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Gravimetric optomechanical laser: combining VECSEL technology with optomechanical resonators

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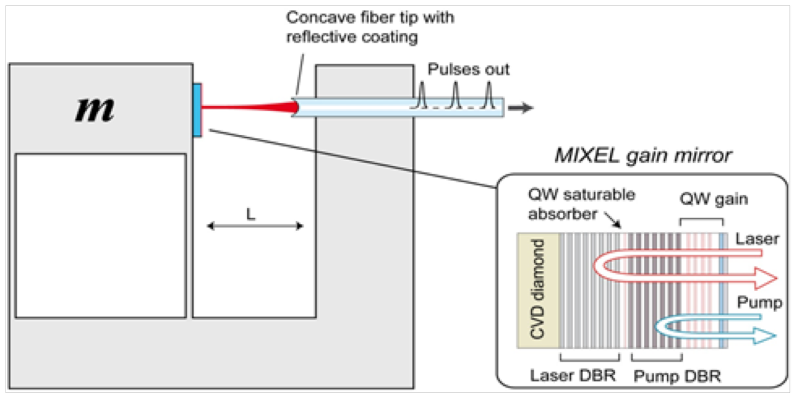
Motivation

We seek to create a high sensitivity gravimetric optomechanical laser through the combination of a Vertical External Cavity Surface Emitting Laser (VECSEL) and a fused-silica mechanical resonator. This system will allow accurate measurements of acceleration, which currently has applications in geodesy, gravimetry, seismometry, and inertial navigation. In addition to being a high sensitivity system, we hope to improve upon current gravimetric measurement devices by making this system more compact, increasing it's overall utility. The VECSEL is crucial in shrinking the system. Current systems have the gravimetric sensor as a part of an overall system, requiring the use of external optics that all must be stabilized together. This system eliminates that by making the laser apart of the oscillator itself. The VECSEL's silicon chip will be mounted on the frame of the oscillator, while the mirror for the VECSEL will be incorporated into the test mass. As the test mass moves, the frequency of the laser will change due to the changing cavity length. The mounting method of VECSEL components will ensure that the motion of the test mass will be the only motion encoded into the laser's output frequency. This will allow the system to be more compact and portable compared to current systems



VECSELs

A Vertical External Cavity Surface Emitting Laser (VECSEL) is a laser that consists of a silicon chip, a reflecting surface, and an in air cavity. A laser diode emits power into the silicon chip, which is the gain medium for this laser. A concave mirror completes the other end of the in air cavity, which creates the resonance required to make the silicon chip lase. The air cavity is an advantage because it allows the silicon chip and mirror to move independently. This will allow it to be mounted to a mechanical resonator in the future. The current VECSEL is a multimode laser, but will be reduced to a mode locked laser in the future.

