Progress in diamond Raman lasers for sodium beacon applications

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Contents

1. Intro to *diamond Raman lasers* – what are they?
2. Single frequency operation
3. 589 nm and 330 nm
4. Conclusion / Future directions
Inversion lasers vs Raman lasers

**Inversion**

- Light Source
- Excited atoms

**Raman**

- Light Source
- Vibrations

**TOPTICA APPROACH:**

- 1178 nm seed
- Yb Fiber
- Pump Diodes
- Raman Fiber Amp
- SHG
- 589 nm

- Greater wavelength range
- Coherent output
- BUT Raman is a weak effect - need to pump hard or have long gain lengths

*TOPTICA APPROACH:*

- High power
- Easy to add a repump line
- Fiber based

# Raman materials

## Some standout materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>Plusses +</th>
<th>Minuses -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glasses (SiO₂, GeO, P₂O₅)</td>
<td>Low cost fibers, high damage threshold, transparency</td>
<td>Low g and ωₗ, high parasitic nonlinearities in fiber form</td>
</tr>
<tr>
<td>Metal-WO₄, YVO₄, Metal-MoO₄, etc.</td>
<td>High gain, moderate damage threshold, good transparency</td>
<td>Waveguiding is challenging</td>
</tr>
<tr>
<td>Diamond, silicon</td>
<td>High gain, excellent thermals Simple Raman spectra</td>
<td>Diamond – immature fabrication Si – high parasitic nonlinearities</td>
</tr>
</tbody>
</table>
Diamond Raman lasers

- High thermal conductivity
- High Raman gain
- Wide transmission

Efficient Gain Switched Lasers

- ns
- ultrafast
- CW

High Average Power

Deep UV to Mid-infrared

Continuous Power
Quasi-steady state (>100 μs)


‘Laser grade’ material

CVD slabs

Absorption $< 0.15 \text{%/cm} (1.06 \mu m)$

Birefringence:

$\delta n = 1 \times 10^{-5}$

$\delta n = 1 \times 10^{-6}$

Growth direction

Raman frequency:

$\omega_v = 1332.3 \text{ cm}^{-1}$

Post-2015 Material

Slab top view

Diamond Raman laser research directions

- UV to Mid-infrared
- Polarization Conversion
- Ultrafast
- High Power
- Beam Combination
- Single Frequency

48 papers, 5 patents
Enforcing a single frequency in Raman Lasers

**SLM Methods:**

- **H<sub>2</sub> Raman laser**
  - Short cavity, cavity mode spacing > Raman gain linewidth

- **Silicon Raman laser**
  - Unknown longitudinal-mode suppression

- **Raman Distributed Feedback Fiber Laser**
  - Short cavity, \( \pi \) phase-shifted FBG

- **Nd:YVO<sub>4</sub> self-Raman laser**
  - Low temperature, cavity mode spacing > Raman gain linewidth

- **Intracavity BaWO<sub>4</sub> Raman laser**
  - F-P etalons

- **CH<sub>4</sub> Raman laser**
  - SLM pump, SLM Raman seed

- **Raman fiber amplifier (RFAs)**
  - SLM Raman seed, backward pumping

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Spatial hole burning

Inversion lasers: Spatial hole burning destabilizes single frequency output:

- Complicates design (ring cavities, etalons, gain medium near mirror, etc)

**In stimulated scattering lasers** → no energy storage → **no spatial hole burning**

- Simplifies design

Single frequency operation in diamond

- Up to a few watts
- Eg. at 1240 nm


- Much higher power
- 30 W SLM
- Visible output (620 nm)

Targeting 589 nm

Using a Yb$^{3+}$-doped 1018 nm fiber laser pump:

- 1018 nm Seed + amp
- 60 W
- LBO
- 589 nm
- 22 W
- < 7 MHz

Features:
- Builds on Yb fiber technology
- Tunable from 588 – 620 nm
- Extend to the UV

Locking and linewidth

- Early results - un-optimized
- 3 W level
- Linewidth 8 MHz (effective), < kHz (intrinsic)
330 nm laser (polychromatic guide stars)

- 1045 nm Seed laser
- 300 W Amplifier
- 607 nm DRL Stage
- 330 nm DRL
- Locking

- Design avoids high power isolator
- 25 W so far, mode is unstable

L4AO-14 Workshop, Marseille 2023
Power limit - The SBS Problem

1. Stimulated Brillouin scattering (SBS)

2. Since $g_B > g_R$ (generally), the Brillouin gain dominates

3. Brillouin lasing spoils efficiency and degrades spectrum

Mitigations

Raman fiber lasers
– strain and/or temperature gradients

Crystal Raman lasers
– cavity suppression

Higher order modes – aperture suppression
Summary

1. Diamond Raman lasers
   • Generic high power laser technology with large $\lambda$ reach
   • Single frequency (if you do it right)
   • SBS mitigations are different from Raman fibers

2. Current status
   • 22 W single frequency 589 nm
   • 25 W at 607 nm (first stage to 330 nm)
   • Locking has been achieved recently

3. Current projects
   • Aiming for 100 W at 589 nm
   • 10 W at 330 nm
   • (Pulsed guidestars for pulse tracking)