FY23 Innovative Spontaneous Concepts Research and Technology Development (ISC)

Integrated narrow-linewidth external cavity laser (ECL) in low loss silicon nitride

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Objectives

The design and fabrication of an integrated narrow linewidth external cavity laser (ECL) in Si_3N_4 at 780-852 nm for cold atom-based sensors and atom interferometry to reduce SWaP.

Commercial lasers at these wavelengths don't meet the specs for cold atom sensors laser optics system

External cavity with ring resonators have excellent performance in 1550 nm => However, it is not trivial to transition to a shorter wavelengths.

Scattering losses in waveguides increase as the wavelength decreases => Low loss platform is required

Significance/Benefits to JPL and NASA:

Systems based on cold atoms provide unique opportunities for an array of metrology and sensing applications. To date, these have primarily been demonstrated with bench-scale experiments in controlled laboratory environments. All of these systems require sophisticated laser systems to prepare, control, and interrogate the atomic ensemble, representing a major contribution to overall instrument footprint and power consumption.

Developing low loss silicon nitride (Si_3N_4) and leveraging this reliable platform especially in the shorter wavelengths (780-852 nm) to realize a high power and narrow-linewidth external cavity laser (ECL), positions JPL at the forefront of low SWaP and robust components for quantum-based sensors and systems. In addition to the on-chip laser, this capability allows for integration of other passive and active components i.e., optical isolators, modulators, and wave-meters. This integrated photonics technology brings a lot of opportunities to NASA/JPL in the areas of quantum sensing and systems by addressing the challenges of a demanding laser optic system that satisfies the demanding requirements of space-qualified quantum sensor.

Background

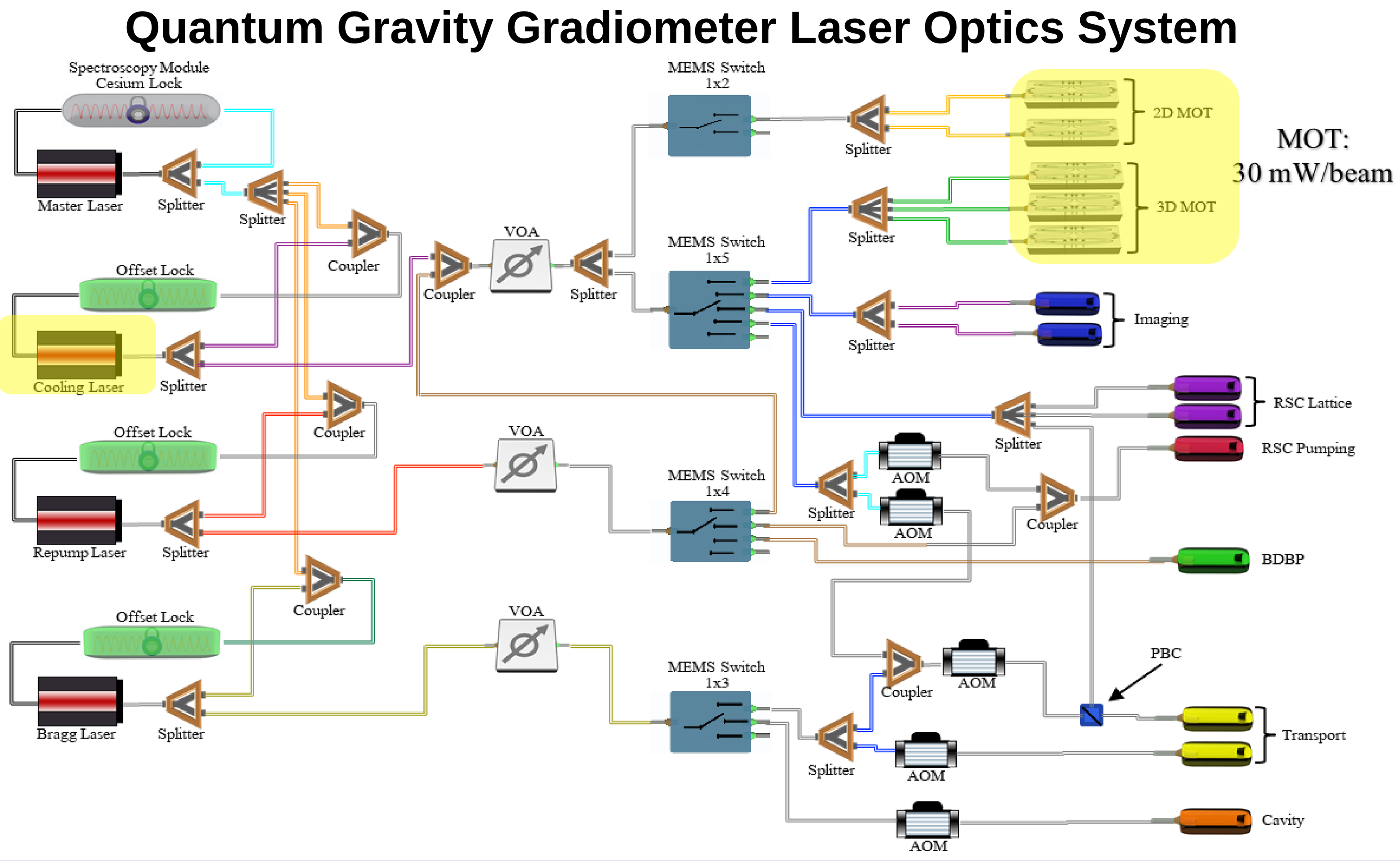
Lasers are essential to cold atom sensors and quantum applications

