An Ultra-High Vacuum Compatible Optics Positioning System for Quantum Science with a Ytterbium Atom Array

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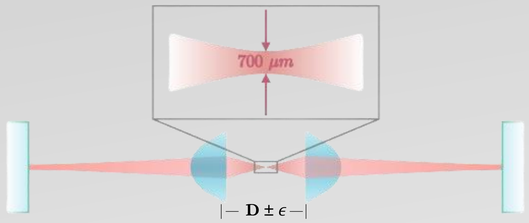
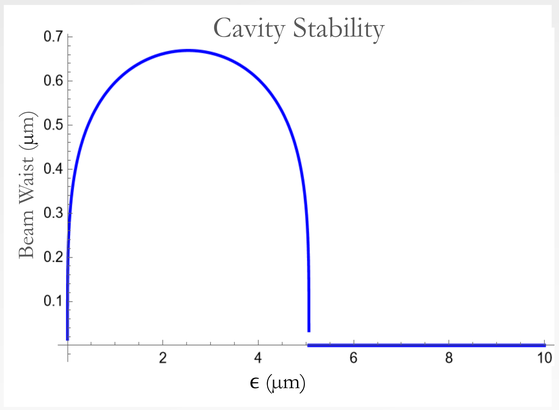
Motivation and Introduction

- Design optical cavities to serve as an efficient interface between atoms and single photons
- Use array of Ytterbium atoms as qubits for a quantum processor
- Use cavities for fast and efficient readout of the qubit state for quantum error correction and networking



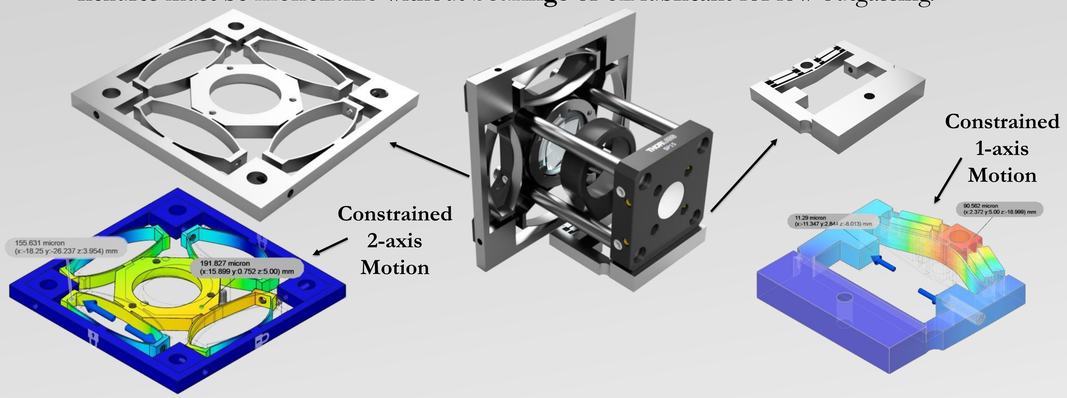
- Trap atoms with lasers at the **beam waist** (highest intensity)
- Small (~1 μm) differences in alignment between optical elements lead to larger beam waists and less efficient coupling
- Creating a cavity using mirrors and aspheric lenses (to remove aberrations) allows us to achieve small beam waists. However, this waist only exists for certain distances between the lens and mirrors (ϵ)

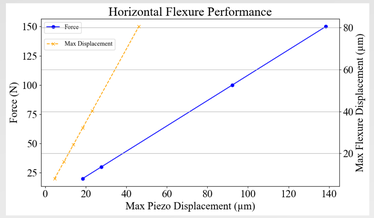


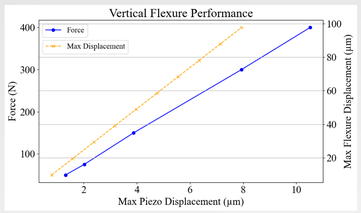
- The waist exists for ranges of 0-6 microns!
- This requires precise optical positioning without standard actuators (which use lubricants) that cannot be used in an ultra-high vacuum

Experimental Setup and Results

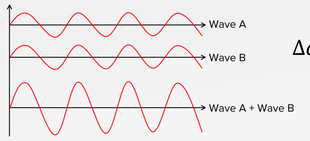
- **Piezo flexure stages** allow for precise positioning of lenses. For ultra-high vacuum compatibility, flexures must be **monolithic** without **bearings** or **oil** lubricant for low outgassing.



