Compact Fiber Laser Approach to Generating 589 nm Laser Guide Stars

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* The pulsed laser work is being supported by a grant from the NSF Adaptive Optics Development Program.
We have developed CW and pulsed fiber laser approaches to generating 589 nm light for laser guided adaptive optics.

Scaling components to high average power is the main technical challenge.

We have demonstrated 11 W EDFA for CW 589 nm light generation

- System uses commercially available subsystems
  - Koheras oscillator
  - 11 W IPG amplifier
- Components were not commercially available at project start
- Technology exists to scale to > 50 W
Neodymium Doped Fiber Amplifier (NDFA)

**938 nm Seed**

**808 nm Pump**

Dichroic passes pump light and reflects signal

**Goal:** 10 W of linearly polarized light at 938 nm

**Toptica Diode Laser**
- 0.3 W, 938 nm
- Tunable

**Prototype double-clad Nd:silica fibers:**
- 8 W linearly polarized with $M^2 < 1.01$
- Power scaling in progress

**Limo Laser Systems**
- 25 W, 808 nm pump diodes
Two stage performance yields 8 W out with good polarization and beam quality

- $M^2 < 1.01$
- Polarization 10:1

- In theory, design should scale to >100 W with additional pump diodes
- AURA provided a 150 W laser pump diode, scaling is in progress
  - Determined thermal management of fiber is required to achieve higher power
Toptica was replaced with home-built oscillator while being repaired

- We demonstrated both fiber and diode oscillators

1800 gr/mm grating

Laser output

Dichroic

Short pass filter

27 meters Nd: fiber

Polarizing Beam splitter

Fiber oscillator produced > 800 mW

• Toptica failure cause an 8 month delay in frequency conversion experiments due to lack of funding to replace it
An arbitrary pulse format can be achieved by adding modulators and modifying fiber design.

\[ P_{\text{peak}} = P_{\text{avg}} \frac{\tau_{\text{rep}}}{\tau_{o}}, \quad \text{Duty cycle} = \frac{\tau_{\text{on}}}{\tau_{\text{rep}}}, \quad \text{Repetition rate} = \frac{1}{\tau_{\text{rep}}} \]

Rep rate < 2 kHz is not optimal for CW pumping NDFA.

- Nd\(^{3+}\) upper state lifetime \(\sim 470 \mu s\)

\[ \rightarrow \text{Repetition rate} > 2 \text{ kHz and } > 1\% \text{ duty cycle} \]
Pulsed 938 nm fiber design was based on experimental measurement of SBS threshold.

<table>
<thead>
<tr>
<th>Bandwidth (MHz)</th>
<th>Measured Output Power (W)</th>
<th>Theoretical Output Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>18.84</td>
<td>18.835</td>
</tr>
<tr>
<td>20</td>
<td>19.78</td>
<td>19.864</td>
</tr>
<tr>
<td>50</td>
<td>22.6</td>
<td>22.448</td>
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<tr>
<td>160</td>
<td>33.1</td>
<td>32.136</td>
</tr>
<tr>
<td>310</td>
<td>47.3</td>
<td>46.245</td>
</tr>
</tbody>
</table>

The measured SBS line-width was considerably higher than expected.

- Pulsed fiber has been designed and we are waiting on a formal quote.

Theoretical Curve with Fixed 20dB Gain

<table>
<thead>
<tr>
<th>Units</th>
<th>Original Estimate</th>
<th>Theoretical Fit to data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_B$</td>
<td>m/W</td>
<td>$5 \times 10^{-11}$</td>
</tr>
<tr>
<td>$\Delta v_B$</td>
<td>MHz</td>
<td>100</td>
</tr>
</tbody>
</table>

$4 \times 10^{-11}$
Our initial sum frequency experiments utilize periodically poled materials

Periodically poled crystals allow high efficiency sum-frequency generation

- Risk is photorefractive damage at visible wavelengths (GRIRA)
Thermally-induced spatial & temporal dephasing limits second harmonic generation in PPKTP

- We have developed a model that validates our experimental data.
- SH intensity $> 15 \text{ kW/cm}^2$ causes two-photon nonlinear absorption.
- Absorption causes thermal detuning phase mismatch.
- Effect degrades conversion efficiency from 19% to $\sim 8\%$ in 2 hours at 145 kW/cm$^2$ of pump intensity.
- Loss is unrecoverable.
- Effect may depend on:
  - length of crystal
  - wavelength
  - pulse format

- Experiments at Stanford and PSI indicate PPSLT may alleviate damage.
- We are testing PPSLT from both.
- Back-up solution is to use bulk crystals in a resonant ring cavity.
Preliminary SFG yielded 1.54 W of 589 nm in PPKTP, and power scaling is in progress

- PPSLT has >2X higher efficiency
- PPSLT expected for test next month
- Near term goals:
  - > 5 W CW @ 589 nm
  - Demonstrate 938 nm power scaling

- 1.52W @ 589nm with 7W @ 1583nm and 5W @ 938nm
- Spot size optimization in progress
- Additional 938 nm will require thermal management of fiber
Future plans

• 5W CW 589 nm demo
• Complete the 938 nm amplifier power scaling
• Test PPSLT and down-select on PP materials
• Field-harden frequency-mixing setup
• 10W CW at 589 nm demo
• Field-harden 938 nm amplifier
• Continue commercialization efforts
  - Completed a preliminary systems engineering design
  - Responded with CTI to Gemini RFP- RFP withdrawn
  - Actinix is willing to commercialize fiber laser technology,
    but not as the prime contractor for LGS application