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Infrared Fiber Lasers

Dr. Shibin Jiang

President/CEO
AdValue Photonics Inc.
Tucson, Arizona

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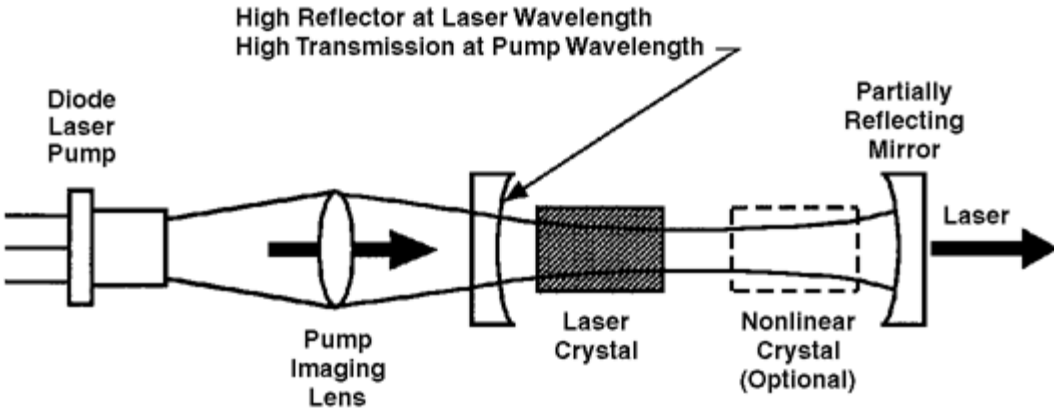
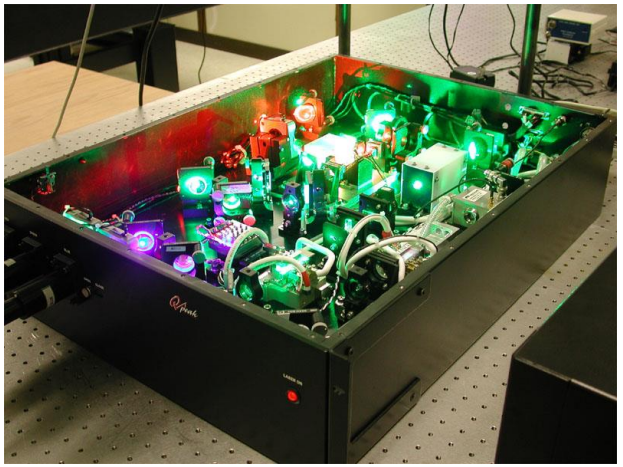
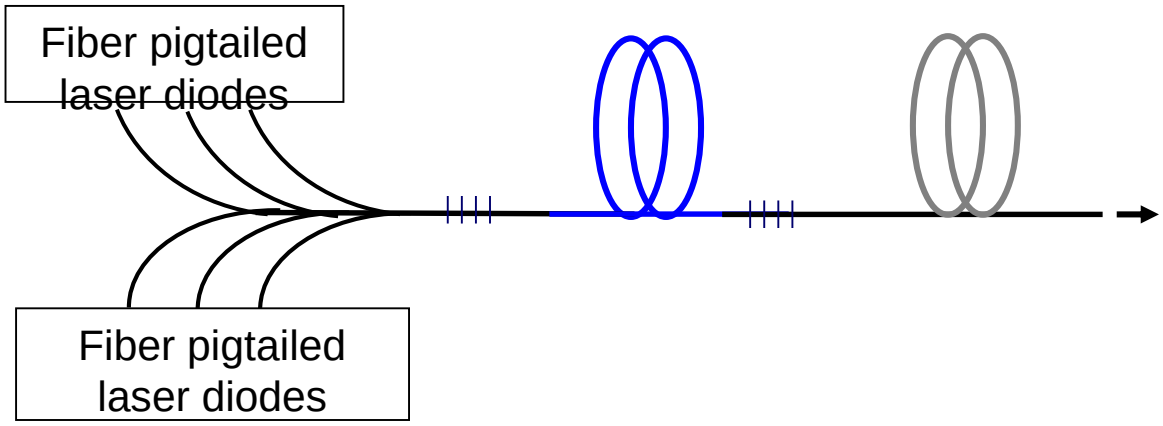
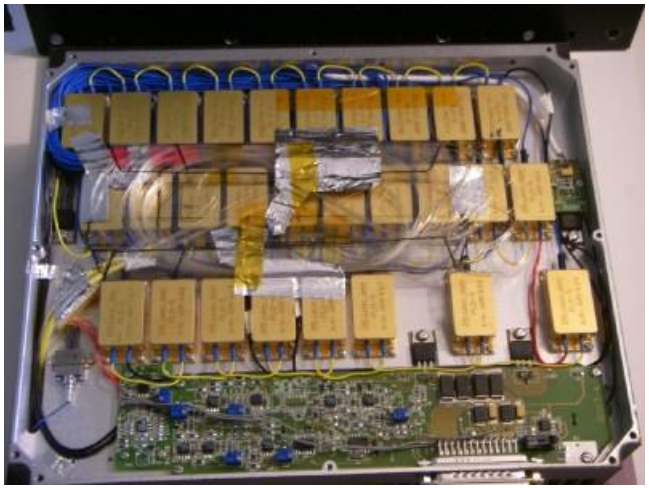
Free-Space & Fiber Lasers









From scientific point of view fiber laser is very simple

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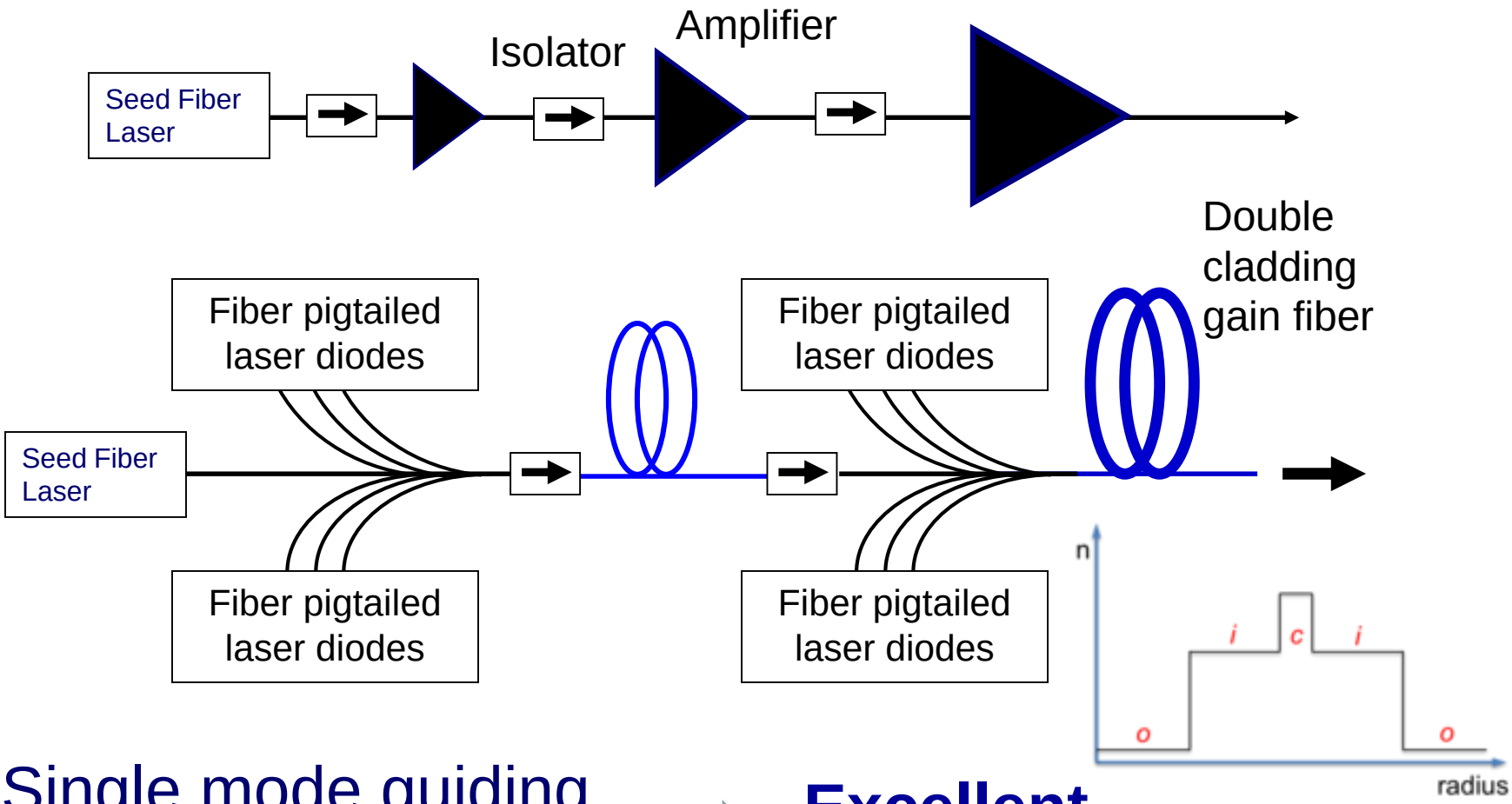
Features of Fiber Lasers



Single mode guiding

Multimode pumping

Excellent Brightness Converter

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Features of Fiber Lasers

Small Fibers – Compact

Simple Design – Reliable

Simple Manufacturing Process – Low Cost

Lots, lots, and lots of engineering work

Industrial engineers love it

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Laser Companies

Newport Corp/Spectra Physics

Range	15.22 - 15.60
52 week	13.23 - 20.85
Open	15.56
Vol / Avg.	161,277.00/134,806.00
Mkt cap	612.21M
P/E	20.28

Founded over 50 years ago as the first commercial laser company, Spectra-Physics delivers breakthrough technologies that transform the way businesses operate and people live.

Coherent, Inc

Range	62.15 - 64.00
52 week	52.15 - 69.67
Open	63.95
Vol / Avg.	160,829.00/144,454.00
Mkt cap	1.57B
P/E	20.35

Founded in 1966, Coherent, Inc. is one of the world's leading providers of lasers and laser-based solutions for scientific, commercial and industrial customers competing in the most demanding markets.

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Fiber Laser Company

IPG Photonics Corporation

Range	85.50 - 87.74
52 week	69.86 - 102.49
Open	87.74
Vol / Avg.	375,455.00/280,054.00
Mkt cap	4.71B
P/E	19.21

IPG was founded in 1990 in Russia by physicist Valentin P. Gapontsev, a pioneer in the field of fiber lasers, in the basement of a small laboratory in the Institute of Radio Engineering near Moscow.

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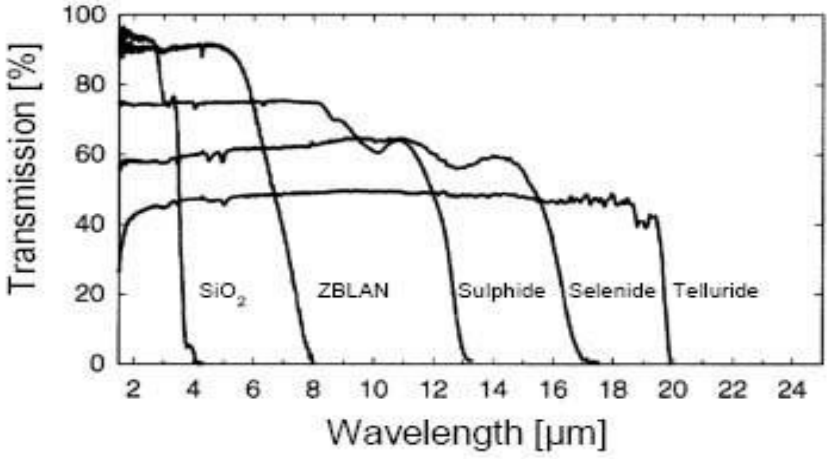
What is glass? – Most People

A transparent solid that breaks easily

Chalcogenide and metallic glasses are opaque in the visible spectrum



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What is glass?

High-strength glass

Bulletproof glasses

Glass Bridge in Grand Canyon

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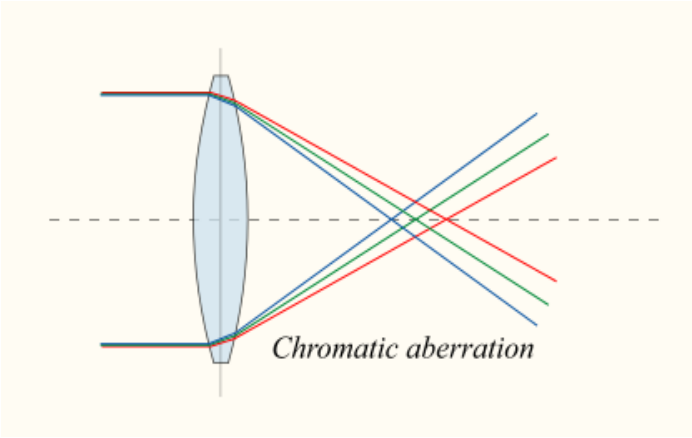
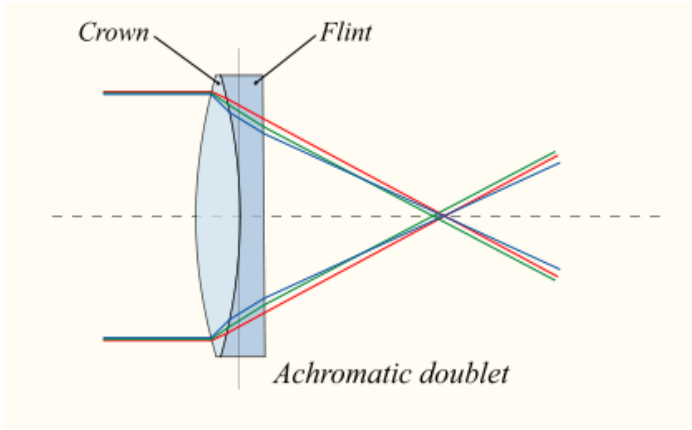
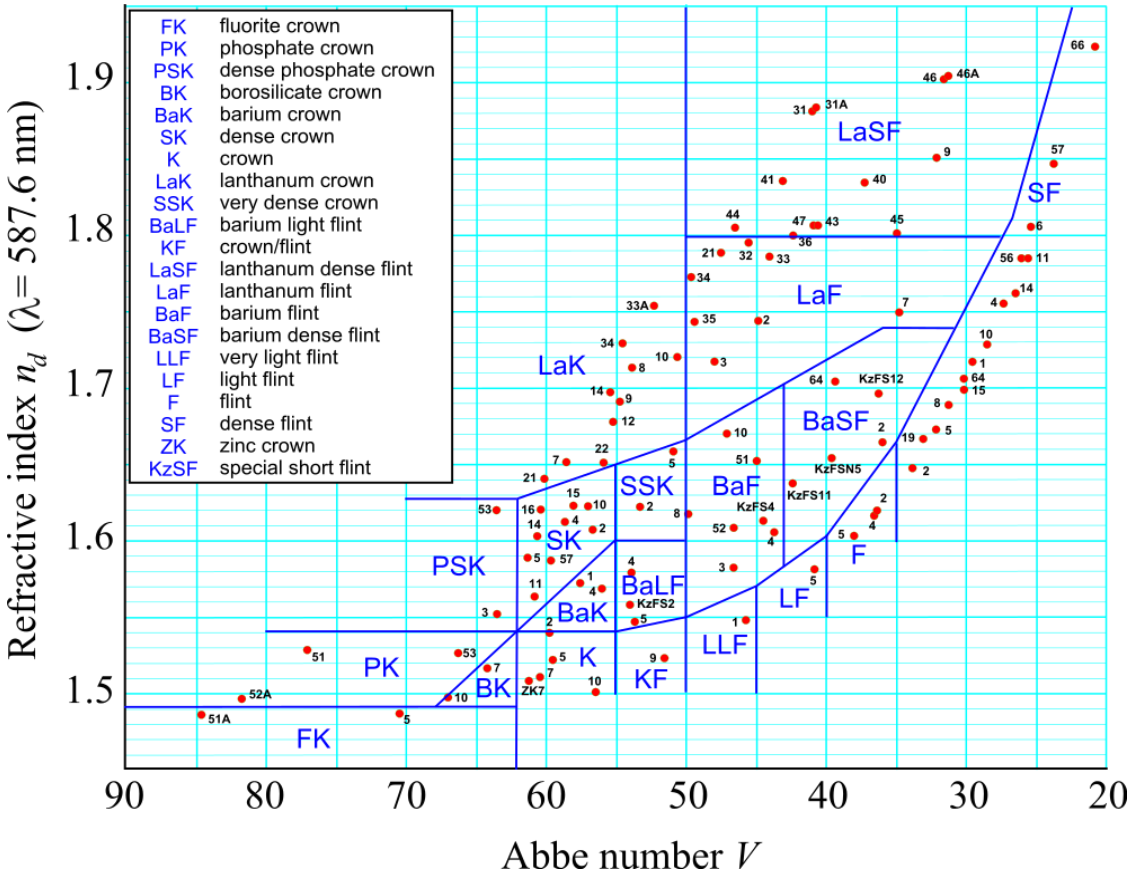
What is glass?







