High power, high repetition rate, 700 - 850 nm pulsed laser

Laser Innovation Since 1985

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Sub-contractor PI: Dr. Shukui Zhang, JLab
Program Manager: Dr. Michelle Shinn, NP, DOE
Contract No. DE-SC0015149
Contract Period (NCE): 04/10/2017 - 1/09/2019
Technical Performance (NCE): 7/26/2017 – 10/09/2019

August 13, 2019

DOE-NP SBIR/STTR Exchange Meeting 2019

Outline

- Company overview
- Program goals and KPPS
- Technical approach
- Achieved results
- Publications
- Commercialization
- Outcome at end of Phase II
- Conclusions
- Acknowledgement

Q-Peak Inc. overview

- Founded in 1985 as the Research Division of Schwartz Electro-Optics
- Serving Defense/Aerospace and Commercial Laser Markets
- Laser Research and Product Development
- Our 17,000 ft^2 facility includes Offices, Optical Labs, Assembly & Production with Class 1,000 Clean Room
- Small Business Entity with 16 Scientists and Engineers

Physical Science Inc. is a 40 year-old company of 200 Scientists / Engineers headquartered in Andover, MA with Subsidiaries,

- **Q-Peak** (Bedford, MA)
- **Research Support Instruments** (Lanham, MD) supports Space Systems operations
- **Faraday Technology** (Dayton, OH) develops Industrial Processes

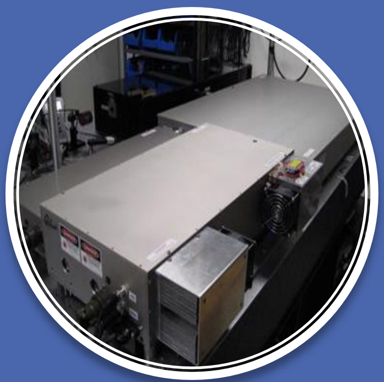
Q-Peak Inc. laser technology

Solid State Laser

- Diode Pumped
- Multiple Gain Materials
- UV to Mid IR Wavelengths
- Picosecond to CW
- Single Frequency
- Broadly Tunable
- Mode Locked
- High Pulse Energy – High Average Power
- Nonlinear Optical Frequency Conversion

Fiber Laser

- Direct Diode Pumped
- Tm and Yb Gain Materials
- NIR and Mid IR Wavelengths
- Picosecond to CW
- Narrow Linewidth
- Broadly Tunable
- Supercontinuum
- High Average Power Tm:Fiber
- Tm:Fiber pumped Solid State Gain Medium
- Nonlinear Optical Frequency Conversion



Ultrafast Laser

- Diode and Fiber Pumped
- Cr:ZnSe for MIR
- Ytterbium for NIR
- Femtosecond
- Single Frequency
- Broadly Tunable
- Frequency Conversion down to UV
- High Peak Power

Program goals and KPPS

From FY2016 DoE SBIR Phase I Release 1 Solicitation

Topic/subtopic: 23 e

"**Grant applications also are sought to develop wavelength-tunable (700 to 850 nm) mode-locked lasers, with pulse repetition rate between 0.5 and 3 GHz and average output power >10 W**."

Parameter	**Value**
Average power	>10 W
Repetition rate	0.5 - 1.5 GHz
Center wavelength	780 nm
Tuning range	+/- 10 nm
Pulse width	20 - 50 ps
Timing jitter	<1 ps (10 Hz to 10 MHz)
Power stability	<5 % over 24 hours
Wavelength stability	<1 nm over 24 hours
Beam quality, M^2	~1.3
Beam diameter	~2 mm

Technical approach / Current mode-locked lasers and limits

Company	Pulse Width (ps)	Rep Rate (MHz)	Output Power (W)	Wavelength (nm)	Model	Technology
Coherent	<2	76	>1	700-980	Mira HP-P	Ti:sapphire laser
Spectra-Physics	<0.1	80	>0.3	690-1040	Mai Tai HP	Ti:sapphire laser
Ekspla	3-4	87	0.4	690-1000	PT257	OPCPA
Laser Quantum	<0.05	1000	0.7-1.4	750-850	Gigajet tune	Ti:sapphire laser
IMRA	<0.1	50	>0.02	780	AX-20	Fiber laser + SHG
Calmar Laser	<0.09	10-80	0.25-1.0	780	Mendocino	Fiber laser + SHG
Laser-Fermto	0.07-0.15	20-100	>0.2	790	Mercury 780-200	Fiber laser + SHG

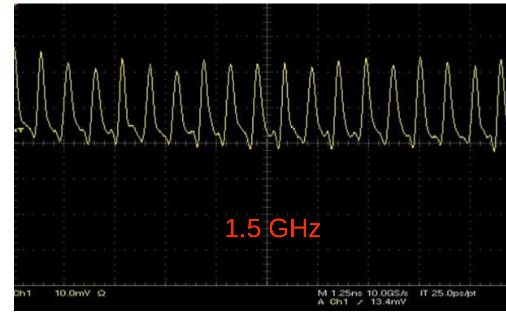
- ❑ Mode-locked Ti:Sapphire lasers: 700 - 1000 nm, picoseconds, 0.3 - 1.4 W, 80 MHz
- ❑ Mode-locked 780-nm lasers (frequency doubling of mode-locked Erbium fiber lasers): 100 mW, 10's MHz with no wavelength tuning
- ❑ Erbium fiber laser's bandwidth limited to 40 nm (1525 - 1565 nm)

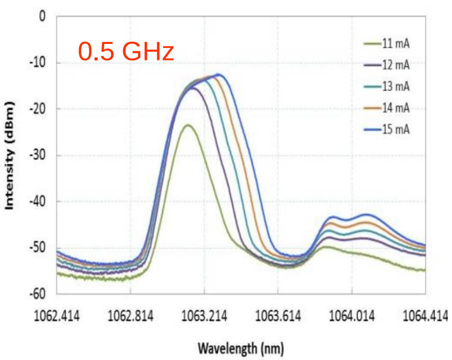
Commercially available mode-locked 780-nm laser is significantly far from DOE's requirements of 700 - 850-nm pulsed laser

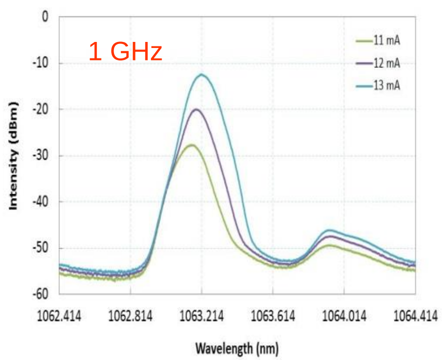
Technical approach / Our proposed approach

