Sodium Beacon VECSELs and SOR Laser Overview

Robert Johnson, Keith Wyman, M. Olivia Byrd, Greg Fetzer, Steve Rako, Michael Hart, Garrett Cole, Mansoor Sheik-Bahae, Alex Albrecht

AFRL/RDSS 11 June 2019
Next Generation at SOR

Efficiency
- Polarization Switching
- Chirping

Phonon Greediness

Lasers
- VECSEL
- System
- RFA
- 75 W LGS

Thermal Management
- Chip/Materials
- Cavity/Setup
Efficiency

Chirping

- Recoil/Radiation Pressure
- Red-shifted 50 kHz based on Doppler effect
- Stops with: Collision, spin exchange or inability of source radiation to keep up
- Rate depends on radiative lifetime and fraction of atoms in $^2P$ state
- Chirping over the length of a mean free time could increase photon returns

Polarization Switching

- Larmor precession due to the Earth’s geomagnetic field (0.48G)
- Redistributes the magnetic sub-level population
- Negates $F = 2$ to $F = 3$ transition of optical pumping if angle between the laser and the geomagnetic field is large enough
- Switch beam polarization at the Larmor frequency (~328kHz) to trap atom between two ideal repumping states

Poster by Keith Wyman ‘Sodium Recoil at SOR’

\[
\Delta v = 2.95 \text{ cm/s} \quad \Delta f = 50 \text{ KHz}
\]

Efficiency

Chirping

- Recoil/Radiation Pressure
- Red-shifted 50 kHz based on Doppler effect
- Stops with: Collision, spin exchange or inability of source radiation to keep up
- Rate depends on radiative lifetime and fraction of atoms in $2P$ state
- Chirping over the length of a mean free time could increase photon returns
- Larmor precession due to the Earth’s geomagnetic field (0.48G)
- Redistributes the magnetic sub-level population
- Negates F = 2 to F = 3 transition of optical pumping if angle between the laser and the geomagnetic field is large enough
- Switch beam polarization at the Larmor frequency (~328kHz) to trap atom between two ideal repumping states

Polarization Switching

LIDAR

24-7 atmospheric monitoring
- Includes detectors, filters, data acquisition managers, optics, and pulsed 3-frequency solid state laser system
- Center wavelength 589nm
- Un-conditioned environments w/ minimal human intervention
- Signal to noise ratio greater than 5 in day and night conditions
- Reasonable cost for small observatories
- Monitoring of sodium layer height, wind, temperature

Poster by Keith Wyman ‘Sodium Recoil at SOR’
Next Generation at SOR

- Efficiency
  - Polarization Switching
  - Chirping

- Photon Greediness

- Lasers
  - VECSEL
  - System
  - Chip/ Materials
  - Cavity/ Setup

- RFA
  - 75 W LGS
75 W Laser Beacon

Two-Phase OTA:

1. RFA risk reduction- 15 months
2. 75 W beacon prototype- 27 months

Technical goals for Phase II:

- Laser power of at least 75 W at 589.159 nm
- Re-pumper 1717.8±10 MHz away from laser line center with at least 22.5% power
- Tunable across entire D2a line
- Bandwidth 12.5 MHz FWHM or less
- Wavelength stabilized to peak of sodium line by ±10 MHz or better
- Include frequency chirping

Date closes: 21 June 2019
Located on FedBizOpps, Solicitation Number: FA9451-19-9-0001
VECSEL effort overview

VECSEL, OPSL, SDL, etc
different from VCSEL
diffraction-limited beam and higher optical powers

Benefits of VECSELS
low cost
low complexity and compact
reliable, little maintenance

Potential use as next-generation beacon
beam combination, multiple beacons, or small observatories
dedicated repumper

Difficulties with VECSELS
difficult to get high power and single-frequency
thermal management issues
Current Phase II of a Small Business Technology Transfer (STTR) program to develop Vertical External-Cavity Surface-Emitting Laser (VECSEL) technology

- The STTR program helps provide financial assistance to pursue technologies in support of DoD missions
- Encourages collaboration between industry and research institution

For a polychromatic VECSEL at 589nm and 1140nm

- Phase I: Develop plan for <1GHz, 6GHz tunable, >10W VECSELs at 1140 and 589nm
- Phase II: Develop lab demonstration with λ stability, system robustness, and proof of concept implementation on-sky
- Phase III: Deliver working prototype capable of attaching to telescope for use at 1140 and 589nm