We can control the refractive index and dispersion

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What is glass?
– Glass Scientists

- Solid with liquid like structure
- Noncrystalline solid
- Amorphous solid
- Supercooled liquid
- Product of fusion which has been cooled to a rigid condition without crystallizing (ASTM)

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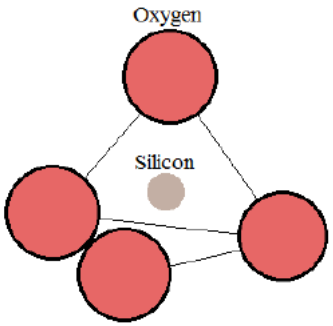
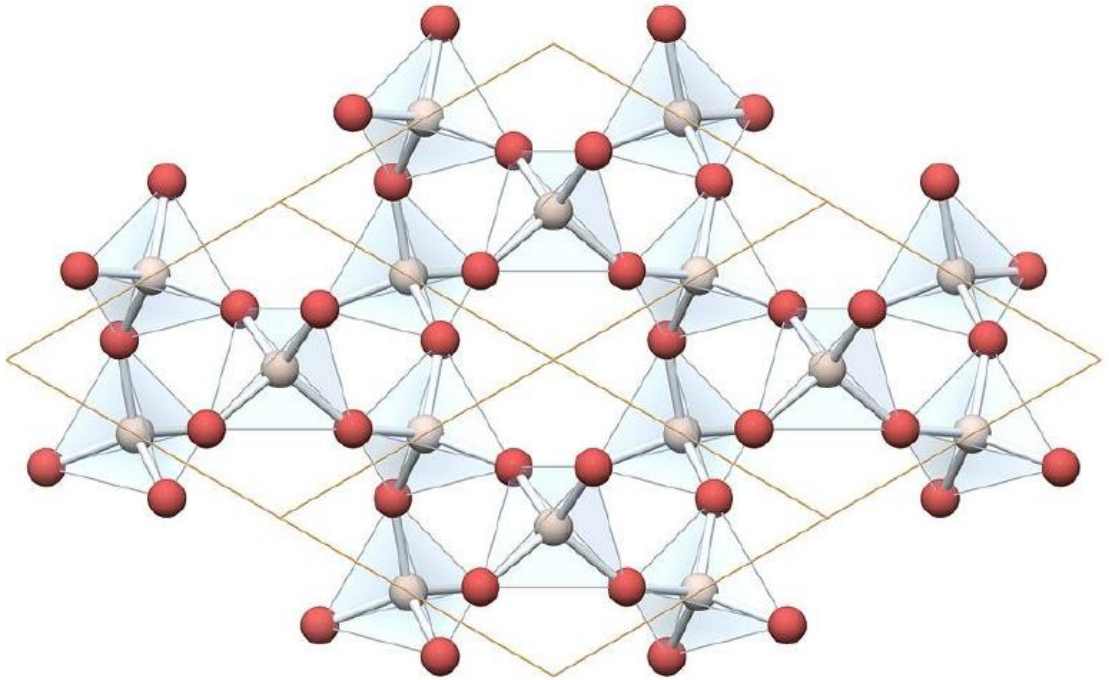
Silica Glass

Silica: SiO_2





It is sand

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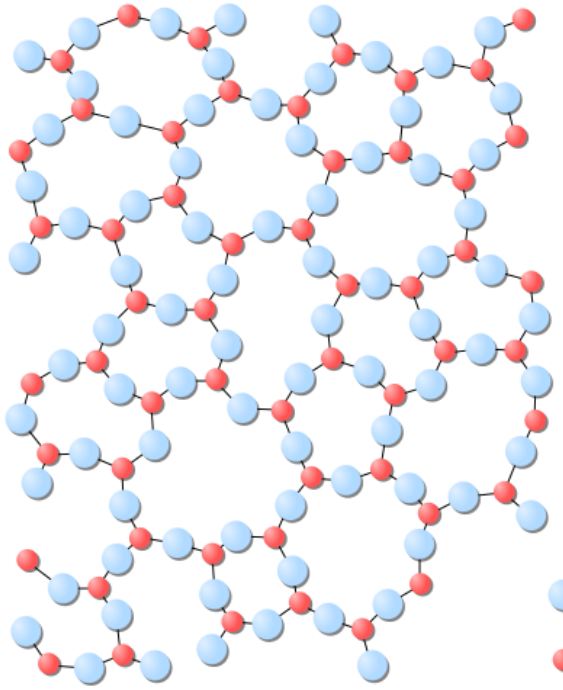
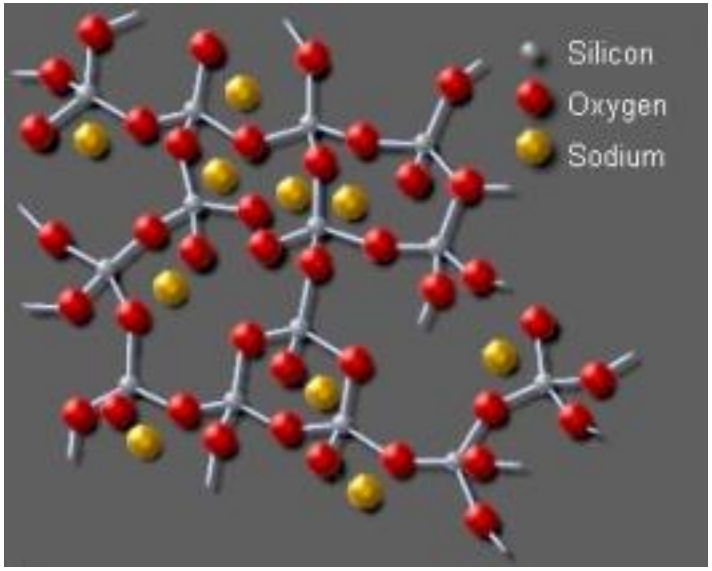
Glass Structure



From Silica to Silicate



More non-bridging oxygen, loose glass structure

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Glass Types

Silica

Silicate, borate, phosphate, germanate, tellurite, aluminate, borosilicate, borophosphate, borogermanate, aluminosilicate, aluminophosphate, fluorophosphate

Non-silica oxide glasses

Oxide glasses

Fluoride glass, chalcogenide glass, halide glass

Non-oxide glasses

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Multi-Component Oxide Glass

Non-silica Oxide Glass ≈ Multi-component oxide glass

Glass network former; modifier; intermediate

SiO_2; P_2O_5;
B_2O_3; GeO_2

K_2O; Li_2O;
Na_2O; BaO;
CaO; MgO

Al_2O_3; B_2O_3;

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Multi-Component Oxide Glass

For Laser Application

Advantages:

- Large glass forming area
- Low process temperature
- Low cost
- High rare-earth solubility
- High or low phonon energy
- High resistance to photodarkening

Doping concentration up to 50 wt% compare to 0.5wt% in silica

- *Phosphate glass has higher phonon energy than silica;*
- *Germanate glass has lower phonon energy than silica*

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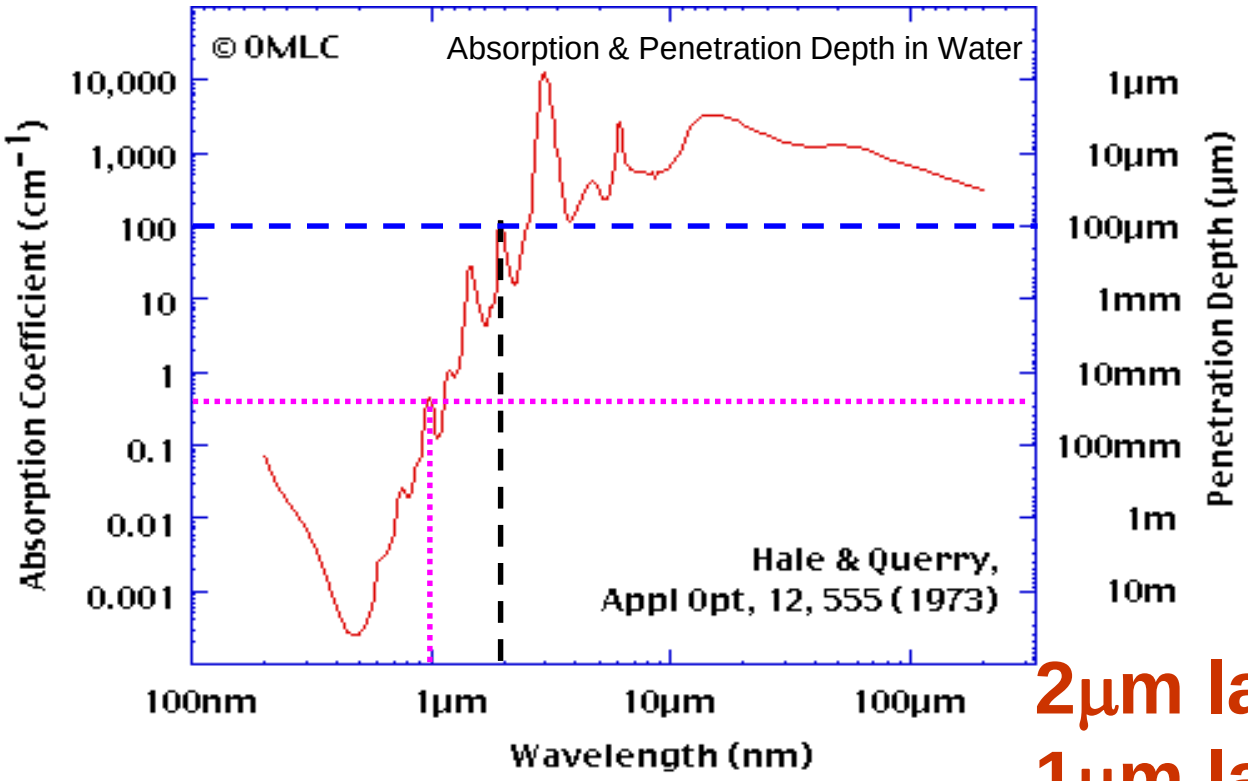
Motivation for 2μm Fiber Laser

2-micron laser: Absorption co. 100 cm^{-1};

1-micron laser: Absorption co. 0.5 cm^{-1};



Applications

- Mid IR generation
- Medical
- Remote sensing
- Lidar
- Pumping source for mid-infrared laser

Retina Safe Wavelength

2μm laser is better than 1μm laser for many applications

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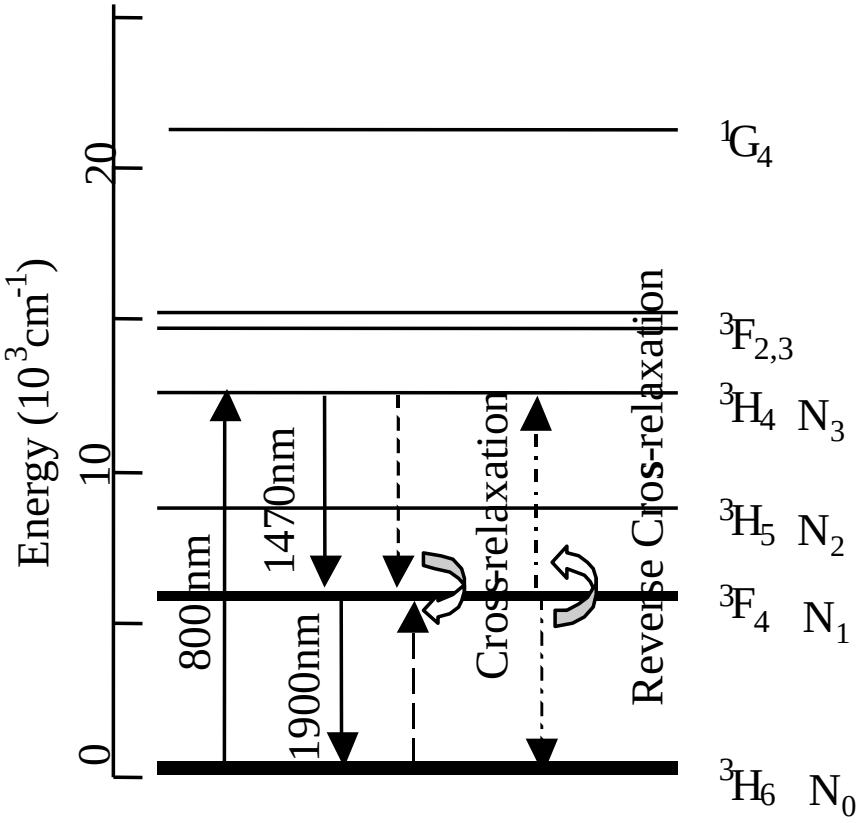
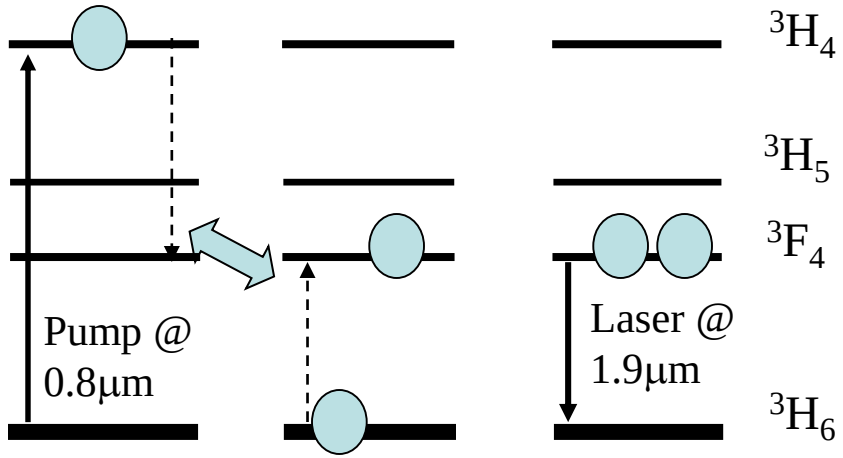
Cross-relaxation Energy Transfer of Tm^{3+}