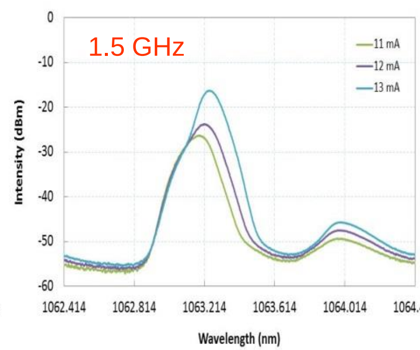
- Build 100 W, ~20 ps, 1064-nm fiber laser at 0.5-GHz
- Build 32 W, ~20 ps, 532-nm green laser
- Generate over 10-W average power at 780 nm
- Demonstrate tunable range from 700 to 850 nm
- Demonstrate laser with a low phase noise

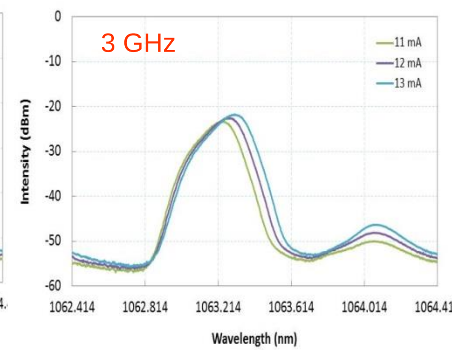
Seed laser





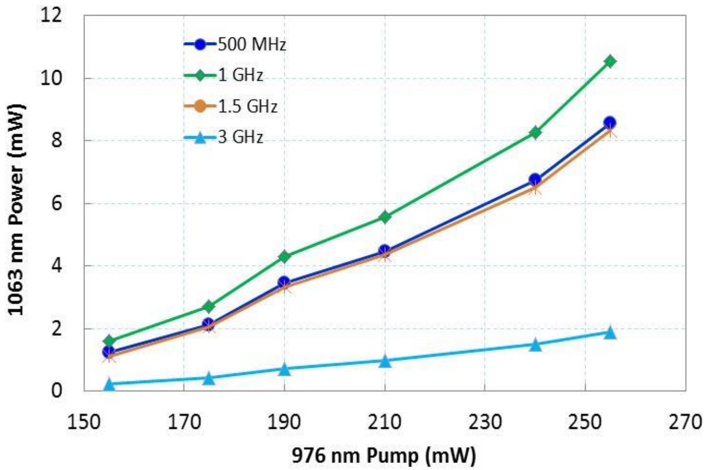




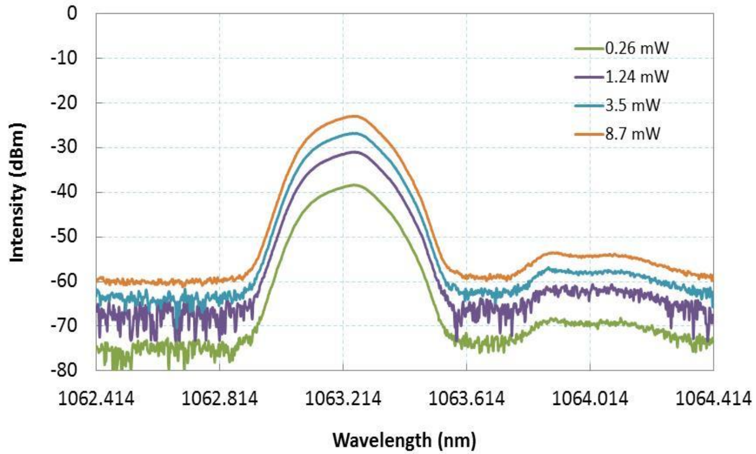


- ❑ Repetition rate: 0.5 - 3 GHz
- ❑ Average power: >0.1 mW
- ❑ Pulse width: 21 – 200 ps
- ❑ FWHM bandwidth: <0.2 nm

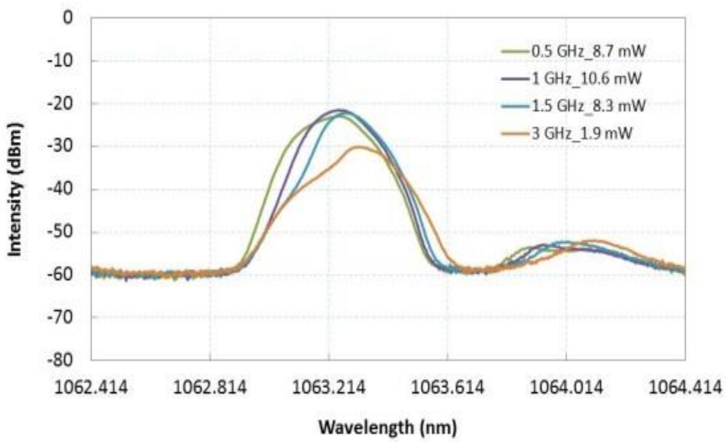
Fiber pre-amplifier



Fiber pre-amplifier power vs pump power (21ps)



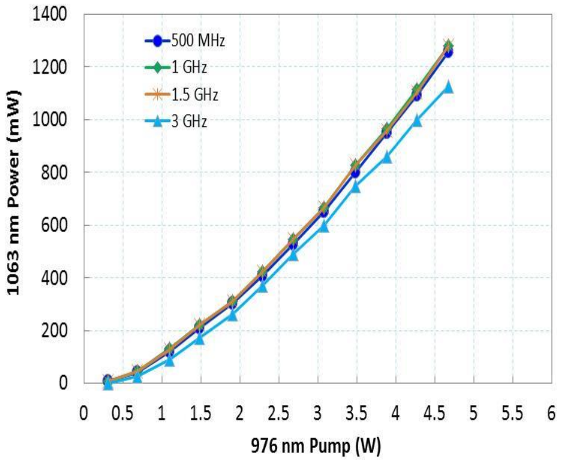
Optical spectra at 0.5 GHz (21 ps)

