High Gain Fiber Amplifiers for DWDM and Metro Networks

N. Peyghambarian
Optical Sciences Center,
University of Arizona

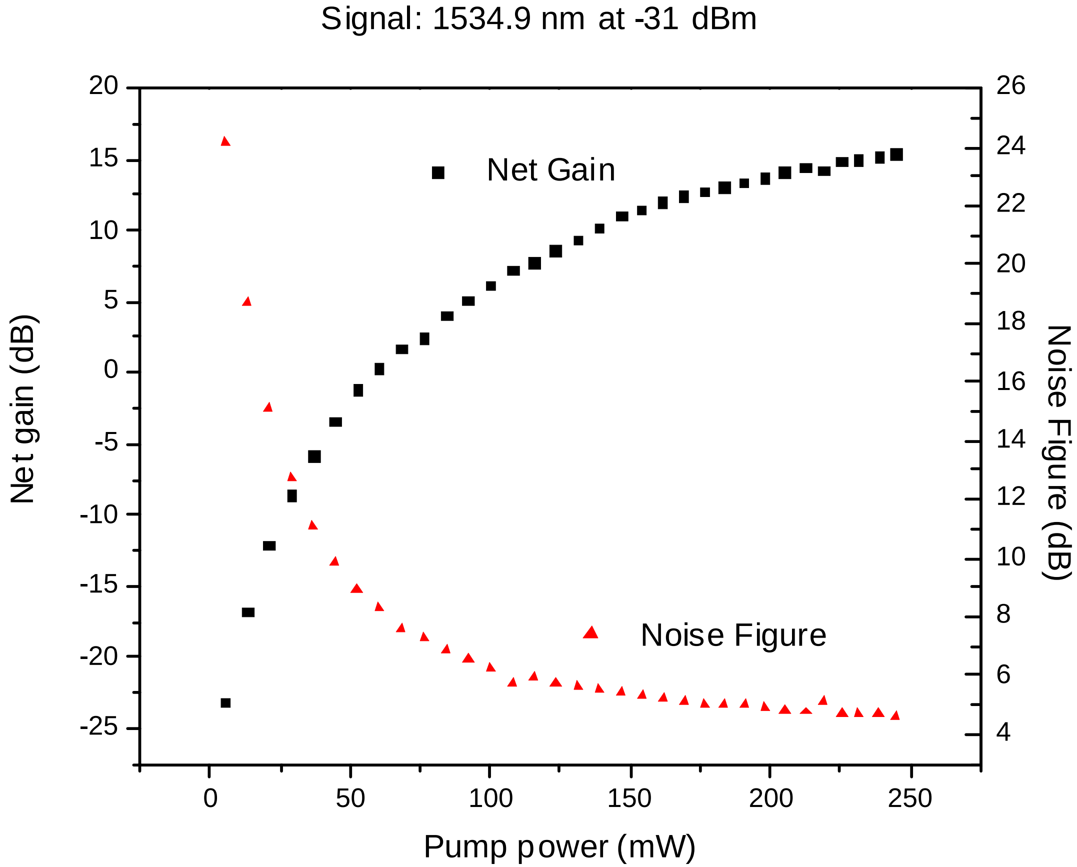
THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

OUTLINE

- Motivation
- Glass and Fiber Fabrication
- Spectroscopic Characterization
- Gain Performance
- Conclusion

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

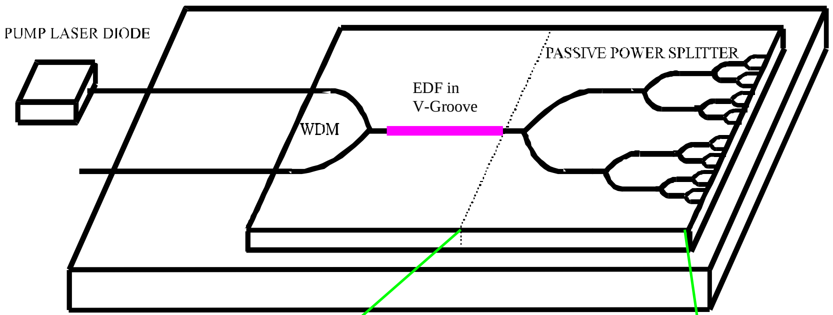
Amplifier Performance



15.5 dB **net** gain for 5.1 cm fiber

Motivation

Lossless Splitter



1x16 splitter: 15dB loss

Commercial EDFA
gain : 0.02dB/cm

Ultra Compact 1.54 μm Fiber Amplifier

↓

High Er^{3+} Doping Concentration

↓

Low Cooperative Upconversion Co.