Tm:YAG 5wt% Tm_2O_3,
Quantum efficiency ~200%

L. Esterowitz's group at NRL

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Glass Fabrication

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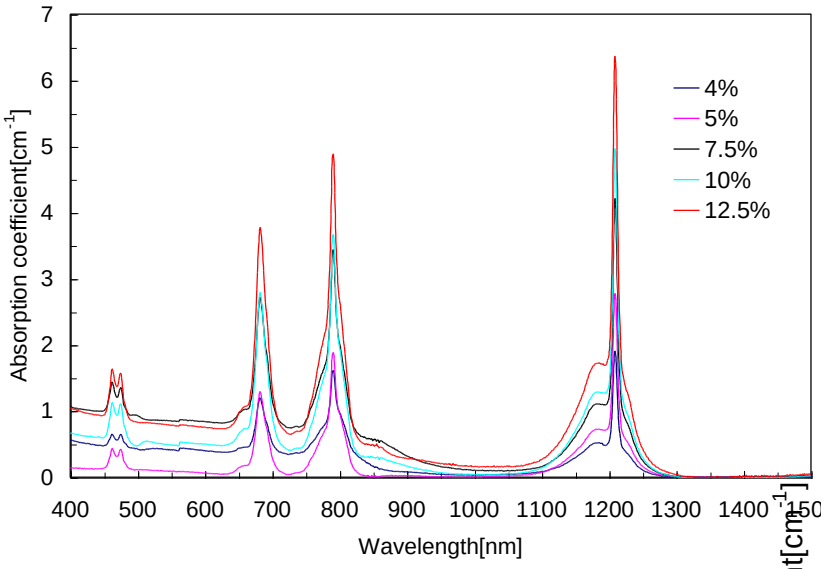
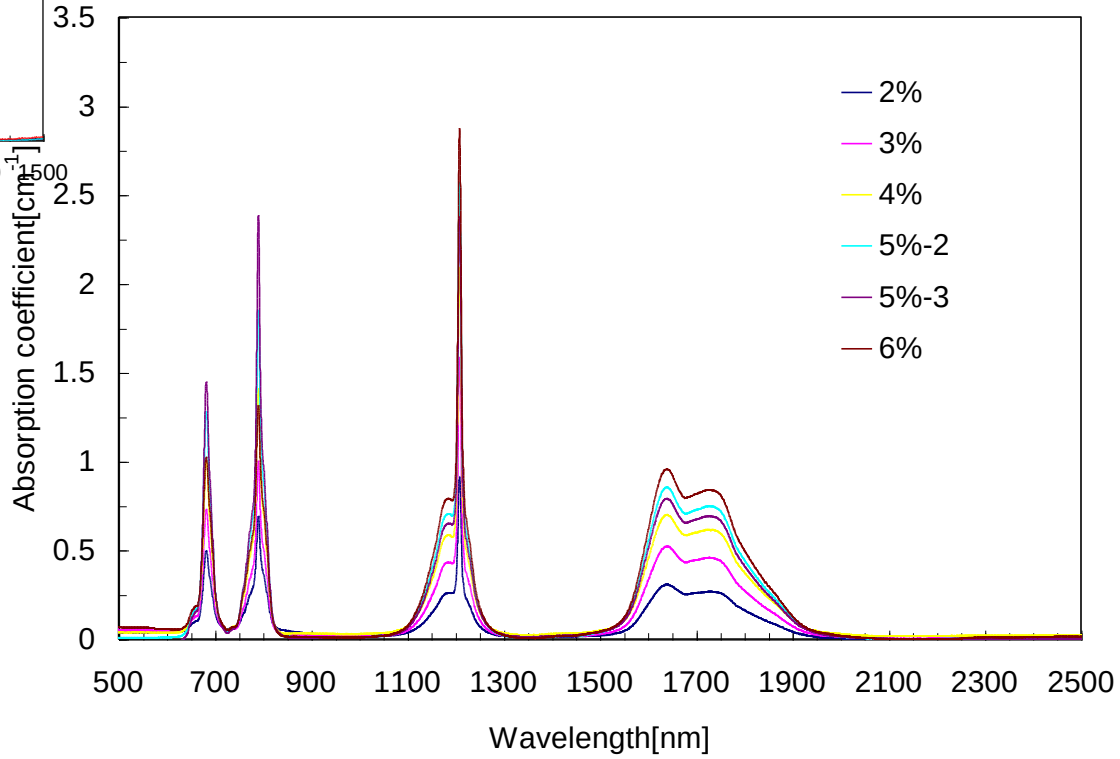
Absorption Spectra of Tm-doped Core Glasses





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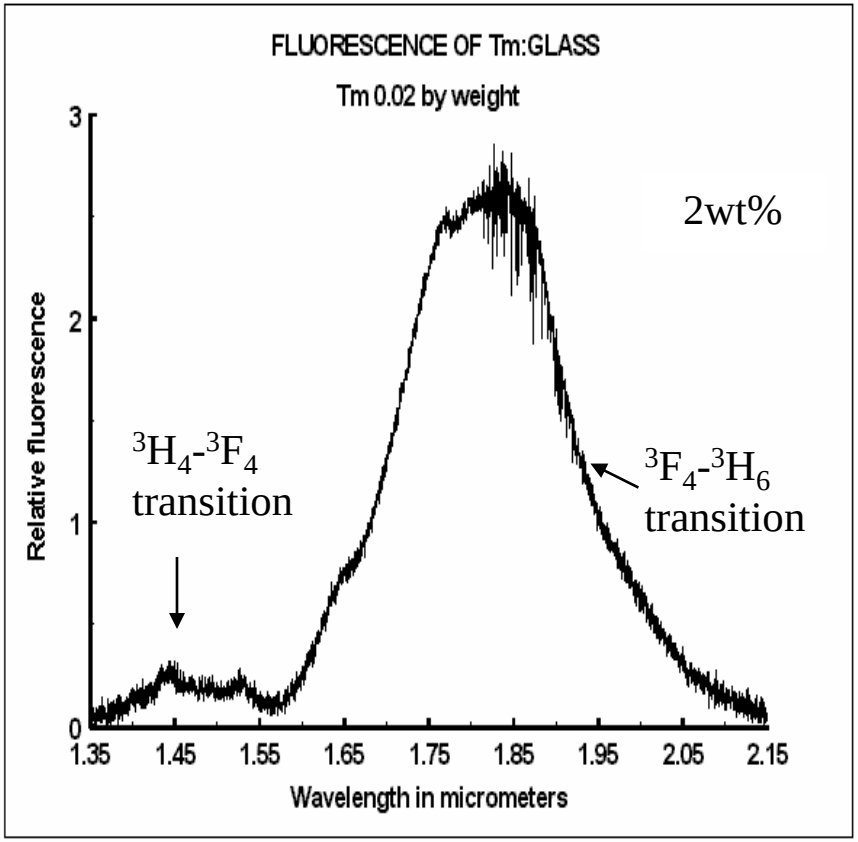
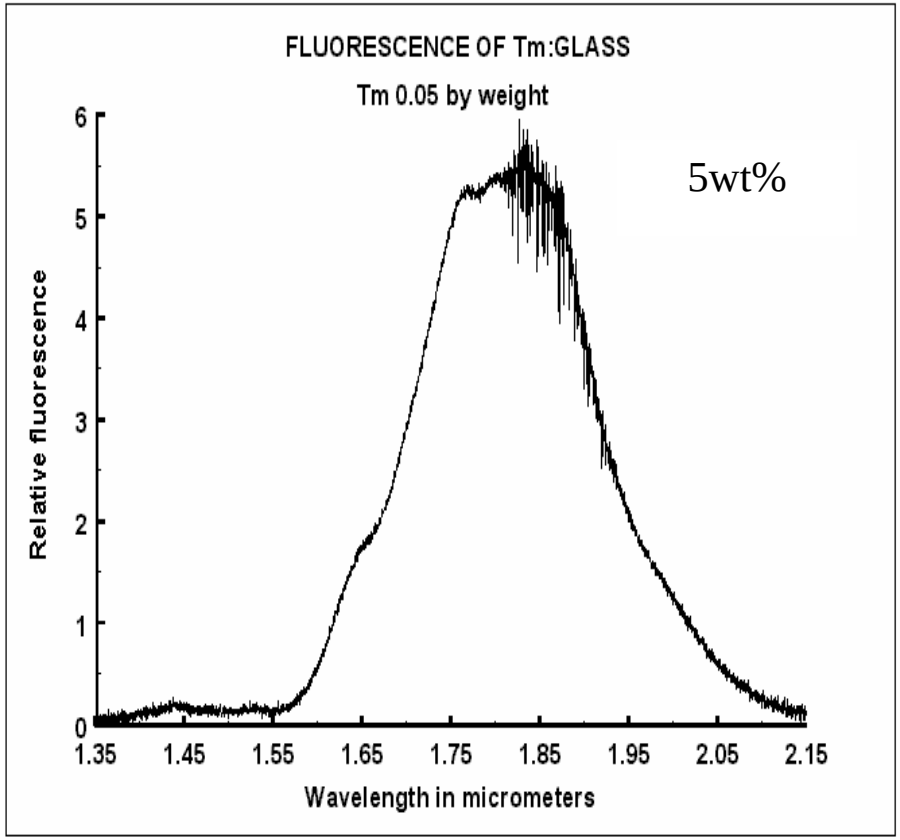
Emission Spectra of Tm-doped Core Glasses





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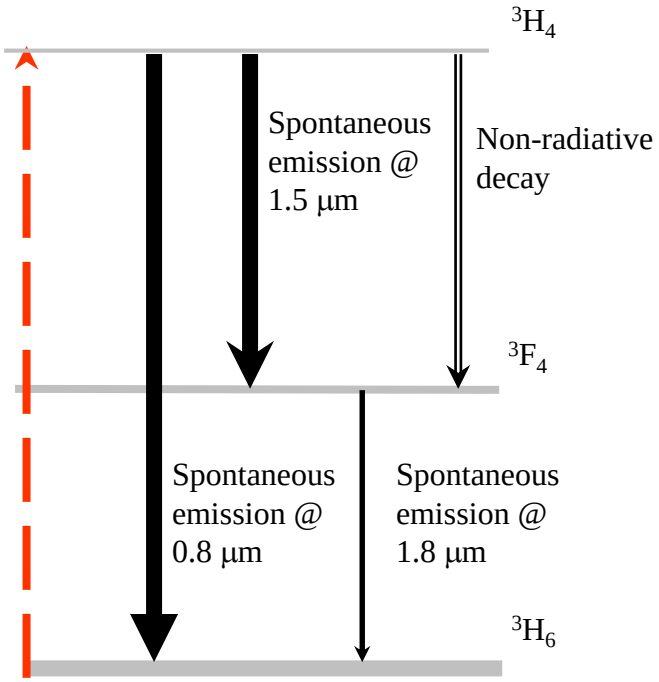
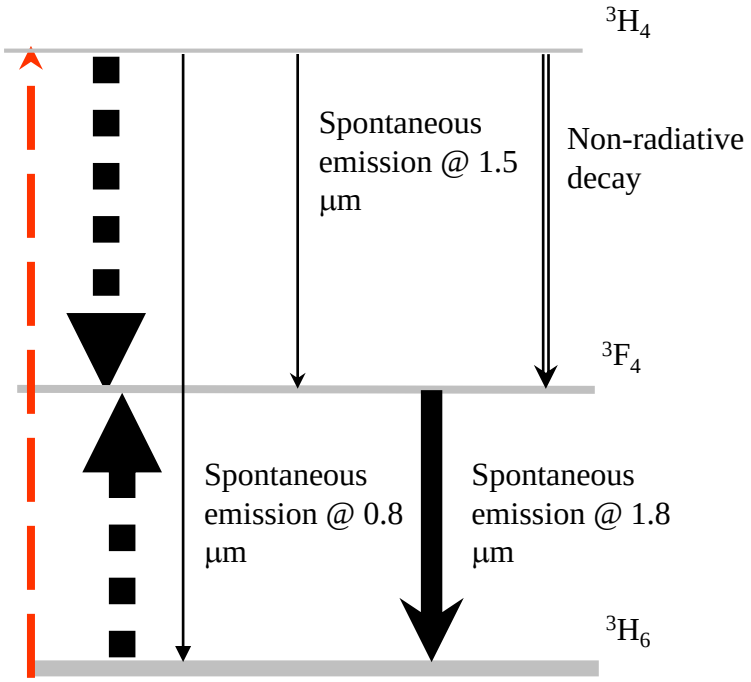
Cross-relaxation Energy Transfer of Tm^{3+}