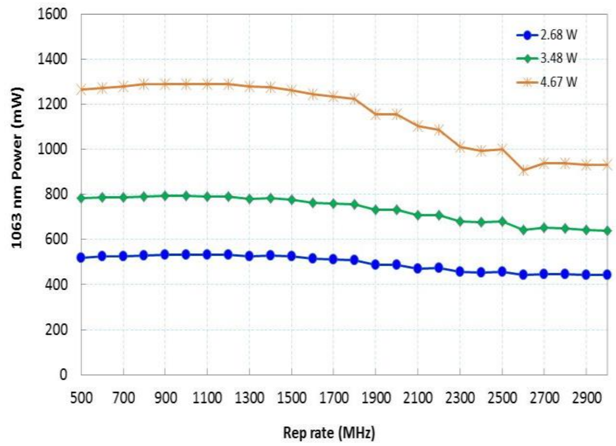


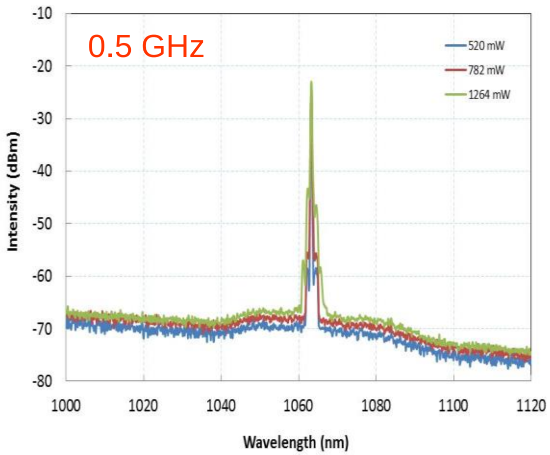
Optical spectra at 0.5 - 3 GHz (21 ps)

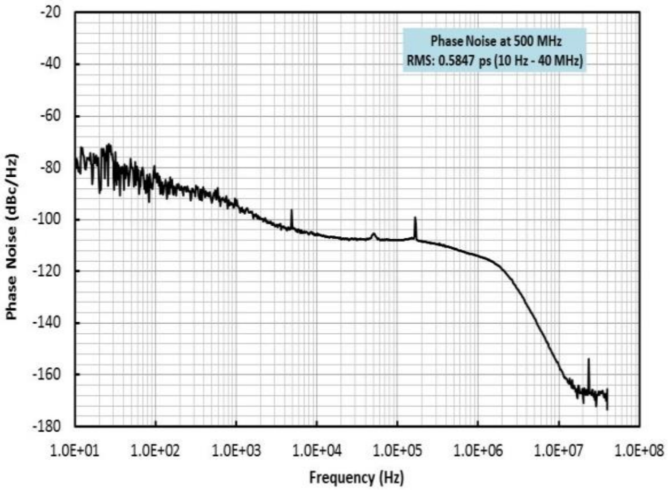
- Seed laser powers: 0.13, 0.16, 0.12, and 0.03 mW at 0.5, 1, 1.5, and 3 GHz
- Average output powers: 8.6, 10.5, 8.3, and 1.9 mW
- FWHM bandwidth: < 0.2 nm

Fiber mid-amplifier









- ❑ Average output power: >1.1-W (0.5 – 1.5 GHz)
- ❑ FWHM bandwidth: < 0.21 nm
- ❑ Optical signal-to-noise ratio: > 45 dB
- ❑ Timing jitter: 0.6 ps (10 Hz to 40 MHz)
- ❑ Repetition rate: 0.5, 1, and 1.5 GHz

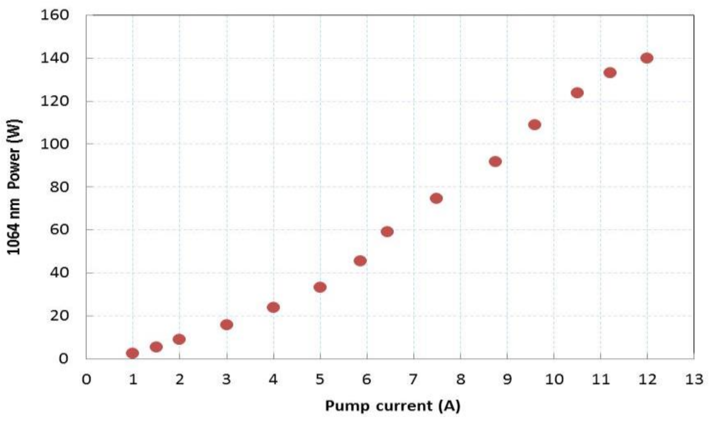
Re-design high power 1064-nm fiber laser

- ❑ Components can not handle such high power
- ❑ Component failure
- ❑ Reliability issue

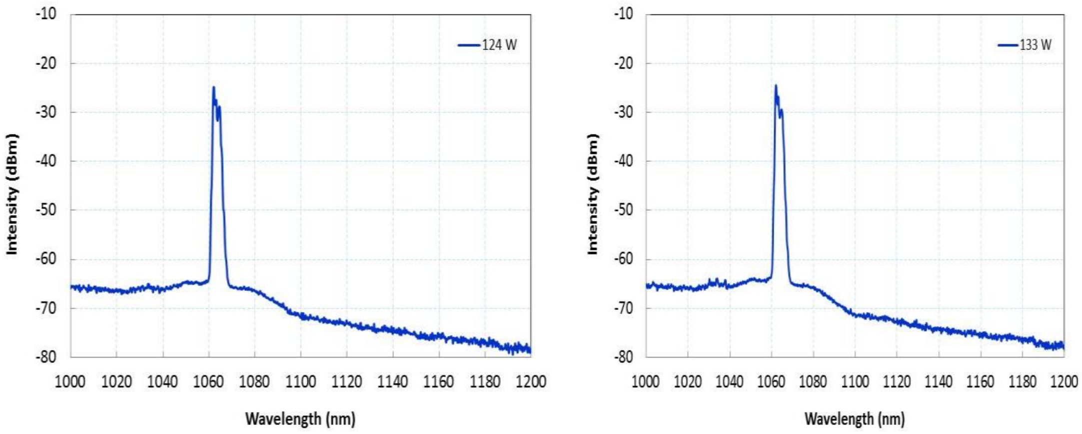
- ❑ Optimized high power pump laser design
- ❑ Custom made high power isolator
- ❑ Custom made fiber laser delivery

