The Dual Wavelength UV Transmitter Development for Space Based Ozone DIAL Measurements

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NASA Langley Research Center
Hampton, VA 23681
# UV Wavelength Conversion Task

**Laser Risk Reduction Program**

**Technical Lead:** Dr. Narasimha S. Prasad

## Overall Objective:
To develop efficient 1-micron to UV wavelength conversion technology to generate tunable, single mode, pulsed UV wavelengths of 320 nm and 308 nm

## Performance Goals
Solid-state, conductively cooled, single longitudinal mode, output energy $\geq 200$ mJ, pulsewidth $\sim 25$ ns and pulse repetition frequency of 50 Hz

## Merits
High pulse energy allows enhanced performance during strong daylight conditions

## Technical Approach
- The 532 nm wavelength radiation is generated by a 1064 nm Nd:YAG laser through second harmonic generation. The 532 nm pumps an optical parametric oscillator (OPO) to generate 803 nm. The 320 nm is generated by sum-frequency generation (SFG) of 532 nm and 803 nm wavelengths
- The hardware consists of a conductively cooled, 1 J/pulse, single mode Nd:YAG pump laser coupled to an efficient RISTRA OPO and SFG assembly-Both intra and extra-cavity approaches are examined for efficiency

## Potential Applications
Space-based lidar operation for future NASA missions including atmospheric ozone profiling using Differential Absorption Lidar (DIAL) technique

## Partners
- **Sandia National labs,**
  POC: Dr. Darrell Armstrong
- **Fibertek, Inc.,**
  POC: Dr. Floyd Hovis
Accomplishments

• Efficient, state-of-the-art, tunable, single longitudinal mode UV conversion technology using 1 micron wavelength pump source and novel nonlinear optics based technology has been developed for remote sensing of ozone from space-based platforms
• The Nd:YAG pump laser unit that generates >1J/pulse, 50 Hz PRF and ~25 ns pulsewidth, with space qualifiable components and conforming to TRL 3 hardware has been built and tested
• Highly efficient nonlinear linear optics scheme to obtain UV wavelengths at >200 mJ/pulse output energies has been demonstrated
• The developed UV converter scheme is a highly stable and reliable technique suitable for space based lidar operations
• A technical path to develop highly compact (<2 Cu. ft), rugged, UV transmitter technology for space environments has been identified
High energy low PRF is anticipated to provide high SNR under strong daylight conditions

Basic Scheme comprises of a Nd:YAG laser pumped nonlinear optics based converter comprising of a second harmonic generation (SHG), optical parametric oscillator, (OPO) and sum frequency generation (SFG) processes

The pump Laser is an upgrade of a ~300 mJ/pulse system built under NASA’s Advanced Technology Initiative Program (ATIP)

The UV converter hardware TRL = 3
Nd:YAG Pump Laser
-Technical Scheme to achieve 1 J/Pulse-

Final System Optical Configuration

- Ring Resonator
- Optical isolator
- Expansion telescope
- Fiber port
- Fiber-coupled 1 μm seed laser
- Amplifier #1
- Amplifier #2
- Amplifier #3
- Amplifier #4
- KTP doubler

532/1064 nm output

Amplifier Upgrade Section

Original ATIP Laser
Pump Laser Performance

Oscillator

- 100 µs pump pulse
- 55 W/bar
- 100 bars

Oscillator Configuration

- 50 mJ/pulse
- PRF = 50 Hz
- 0.41 cm x 0.41 cm square beam
- $M^2 = 1.2$

Pre-Amplifier Stage

- Vary pump pulse width
- 55 W/bar
- 112 bars/amp

Amplifier Configuration

- Peak Dual Amplifier Output
  - 350 mJ/pulse
  - $M^2 = 1.6$

First Stage Amplifier

- Input = 280 mJ
- First Stage Output > 700 mJ
- PRF = 50 Hz
- Pulsewidth = 16 ns
- Spatial Mode = Rect. Super Gaussian
- $M^2 = 2$
- Optical Eff. > 11%
- Wall Plug Eff. > 7%

Second Stage Amplifier

- Input = 700 mJ
- Second Stage O/P > 1100 mJ
- PRF = 50 Hz
- Pulsewidth = 22 ns
- Spatial Mode = SG
- $M^2 = 2.5$
- Optical Eff. = 11%
- Wall Plug Eff. = 7%

ATIP Laser

- 50 mJ

LRRP Laser Upgrade

- 300 mJ

- 700 mJ

- ~1200 mJ
Amplifier Modeling and Configuration

Modeling Results

- 3 Bounces-Rectangular Shape-2 sided pumping in the TIR axis, 2 sided conduction cooling, Pump faces uncoated (~10% loss)
- 808 nm pump pulse width (μs)
- Amplifier output energy (mJ)