W/O Cross-Relaxation Energy Transfer



W/ Cross-Relaxation Energy Transfer



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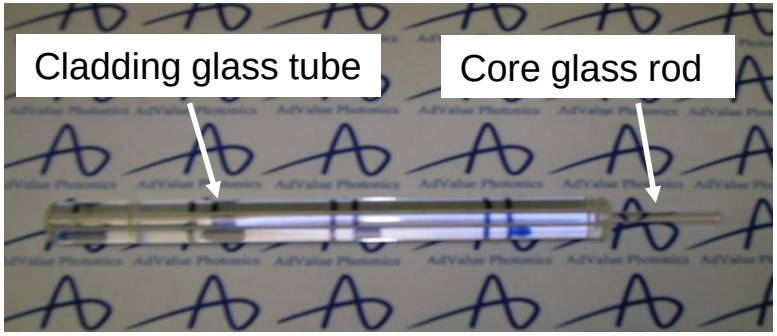
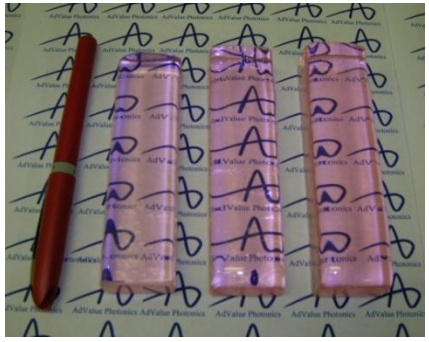
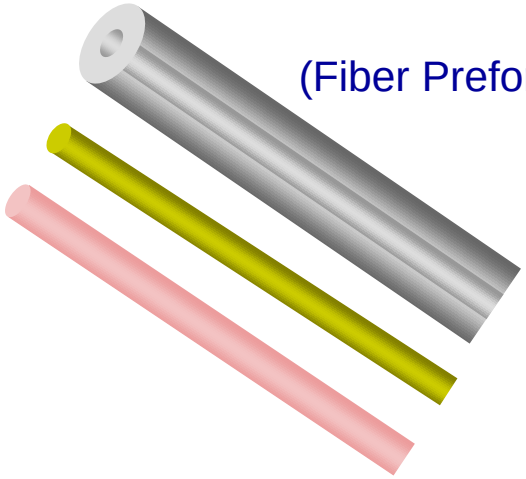
Fiber Fabrication

High Gain Specialty Fibers







(Fiber Preforms)

(Fiber Drawing Tower)

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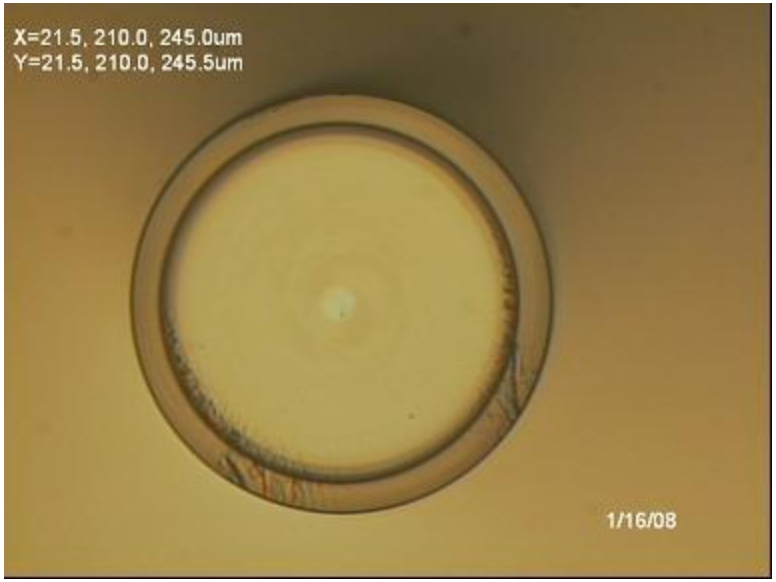
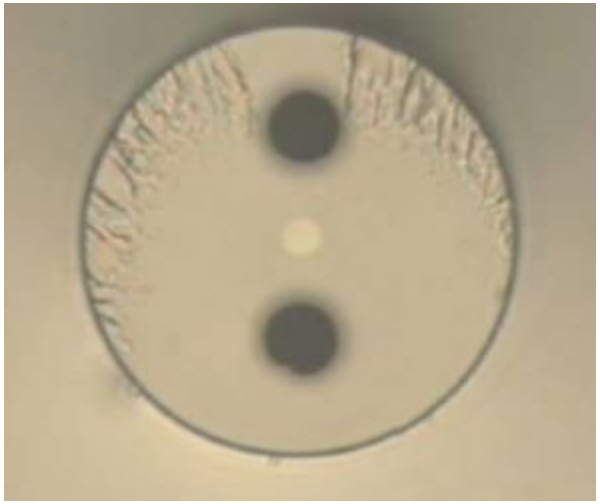
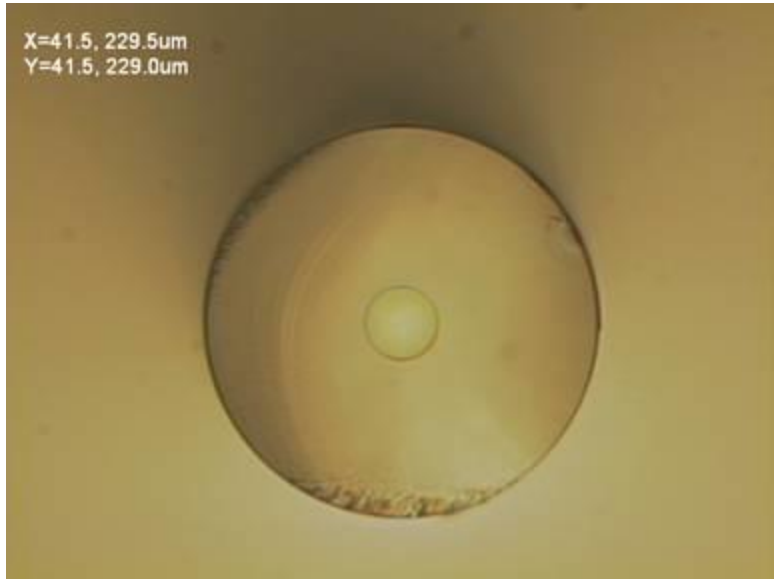
Tm^{3+}-Doped Silicate Fibers







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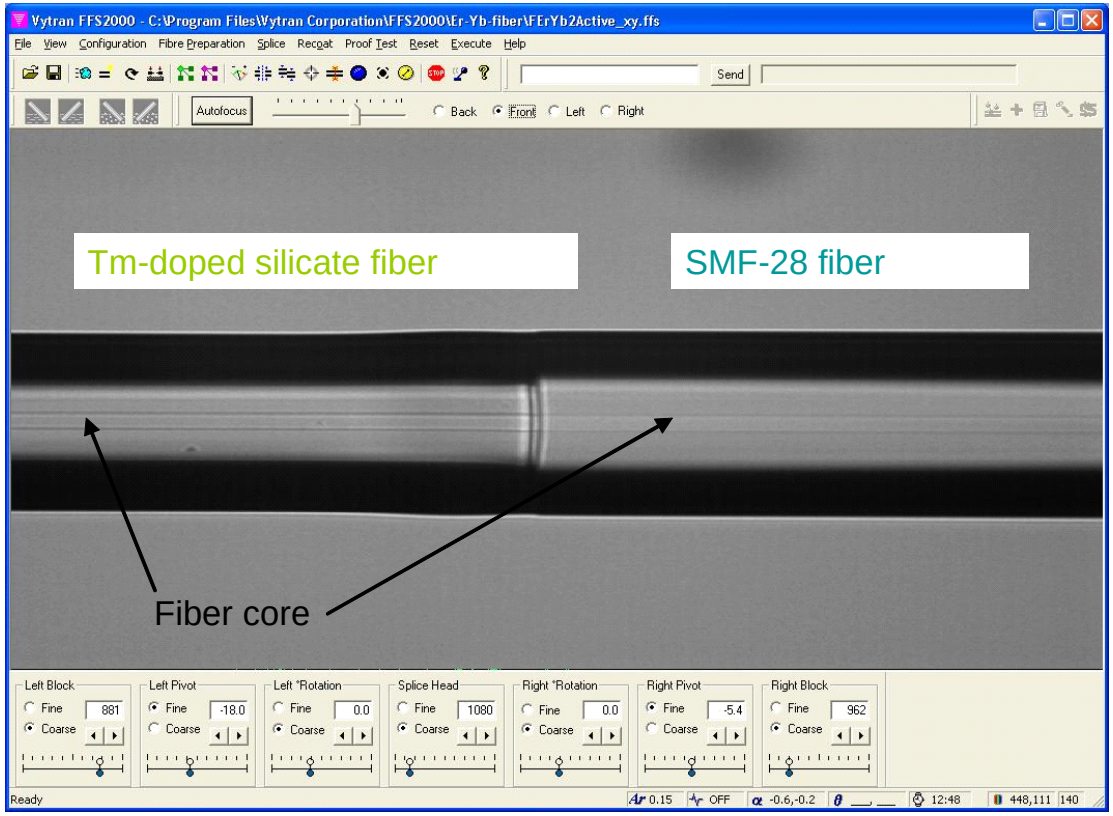
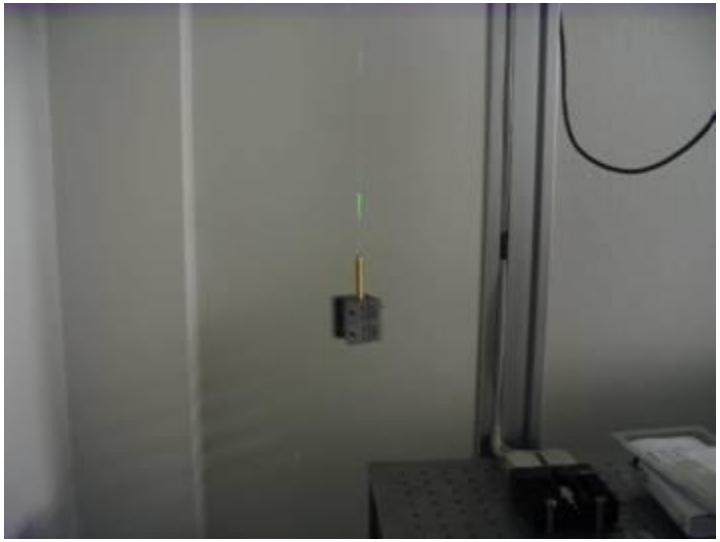
Fusion Spliced Joint





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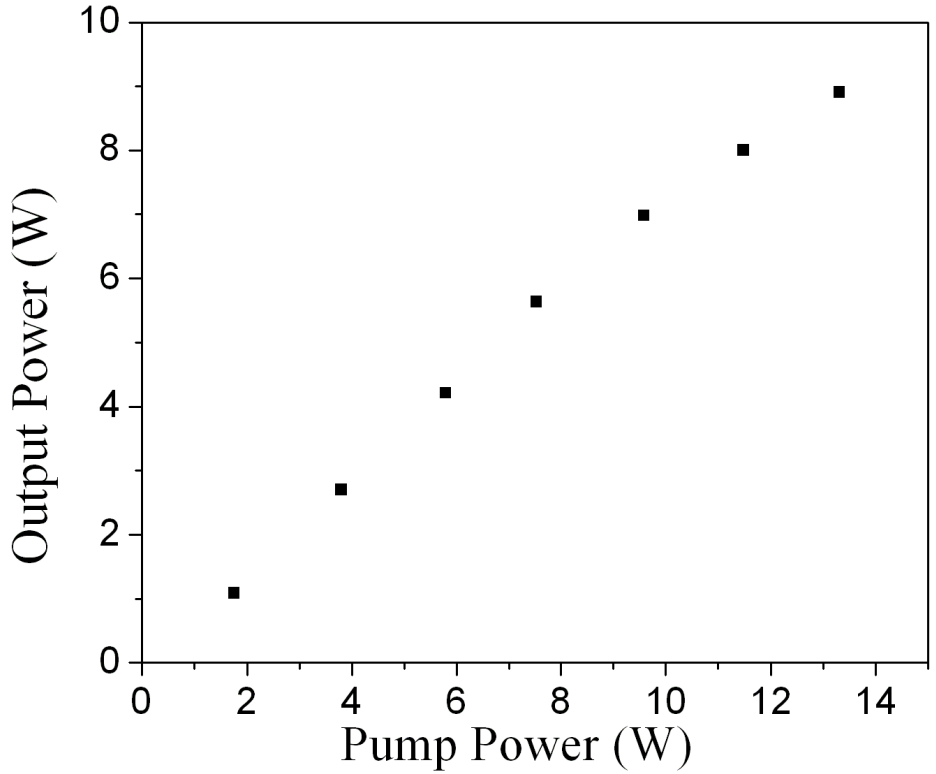
High Laser Efficiency



- 18μm core and 20cm long fiber.
- HR dielectric mirror and 4% Fresnel reflection.
- 68.3% slope efficiency

Quantum Efficiency >180%

Gain >5dB/cm

Jihong Geng, Qing Wang, Tao Luo, Shibin Jiang, Farzin Amzajerdian, "Single-frequency narrow-linewidth Tm-doped fiber laser using silicate glass fiber," Optics Letters, Vol. 34, No.22, 3493-3496 (2009).