↓

Phosphate Glasses

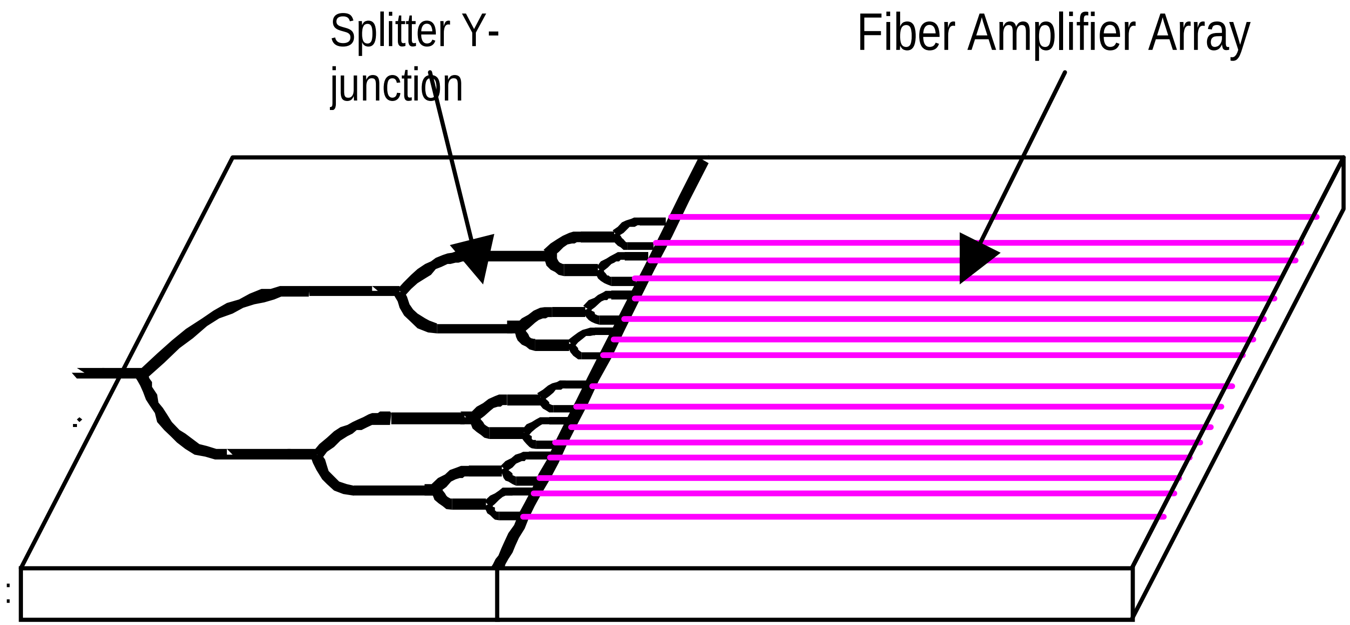
⇓

Phosphate Glass Fiber Amplifier

Amplifying Splitter

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

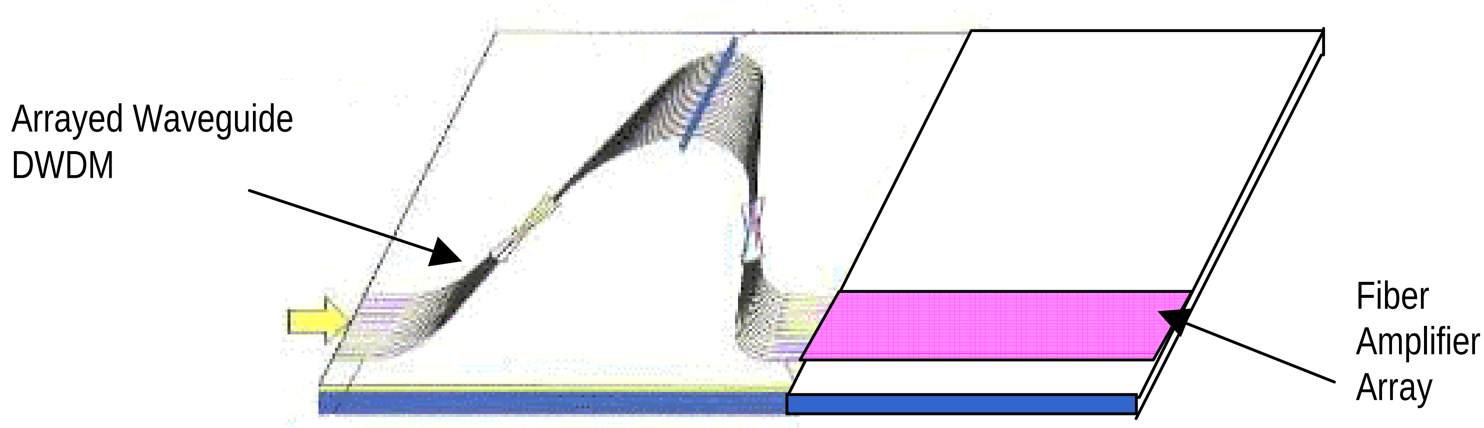
NP Integrated Power Splitter Concept



THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

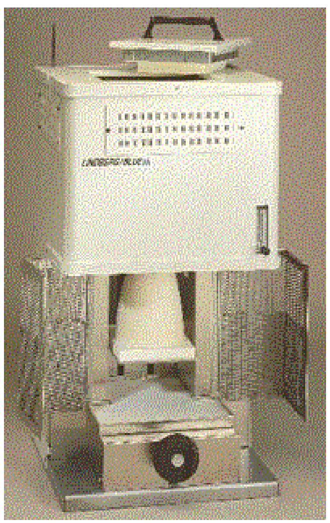
NP Amplifying Arrayed Waveguide Multiplexer

NP Arrayed Waveguide Multiplexer

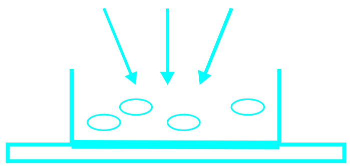


THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

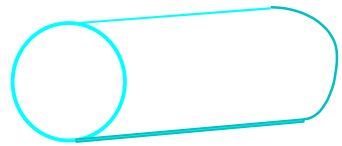
Glass Fabrication



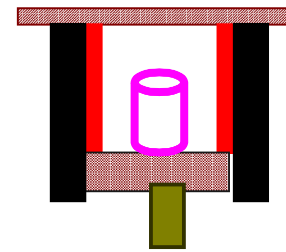
P_2O_5 Al_2O_3 R_2O, et al



Batch



Mixing

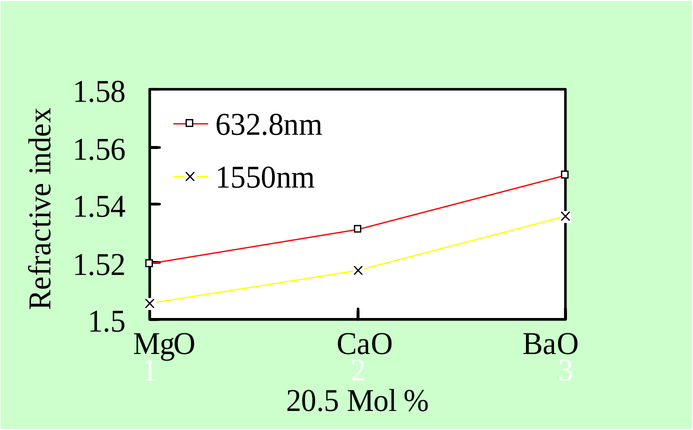


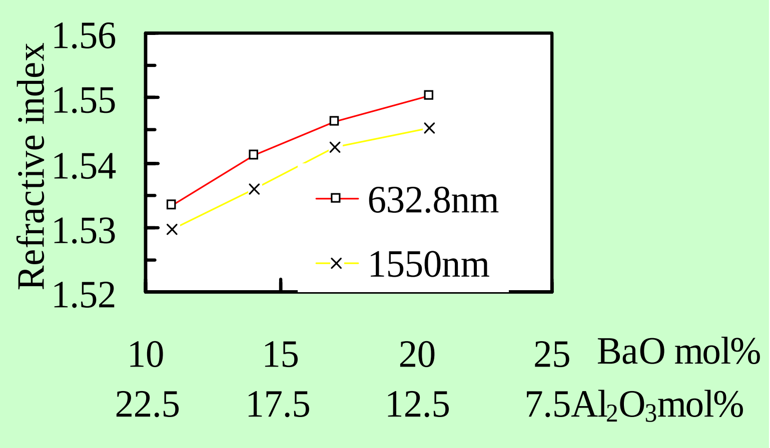
Melt

Cast | **Annealing** | **Inspection** | **Fabrication**

Influence of Glass Composition on Refractive Index

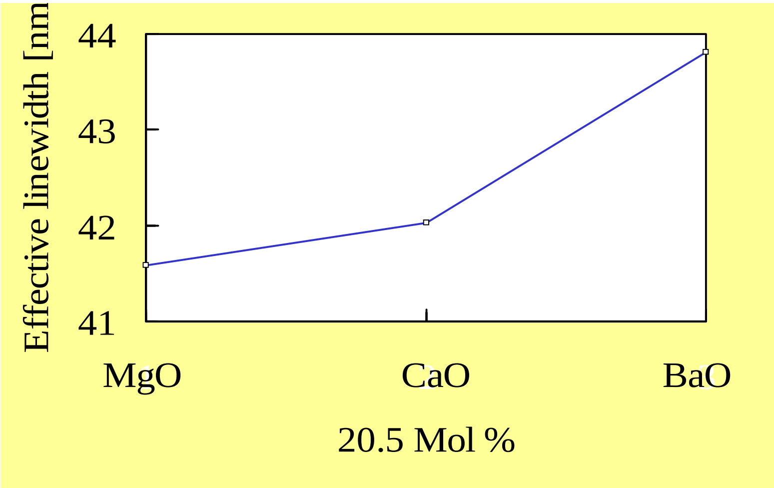
Glass type	Glass composition (Mole %)					
	P_2O_5	Al_2O_3	La_2O_3	MgO	CaO	BaO
P1	64	12	3.5	20.5		
P2	64	12	3.5		20.5	
P3	64	12	3.5			20.5
P4	64	15.5	3.5			17
P5	64	18.5	3.5			14
P6	64	21.5	3.5			11

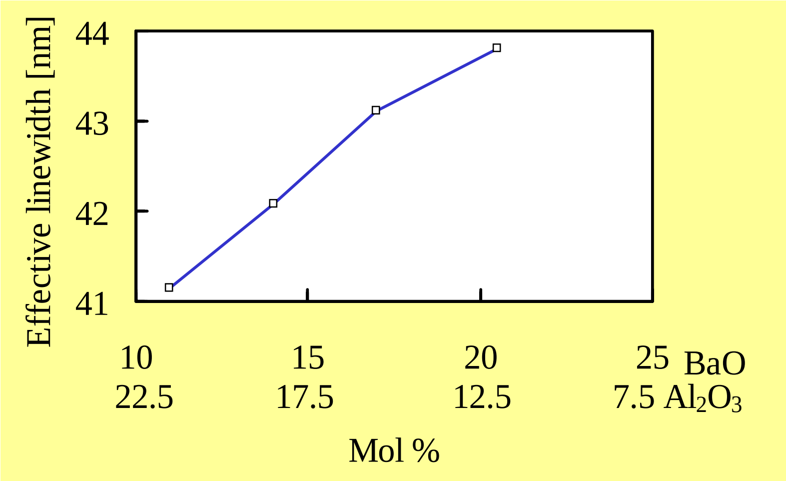




THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

Influence of Glass Composition on Effective Linewidth of Er^{3+} $^4I_{13/2}$ - $^4I_{15/2}$ Transition





