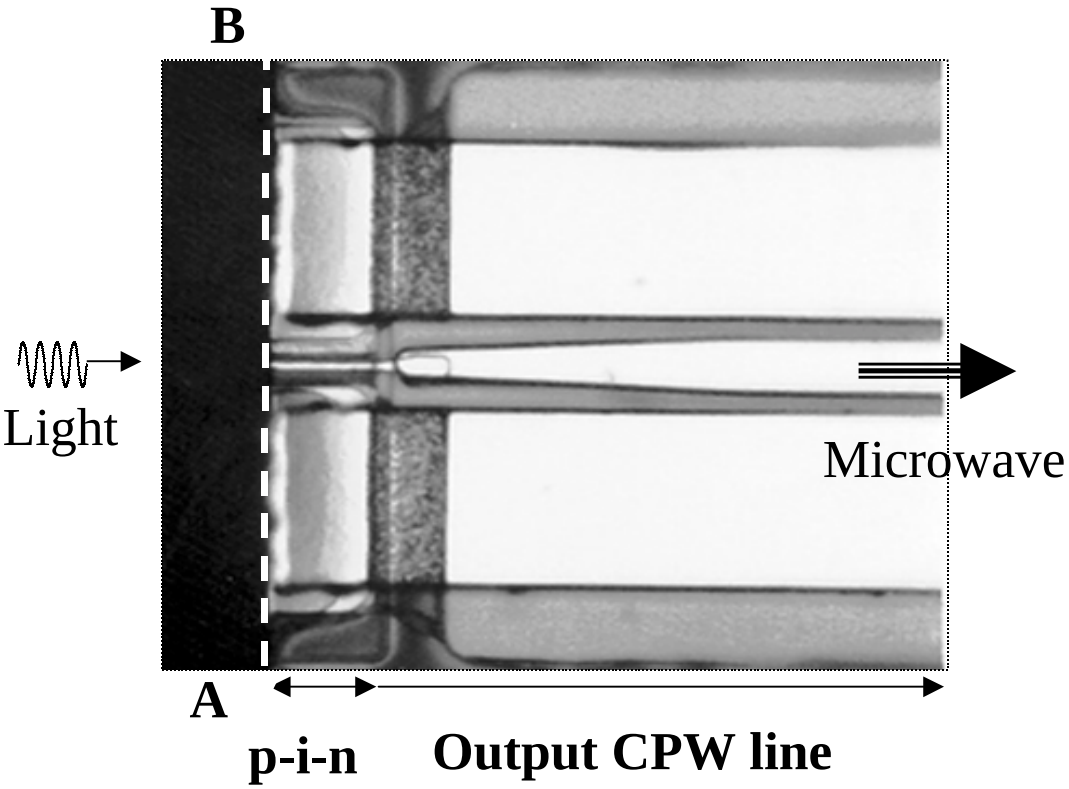

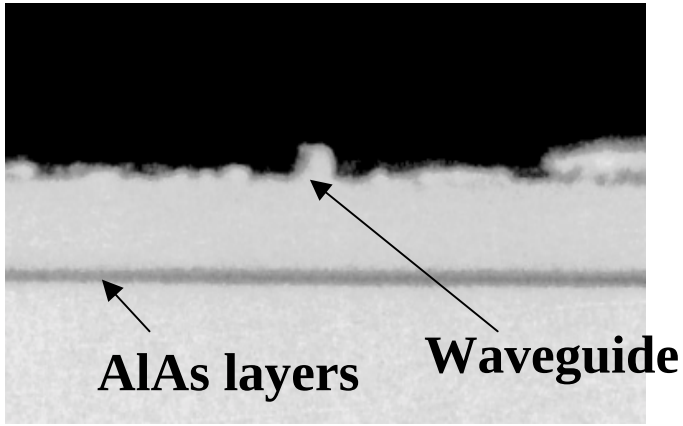

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