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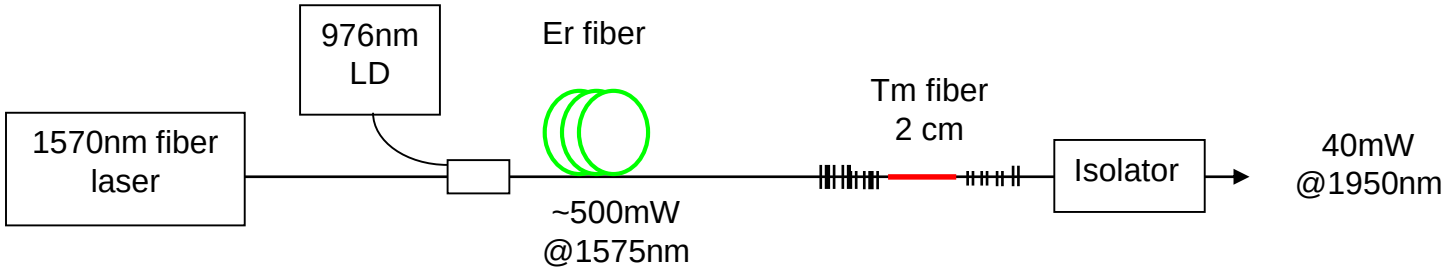
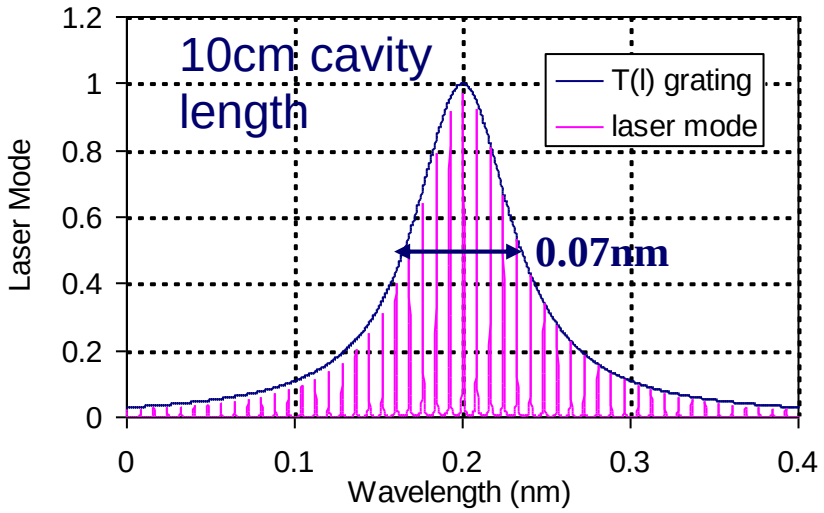
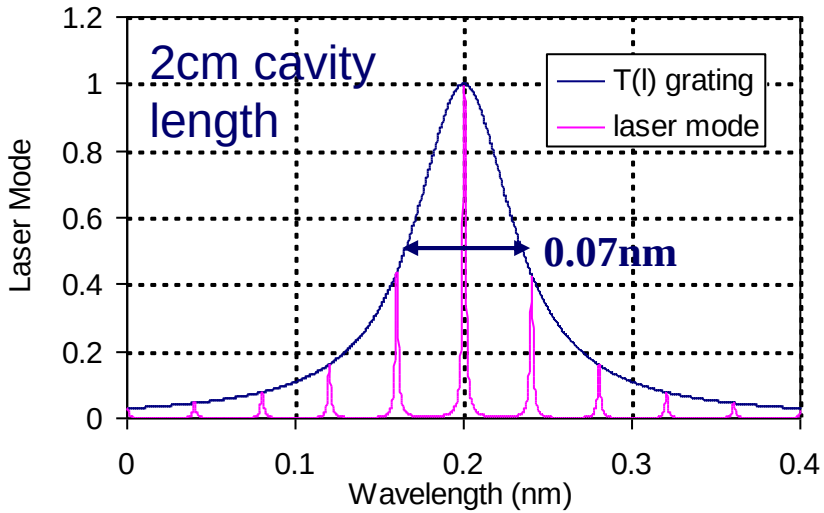
Single Frequency 2μm Fiber Laser







Jihong Geng, Qing Wang, Tao Luo, Shibin Jiang, Farzin Amzajerdian, "Single-frequency narrow-linewidth Tm-doped fiber laser using silicate glass fiber," Optics Letters, Vol. 34, No.22, 3493-3496 (2009).

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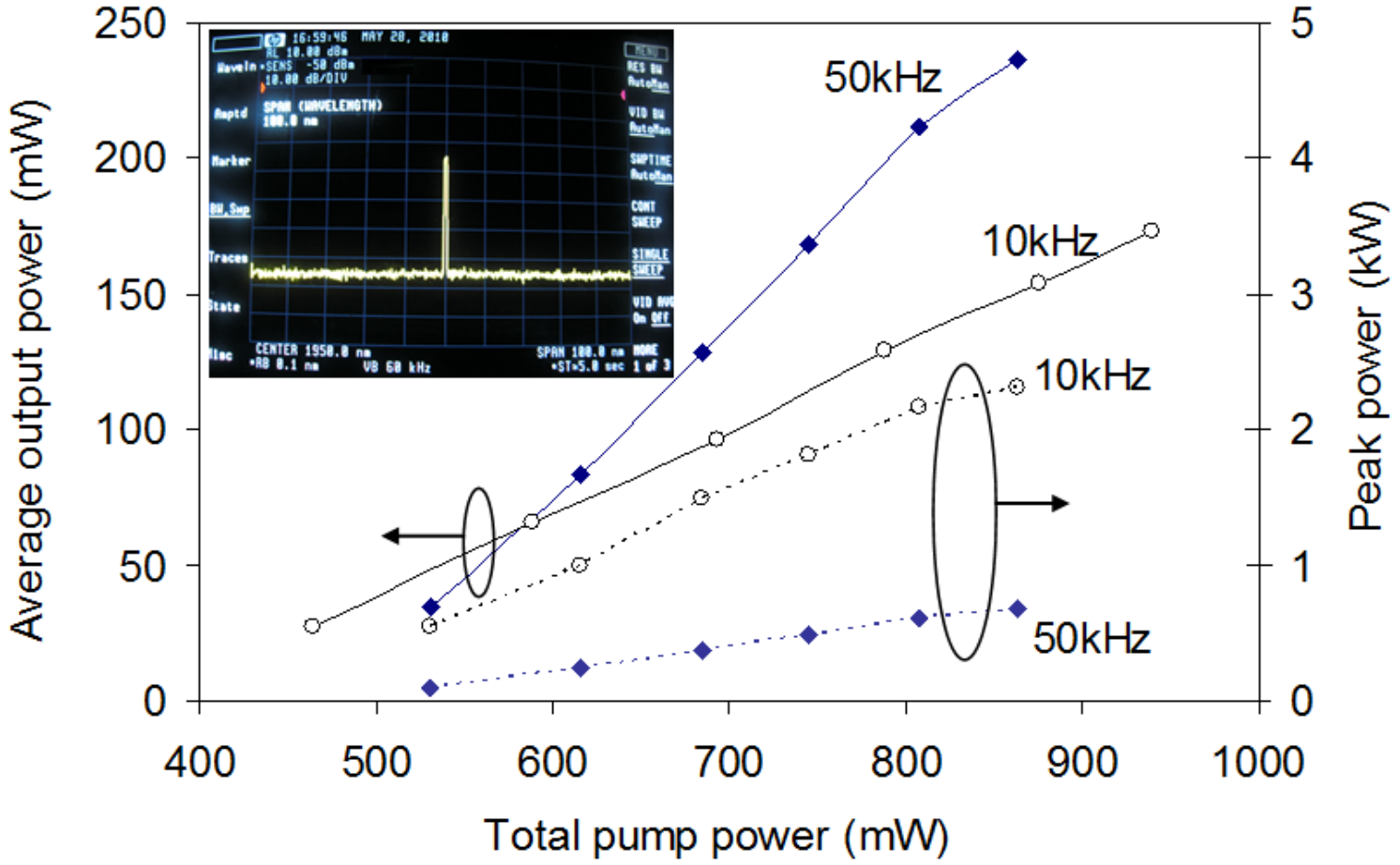
2μm Q-Switched Fiber Laser



Jihong Geng, Qing Wang, Zack Jiang, Tao Luo, Shibin Jiang, and Gregory Czarnecki, "Kilowatt-peak-power, single-frequency, pulsed fiber laser near 2 μm," , / Vol. 36, No. 12 / OPTICS LETTERS , pp.2293, June 15, 2011

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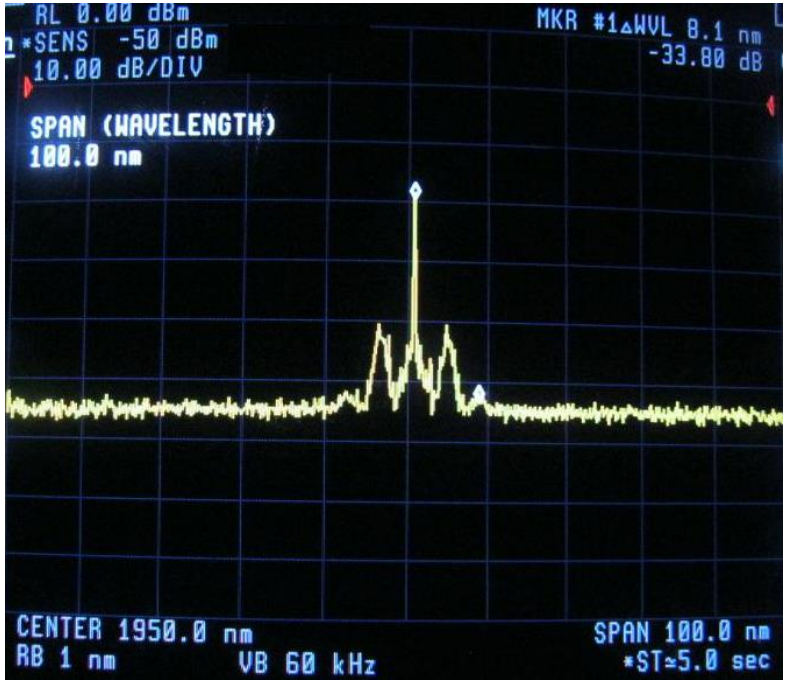
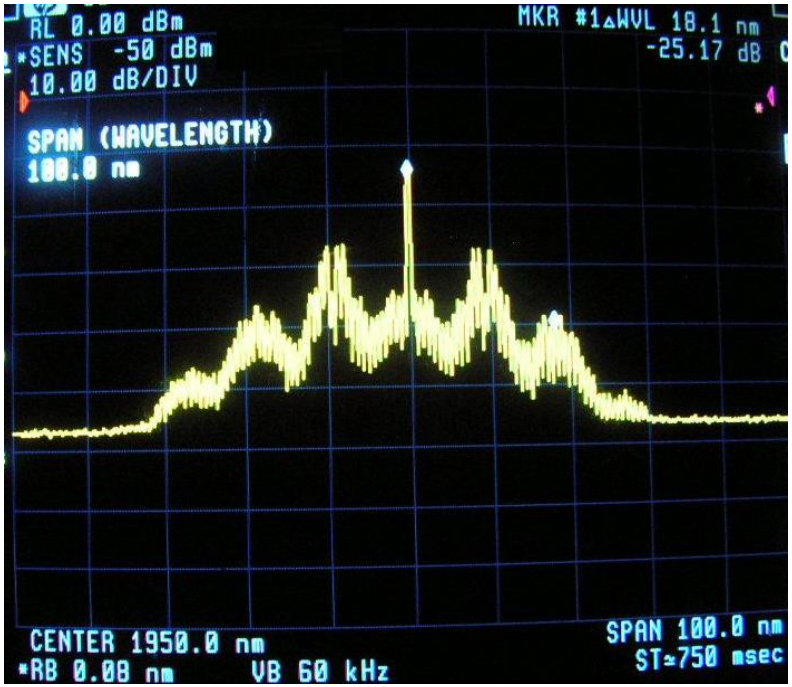
Modulation Instability in Long Single-mode Fiber





~300W peak power pulses in a 75m fiber

1kW peak power pulses in a 5m fiber.

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2 μm Q-Switched High Power Laser: AP-Tm-QS01

- ✓ Average power 10W
- ✓ Pulse width 20-200 ns
- ✓ Rep. rate 10 to 30 kHz
- ✓ Peak power up to 10 kW
- ✓ Polarization: random
  (option: linear polarization)
- ✓ Collimated single mode output
- ✓ Package dimensions:
  449(W) x 433(D) x 133(H) mm

CLEO/*Laser Focus World*
Innovation Award
2011 Honorable Mention

AdValue Photonics

Pulsed Single Frequency Fiber Laser

Pulsed Single-Frequency Fiber Laser *New*

AP-P-SF

(Wavelength: 2 μm, 1.55 μm, 1 μm)

The pulsed single-Frequency fiber lasers are designed to provide the highest pulse energy in a single longitudinal mode. This series of products at 2 μm, 1.55 μm, and 1 μm provide new capabilities to research and industry applications.

With their compact size, high efficiency, low maintenance, and ease of operation, AdValue Photonics' fiber lasers provide many advantages over traditional bulk solid state lasers.

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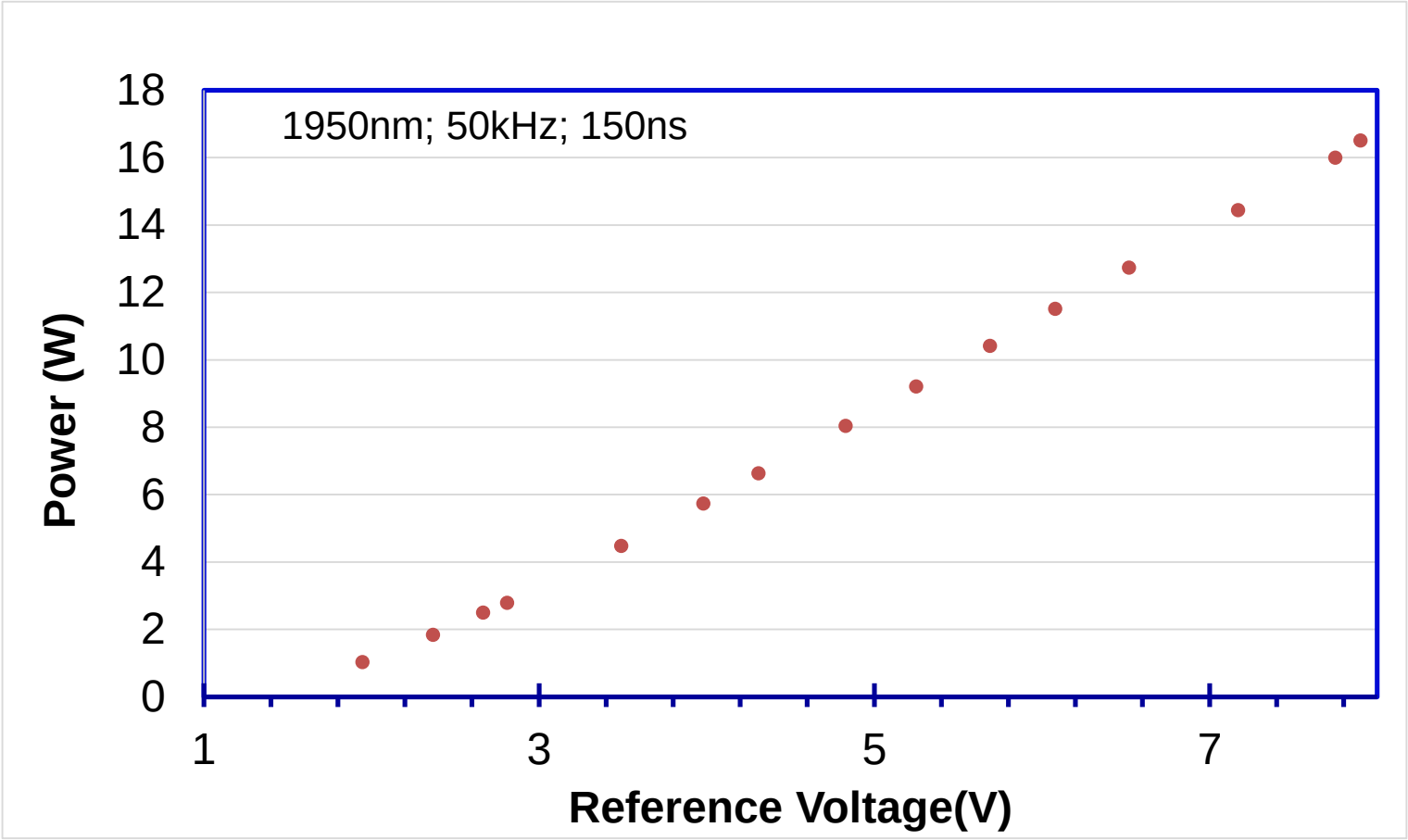
2 micron Pulsed Single-Frequency Laser Output