Effective Line width of the 1.54 μm transition

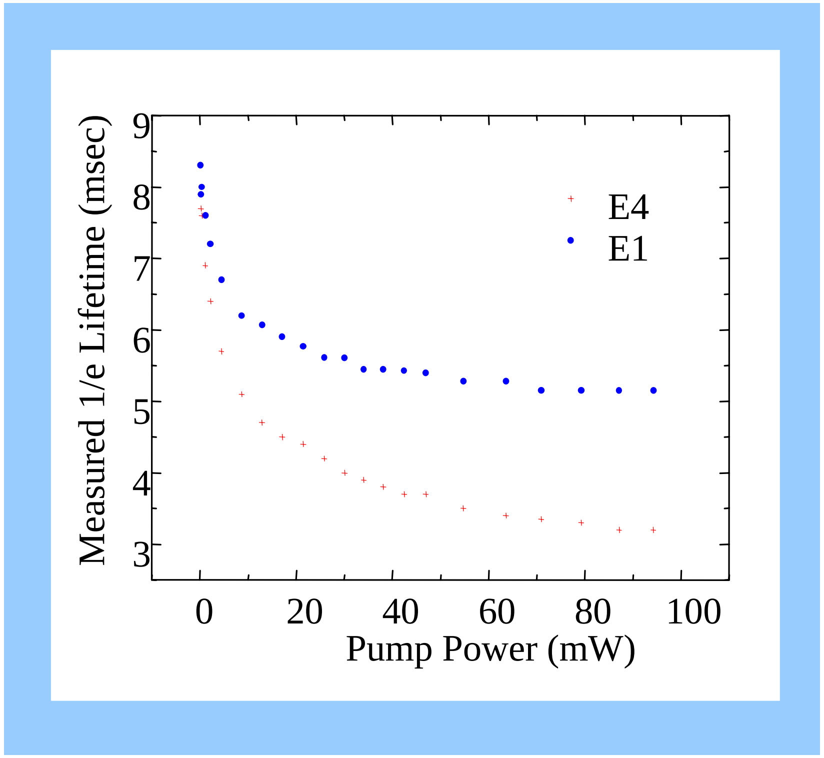
$$\Delta\lambda_{eff} = \frac{\int \alpha(\gamma)\, d\gamma}{\alpha_{peak}}$$

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

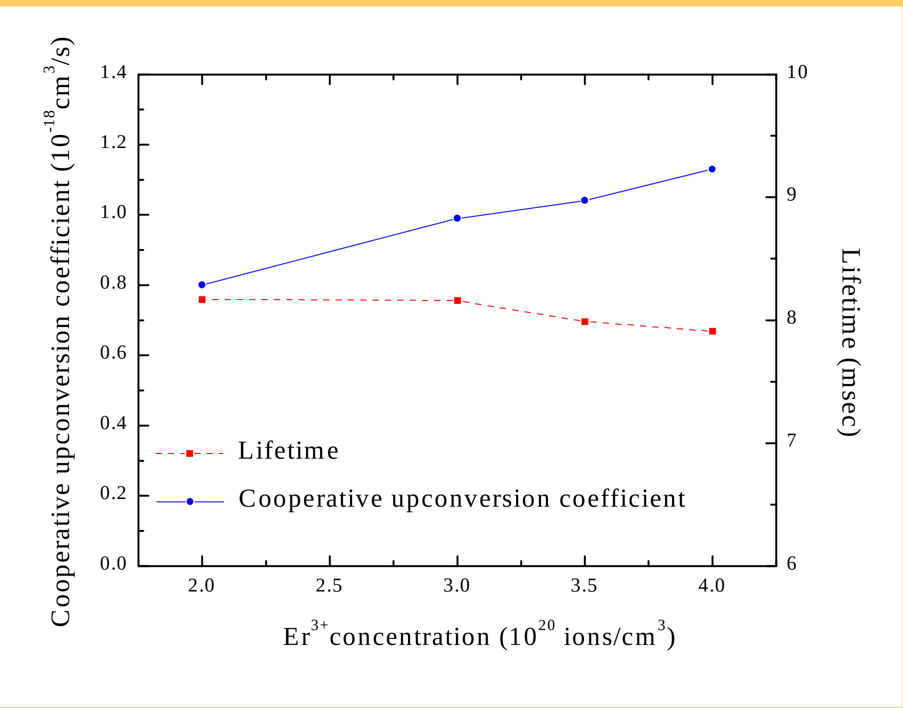
Measured 1/e Lifetime of Er^{3+} Ions

Samples	Er^{3+} concentration (ions/cm^3)	Yb^{3+} concentration (ions/cm^3)
E1	2.0×10^{20}	0
E2	3.0×10^{20}	0
E3	3.5×10^{20}	0
E4	4.0×10^{20}	0
YE1	2.0×10^{20}	2.0×10^{20}
YE2	2.0×10^{20}	4.0×10^{20}
YE3	2.0×10^{20}	6.0×10^{20}



THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Cooperative Upconversion Coefficient and Spontaneous Lifetime

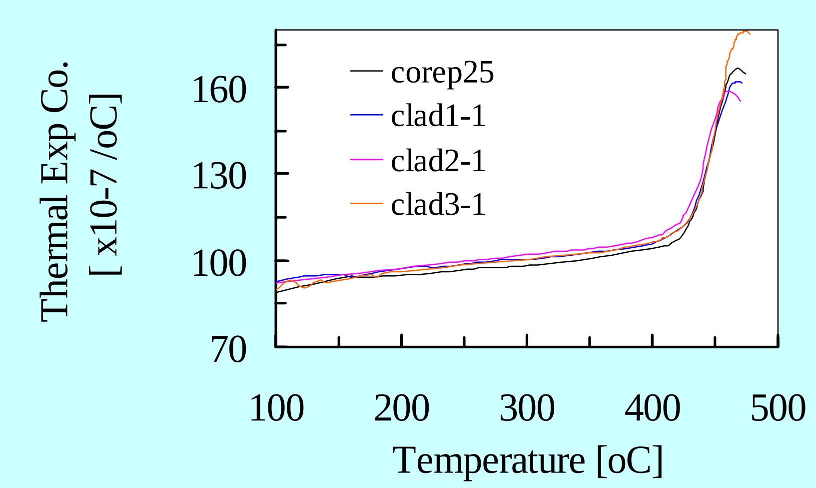


$$N_{E2}(t) = \frac{1}{\tau_E^o}\left[\left(\frac{1}{\tau_E^o N_{E2}(0)} + C\right)\exp\left(\frac{t}{\tau_E^o}\right) - C\right]^{-1}$$

$$N_{E2}(0) = \frac{R_{E13}\tau_E^o + 1}{2C\tau_E^o}\left(\sqrt{1+\frac{4CN_E R_{E13}\tau_E^o}{R_{E13}\tau_E^o+\tau_E^o}} - 1\right)$$

Cladding Glasses

Glass type	Refractive index			
	632.8 nm	830 nm	1300 nm	1550 nm
Core P25	1.5431	1.5389	1.5318	1.5290
Cladding1-1	1.5365	1.5309	1.5249	1.5217
Cladding2-1	1.5298	1.5250	1.5187	1.5158
Cladding3-1	1.5257	1.5206	1.5150	1.5116