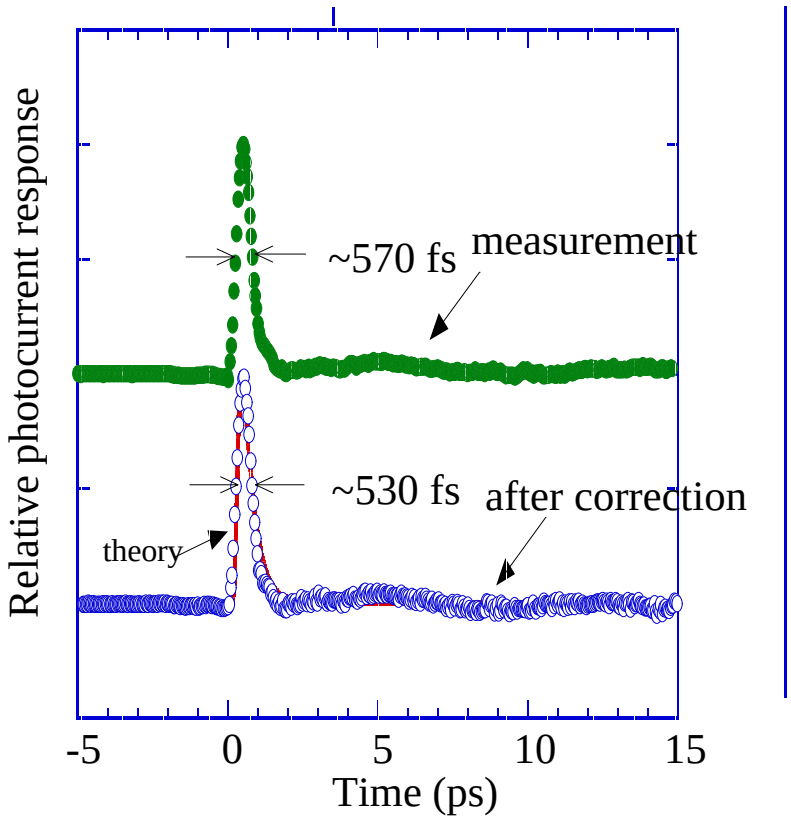
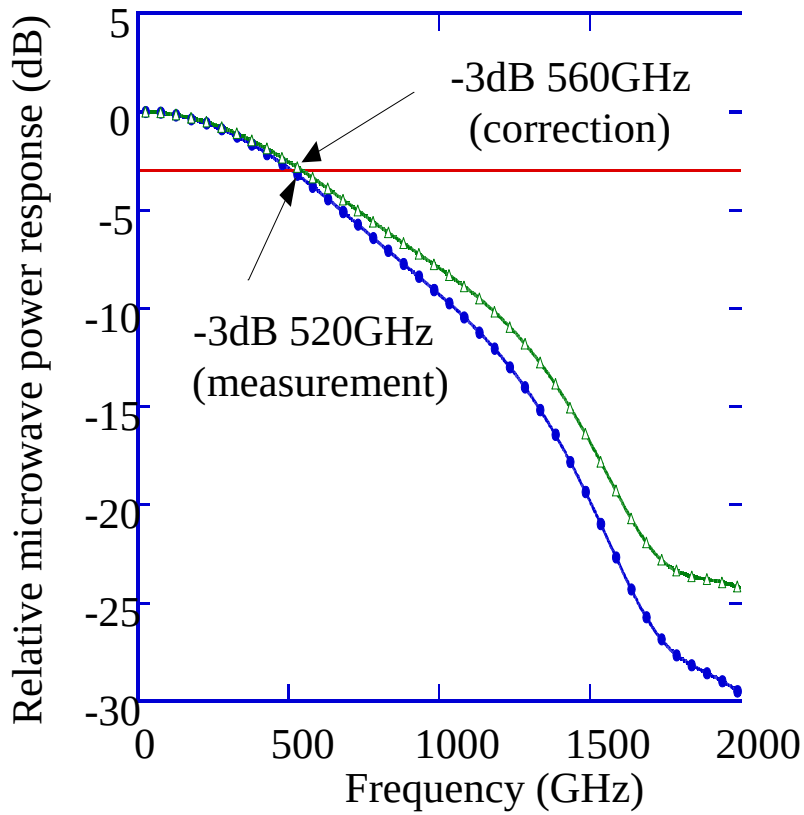
Traveling wave photodetector