Amplifier modules

- Dimensions: 6.8 x 13.0 x 75.3 mm³
- Incident Angle: Near Brewster (57°)
- Extraction: 100% at full aperture
- Aperture: 11.5 x 6.8 mm² (internal)
- 7.1 x 6.8 mm² (external)
- Doping Level: 0.5 ± 0.1 % Nd³⁺
- Pump Diodes: 192 ea. 50 watt QCW bars (12 ea. 16 bar arrays)

2-Sided Pumped & Cooled Amplifier

- Pump Diodes and Cooled Head Design

Prototype Two-Sided Pumped and Cooled Head Design

- Slab
- Pump Diodes
- Diode Protection Circuitry
- Heat Exchanger

Model is based on Franz-Nodvic result for a amplifying a square (in time) pulse

Model includes all key parameters explicitly
- Number of pump diodes (192)
- Peak diode power (75 W)
- Diode pulse width
- Input oscillator pulse energy (60 mJ)
- Input beam diameter
- Gain path length in amp
- Slab volume

Accounts for reduced gain for second pass

1 J per pulse output is predicted for 210 µs diode pump pulses
Second Stage Amplifier Design Configuration

2-Sided Pumped Brewster Angle Slab Design Features

- Brewster angle design: Simplifies optical alignment, only single passed
- Mature technology: Reduces risk, based on synthesis of previously developed pump on bounce and Brewster angle designs
- Reduced tendency for parasitic oscillation: Parasitic control in Brewster slabs is well established
- Pump on bounce geometry: Allows good beam overlap with high gain regions with minimal diffraction effects

Design is a synthesis of Brewster angle and pump on bounce approaches
The dimensions of this laser unit, including a SHG module, is 34” x 22” x 8”.
With latest diode bars and modified opto-mechanical components, the above package can be reduced to less than a quarter of its size.
Custom power supplies and control electronics for the upgrade have been built:

- Control electronics consists of two 19" rack mountable boxes.
- All power supplies are contained in two 19" rack mountable power supply modules.
- Each amplifier can be individually set between high power and low power operation to allow the user to achieve a wide range of output powers at 50 Hz.
Diagnostic Waveforms

Resonance Detection Photodiode, Oscillator Current, Preamp 1 Current, and Amp 1 Current Temporal Profiles in Low Power Mode

Resonance Detection Photodiode and RTP Modulator Drive Waveforms
Full System Results:
Beam Profile & Typical Output Energy

Near field beam profile of final amplifier output

Average power at 50 Hz of 51.0 W (1020 mJ/pulse) for an input electrical power to all pump diodes of 724 W

1020 mJ/pulse and an electrical to optical efficiency >7% was achieved with only 58 W peak power per diode bar pumping the amplifiers.
Output Spatial Performance

20 W output near field profile
- Amplifiers 1 & 2 low power, amplifiers 3 & 4 high power
- X diameter 4.4 mm, Y diameter 5.5 mm

52 W output near field profile
- All amplifiers high power
- X diameter 5.2 mm, Y diameter 7.2 mm

Flat spatial profiles are required for efficient harmonic conversions
50 Hz, Full Power Beam Quality Measurements

\[ M_x^2 = 2.5, \quad M_y^2 = 2.5, \]
Temporal Characteristics

Oscillator Only: 16.5 ns

Oscillator + Preamp 1 + Preamp 2: 19.5 ns

Oscillator + Amp 1 + Amp 2: 20.9 ns

Full System:
Pulsewidth ~ 22 ns
## Final Design and Performance Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Goal</th>
<th>Final Design/Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Energy (mJ)</td>
<td>900</td>
<td>1200</td>
<td>1040</td>
</tr>
<tr>
<td>M²</td>
<td>NA</td>
<td>2</td>
<td>2.5</td>
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<tr>
<td>Laser head package</td>
<td>Single breadboard</td>
<td>NA</td>
<td>Single breadboard in custom enclosure</td>
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<tr>
<td>Cooling</td>
<td>Conductive to diodes and slabs</td>
<td>NA</td>
<td>Conductive to diodes and slabs</td>
</tr>
<tr>
<td>Seeding</td>
<td>Ramp &amp; fire</td>
<td>NA</td>
<td>Ramp &amp; fire</td>
</tr>
<tr>
<td>Electronics</td>
<td>Separate custom module</td>
<td>NA</td>
<td>Separate custom module</td>
</tr>
</tbody>
</table>
UV Wavelength Conversion

• The nonlinear optics based technology to efficiently generate UV wavelengths has been established using a flash lamp pumped Nd:YAG laser

• Utilizes a novel (Rotated Image Singly Resonant Twisted RectAngle) RISTRA OPO to generate 803 and 731.5 nm wavelengths from 532 nm pump
  – Two RISTRA OPOs are used stable and single mode 803 nm:
    • A small or low energy RISTRA OPO that is locked by Pound-Drever-Hall (PDH) technique and seeded by New Focus tunable diode laser operating at 803 nm
    • The big or high energy RISTRA OPO that is pulse seeded from the small OPO and locked by energy stabilization technique
State-of-the-art conversion efficiencies have been demonstrated

