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

Principal Investigator: Dr. Wenyan Tian, Q-Peak Inc.
Sub-contractor PI: Dr. Shukui Zhang, JLab
Program Manager: Dr. Michelle Shinn, NP, DOE
Contract No. DE-SC0015149
Contract Period: 04/10/2017 - 04/09/2019
Technical Performance: 7/26/2017 – 04/09/2019

August 7, 2018

DOE-NP SBIR/STTR Exchange Meeting 2018

Outline

- Company overview
- Program goals and KPPS
- Technical approach
- Year 1 results
- Commercial plan
- 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

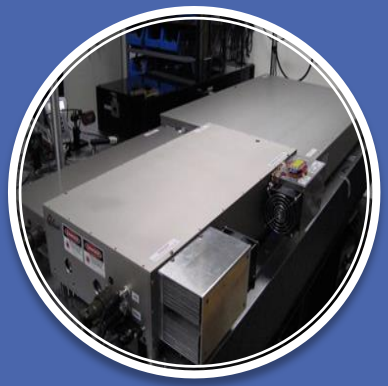
Q-Peak Inc. laser technology

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)

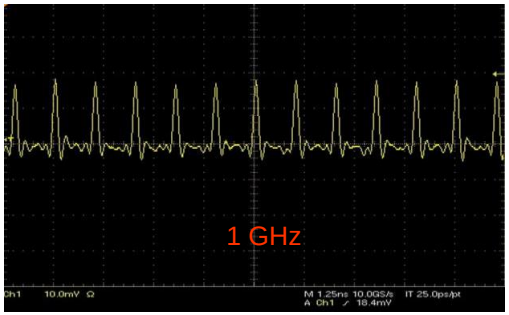
The state-of-the-art of commercially available mode-locked 780-nm laser are significantly far from DOE's requirements of a 700 - 850-nm wavelength tuning range, 0.5 - 3 GHz repetition rate, and an average power of over 10 W

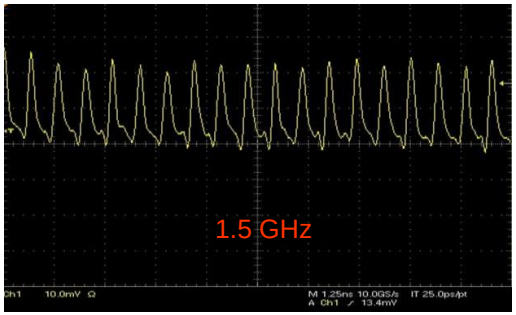
Technical approach / Our proposed approach

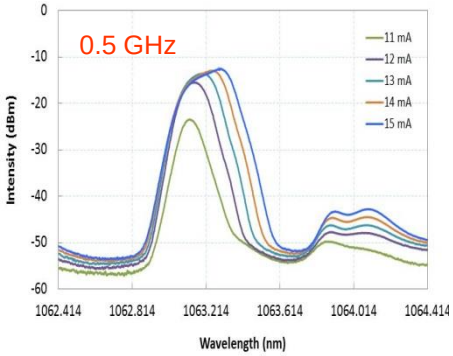
- Build 130 W, 20 ps, 1064-nm fiber laser at 0.5-GHz
- Generate over 10-W average power at 780 nm
- Demonstrate tunable range from 700 to 850 nm
- Demonstrate laser with a low phase noise