⟹ Improve reliability

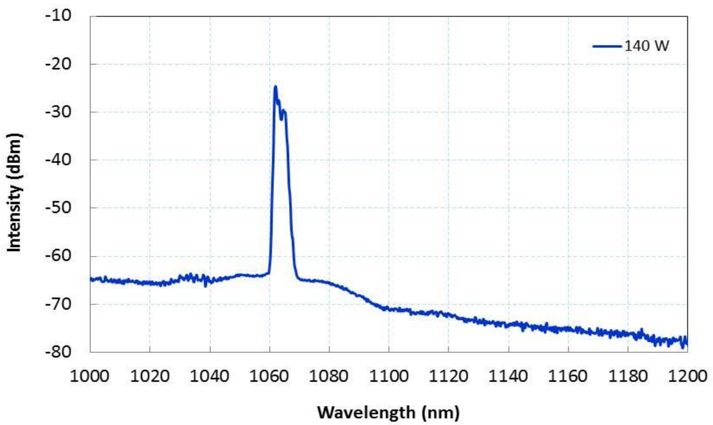
High power 1064-nm fiber laser



Average power vs 976-nm pump laser



Spectrum of 1064-nm fiber laser

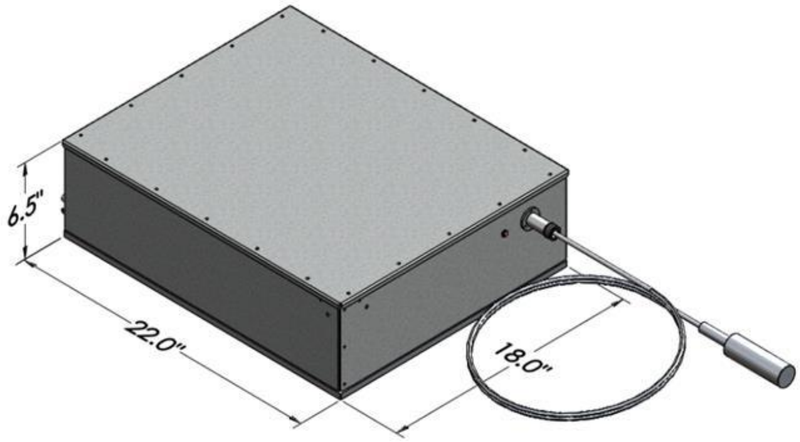


Spectrum of 1064-nm fiber laser

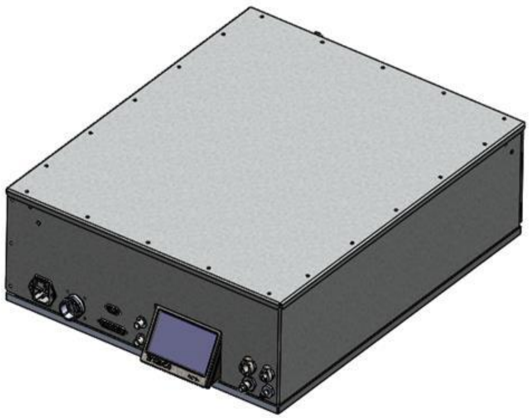
- ❑ Demonstrated average power: 140 W
- ❑ Target average power: 100 W
- ❑ Repetition rate: 0.5 GHz
- ❑ Pulse width: 21 ps
- ❑ FWHM: 1.0 nm at 124 W, 1.5 nm at 140 W
- ❑ Optical signal-to-noise ratio: 39 dB

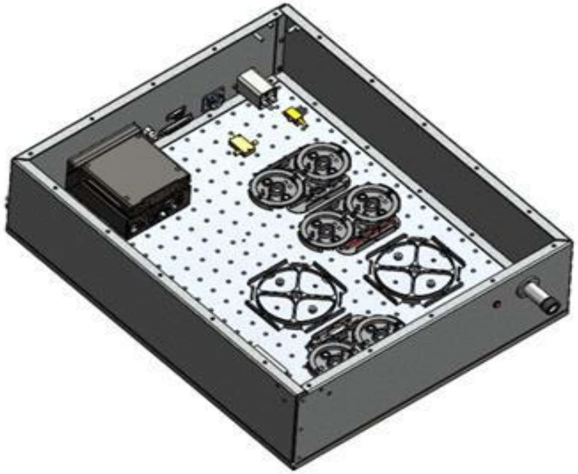
Mechanical design for 1064-nm fiber laser