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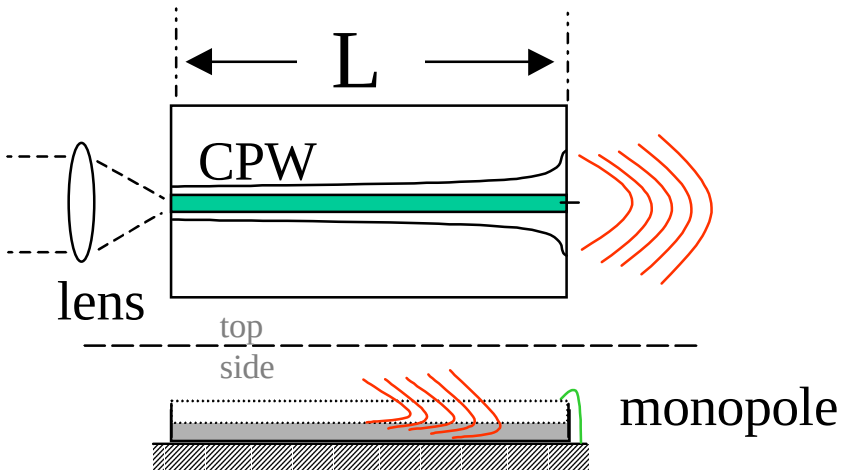
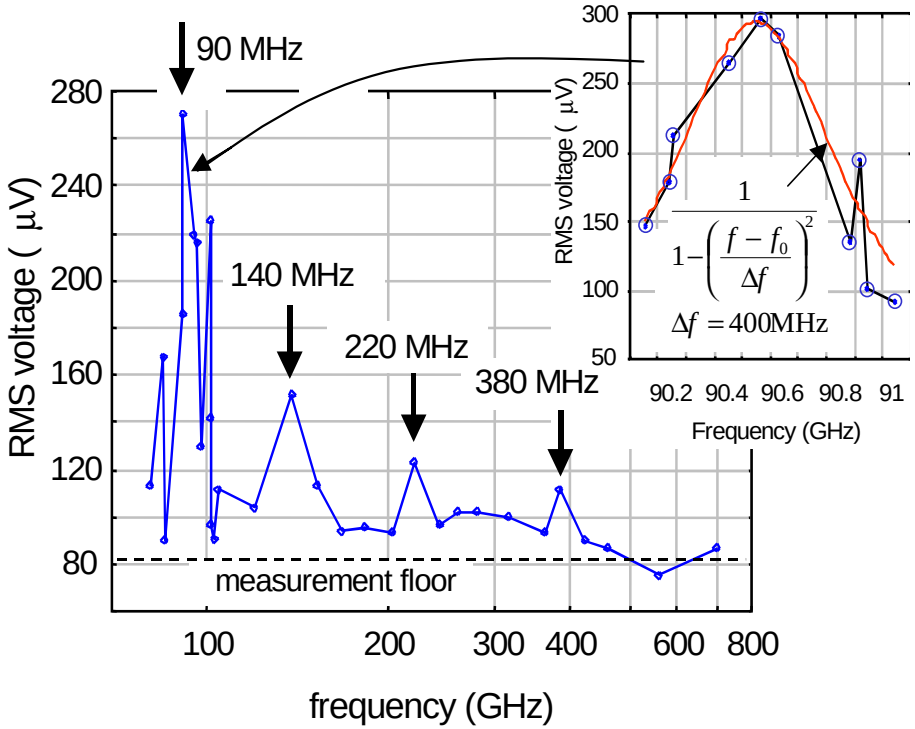
Near terahertz generation from TWPD