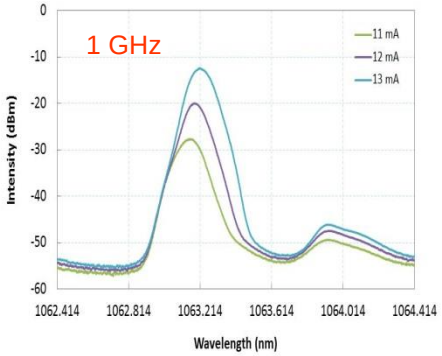
Year 1 results

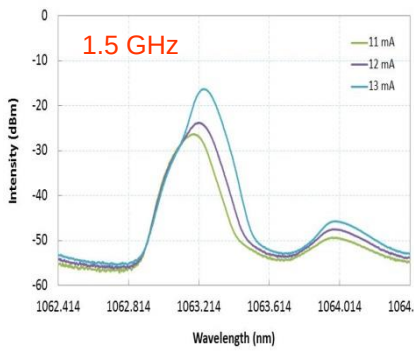
Seed laser

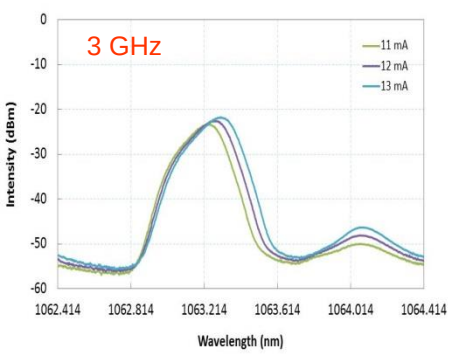






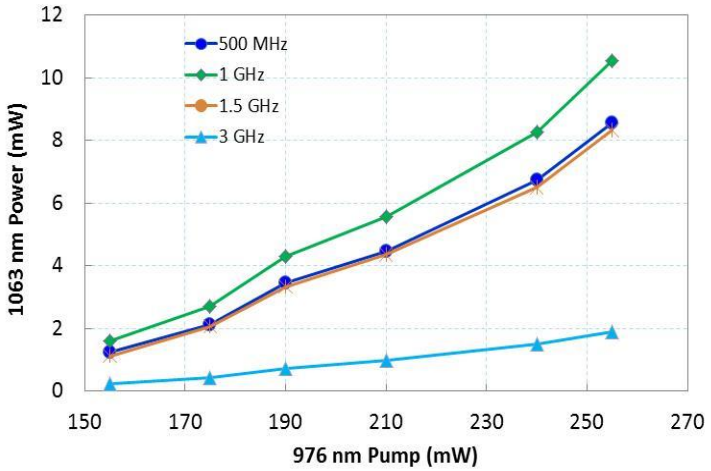




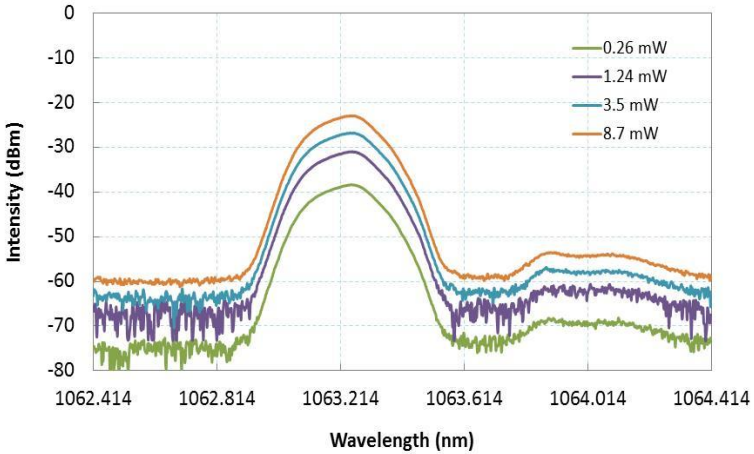


- Repetition rate: 0.5 - 3 GHz
- Average power: >0.1 mW
- Pulse width: 21 – 200 ps
- FWHM bandwidth: <0.2 nm

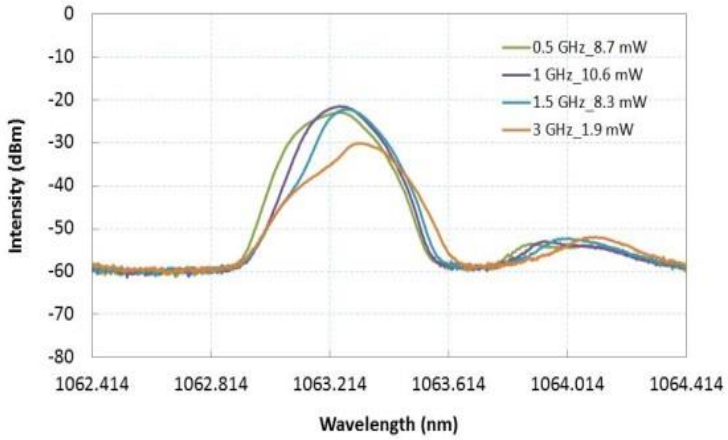
Fiber pre-amplifier



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



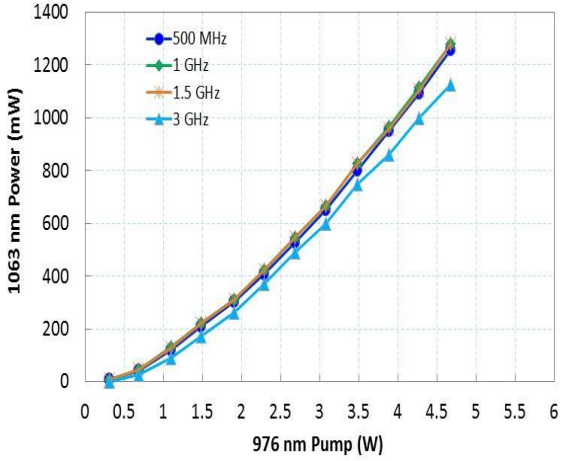
Optical spectra at 0.5 GHz (21 ps)