Fiber laser enclosure



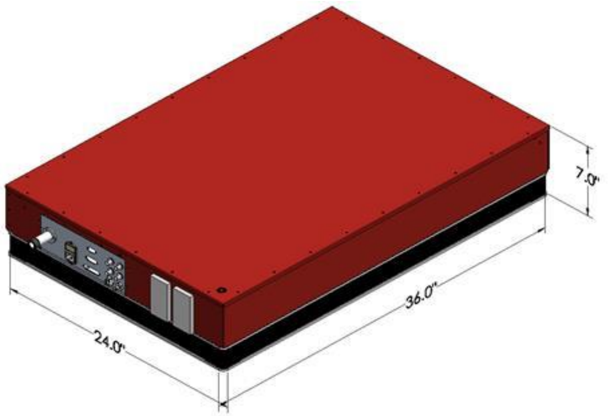
Fiber laser enclosure back panel



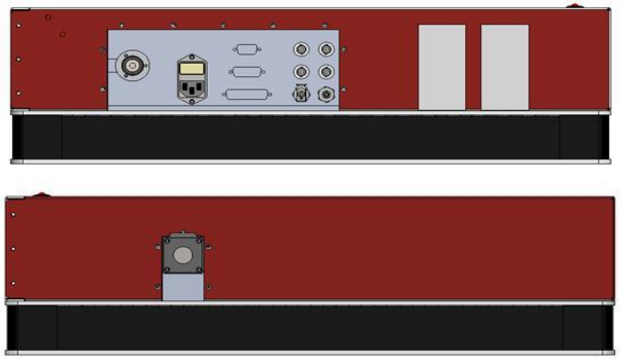


Mechanical design for green laser and 780-nm laser

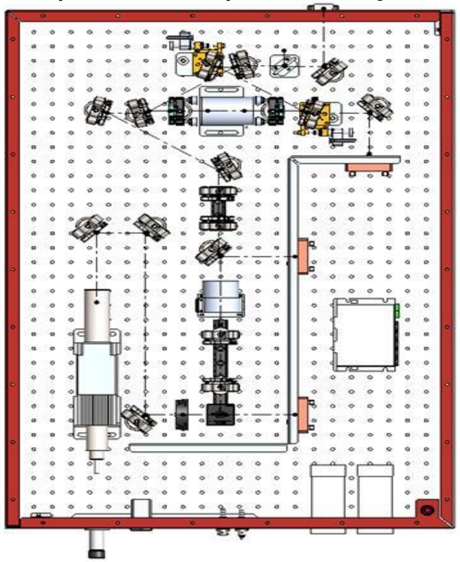
780-nm Laser enclosure



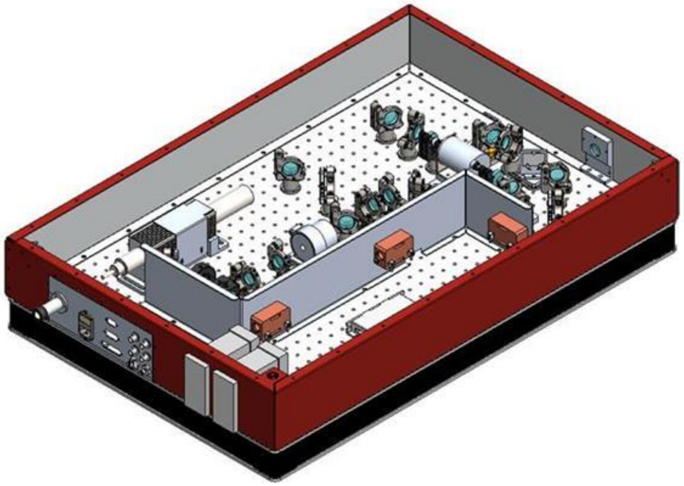
Back panel and front panel



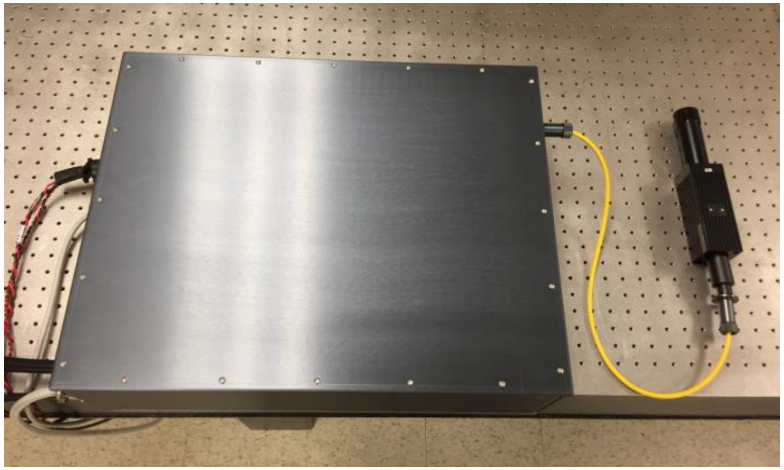
Optical component layout

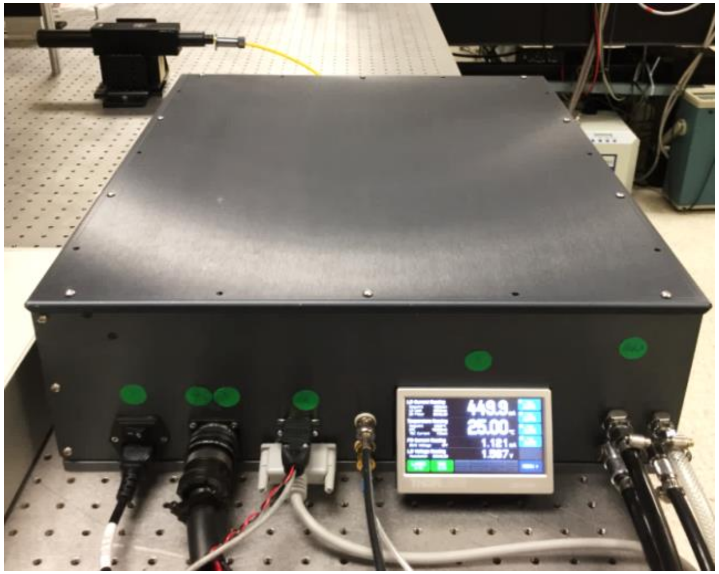


Optical component layout

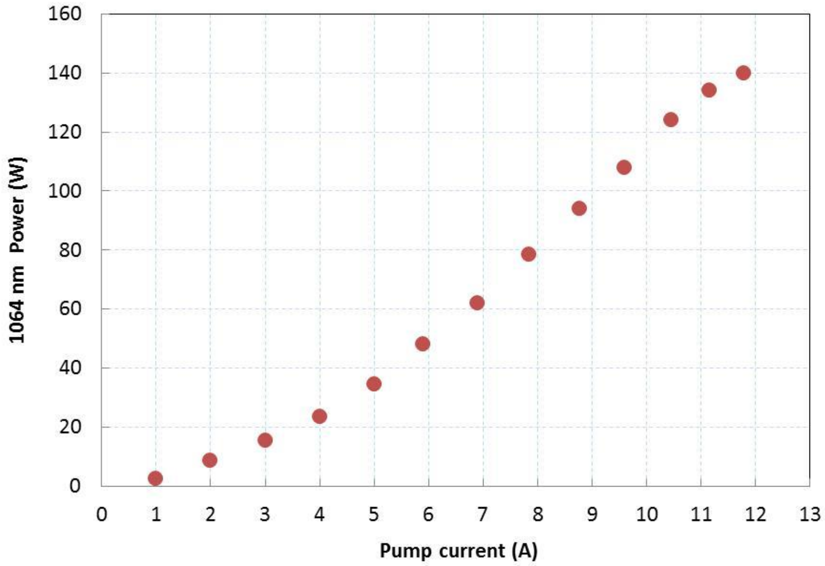


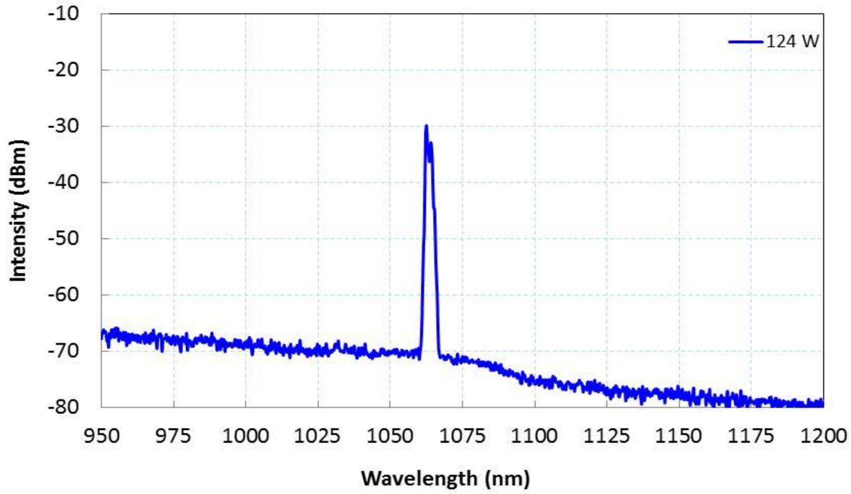
Assemble 1064-nm fiber laser