$\Delta n/n_1$=0.48% ~1.14%,
NA=0.149 ~ 0.230

$\Delta\, \alpha/\alpha_1 < 3\%$

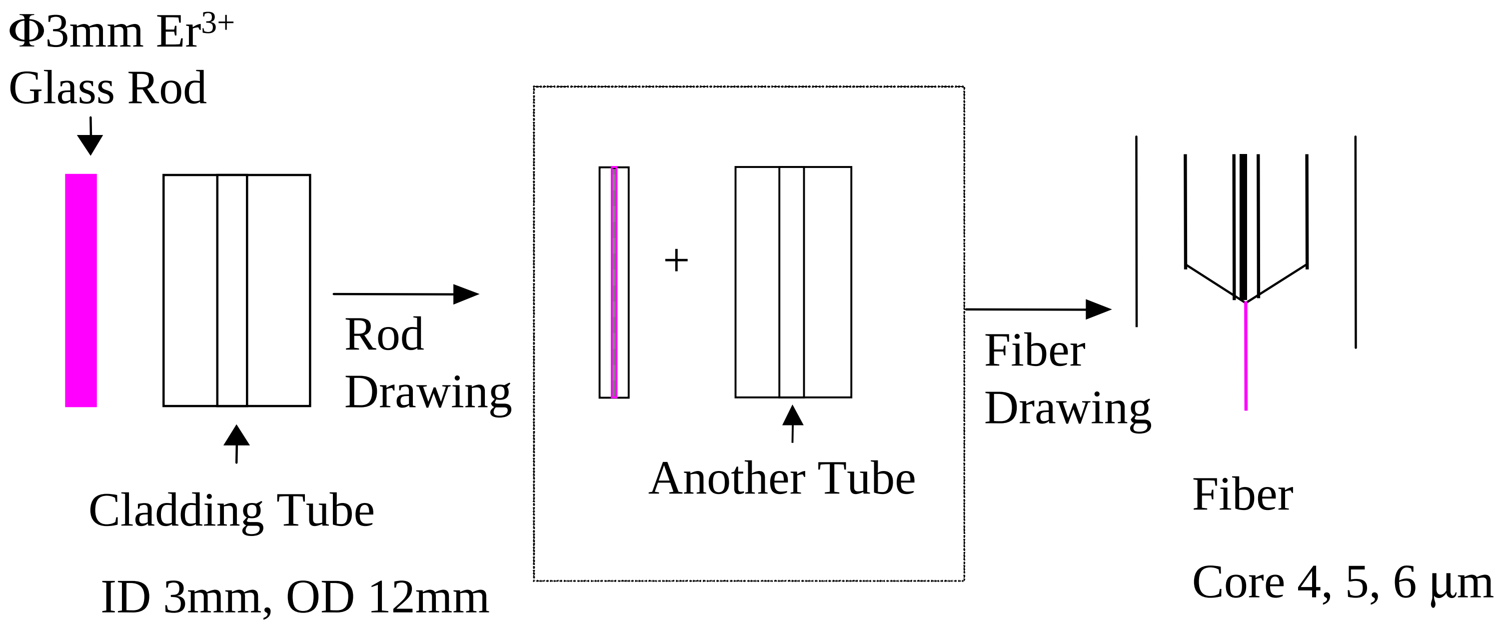
$\Delta\, T_g/T_{g1} < 1\%$

$\Delta\, T_f/T_{f1} < 3\%$

THE UNIVERSITY OF ARIZONA® TUCSON ARIZONA

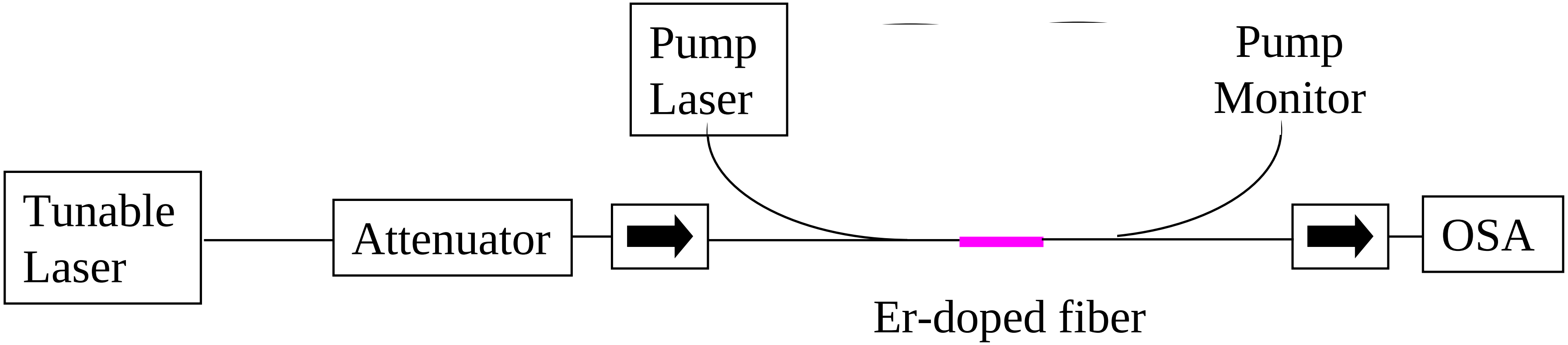
Fiber Drawing

Rod-in-tube technique