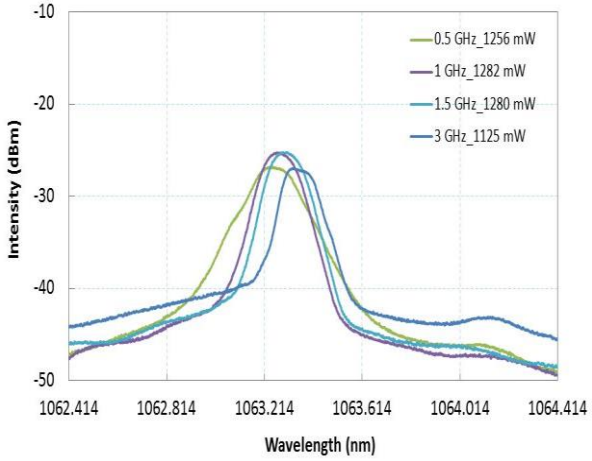


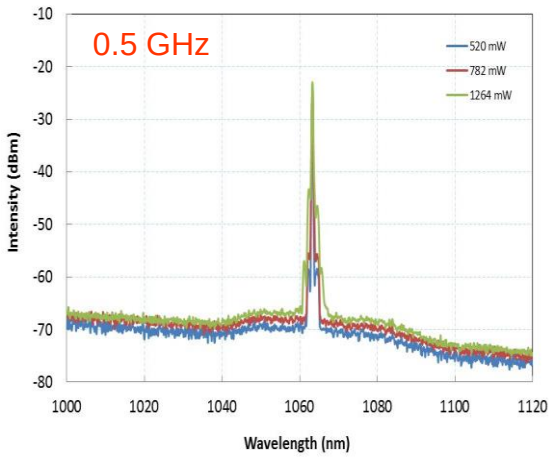
Optical spectra at 0.5 - 3 GHz (21 ps)

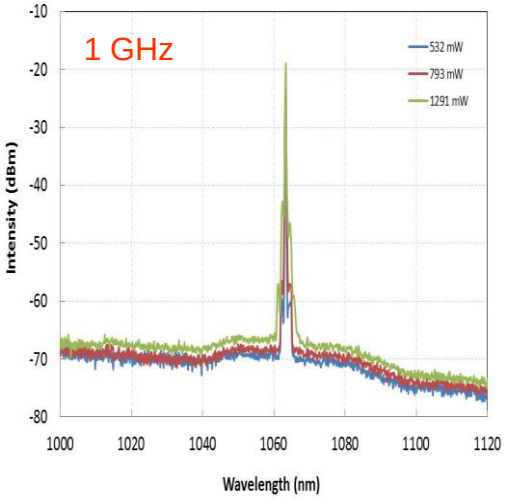
- Seed laser powers: 0.13, 0.16, 0.12, and 0.03 mW at 0.5, 1, 1.5, and 3 GHz
- Average output powers: 8.6, 10.5, 8.3, and 1.9 mW
- FWHM bandwidth: < 0.2 nm