- At 320 nm, >200 mJ extra-cavity SFG with good beam Quality
  - IR to UV efficiency > 21% (> 27% for 1 mJ seed)
- At 320 nm, up to 160 mJ intra-cavity SFG
  - IR to UV efficiency up to 24%
- Fluence ≤ 1 J/cm² for most beams
OPO signal near-field spatial fluence profile, Fresnel Number > 450

Flat pump profiles have facilitated high OPO conversion with good beam quality

Self-seeded oscillation in two-crystal RISTRA ~85% pump depletion

OPO signal far-field spatial fluence profiles, Fresnel Number > 450
Laboratory Setup

Breadboard with electronics and diagnostics used for technology demonstration

PDH stabilized injection-seeder OPO

Extensive diagnostics are utilized for characterization of temporal and spatial profiles
Laboratory Set-up

Pulsed idler-seeded 803 nm OPO

Grating-tuned diode laser, phase modulation and RF electronics for PDH stabilization
Current Status

• Second harmonic generation efficiency (for pumping OPO and for SFG stage) exceeds 80%
• All components of 1576 nm pulsed idler-seeding system fully operational
  – Pound-Drever-Hall (PDH) stabilized RISTRA OPO
  – Sandia-built stabilization electronics
  – 1576 nm beam shaping optics and beam delivery optics
• 803 nm RISTRA OPO
  – Pulsed-idler seeded oscillation recently obtained
  – Frequency stabilization under construction
• Sum-frequency generation stage
  – All beam combining optics in place
  – LBO (12 mm x 12 mm x 40 mm) crystal for SFG stage to be delivered by 8/31
Current Status (Contd..)

• Method for pulsed injection seeding
  – Signal seed-pulse generated by backward pumping scheme replaced by idler pulse from separate small OPO

• Dimensions of 803 nm RISTRA OPO scaled up by factor of 1.5 to safely accommodate higher pulse energies

• To improve overall conversion efficiency
  – KTP crystals in OPO replaced by BBO in the big OPO
  – The small 803 nm diode seeded OPO is based on KTP
  – BBO crystal for SFG replaced by LBO for efficient conversion

• The UV converter scheme is being assembled on a 2’ x 2’ breadboard
Sub Tasks Nearing Completion

• Frequency stabilization of 803 nm OPO
  – Uses simple grazing incidence grating and split photodiode for feedback to control frequency of seeder OPO

• Sum-frequency generation stage
  – Requires delivery of LBO crystal
  – Final integration of all breadboard components

• Characterization of complete system on a 2’ x 2’ breadboard
  – Measure UV energy output and overall optical-to-optical conversion efficiency
Testing and Integration Efforts at NASA LaRC

- Nd:YAG laser installation, testing and calibration complete
  - Flat pump profiles from Nd:YAG laser achieved
- SHG scheme to achieve 532 nm from 1064 nm established with >80% conversion efficiency
- Pump laser with UV converter setup integration
  - Procurement of components for integration of the 1064 nm pump laser and UV converter complete
  - Small RISTRA OPO with a 803 nm diode assembled on a breadboard
  - Full integration will begin soon as soon as SFG module is ready
On Going and Future Work

Goal: To build fully Ozone functional DIAL System

Initial LRRP Goal

- Nd:YAG pump Laser
- 320 nm UV Converter
- 308 nm UV Converter
- >200 mJ/pulse at 320 nm and 308 nm

Current Effort with reduced Funding

- Nd:YAG pump Laser
- 320 nm UV Converter
- >200 mJ/pulse at 320 nm
- Accomplished

Near Term Goal

- Nd:YAG pump Laser
- 320 nm UV Converter
- 308 nm UV Converter
- >60 mJ/pulse at 320 nm and 308 nm
- Telescope + Scanner

Single pump laser based DIAL System: Components in yellow boxes will be built with additional resources
Summary and Conclusions

• All solid-state Nd:YAG pump laser development complete
  – The current laser design has been leveraged into other NASA and DOD programs
• Efficient high-pulse-energy UV generation technology has been demonstrated
  – >200 mJ extra-cavity SFG; IR to UV efficiency > 21%
  – 160 mJ intra-cavity SFG; IR to UV efficiency up to 24%
• Custom designed opto-mechanical hardware for final prototype UV converter complete
• The system integration efforts at NASA LaRC is underway
• Current UV Transmitter effort is a technology demonstration with the hardware TRL = 3
  – Space qualifiable components have been used wherever possible
• The overall dimensions of the pump laser, associated electronics and UV converter setups can be reduced to less than 1/3rd their current sizes
• Solid-state UV Transmitter is amenable for space-worthy packaging