DARPA





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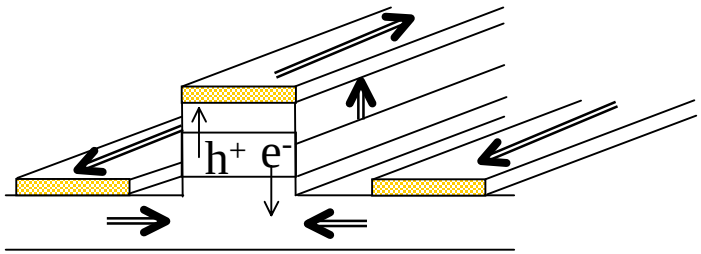
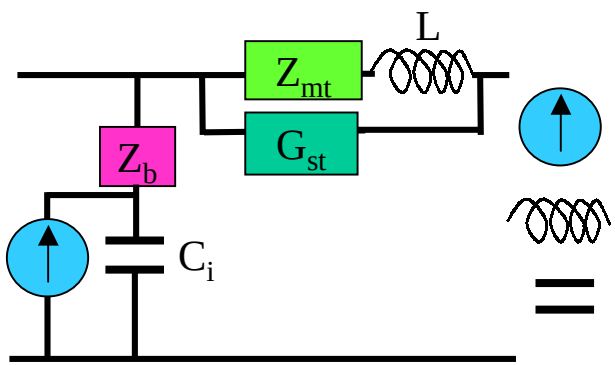
Equivalent circuit model for microwave propagation



: Metal contact

: Current flow



Material response

CPW line inductance

Intrinsic region capacitance

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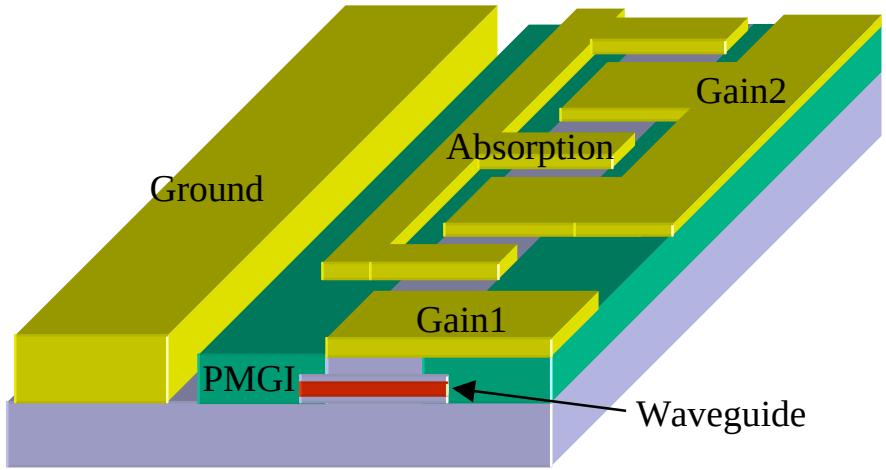
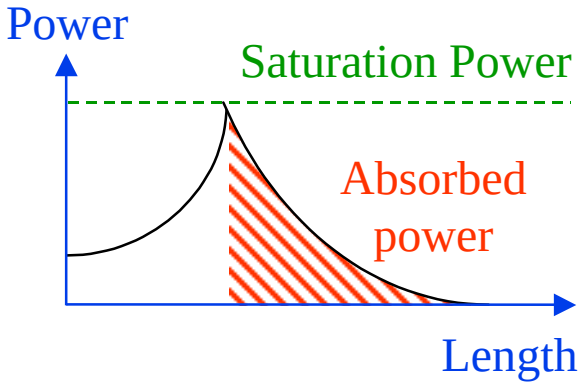
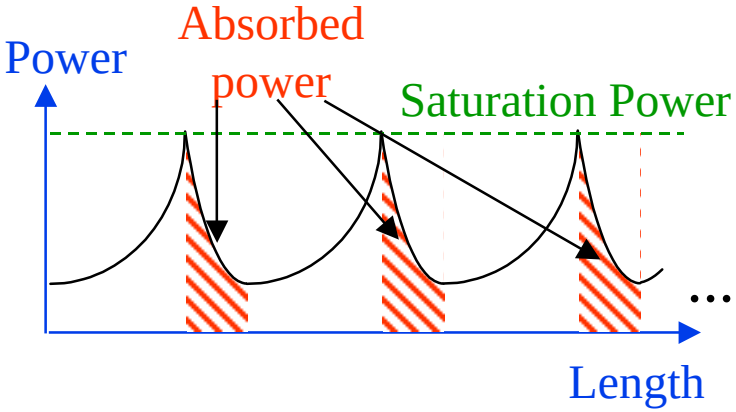
Distributed photodetector and optical amplifier sequential connection