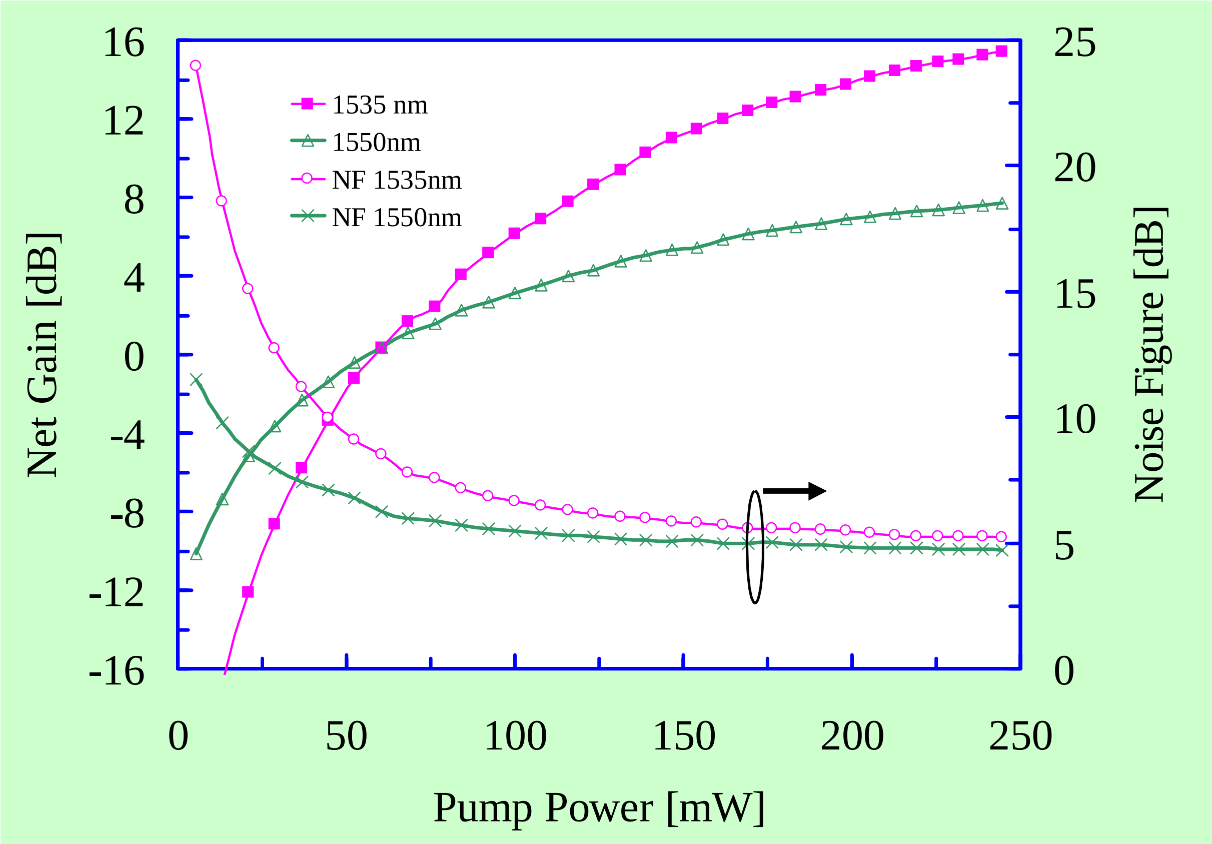
Core Diameter: 4-6 μm

Experimental Setup for Gain Measurement



THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

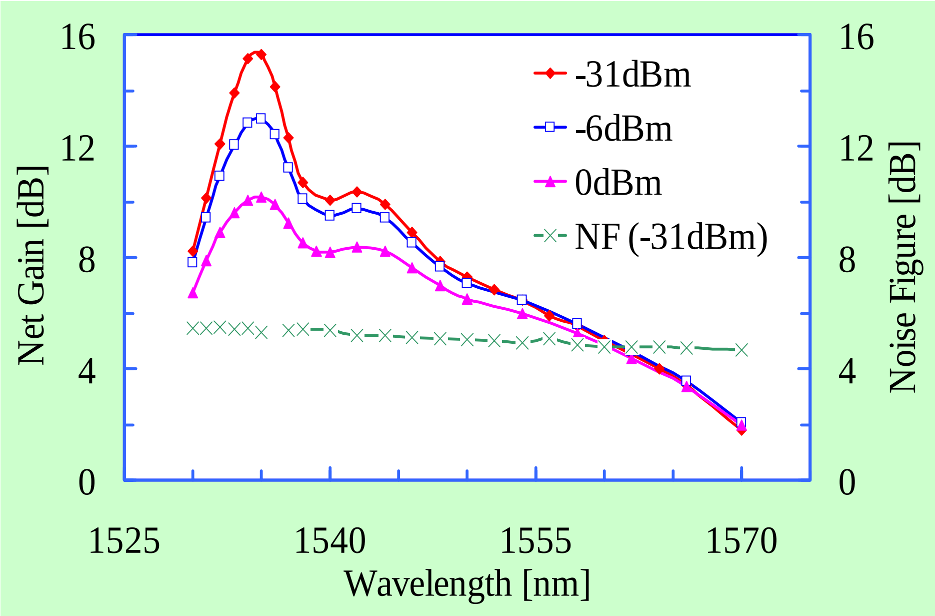
Gain Characteristics

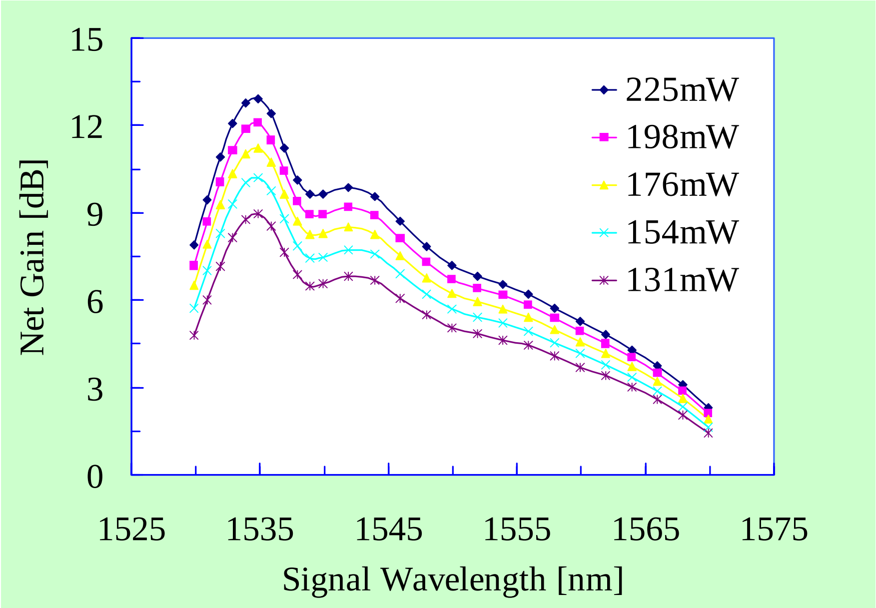


Fiber Length:

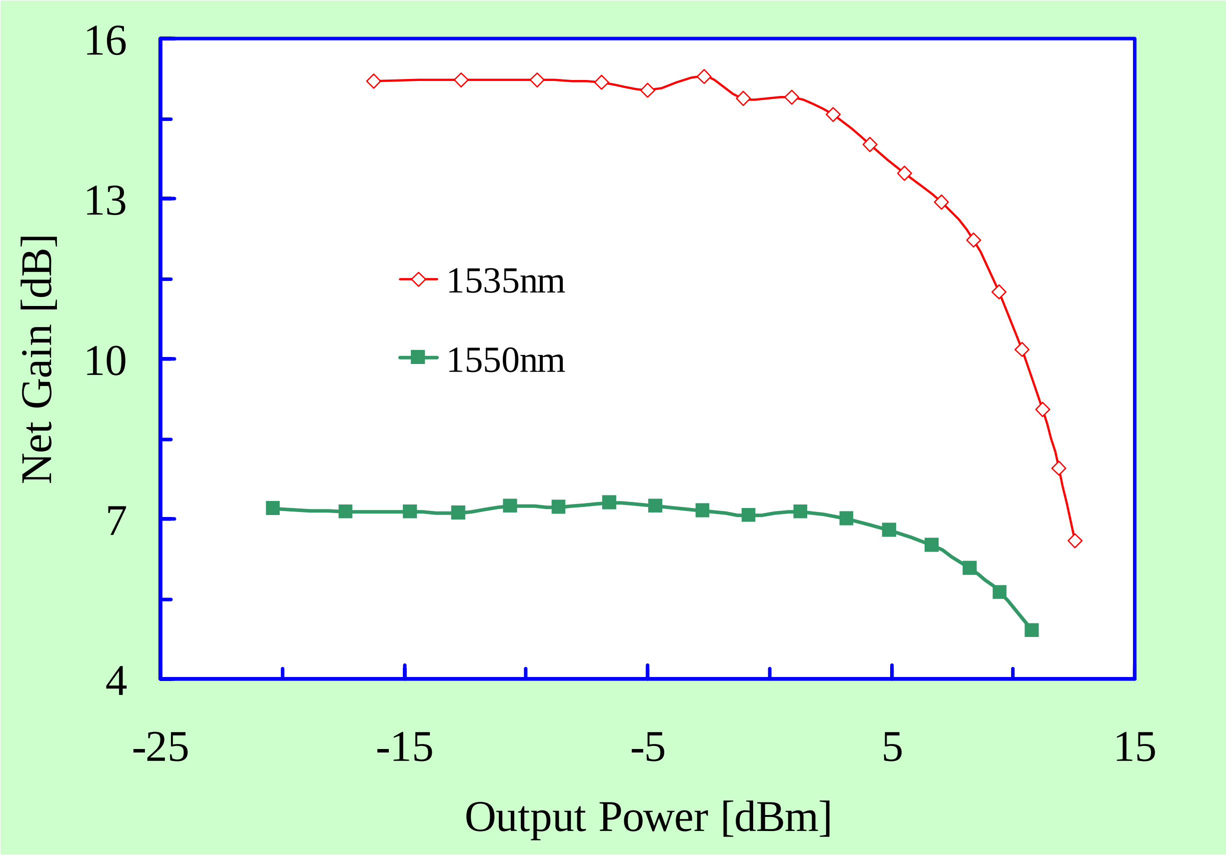
5.1cm

Gain Spectrum



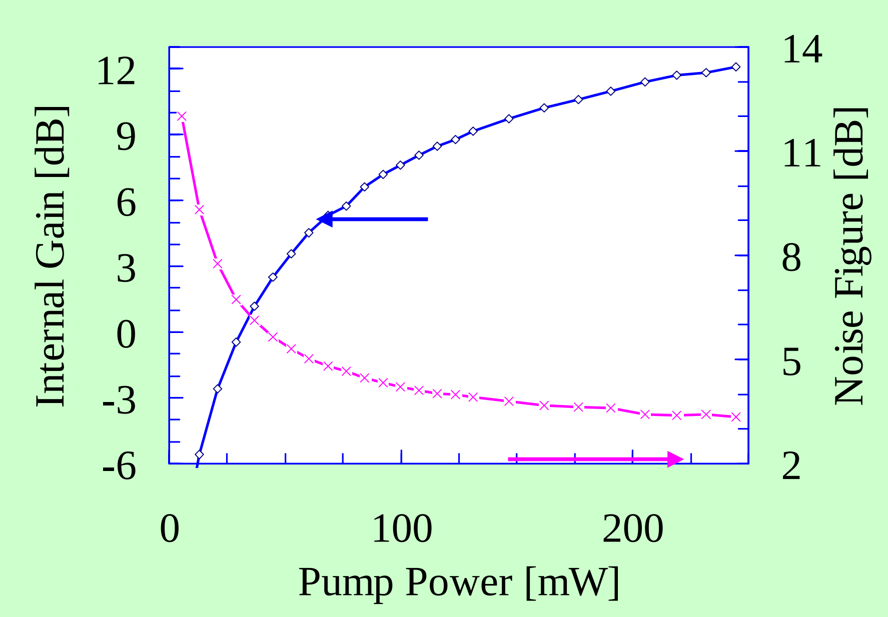


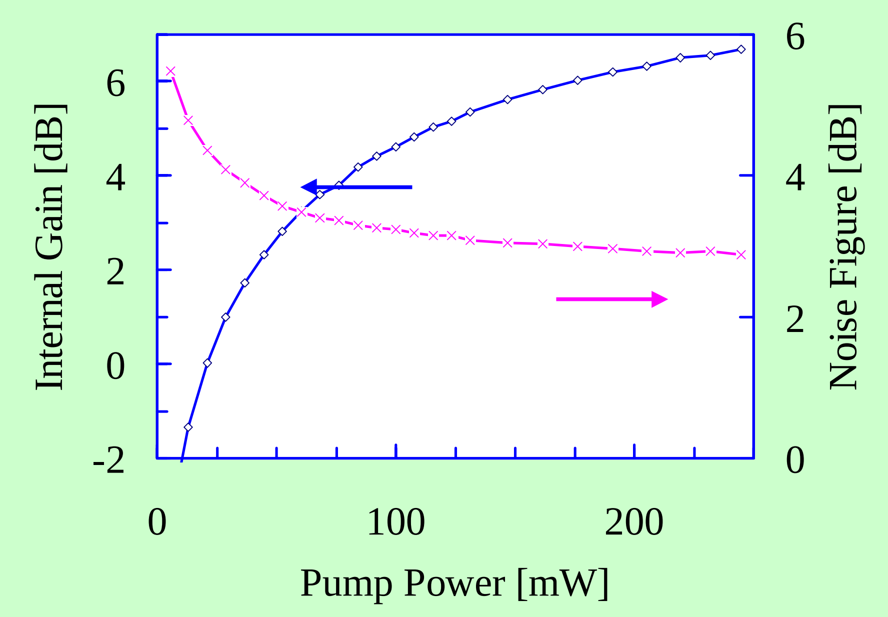
Gain Saturation



The University of
ARIZONA®
Tucson Arizona

Gain Performance





1535nm, -31.6dBm

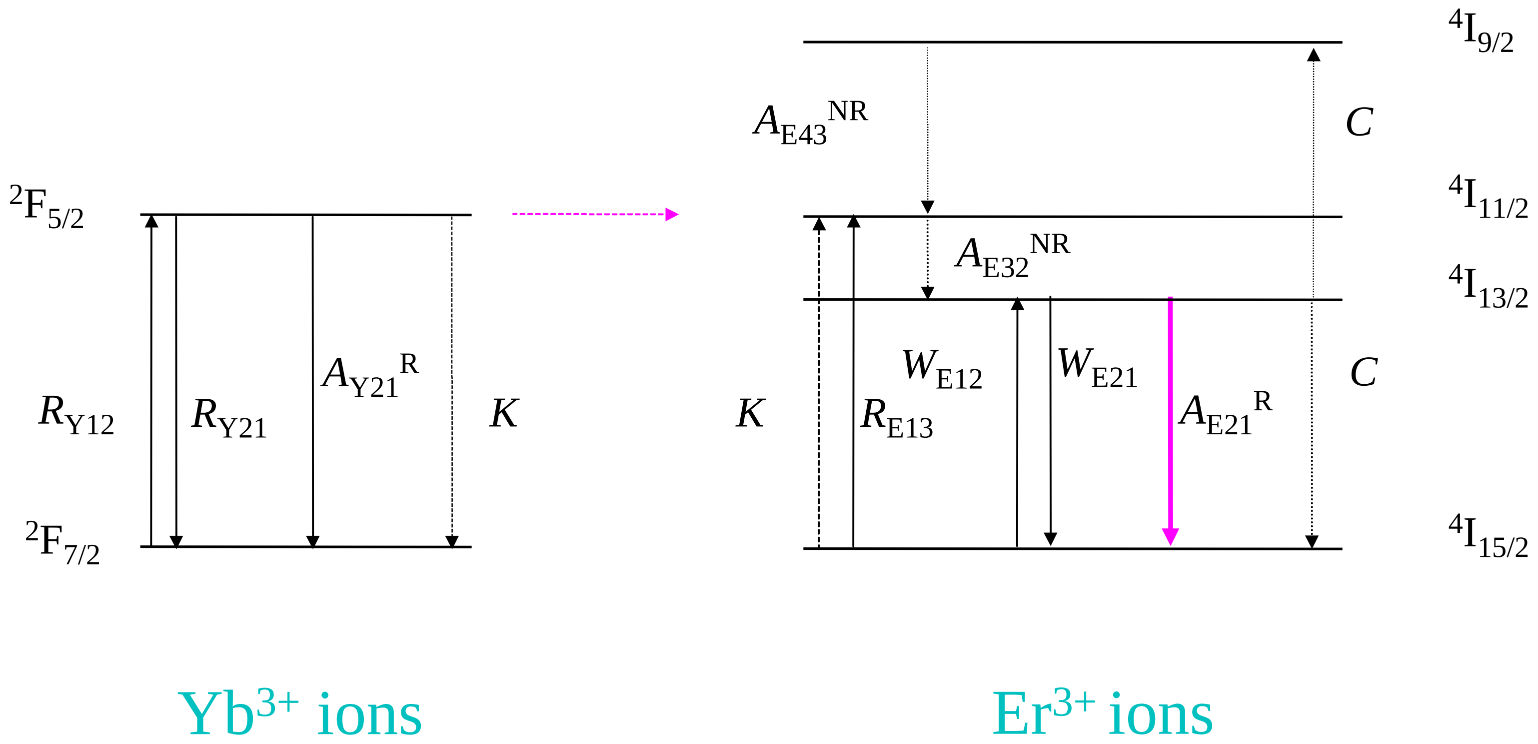
3.2cm-long fiber

1550nm, -31.6dBm

3.2cm-long fiber

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

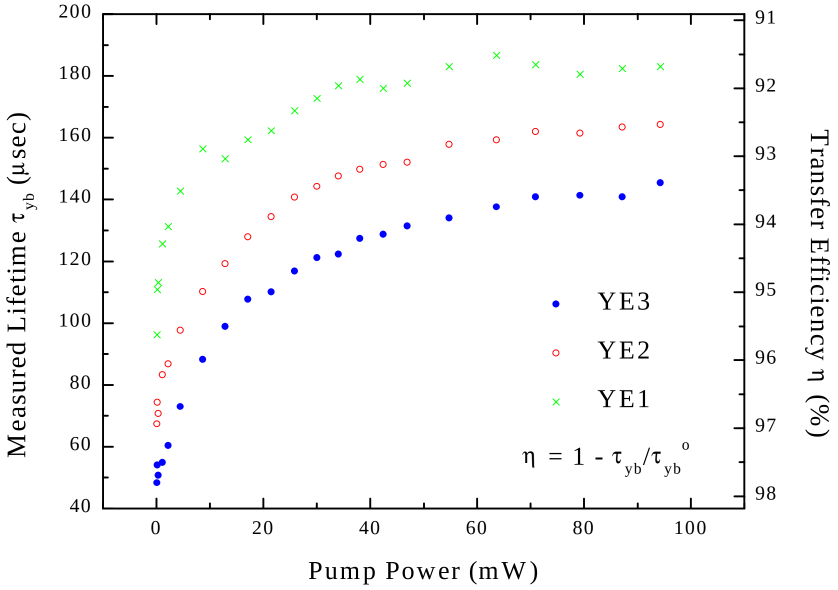
Spectral Properties



Energy Levels of Er^{3+} and Yb^{3+} Ions

Energy Transfer Efficiency

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA



Efficiency

$$\eta = 1 - \frac{\tau_{Yb}}{\tau_{Yb}^{o}}$$

τ_{Yb}^{o} Lifetime without Er^{3+} ions

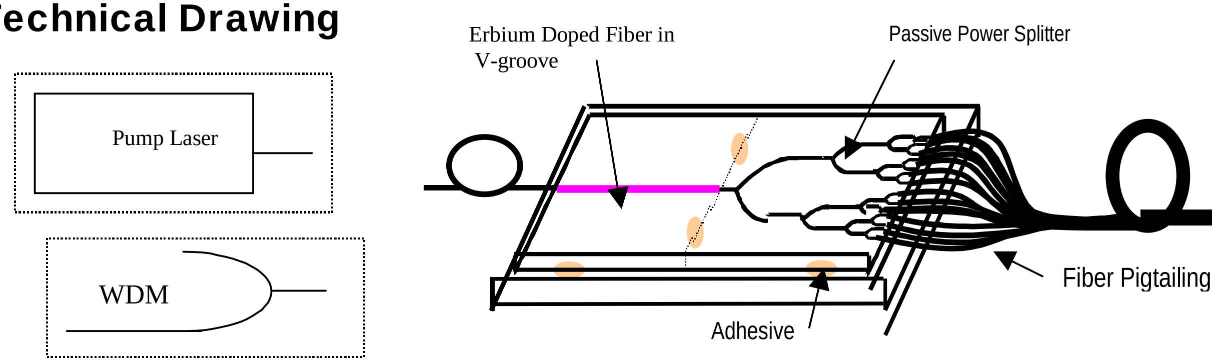
τ_{Yb} Measured lifetime

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Amplifying Splitter (and Combiner)

One Input Port and Multiple Ourput Ports (n) for
Amplifying and Dividing Optical Signals Near 1.54 μm

Technical Drawing



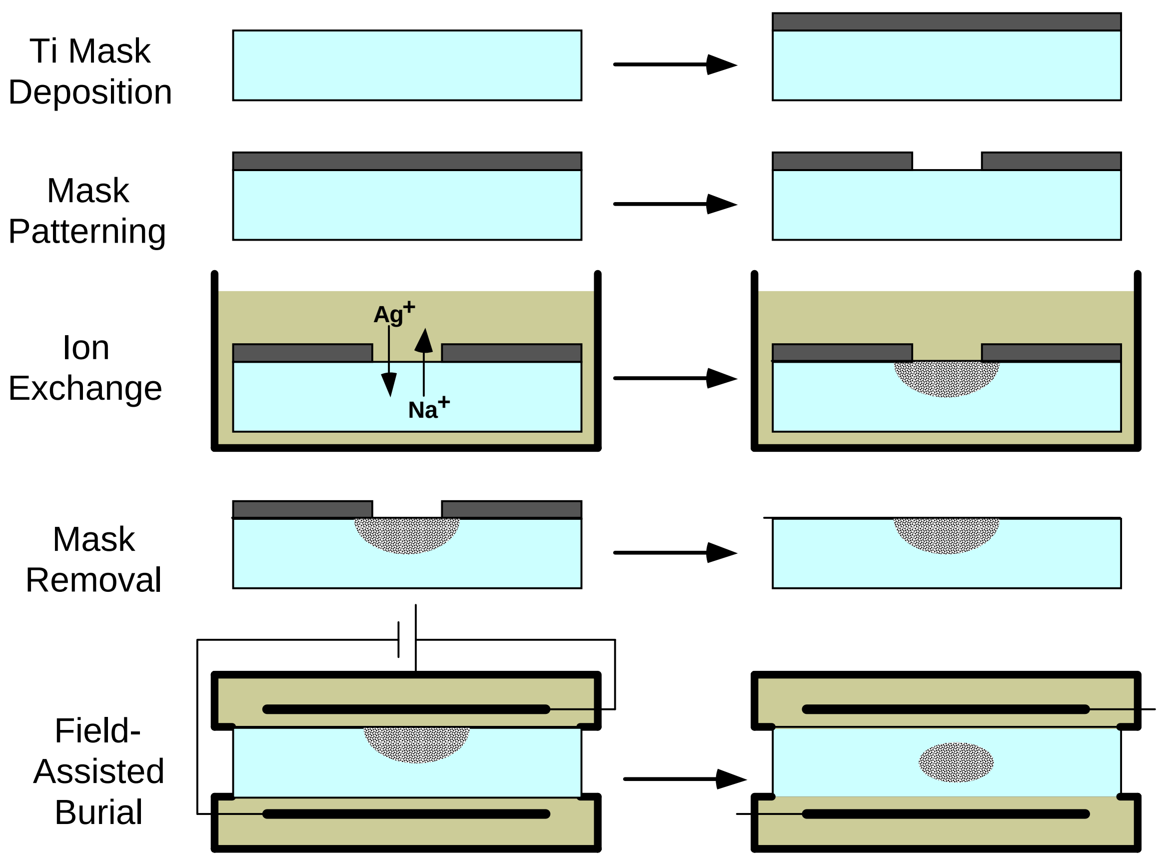
Packaged Product:

Aluminum Case Size
(1 x n: L x W x H mm^3)
1x04: 95 x 11 x 6.5
1x08: 95 x 11 x 6.5
1x16: 115 x 11 x 7
1x32: 150 x 16 x 7