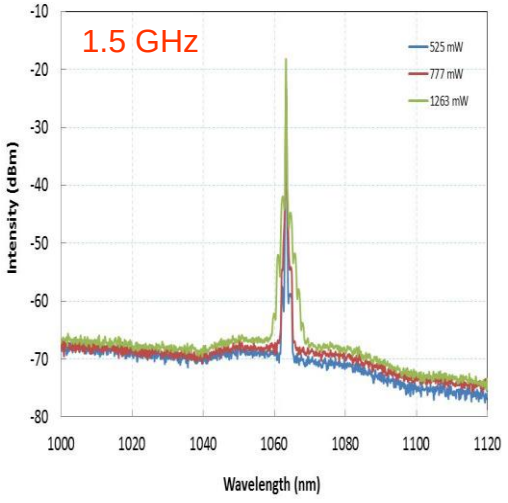
Fiber mid-amplifier





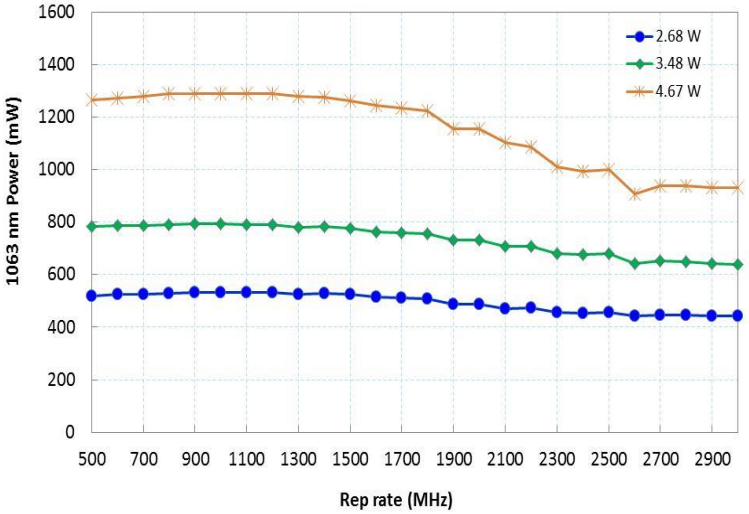


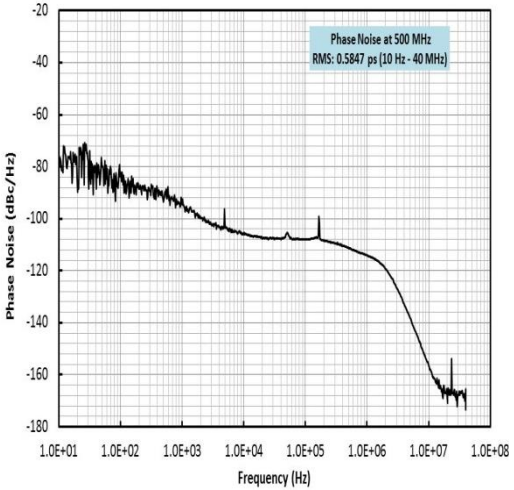


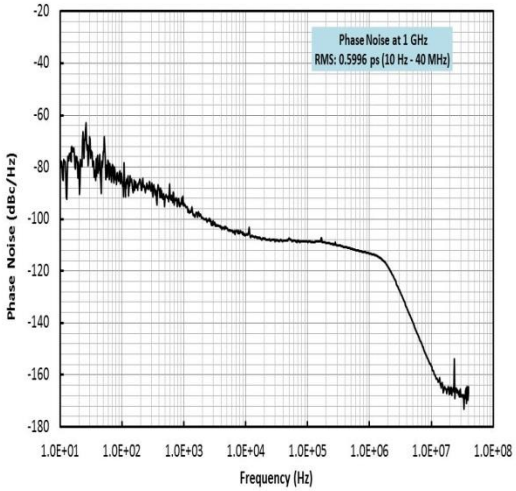


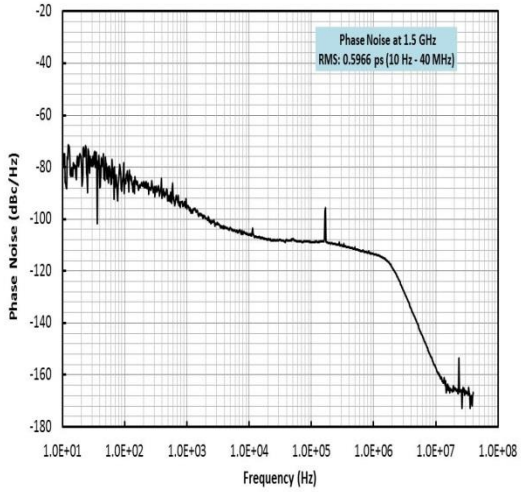
- Output power: > 1.1 W
- FWHM bandwidth: < 0.21 nm
- Optical signal-to-noise ratio: > 45 dB