Preamplifier + TWPD



This work



+Sequential TAP detectors present alternating gain and absorption for higher output power with the same saturation power.

+Velocity and impedance matching are also possible in this configuration.

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Modeling of sequential TAP detectors

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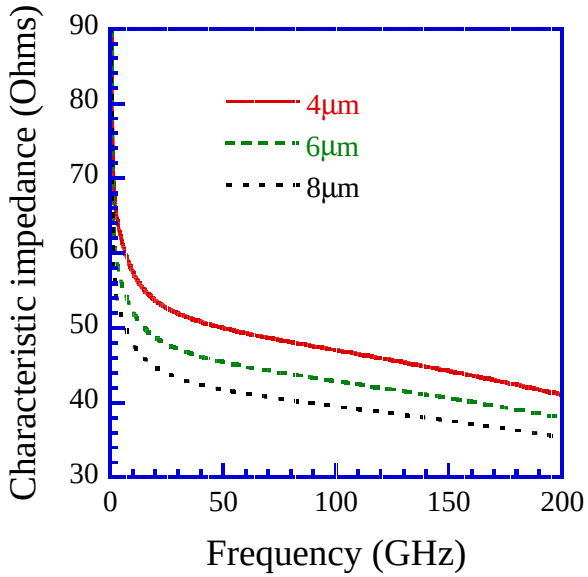
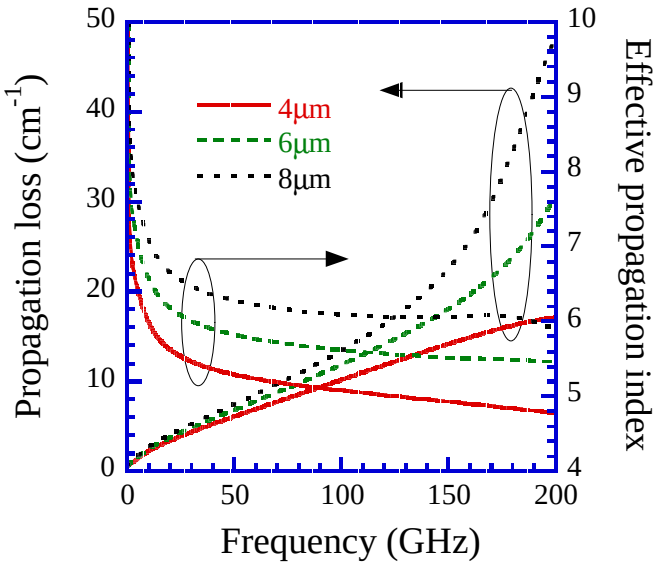
Microwave propagation characteristics for different absorption section lengths





+Assumptions: period is 50μm; devices are terminated in both ends; optical power is the same in each period: $L_{period}\alpha_{loss}=\Gamma(gL_{gain}-\alpha_{abs}L_{abs})$.

+Distributed element and ABCD models were used to calculate propagation characteristics.