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

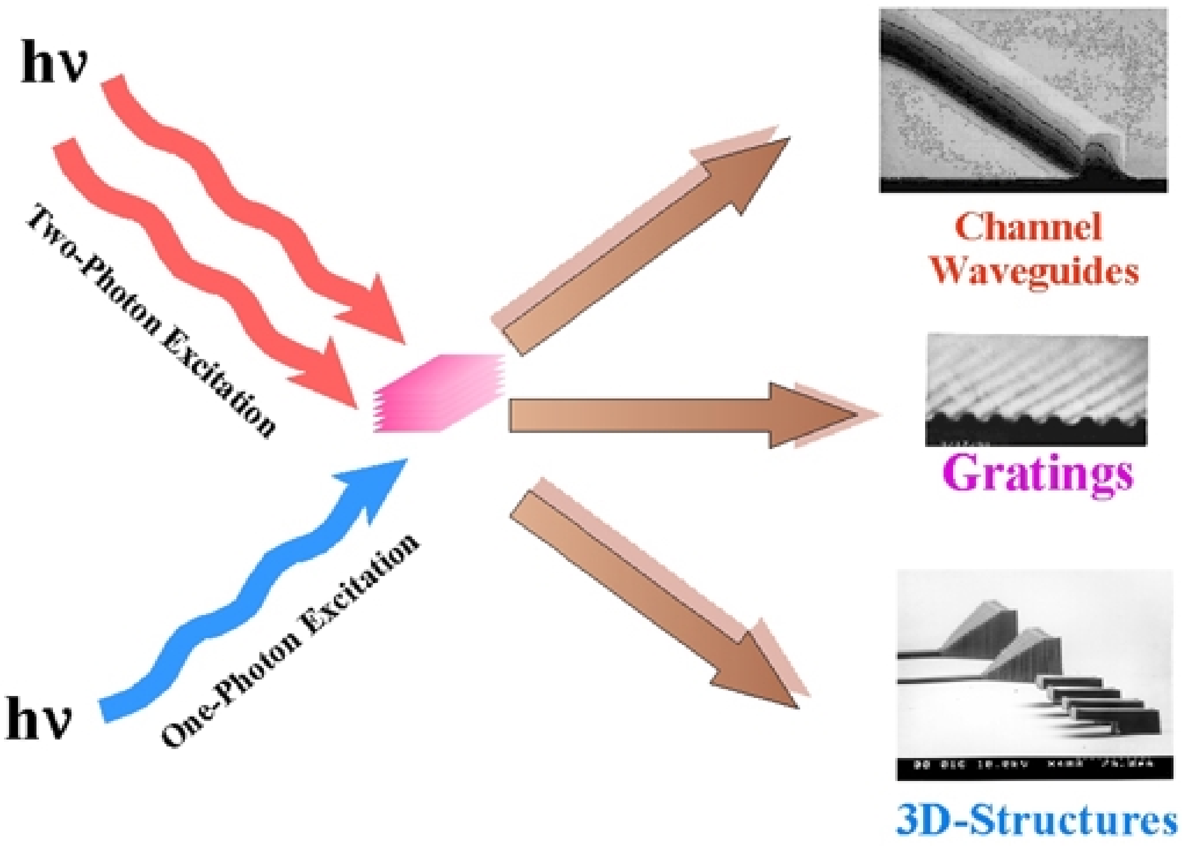
Ion-Exchanged Waveguide Fabrication

The University of Arizona
Tucson Arizona



APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

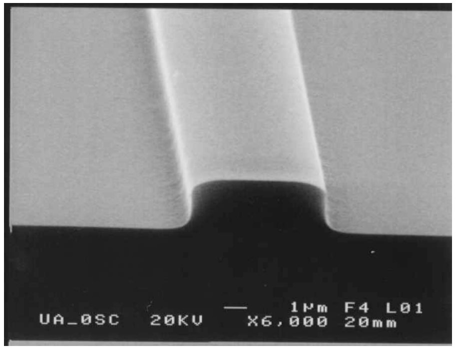
Photoimagable Hybrid Materials

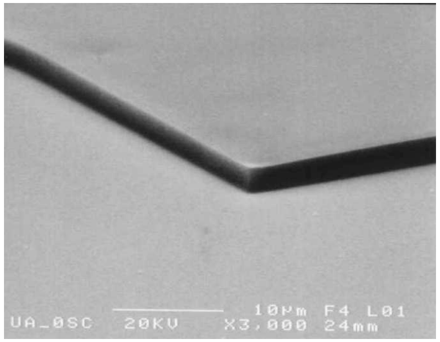


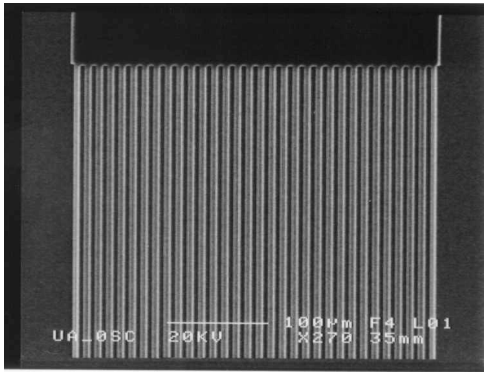
APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

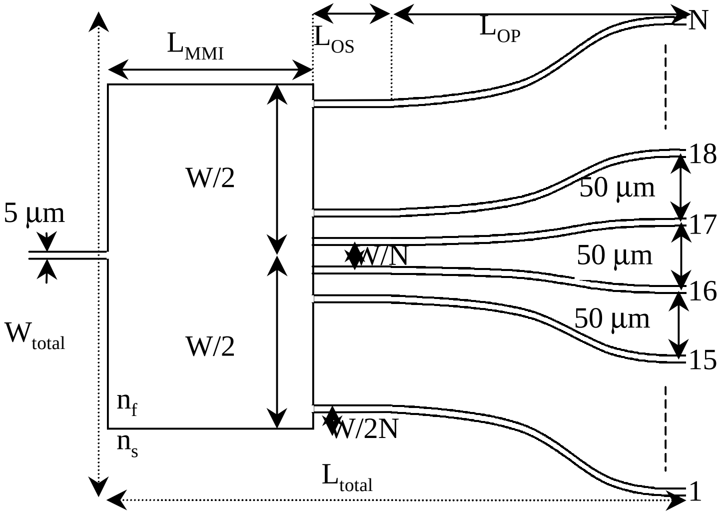
THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

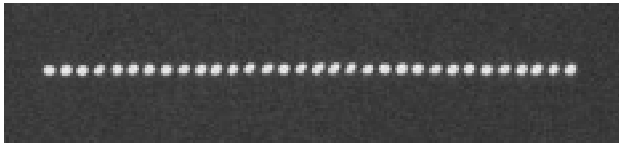
1-N Sol-Gel MMI Splitter











1x32 MMI output

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Conclusions

- Er^{3+}-doped phosphate glasses
- Single mode phosphate glass fiber
- Phosphate glass fiber amplifier
- 15.5dB net gain from a 5.1cm fiber

Modify glass composition to improve gain spectrum

Dope Yb to improve gain efficiency

Optimize fiber design to increase the gain

Improve coupling loss to reduce the NF

THE UNIVERSITY OF ARIZONA®
TUCSON ARIZONA

Acknowledgment

Assistant Research Professor: Shibin Jiang

Ph.D. Students: Bor-chyuan Hwang
Yongdan Hu
Karine Seneschal

Post-doctor: Dr. Jerome Porque

Research Scientist: Dr. Yong Ding

Visiting Scholar: Dr. Gino Sorbello (Politecnico di Milano, Italy)

Collaborator : Dr. Tao Luo (NP Photonics Technologies LLC)
Dr. Seppo Honkanen (NP Photonics Technologies LLC)
Prof. Fred Smektala (Universite de Rennes 1)
Prof. Jacques Lucas (Universite de Rennes 1)

Acknowledgment

BMDO through the SBIR Phase II program

NP Photonic Technologies, LLC

UA Science and Technology Park
9030 South Rita Road, Suite 120, Tucson,
Arizona 85747

THE UNIVERSITY OF ARIZONA ® TUCSON ARIZONA

Parameters of Single Mode Fiber

Core diameter	5 µm
Refractive index of cladding glass at 1.535 µm	1.5170
Refractive index of core glass at 1.535 µm	1.5327
Numerical aperture	0.219
Cut-off wavelength	1.43 µm
Attenuation	<0.3dB/cm
Er^{3+} concentration	35000ppm