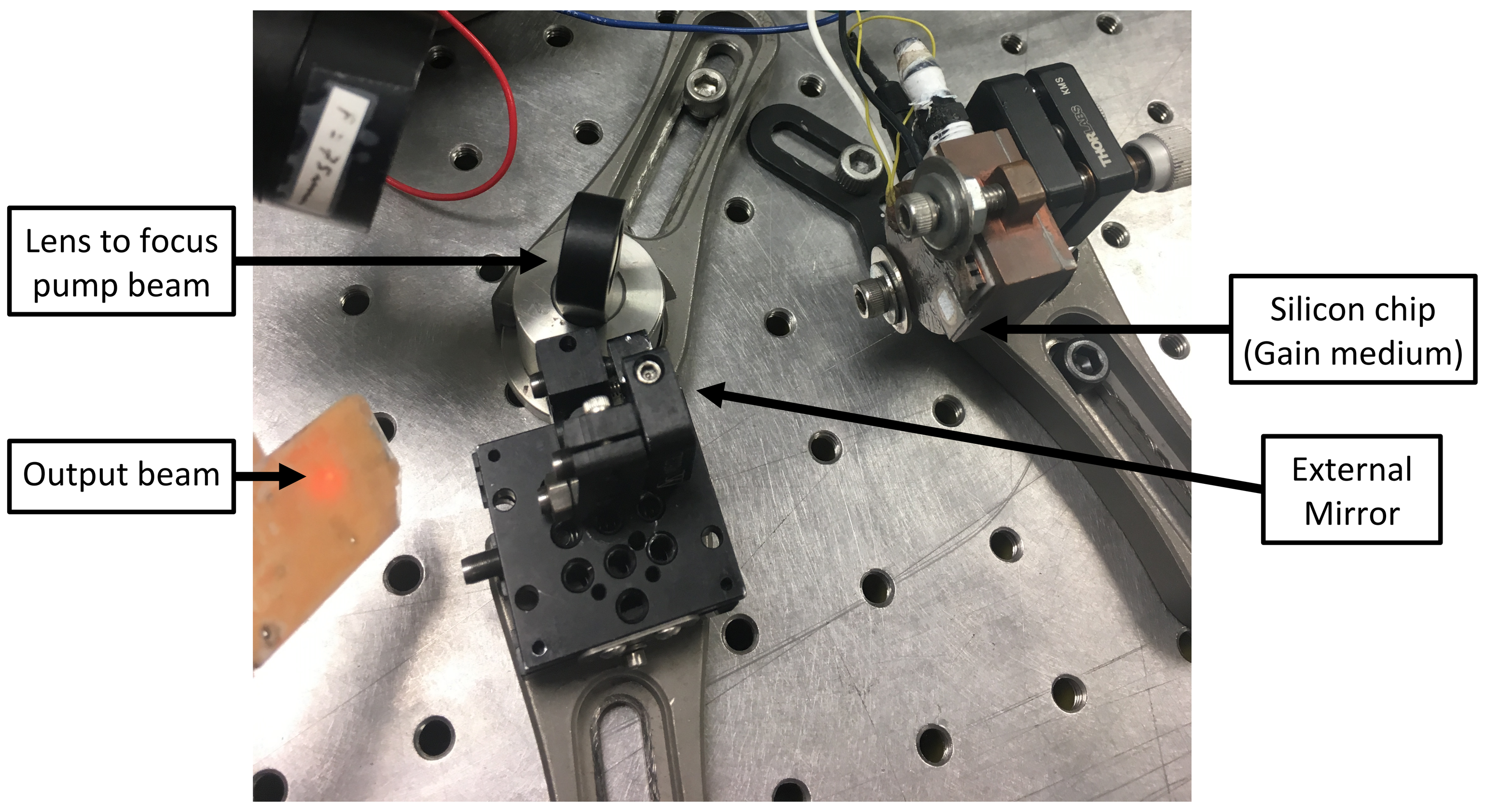


Fig. 1: A VECSEL constructed in the Laboratory of Space Systems and Optomechanics. The silicon chip, external mirror, lens for focusing the pump beam, and the output laser beam can be seen

Fused-Silica Mechanical Resonators

A fused-silica mechanical resonator will be the base for the VECSEL, which will form the Gravimetric Optomechanical Laser when combined. The silicon-chip will be mounted on the stationary outer plate, while the external mirror will be mounted to the test mass. As the test mass/mirror combination oscillates, the output frequency of the VECSEL will change. The motion of the entire system will be encoded into this frequency change. The fused-silica mechanical resonator was chosen because it is monolithic, the materials are compatible for our VECSEL materials, the geometry is lightweight and robust, and it allows for many mirror/chip configurations with it's double test mass set up.