+The total response $I(\omega)$ is calculated from the response of each individual absorption section, $I_{sect}(\omega)$:

$$I(\omega)=I_{sect}(\omega)\cdot\frac{1-e^{-(\alpha+j\beta)\cdot N\cdot L_{period}}}{1-e^{-(\alpha+j\beta)\cdot L_{period}}}$$

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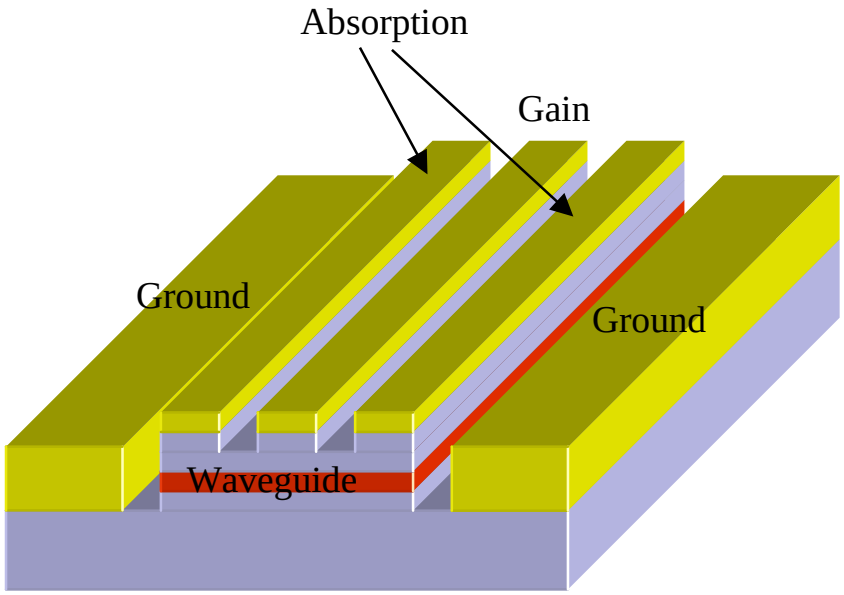
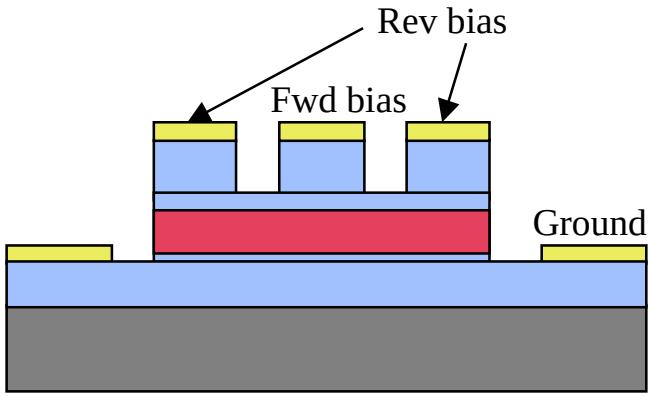
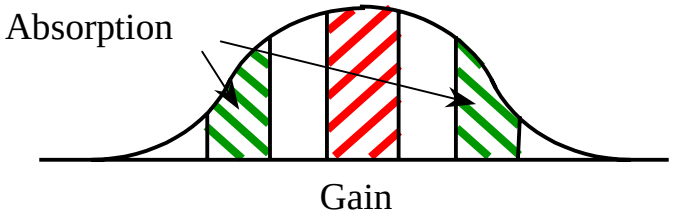
Distributed photodetector and optical amplifier parallel connection







+Parallel TAP detectors present a single waveguide with absorption on the sides and gain in the center, for high efficiency and high saturation power.

+BPM calculations show Γ_{gain}=11%, Γ_{abs}=1.5%.

+We define a net modal gain $\Delta g=\Gamma_{gain}g-\Gamma_{abs}\alpha_{abs}-\alpha_{loss}$.