5 or 6 months into the effort
Polychromatic laser guide stars

- Tip-tilt aberration, cannot be corrected by monochromatic sources, same optical path
- Typically due to atmospheric refraction, causes image smearing for most relevant objects (planets, satellites, etc)
- Usually a separate two-axes, tip-tilt mirror looking at a NGS
- Polychromatic guide star can be used (overlapping, different optical path)
  1140 nm is chosen because atmospheric transmission, difference in index of refraction, source availability, limits Rayleigh
  need >10W in both wavelengths

Pumps the sodium 3P_{3/2} to 4S_{1/2} transition

Imagery of the Ring Nebula taken with and without tip-tilt AO correction


Hackett, Shawn, UNM Digital Repository, November 2016
Single-frequency VECSEL

- The HartSCI/UA approach uses a “twisted mode” cavity – orthogonal circular polarizations in forward and reverse directions.
- Enforces single-line frequency stability with multiple VECSEL devices in the cavity for longitudinal power scaling.
- Currently running at 1178 nm; will use SHG to get to 589 nm.
- Phase II will see a 4-VECSEL laser with SHG fielded at UA’s 1.5 m Kuiper telescope.

Achieved > 10 W single frequency with 2-VECSEL laser at 1178 nm
Areté’s VECSEL GSL System

Goal: Design a system that:
• Demonstrates the viability of VECSELs for Guidestar applications
• Serves as a foundational prototype on which to build future units
  • Lowers acquisition and maintenance costs of GSLs
• Provides utility to astronomy, space situational awareness, communications, and other applications

### Characteristic | Values and Rationale
--- | ---
**Primary λ and Power** | 8-20 W locked to Na(D2a) ~589 nm
**Secondary λ and Power** | Tunable and lockable at D2b,
Δλ= 1.7 GHz from D2a
**Waveform** | Continuous Wave
**Linewidth** | 5-50 MHz
**Fine Tuning** | ~1 GHz, continuous,
*Scan sodium transition to enable line locking*
**Gross Tuning** | ~5 GHz, does not need to be continuous,
*Allow capture of Rayleigh backscatter*
**Beam Quality** | M2 < 1.2 Near Diffraction Limited
**Polarization** | Well defined polarization, contrast ratio >20,
*Circular polarization is broadcast*
**User Interface** | PC Based GUI
**Diagnostics** | Wavelength and power
**Power** | 110-240 V AC
**Water** | 4-8 slpm flow of cool water
Laser Performance

- Power emitted from two mirrors in the cavity – measurement at one end
- Higher single frequency is possible
  - Improved mode selectivity
  - Improved thermal management
  - Optimization of nonlinear crystal parameters

12W Multi-Mode Power at 589 nm

Output Power at 589nm

- Present single-frequency operating point
- Multi-mode in this region
Next Generation at SOR

Efficiency
- Polarization Switching
- Chirping

Photon Greediness

Lasers
- VECSEL
- System
- RFA
- 75 W LGS

Thermal Management
- Chip/Materials
- Cavity/Setup
VECSEL technical overview

- Pump photons are absorbed causing generation of free electrons and holes in the quantum well barrier. Carriers diffuse to QW and recombine for photon emission.
- QW designed so discrete energy levels emit photons at wavelengths of interest
  - Bandgap energy of lasing materials
- Multiple Quantum Well (MQW)
- Amplification in gain region, usually using DBR
  - DBR-free adds additional external mirrors
  - Removes low thermal conductivity DBR
- Highly strained quantum well structures
  - Increase Indium, Increase Wavelength
  - InGaAs, large lattice constant mismatch, degradation
  - Addition of Phosphorus or Nitrogen

Hackett, Shawn, UNM Digital Repository, November 2016
Non-radiative recombination, growth defect, quantum defect

1. Non-radiative recombination: form of recombination in which a phonon is released

2. Growth defects: issues in epitaxial growth; MOCVD or MBE

3. Quantum defect: difference in the energy per photon between pump photons and emitted laser photons

4. Inefficient heat dissipation: DBR low thermal conductivity, soldering, SiC or diamond heatspreader

**To chill or not to chill?**

**CONDENSATION**

**DIAMOND**
- Surface quality
- Expensive for optical grade

**SiC**
- Lower thermal conductivity
Elimination of the DBR in the VECSEL architecture

- Addition of a direct-bonded intracavity transparent heatspreader to MQW active region
- Comparing thermal conductivity and surface quality of diamond and SiC


Maximum 7 W reached at 1178nm
Development of a novel VECSEL architecture: Gain-Embedded Meta Mirror technology (GEMM)

- Broadband active meta-mirror utilizes total internal reflection from a surface grating atop an underlying gain medium

Big Thanks To…

- Sodium team:
  Lee Kann, Mark Eickhoff, David Ireland

- All industry/research teams:
  Areté and MIT/LL
  HartScientific and University of Arizona
  CMS and University of New Mexico
Thank you!

QUESTIONS?