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

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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 ft² 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.”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power</td>
<td>&gt;10 W</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>0.5 - 1.5 GHz</td>
</tr>
<tr>
<td>Center wavelength</td>
<td>780 nm</td>
</tr>
<tr>
<td>Tuning range</td>
<td>+/- 10 nm</td>
</tr>
<tr>
<td>Pulse width</td>
<td>20 - 50 ps</td>
</tr>
<tr>
<td>Timing jitter</td>
<td>&lt;1 ps (10 Hz to 10 MHz)</td>
</tr>
<tr>
<td>Power stability</td>
<td>&lt;5 % over 24 hours</td>
</tr>
<tr>
<td>Wavelength stability</td>
<td>&lt;1 nm over 24 hours</td>
</tr>
<tr>
<td>Beam quality, $M^2$</td>
<td>~1.3</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>~2 mm</td>
</tr>
</tbody>
</table>
Technical approach / Current mode-locked lasers and limits

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

- 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 power vs pump power (21ps)

- 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

- **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

- 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

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
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

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)

- 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**

- 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

780-nm laser enclosure

Started building 780-nm laser
Publications


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

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Contract # DE-SC0015149

Thank Dr. Michelle Shinn!