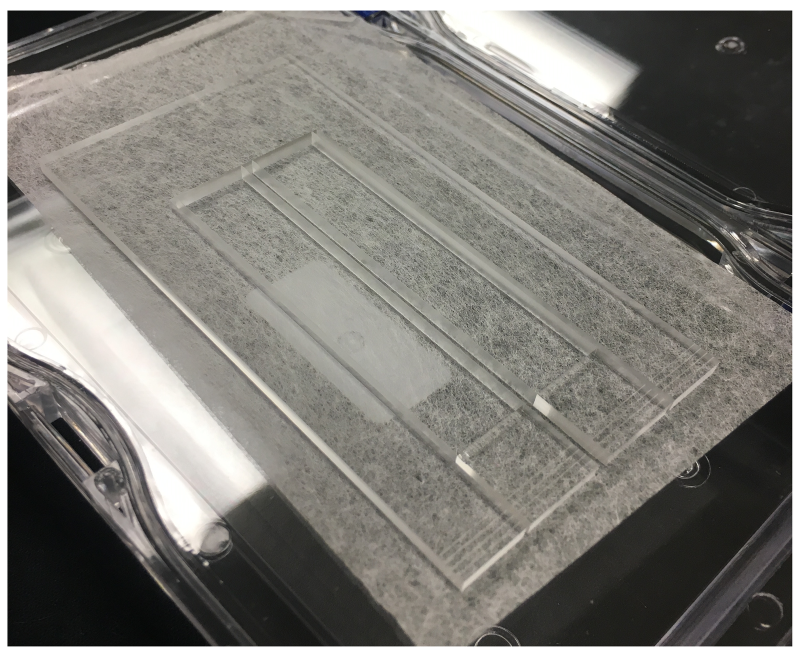


Fig. 2: Fused-silica mechanical oscillator to be used in conjunction with the VECSEL to create the Gravimetric Optomechanical Laser

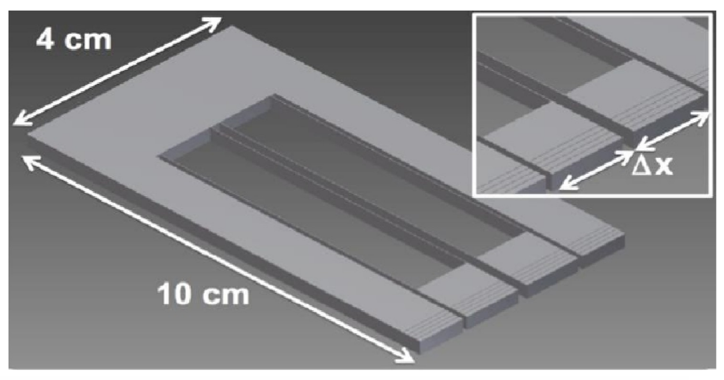


Fig. 3: Rendering of the mechanical oscillator showing the scale of the device. The area adjacent to the Δx is the section that oscillates. This will hold the mirror of the VECSEL.

Current Setup

The current goal of the project is to create and characterize the VECSEL that will be mounted onto the mechanical resonator. Currently an Eagleyard single mode laser diode is being used to pump the silicon chip. This pump beam is focused by a lens onto the silicon chip. The light is amplified by the silicon chip which emits the amplified light at the concave mirror. The space between the silicon chip and the concave mirror constitutes the cavity of the VECSEL laser. Because a VECSEL is defined by it's external cavity, there is no need to create an area of vacuum for the cavity. To induce lasing, the mirror can either be placed close to the chip (cavity length ~5 mm) or far from the chip(cavity length ~50 mm). Due to spatial constraints, the mirror is currently in the far position which allows for extra laser modes. In future iterations of the VECSEL, a shortening of the cavity could eliminate the extra modes, creating a mode locked laser.