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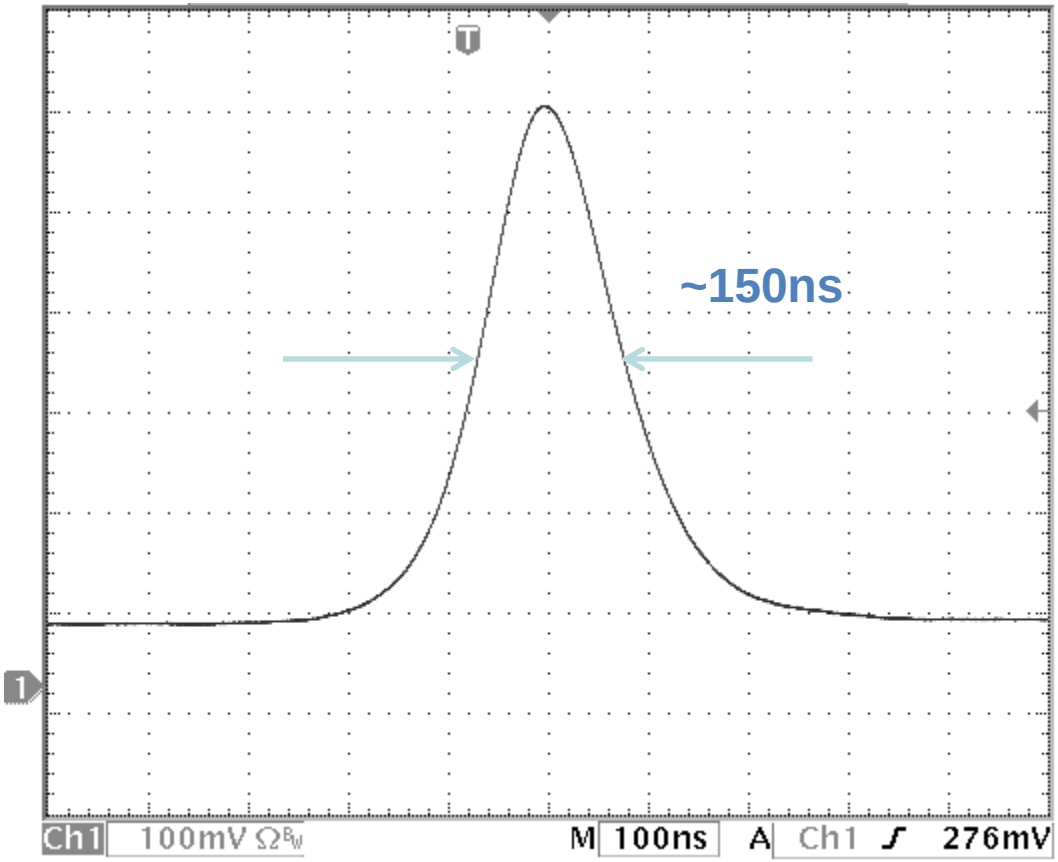
Pulse Trace



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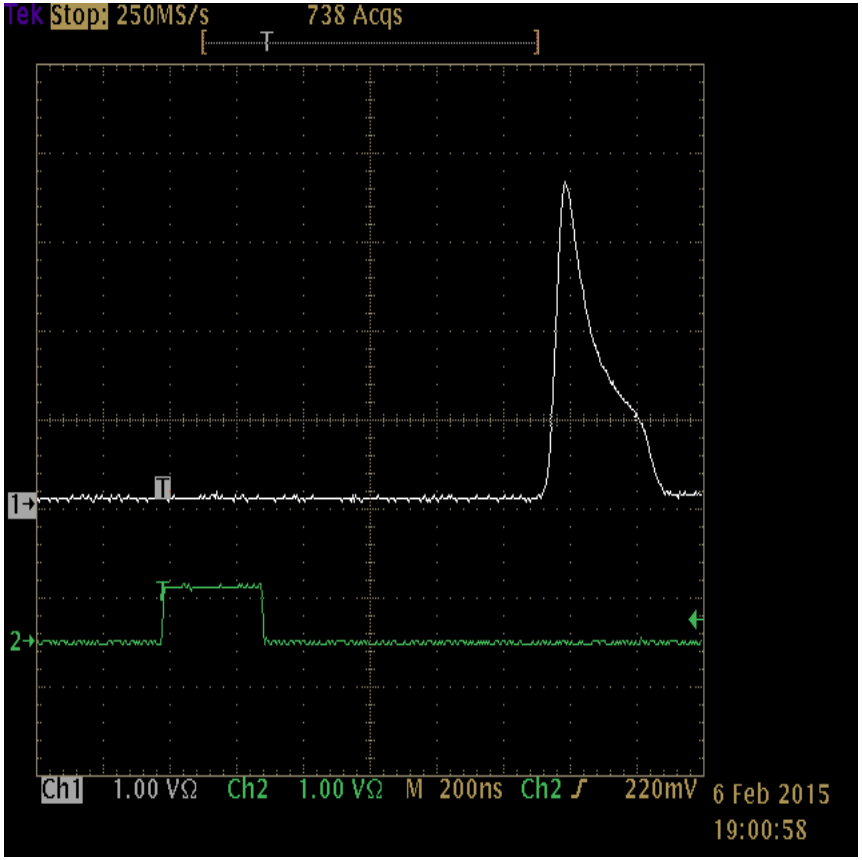
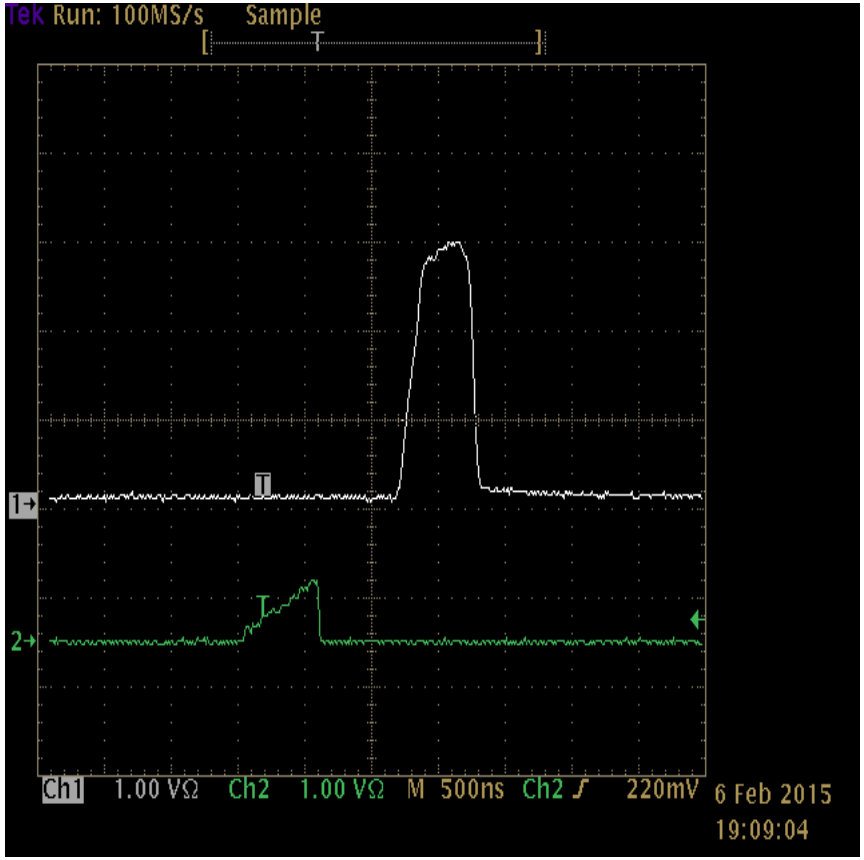
Pulse Shaping





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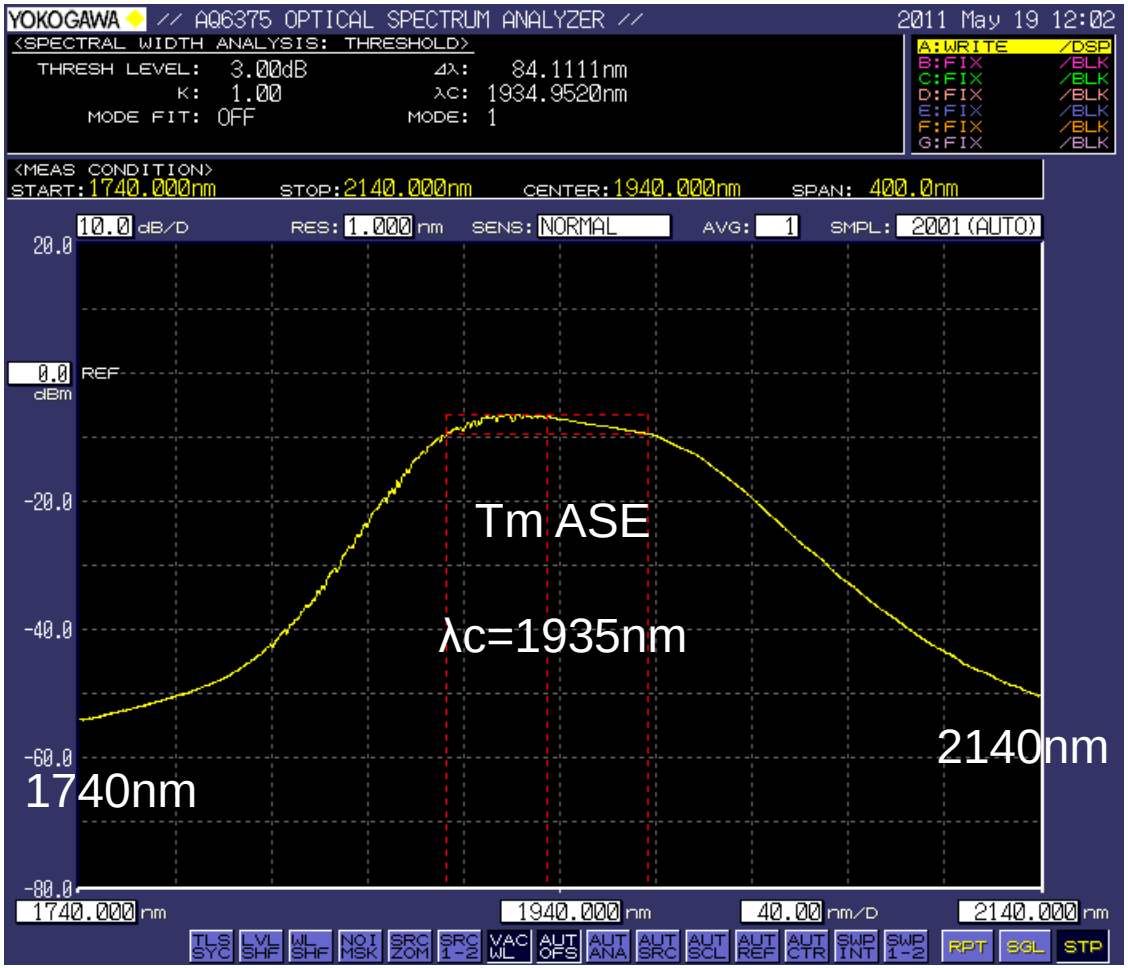
Broad ASE Spectrum



- 5m long fiber with 10μm core. 84mW ASE output with cladding pump.

  More than 2 times broader than other reported 2 micron ASE

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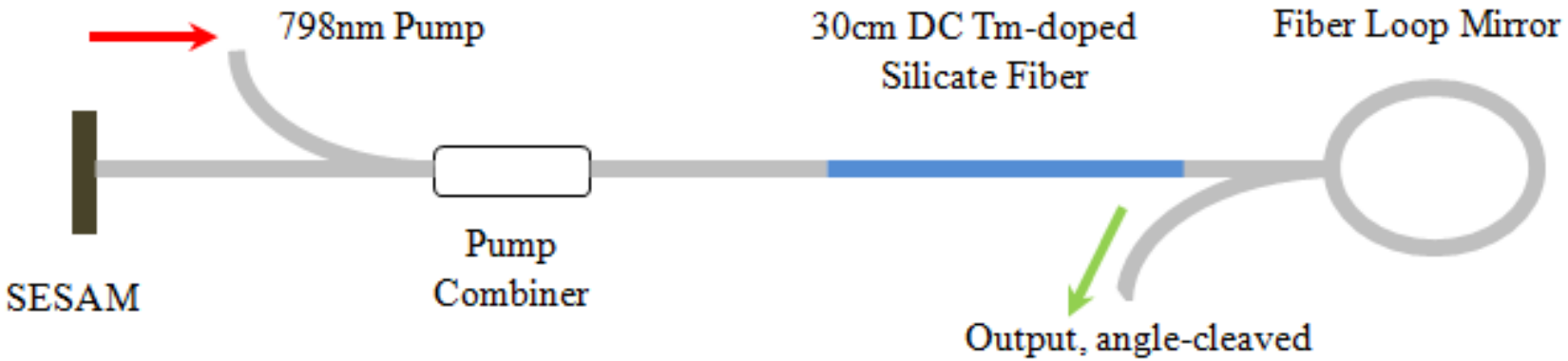
Mode-locked Fiber Laser



- A resonant saturable absorber mirror.
- Fiber loop mirror provides ~90% reflection.
- Cladding pump with 798nm LDs.
- 30cm Tm-fiber was angle-spliced at both ends to prevent detrimental back reflection.