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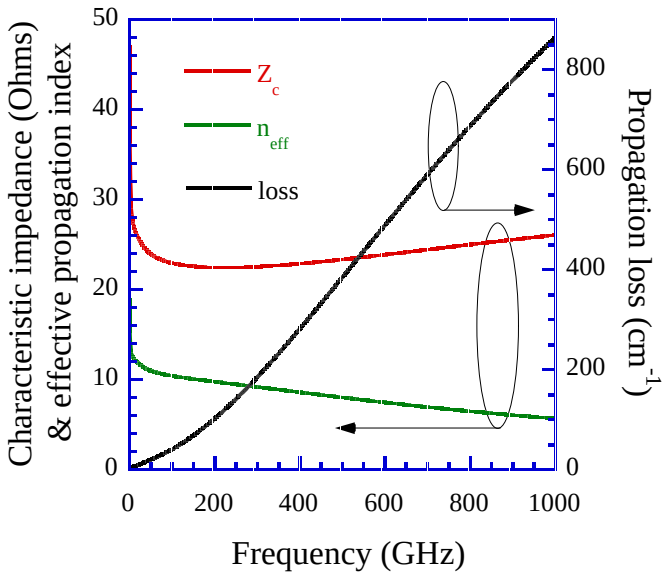
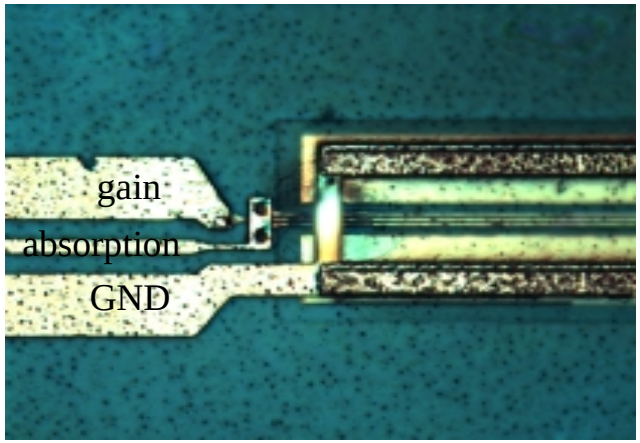
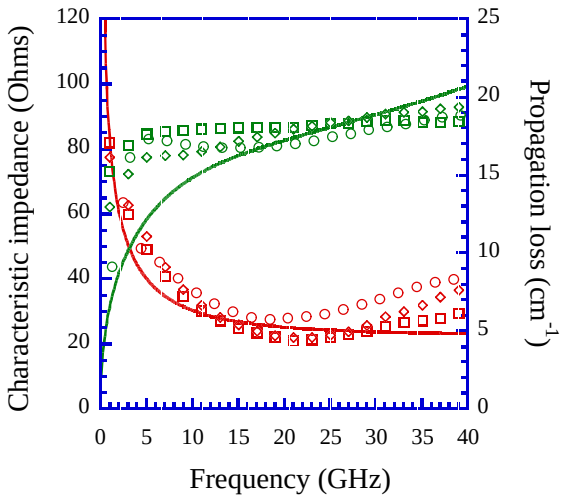
Modeling of parallel TAP detectors

Microwave propagation characteristics







+Width of gain, absorption and isolation is 1μm.

+Characteristics (above) are found using a distributed element model.

+Comparison between simulated (line) and measured (symbols) characteristics for fabricated devices validates the model.

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Simulation results

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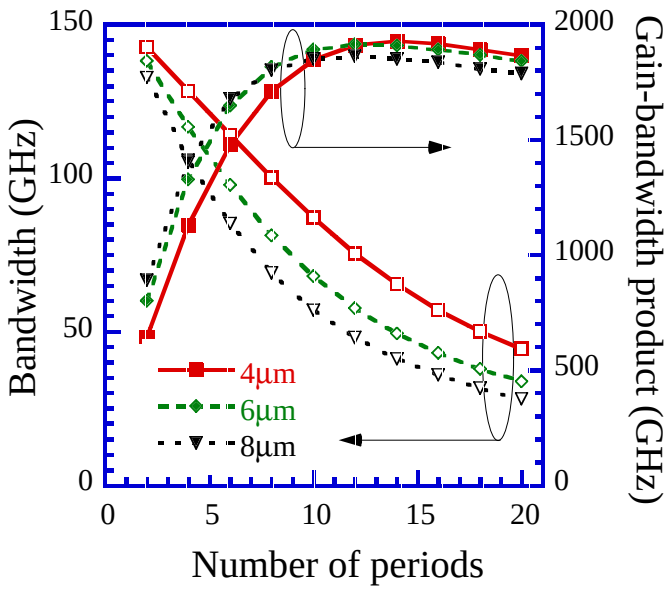
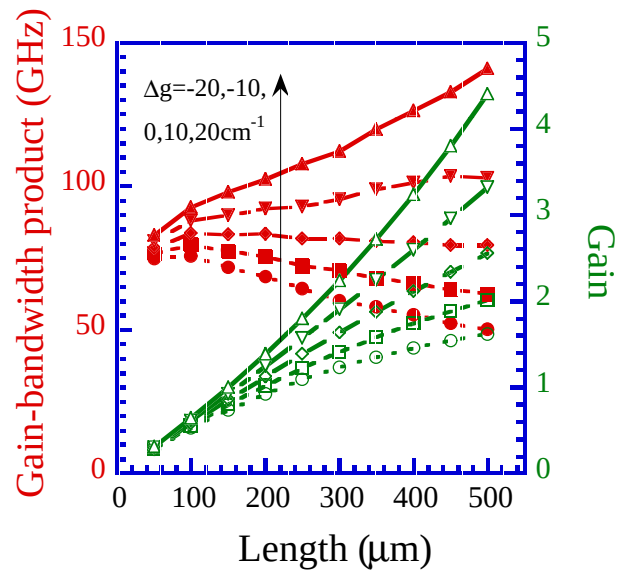
Sequential TAP detectors