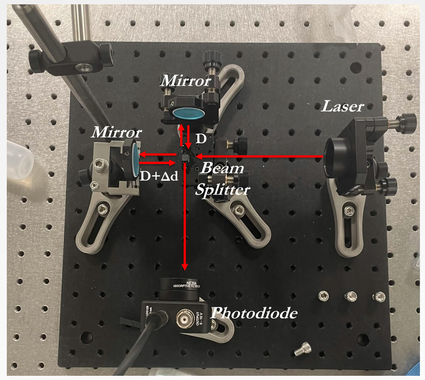


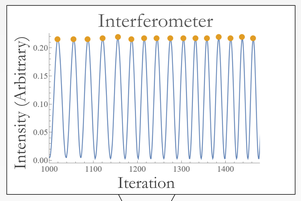


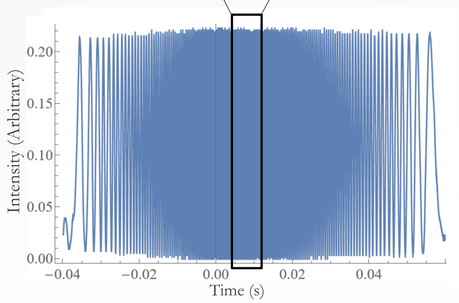
- **Michelson Interferometer**
  - Flexure is driven by oscillating piezo, causing variation in D
  - Variation in *D* causes constructive and destructive interference at oscilloscope output



$$\Delta d = \frac{m\lambda}{2}$$

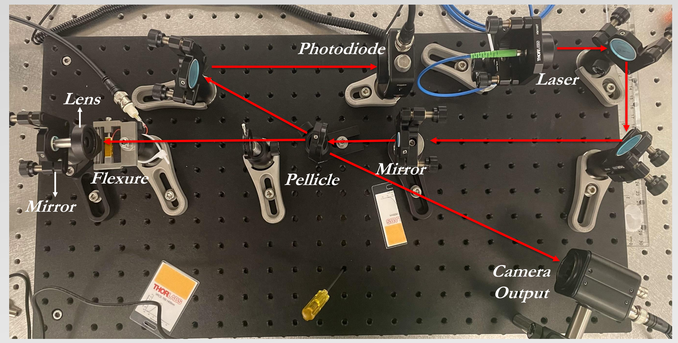


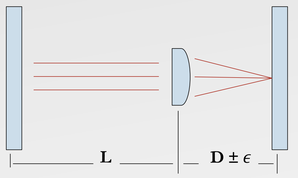


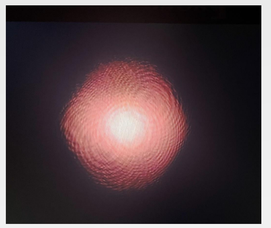


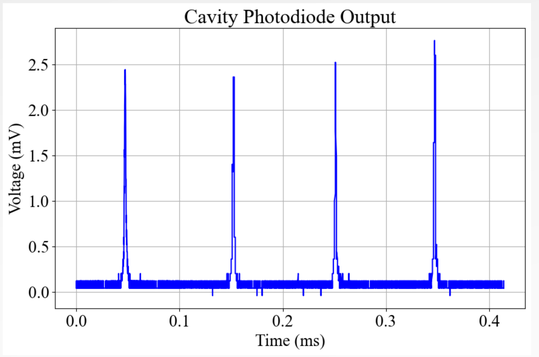
- Each voltage peak corresponds to constructive interference or one value of $\lambda/2$. Total displacement ~80 microns
- We have high peak sharpness, giving us a resolution of ~3 nm

"Toy" Small Waist Cavity









Future Work

We successfully created a **flexure** and demonstrated that it can be used to create **cavity waists**. The next steps are to make the designs **monolithic** and **vacuum safe**. In addition, will do a full testing of the 3D flexure and assemble the two-lens cavity.

Acknowledgements

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References

Shadmany, Danial, et al. "Cavity QED in a High NA Resonator." arXiv preprint arXiv:2407.04784 (2024).