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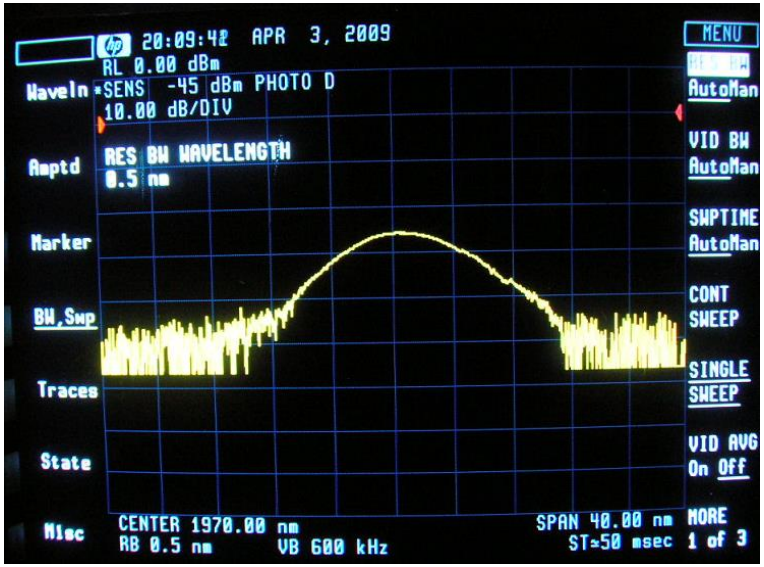
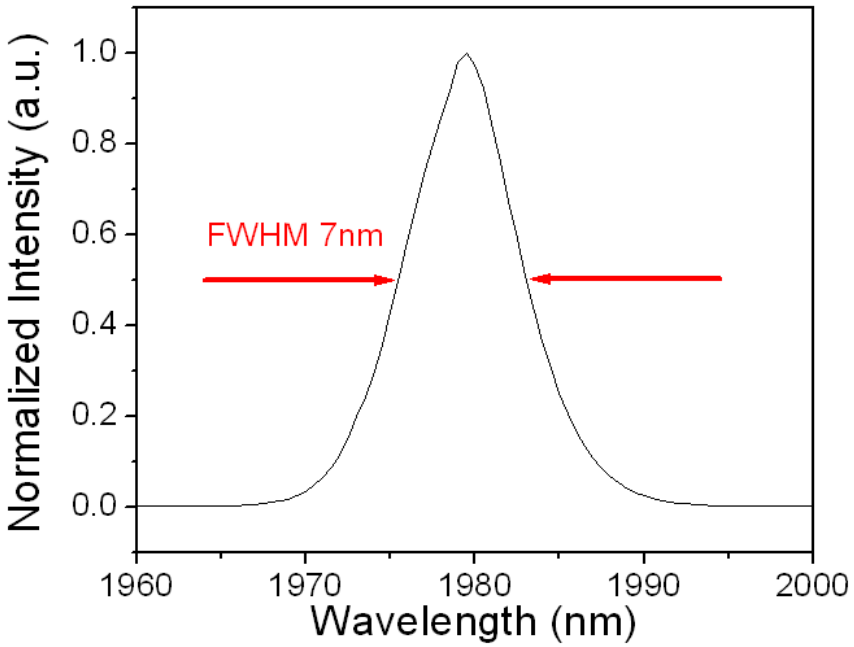
Mode-locked Laser Spectrum



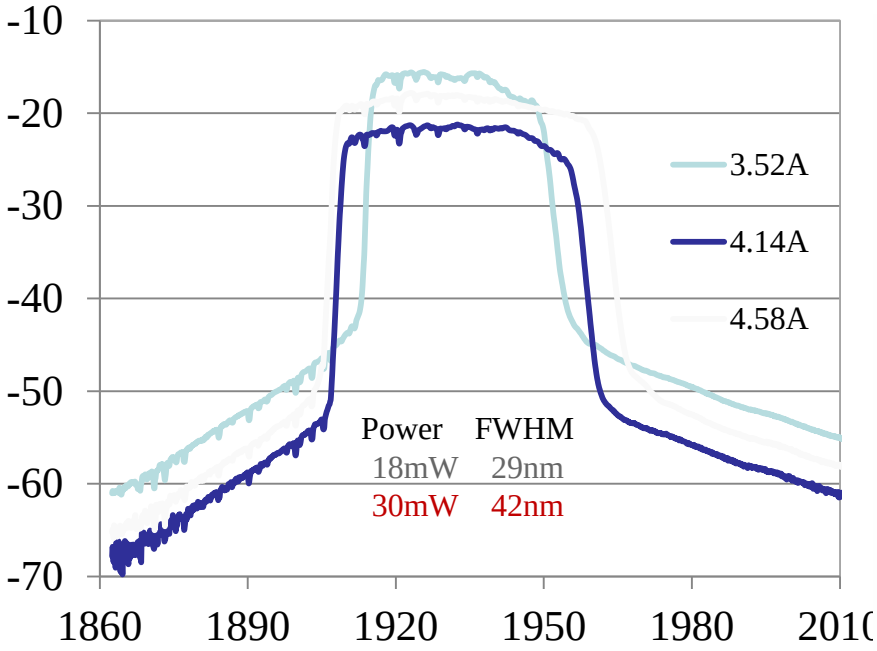


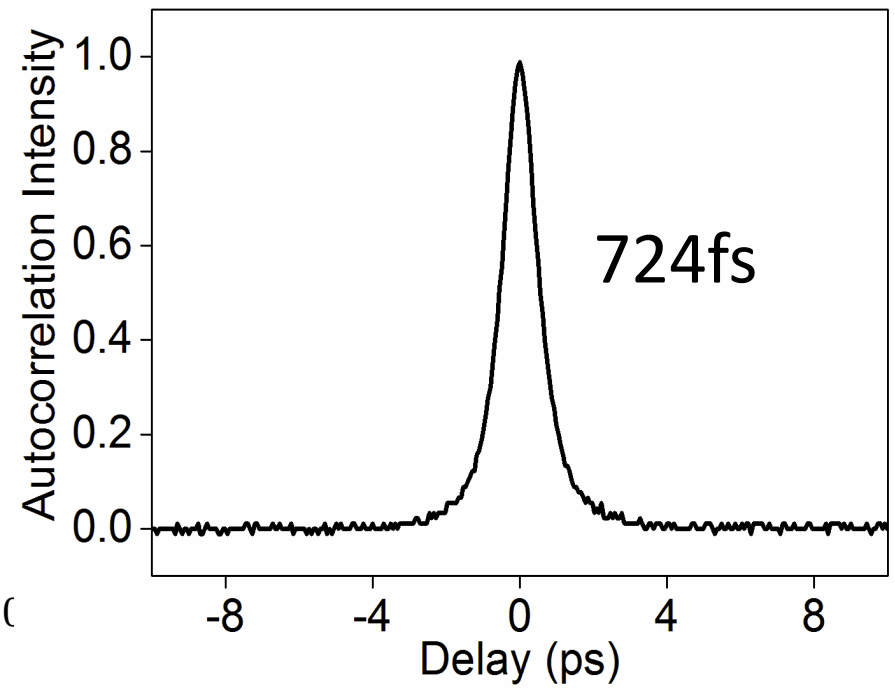
- Center wavelength is ~ 1980nm and wavelength can be tuned by fiber-SAM butting coupling.
- FWHM of spectrum is ~ 7nm. Dispersion compensation can further broaden spectrum bandwidth.

Qing Wang, Jihong Geng, Tao Luo, and Shibin Jiang, "2 micron mode-locked laser with highly thulium-doped silicate fiber," Optics Letters, Vol. 34, No. 23, 3616-3618 (2009).

AdValue Photonics

Normal Dispersion Dominated Regime

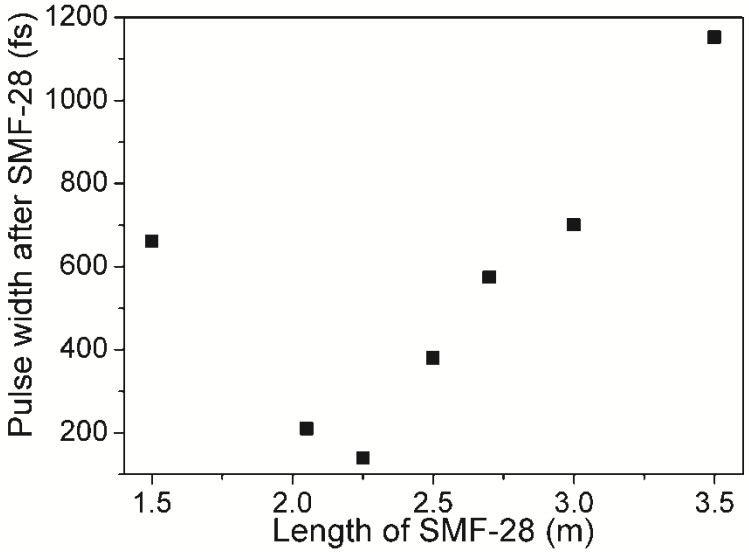


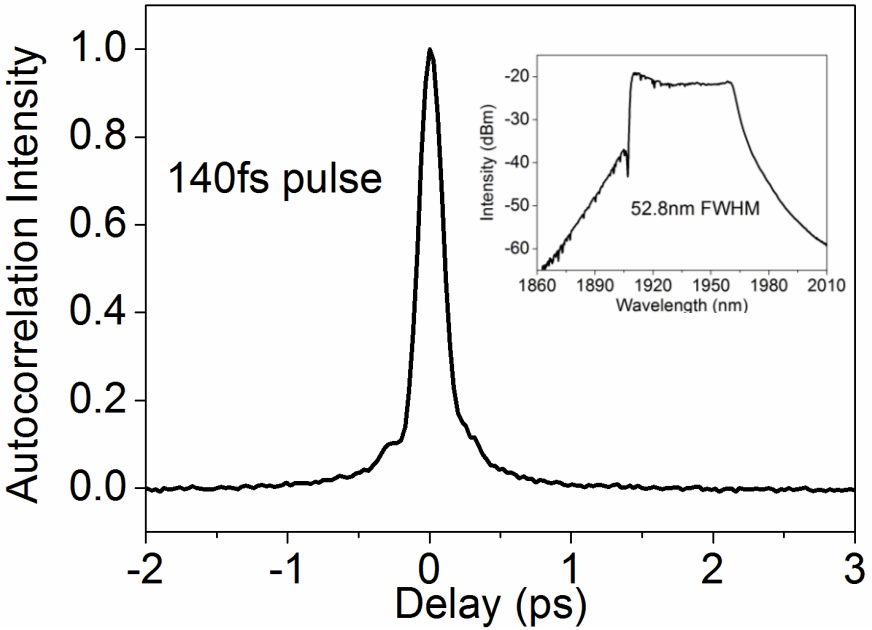


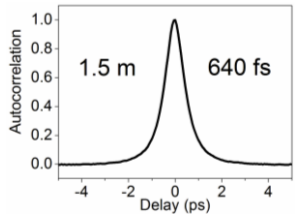
- 50nm FWHM was obtained.
- 724fs pulse width indicates highly chirp.
- The repetition rate is 30.8MHz, and the pulse energy is >1nJ.

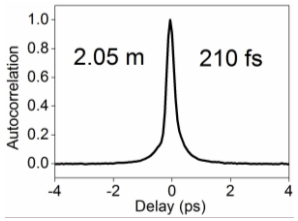
AdValue Photonics

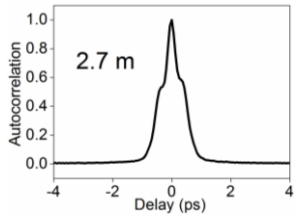
Pulse Compression with SMF-28

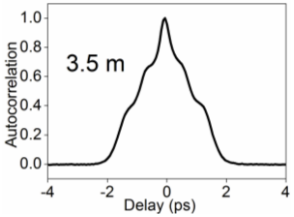












- Use a piece of SMF to compress the pulse.
- The shortest pulse we measured is ~140fs.
- With an appropriate grating pair, the pulse width after compression is expected to be less than 100 fs.

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2 μm Mode-Locked High Power Laser: AP-Tm-ML01

- ✓ Wavelength 2.0 μm
- ✓ Average power 1W
- ✓ Pulse width 3.5 ps
- ✓ Rep. rate 20 to 40 MHz
- ✓ Pulse energy up to 35 nJ
- ✓ Peak power up to 10 kW
- ✓ Spectral bandwidth > 6 nm
- ✓ Polarization: random
- ✓ Collimated single mode fiber output
- ✓ Package dimensions:

  449(W) x 433(D) x 133(H) mm

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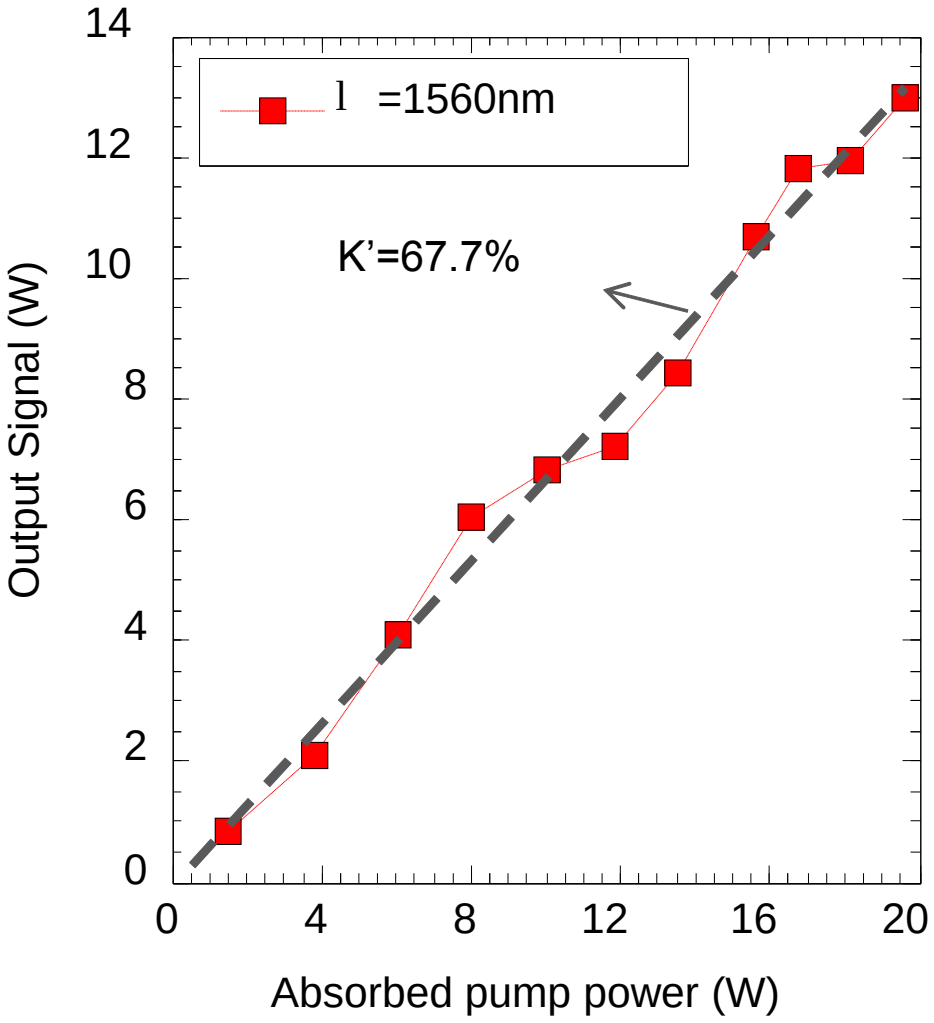
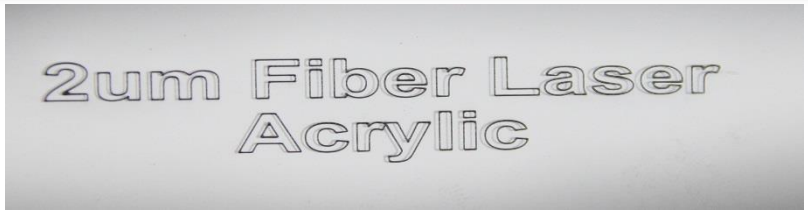
Er-doped Fiber Laser



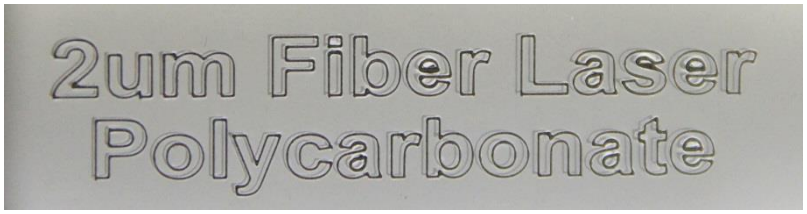
Industrial Applications

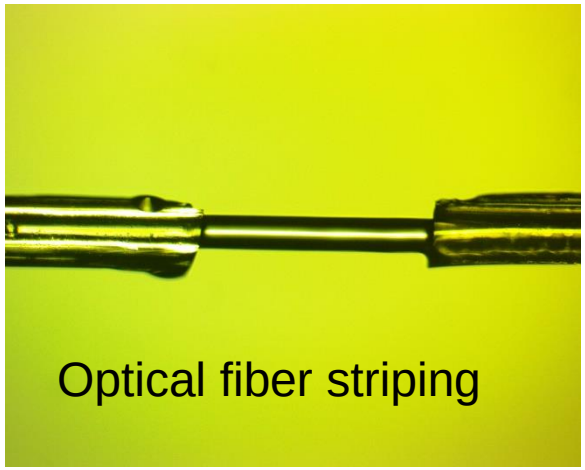
2 µm pulsed fiber lasers can process most metals and non-metals including clear plastics !