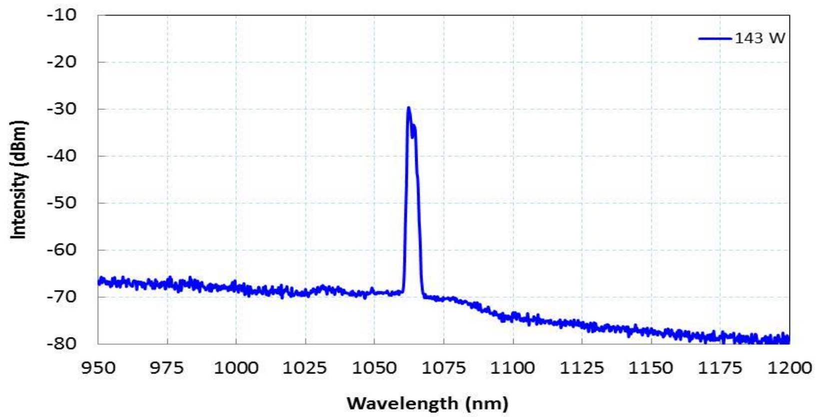




Assembled 1064-nm fiber laser performance

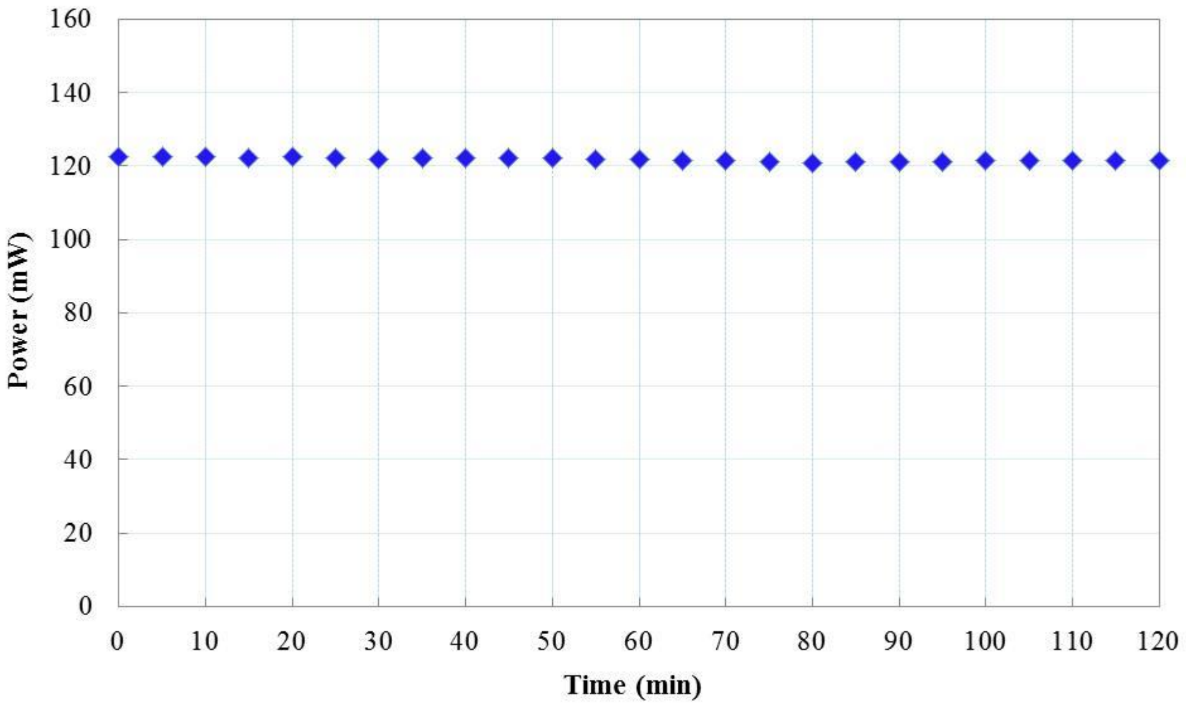






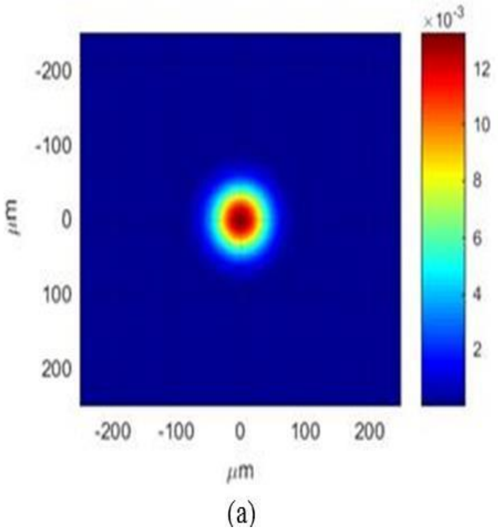
- Demonstrated average power: 140 W
- Target average power: 100 W
- Repetition rate: 0.5 GHz
- Pulse width: 21 ps
- FWHM: 1.0 nm at 124 W
- Optical signal-to-noise ratio: 39 dB

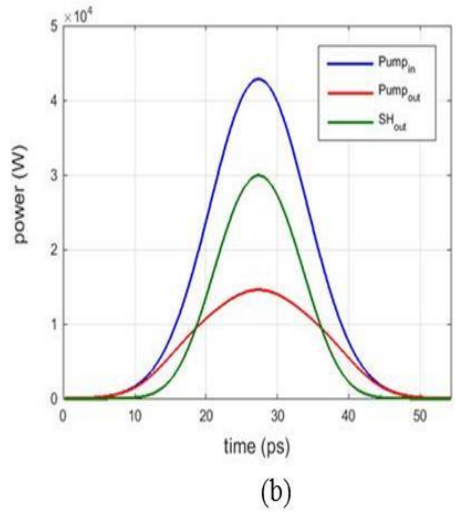
1064-nm Fiber laser power stability



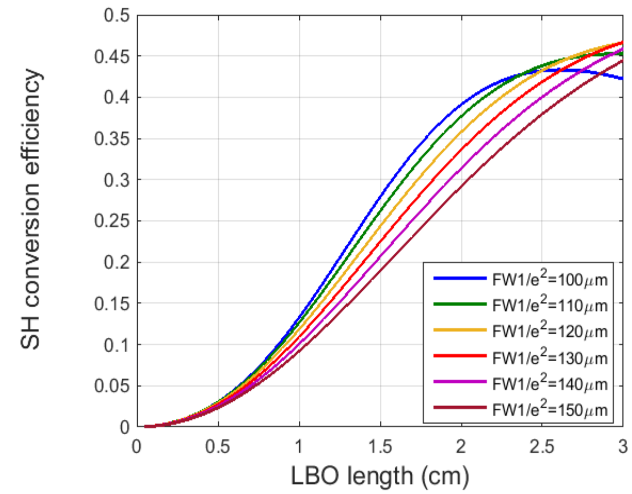
- ❑ Average power: 122 W
- ❑ Repetition rate: 0.5 GHz
- ❑ Warm up: 30 min
- ❑ Power stability: ±0.8% over 2 hours