Fiber mid-amplifier





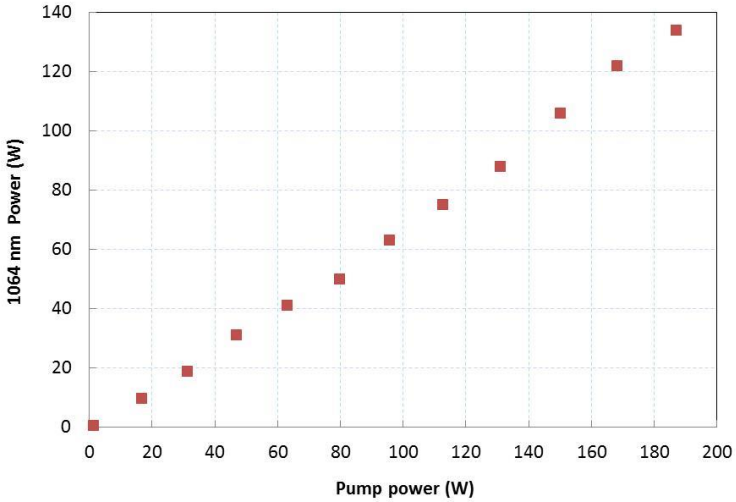


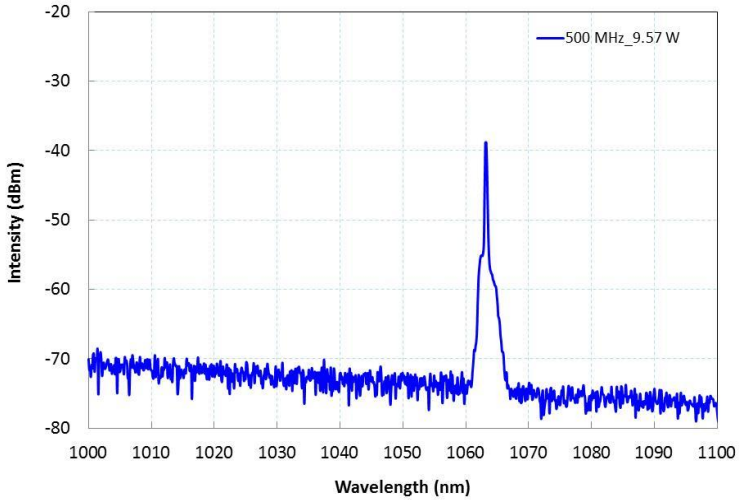


- Average output power: >1.1-W (0.5 – 1.5 GHz)
- Timing jitter: 0.6 ps (10 Hz to 40 MHz)
- Repetition rate: 0.5, 1, and 1.5 GHz
- Phase noise measured by: Dr. Shukui Zhang, JLab

Wenyan Tian and Shukui Zhang, “Picosecond 1064 nm fiber laser with tunable pulse width and low timing jitter”, oral presentation at Photonics West 2018 and published at Proc. SPIE 10512, Fiber Lasers XV: Technology and Systems, 10512-39, March, 2018.

High power fiber laser





- Average output power: 134 W
- Repetition rate: 500 MHz
- Pulse width: 21 ps
- Bandwidth: 0.6 nm at 40 W

Wenyan Tian and Eric D. Park, “High power picosecond 1064-nm fiber laser with tunable pulse width”, submitted an abstract to Photonics West Conference 2019, Fiber Lasers XVI: Technology and Systems.

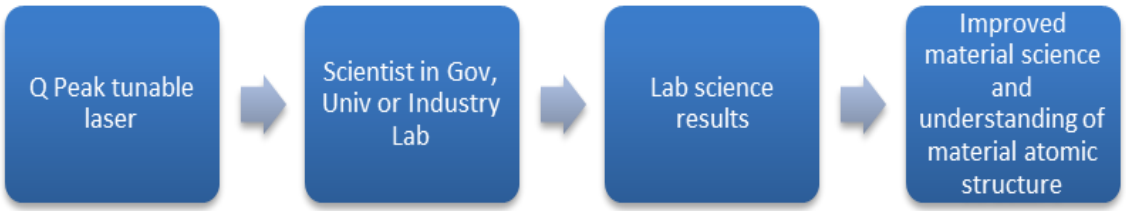
Commercial plan

Accelerator markets

- A laser source which can be used in photoinjectors for accelerators
- Enable synchronization to external system
- Enable facility to operate for longer periods without the need to change the photocathodes
- 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



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

Outcome at End of Phase II

- ❑ Submit Research Performance Progress reports
- ❑ Submit Scientific/Technical report
- ❑ Submit a Final Report
- ❑ Offer a lease of our laser to JLab for one year

Conclusions

- Developed an all-fiber, PM, 130-W, 1064-nm fiber laser
- Demonstrated fiber laser with repetition rate from 0.5 – 1.5 GHz
- Demonstrated tunable pulse width from 21 to 200 ps
- Demonstrated fiber laser with narrow bandwidth
- Designed high power fiber laser enclosure

Acknowledgement

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