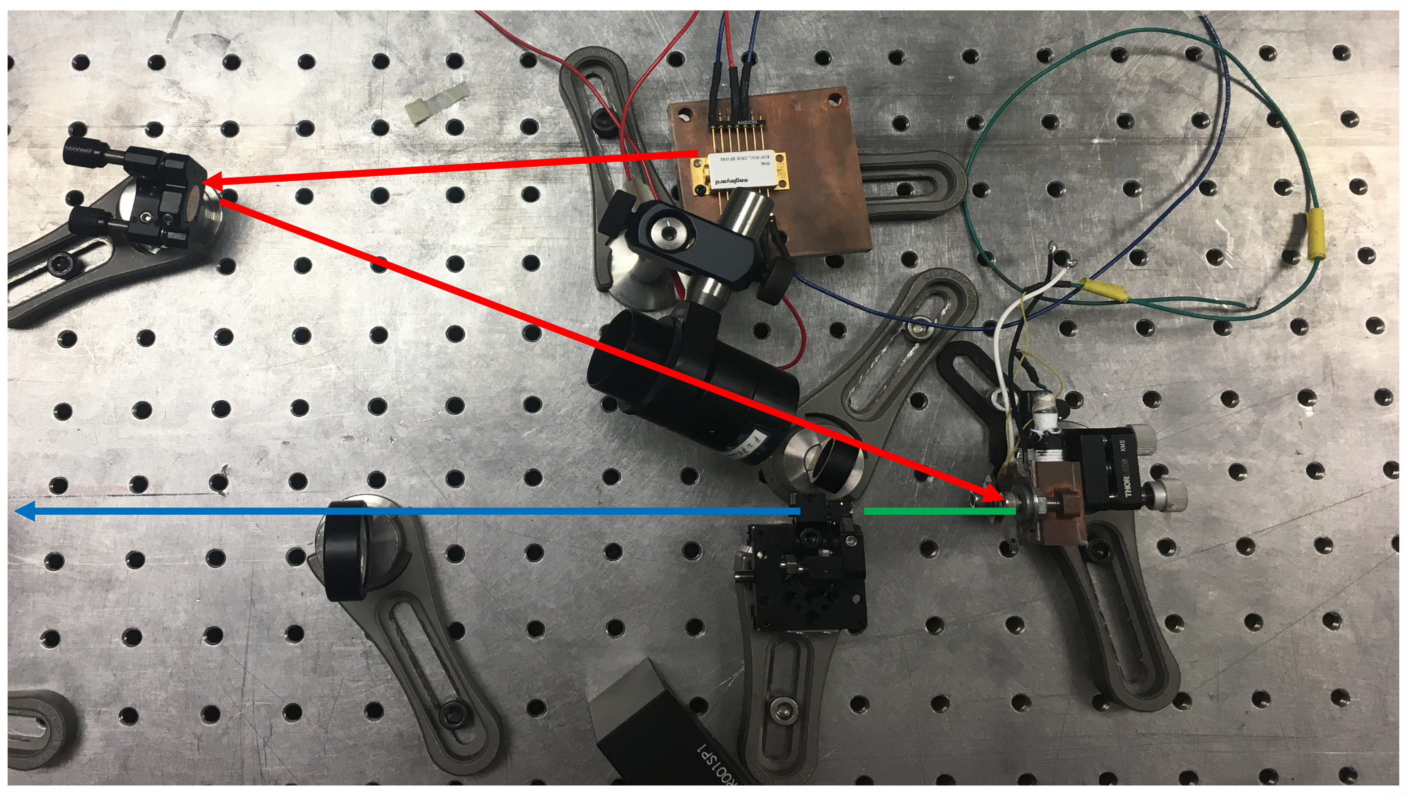


Fig. 4: The full VECSEL set-up can be seen. Lines are drawn to highlight: the pump to chip path (red), the laser cavity (green), and the output path (blue).

Near-term Development

Many steps are required before the gravimetric optomechanical laser becomes a fully realized system. The first thing that must be done is a full characterization of the VECSEL itself. Once characterized we hope to eliminate the multiple modes until it becomes a mode locked laser. Once the VECSEL is ready, the method for mounting must be established. The current plan is to mount the mirror to the test mass and have the silicon chip mounted to the stationary base. The stationary base will be attached to the frame of the resonator. This will ensure that any movement measured by the system is only due to the movement of the mass, and not the base. The final goal is to create a lightweight compact system with accuracy of 10^{-10} ms^-2/√Hz.