Optimize green laser design





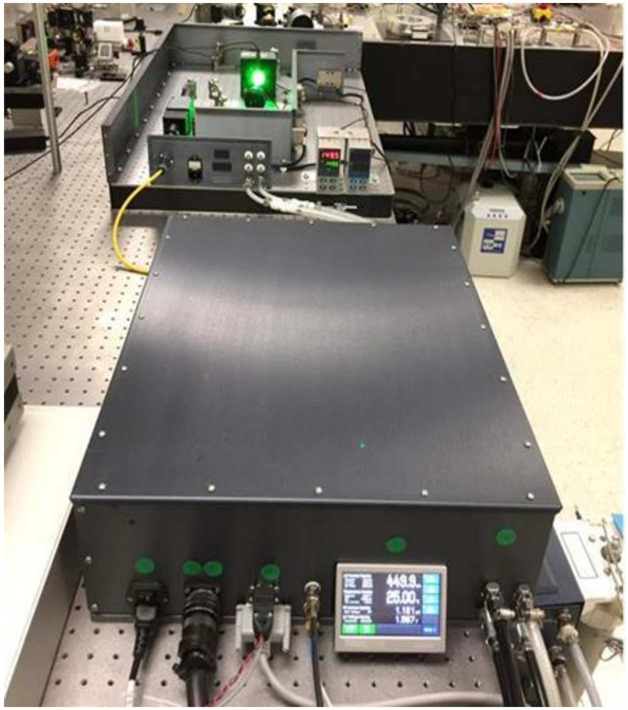
Pump beam profile at the front of LBO crystal for a waist of 100 µm (a) and pulse profile for pump and signal (b)

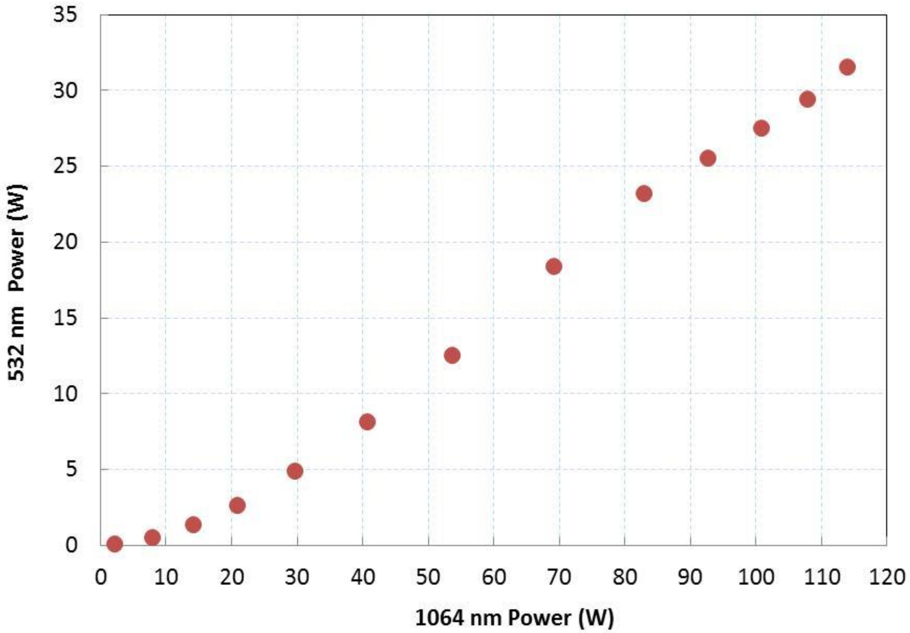


Second harmonic generation (SHG) efficiency in a 3-cm long LBO crystal

- 3-cm long x-cut LBO crystal for frequency doubling
- Noncritical phase matching (NCPM) at ~150°C
- 100-W, 20-ps, 1064-nm fiber laser at 0.5 GHz
- 45% conversion efficiency

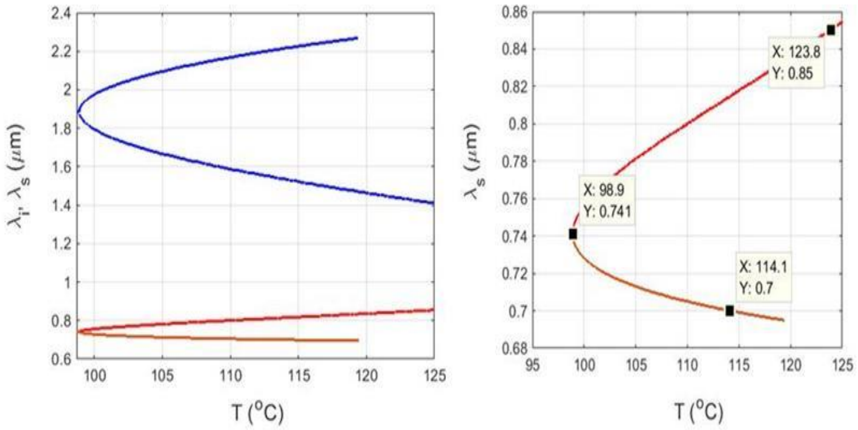
Build pulsed green laser





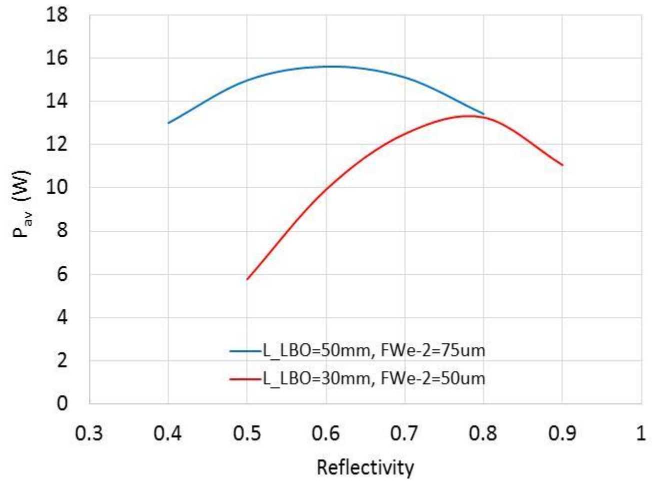
- ❑ Achieved average power: 32 W
- ❑ Target average power: 32 W
- ❑ Repetition rate: 0.5 GHz
- ❑ Pulse width: 21 ps
- ❑ Conversion efficiency: 28%
- ❑ Plan to optimize with better focusing