+Gain-bandwidth product~1.9THz with gain G=10 in the first amplification section.
+D. Wake, J. Light. Tech., vol.10 no.7 (1992), gain-bandwidth=2.4THz with G=86; same would be obtained with sequential TAP detectors with G~12.5.

Parallel TAP detectors



+Gain-bandwidth product~80GHz for Δg=0.
+Similar gain-bandwidth product to traditional TWPDs, with saturation power ~20 times larger.

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Task	2000	2001	2002	2003	COSTS UCSB	COSTS Agility	Subtotals	
1. 0 DBR Lasers, Laser-Amps, and Laser-Modulators								
1.1 Modeling/Design					$50k	$35k		
1.2 F-P MAR					$75k			
1.3 DBR/MAR					$75k			
1.4 DBR/SOA					$75k			
1.5 DBR/SOA/EAM					$75k			
1.6 MX					$75k			
1.7 SGDBR/MAR/SOA/MX					$75k	$55k		
1.8 SGDBR/SOA/EAM/MX					$75k	$55k		
1.9 Predistortion Circuit					$50k			
1.10 Evaluate in Test Beds					$75k	$55k		
							$700k	$200k
2.0 High-Speed, Linear EAMs								
2.1 Lower Voltage Design					$125k	$20k		
2.2 Large Bandwidth Design					$100k	$30k		
2.3 Linearity Design & Fab.					$75k			
2.4 Enhanced Recomb. Design					$50k	$20k		
2.5 ModeX/SOA Integration					$75k	$30k		
2.6 Evaluate in Test Beds					$50k			
							$475k	$100k
3.0 Photodetectors (TAP)								
3.1 Modeling/Design					$75k			
3.2 Integration of SOA and PD					$50k			
3.3 Microwave Design					$100k			
3.4 Longitudinal Design					$100k			
3.5 Integrated Filter					$75k			
3.6 Antenna Intergration					$75k			
3.7 Evaluate in Test Beds					$50k			
							$525k	--
DARPA TOTALs					$1,700k	$300k		

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Key Milestones

Single Freq. 1.55 µm DBR with $\eta_d > 1$ ……4Q 2000
TAP PD with $\eta_d > 1$ …… 4Q 2000
Linearized EAM @ > 30GHz …… 4Q 2001
Fiber coupled DBR with $\eta_d > 10$ …… 4Q 2001
Fiber coupled TAPs & EAMs with mode X-formers …….. 4Q 2001
Fiber coupled SGDBR with $\eta_d > 10$ ……2Q 2002
Integrated SGDBR/SOA/EAM/mode X-formers……4Q 2002
SGDBR with $\eta_d > 10$ @ > 30GHz ……4Q 2002
Analog link demos with TAPs & EAMs @ > 30GHz…. …4Q 2003