- 4-8 Lasers used typically used for cooling process
  - Wavelength of operation: 852 nm (Cs)
- Integration and compact solutions for optical components:
  - i.e., Modulators, attenuators, MEMS switches, splitters

Quantum Applications Requirements

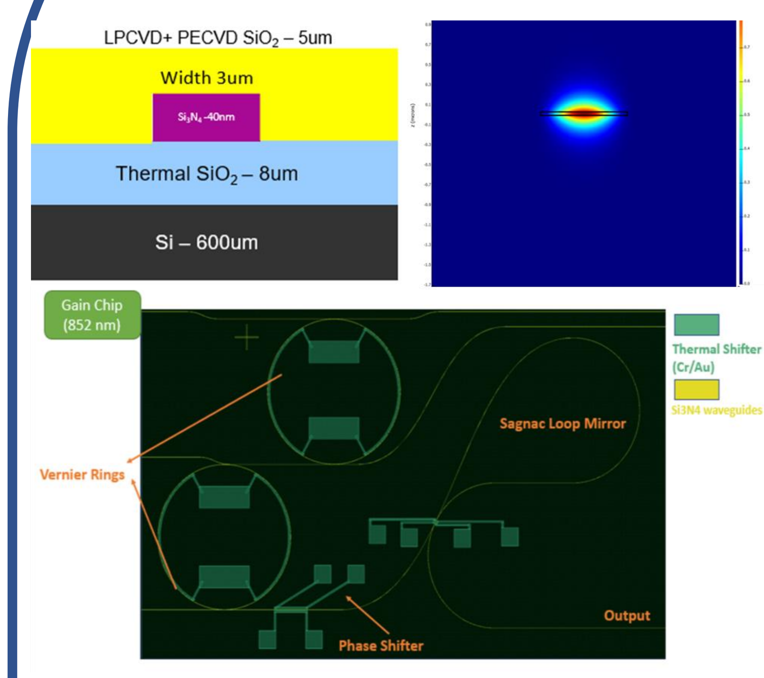
- Narrow Linewidth: Ideally < 10 kHZ-100kHz
- High power: 20-30 mW
- Operation at various wavelengths: wider application range
  - i.e. 852 nm for Cs and 780 nm for Rb

Quantum Gravity Gradiometer Laser Optics System

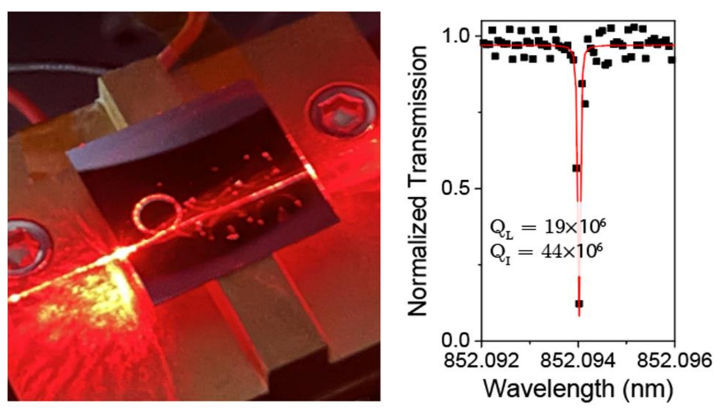


Approach & Results

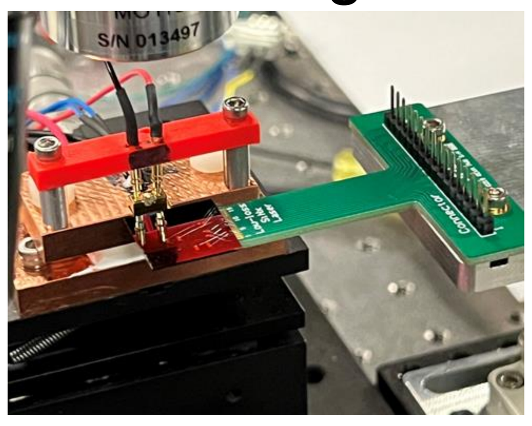
Device design



Device characterization



Device integration



Our device design leverages low loss stoichiometric silicon nitride (Si_3N_4) waveguides by addressing the sources of loss through optimized waveguide designs, high quality thin films, low loss etching and cladding processes.

Material platform development:

In order to realize a narrow-linewidth laser, three conditions should be met

- 1) Providing a long single roundtrip to extend the cavity through low propagation loss in the material.
- 2) Low propagation loss in the cavity allows for implementation of single-mode behavior through spectral filtering through a single roundtrip.
- 3) To prevent the dominance of nonlinear losses, choosing a dielectric material with negligible two-photon absorption to extend the cavity and restrict the spectral filtering to the dielectric part of the cavity only is key.

Device design and fabrication:

- Ring resonators with $Q_{intrinsic}$ = 44 million and Q_{loaded} = 19 million were fabricated to measure the loss of 1.1 dB/m at 852 nm.
- Furthermore, we realize a tunable pair of Vernier ring filters (using the thermo-optic effect) for spectral filtering and single mode operation with radii~ 2 mm and an extended free spectral range (FSR) of 16 nm which will be useful for laser noise suppression.

Integration and characterization:

- GaAs SOA (gain section) and an extended cavity made of a long Si_3N_4 low-loss waveguide circuit that provide the frequency selective feedback to the gain section.

Publications:

NTR 52843 "Integrated Narrow-Linewidth External Cavity Laser (ECL) Using Low Loss Silicon Nitride (Si_3N_4)"

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