Model and design 780-nm pulsed laser



(a) (b)

Modeled signal (red) and idler (blue) wavelengths phase-matching over temperature for Type-I NCPM 532-nm pump propagating along x-axis in LBO (a) and modeled signal wavelength phase-matching over temperature for Type-I NCPM 532-nm pump propagating along x-axis in LBO (b)



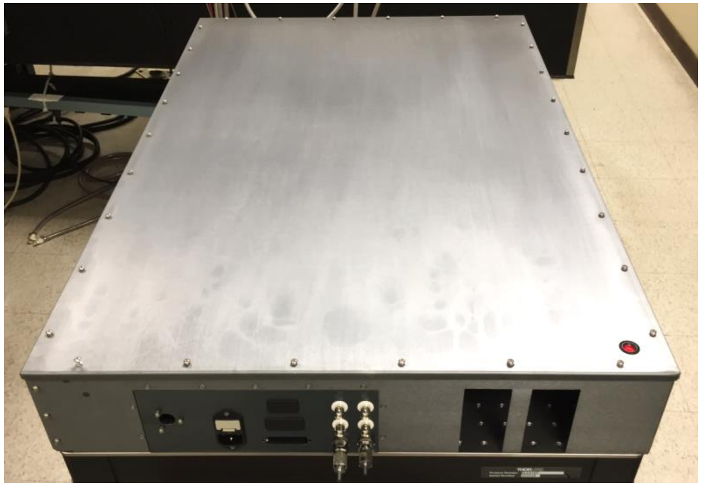
Modeled 780-nm laser power

- ❑ Detune the cavity length to resonate at specific wavelength

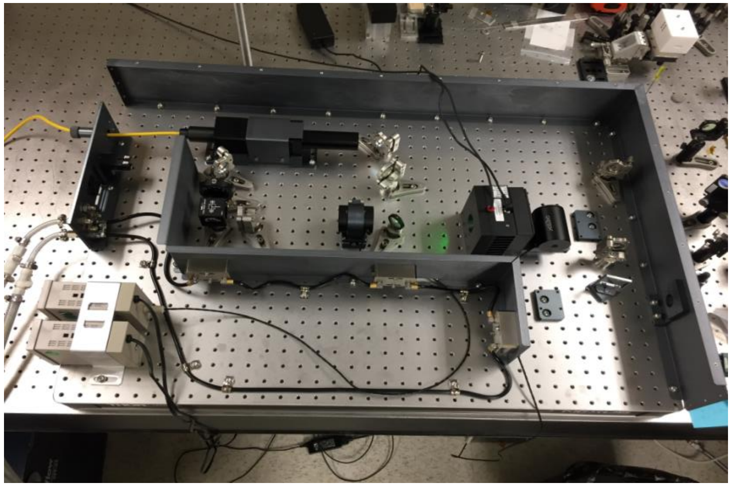
- ❑ 780 nm Laser avg. power: 10 W
- ❑ Rep rate: 0.5 GHz
- ❑ Green laser: 32 W
- ❑ Beam diameter: 75 μm
- ❑ Reflectivity: 0.6

Build 10-W, 700 - 850 nm pulsed laser

780-nm laser enclosure



Started building 780-nm laser



- Procured optical components
- Custom made components took a long lead time
- Received all parts at the end of Aug
- Mounted oven and temperature controller
- Mounted 5-cm LBO crystal in oven
- Plan to complete the build in Aug and Sep
- Plan to ship the laser system to JLab in Oct

Publications

- Wenyan Tian and Eric D. Park, “High power picosecond 1064-nm fiber laser with tunable pulse width”, oral presentation at Photonics West 2019. Proc. SPIE 10897, Fiber Lasers XVI: Technology and Systems, 1089723, (7 March, 2019); DOI: 10.1117/12.2510730

- Wenyan Tian and Shukui Zhang, “Picosecond 1064 nm fiber laser with tunable pulse width and low timing jitter”, oral presentation at Photonics West 2018. Proc. SPIE 10512, Fiber Lasers XV: Technology and Systems, 1051214 (26 February 2018); doi: 10.1117/12.2283411

Commercialization

Accelerator markets

- A laser source which can be used in photoinjectors for accelerators
- Enable synchronization to external system
- Replacement for Ti:sapphire laser (typically pulse width <4 ps)
- Drive photoinjectors with a widely tunable wavelength and tunable pulse width

Scientific research market

- Current commercially available mode-locked Ti:sapphire lasers: 0.3-1.4 W average power, <4 ps pulse width, 80 MHz repetition rate
- Replace current Ti:sapphire lasers widely used in many research institutes, universities, and national research labs when they need to update them for advanced research applications

- Exhibit our product at Photonics West Conference and CLEO
- Advertise our product at Photonics Spectra
- Present technical papers at conferences and publish in journals

- ❑ Won $140K funding from Navy STTR program based on the developed fiber laser tech.
- ❑ Won $100K funds from Navy based on the developed fiber laser technology
- ❑ Potential for over 1 million funds

Outcome at end of Phase II

- Develop high power, high repetition rate, picosecond, 1064-nm fiber laser
- Develop high power, picosecond green laser
- Develop high power, picosecond tunable 780-nm laser
- Develop tunable 780-nm laser prototype
- Final Scientific/Technical report
- Final Commercialization Plan
- Offer a lease of our laser to JLab for one year

Summary

- ❑ Developed and built an all-fiber, PM, 140-W, 1064-nm fiber laser
- ❑ Demonstrated fiber laser with repetition rate from 0.5 – 3 GHz
- ❑ Demonstrated tunable pulse width from 21 to 200 ps
- ❑ Modeled and designed picosecond green laser
- ❑ Modeled and designed tunable 780-nm pulsed laser
- ❑ Designed mechanical enclosures for fiber laser and 780-nm laser
- ❑ Demonstrated low timing jitter for fiber mid-amp
- ❑ Demonstrated fiber laser with an excellent narrow bandwidth of 1 nm at 120 W
- ❑ Demonstrated fiber laser with an excellent signal-to-noise ratio of 39 dB
- ❑ Demonstrated an excellent power stability of ±0.8% over 2 hrs for fiber laser
- ❑ Demonstrated 32-W average power, 21-ps pulse width, 0.5 GHz, green laser

Acknowledgement

This work is sponsored by Office of Nuclear Physics, U.S. Department of Energy

Contract # DE-SC0015149

Thank Dr. Michelle Shinn !