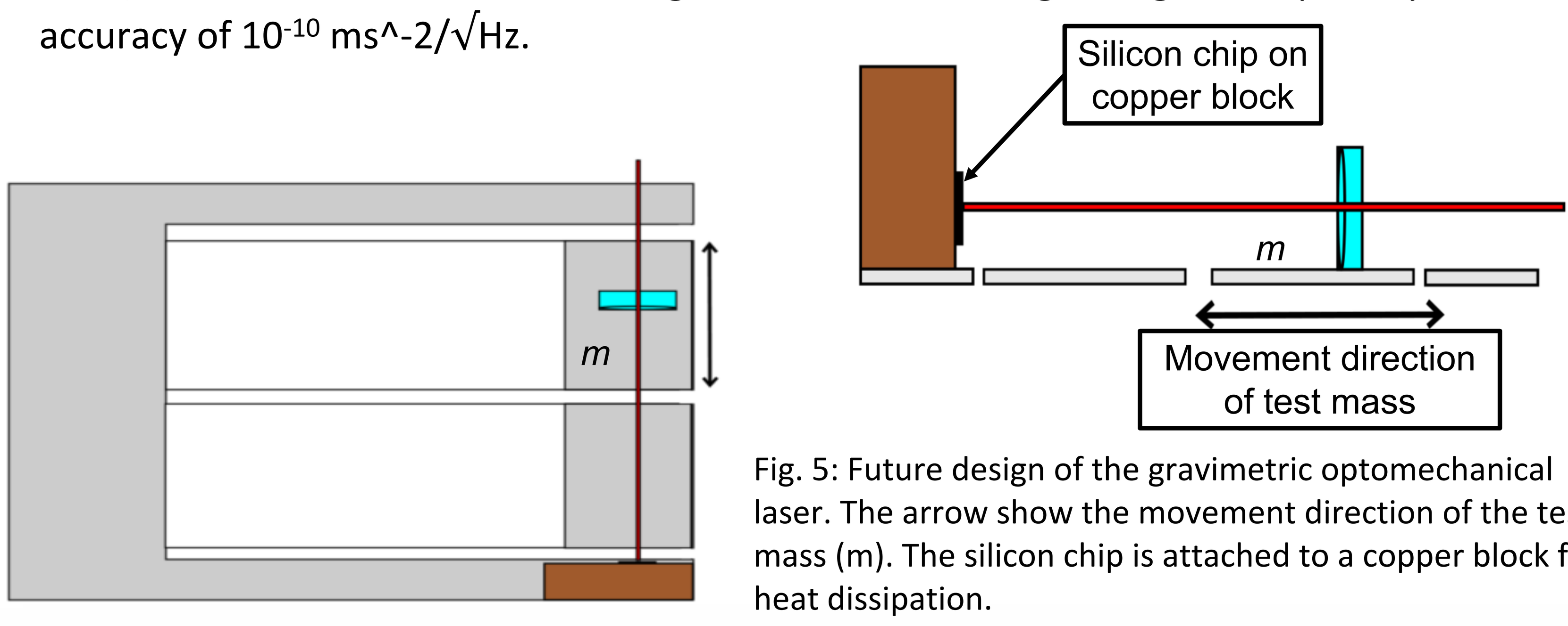


Fig. 5: Future design of the gravimetric optomechanical laser. The arrow show the movement direction of the test mass (m). The silicon chip is attached to a copper block for heat dissipation.

References

[1] Guzman F., Kumanchik L.M., Spannagel R., Braxmaier C. (2018). "Compact fully monolithic optomechanical accelerometer". Physics. App-ph. arXiv: 1811.01049

[2] Guzman F., Taylor J.M., and Pratt J.R. "Optomechanical laser for dynamic measurement", 2017. U.S. patent #US20170373462A1

[3] Rahimi-Iman A. "Recent advances in VECSELs". Journal of Optics. vol. 18. September, 2016.

[4] Okhotnikov O.G., editor. "Semiconductor Disk Lasers". Wiley-VCH, Weinheim, Germany, 2010.