Clear Acrylic

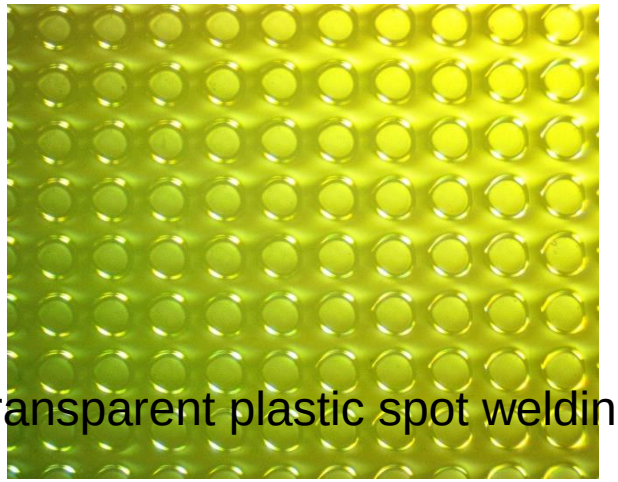


Clear Polycarbonate



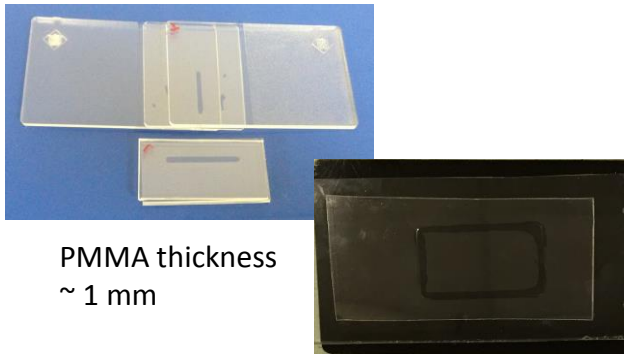


Optical fiber striping

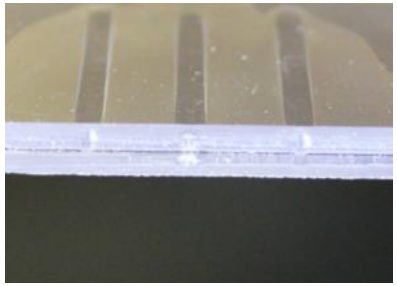


Transparent plastic spot welding

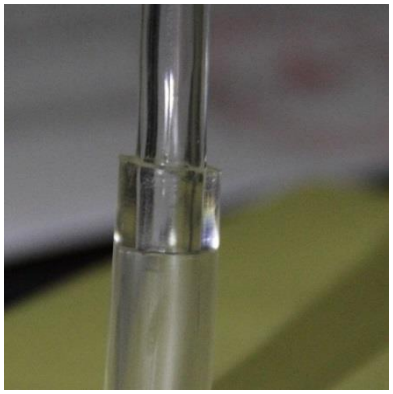
2 µm Pulsed Welding



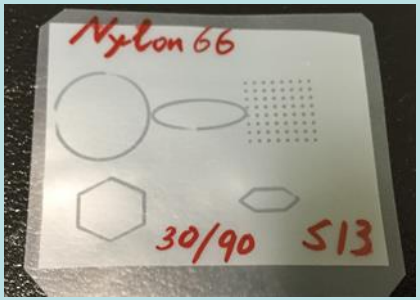
PMMA thickness
~ 1 mm



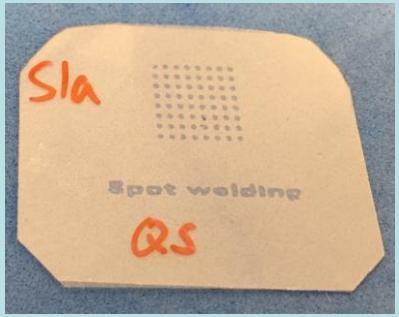
PMMA thickness ~ 2 mm



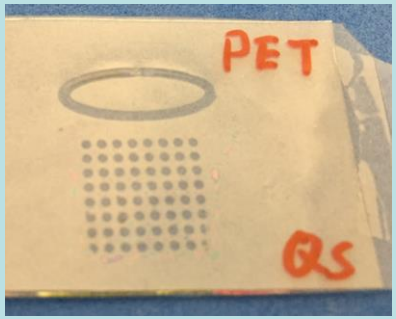
PVC thickness ~ 1 mm



Nylon Film thickness 30 µm on 90 µm



PC thickness ~250 µm

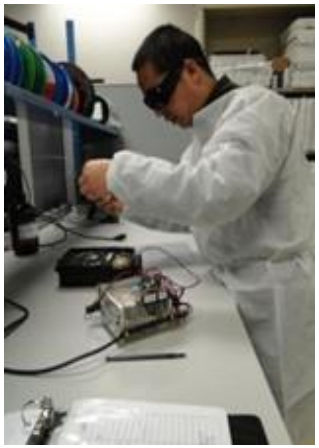


PET Film thickness ~250 µm

Clear Plastic Welding – No Apparent Surface Disturbance

Company Overview

- *Founded in 2007*
- *Located in the Optics Valley – Tucson, AZ*
- *Consistent Profitable Growth*
- *Outstanding Technical Team (10+ PhD)*
- *Innovative and Award Winning Products*
- *Dedicated Application Lab*
- *Glass and Fiber Fabrication Facility*



Vertical Integration Enables Innovative Solutions

Flexible Fiber Design

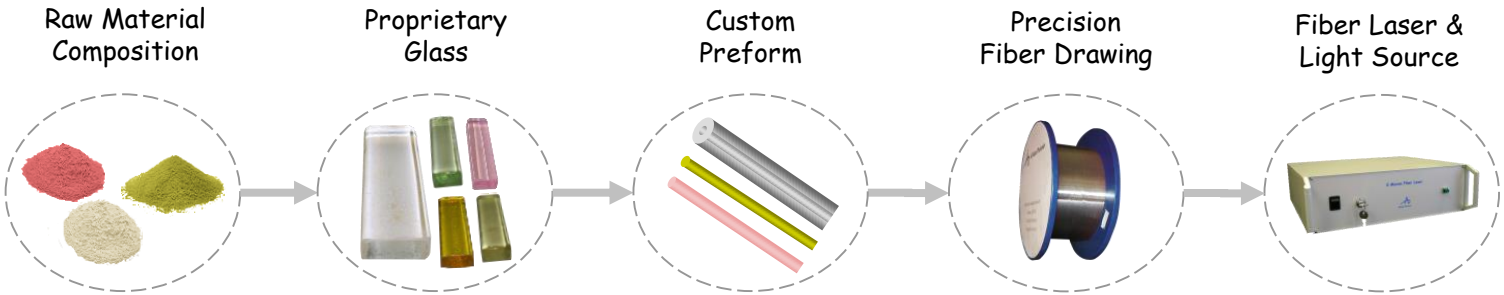
- Higher Doping Concentrations
- Short Gain Fiber Length
- Custom Core Sizes
- Minimized Intra-Cavity Nonlinearities

Enables

Innovative Solutions

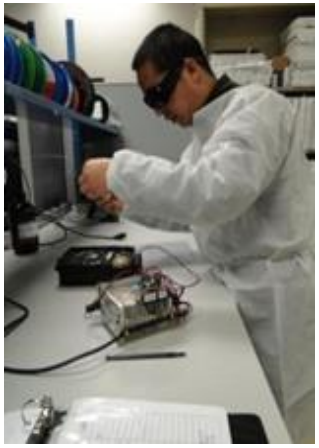
- Shorter Pulse Width
- Higher Pulse Energy
- Higher Peak Power
- Higher Average Power

Raw Materials → Laser Systems



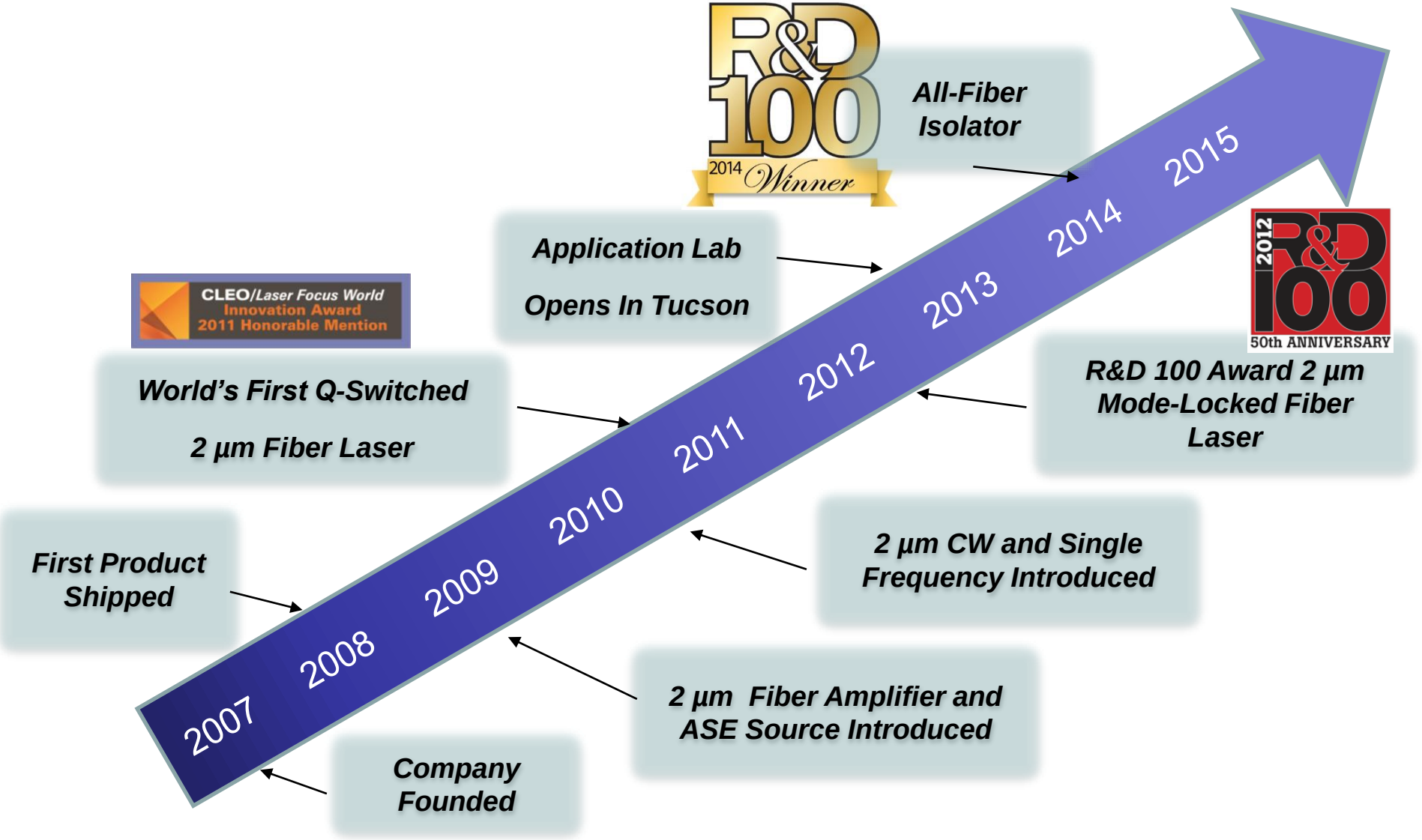
Manufacturing

- *15,000 sq ft Area*
- *Extensive Test and Characterization Equipment for Quality Control*
- *Ability to Quickly Scale Production with Customer Demand*
- *Reliability Test Equipment Onsite or at Contracted Test Facilities*
- *Highly Skilled Manufacturing Engineers and Technicians*



Manufacturing Operations You Can Rely On

Key Milestones



Company Confidential

2μm CW Laser

2μm Q-Switched Laser

2μm Amplifier

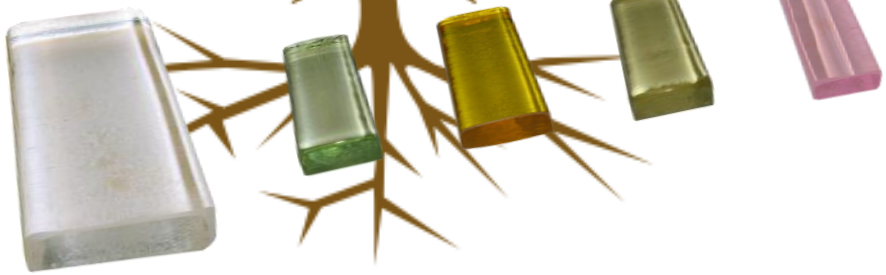
2μm Mode-Locked Laser

2μm ASE Source

2μm Single Frequency Laser

Mid-IR Freq. Comb

Rare-Earth Doped Specialty Glasses and Fibers



- We develop laser glasses and fibers
- We develop fiber lasers
- Fiber lasers have a variety applications
- Commercialized these new technologies

- To start a laser company is challenging and enjoyable