# Construction of a Tapered Amplifier for Use in Ultracold Atom Experiments

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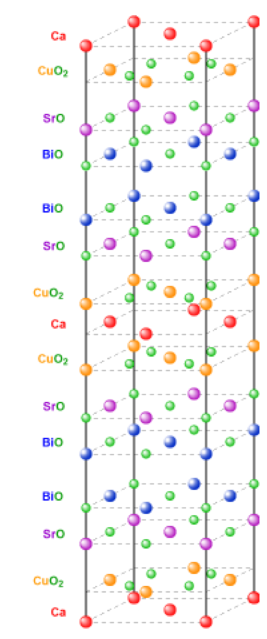
## Project Overview

At temperatures just millionths of a degree above absolute zero, atoms begin to exhibit behaviors that reflect their underlying quantum nature. Additionally, when confined in optical lattices, they provide an effective way to model electron movement in crystal lattices. This is important, as many high-temperature superconductors are complex crystalline structures.

Although there are many techniques that are required to achieve such temperatures, laser cooling is a particularly crucial step. It is used in establishing a Magneto-Optical Trap, which is the starting point of the experiment. Using a tapered amplifier (TA) in the laser beam we use to cool the atoms, we could enjoy shorter timescales to complete an iteration of the experiment.



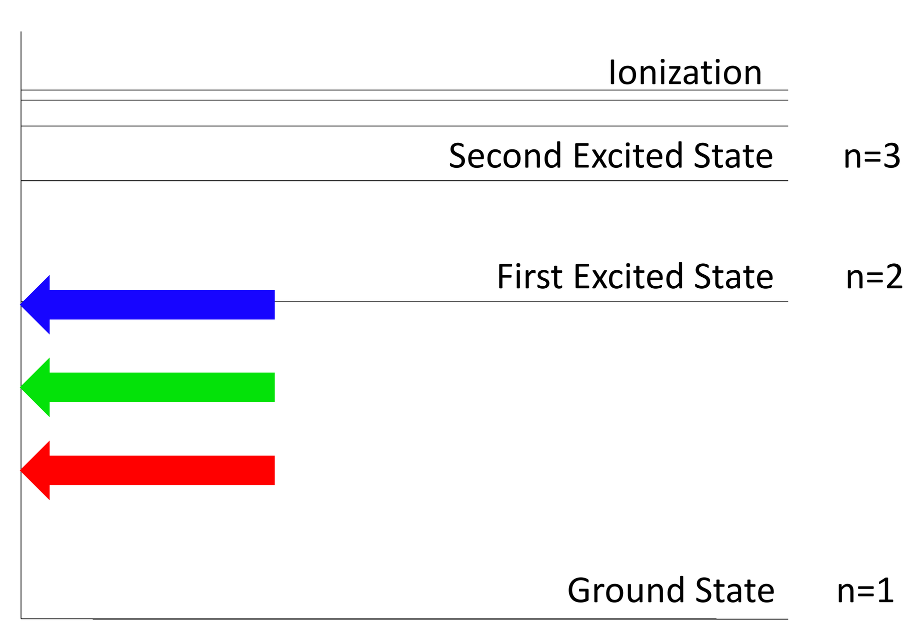
High temp. superconductor BSCCO-2212 (J. Slezak)

## Laser Cooling Theory

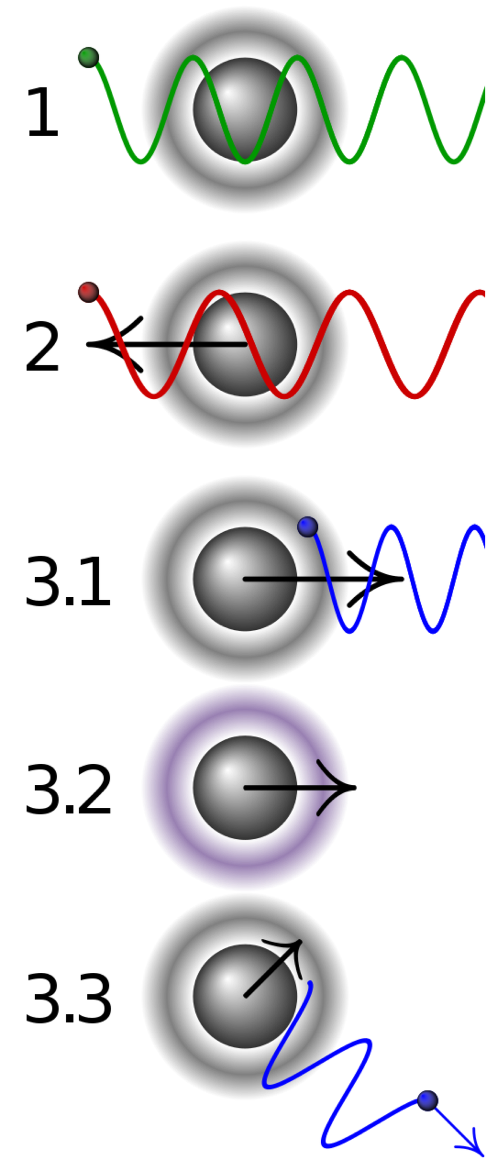
The doppler effect states that the perceived frequency of light is dependent on the observers velocity. Since the energy of a photon is proportional to frequency, the atom will 'see' photons with different energy depending on its speed and direction of motion.

1. A stationary atom sees a green, or medium energy, photon.
2. An atom moving away from the light source sees a red-detuned atom, and does not absorb it.

3.1. An atom moving towards the source sees a blue-shifted atom, which has enough energy to be absorbed.
3.2. Post-absorption, due to the conservation of momentum, the atom recoils after absorbing both the energy and momentum of the incident photon.
3.3. The atom will re-emit the photon in a random direction, and over many cycles, the process will only selectively 'cool' the sample.




The energies of photons as seen by the atom at different relative velocities. Only the blue-shifted photon matches an allowed energy level.

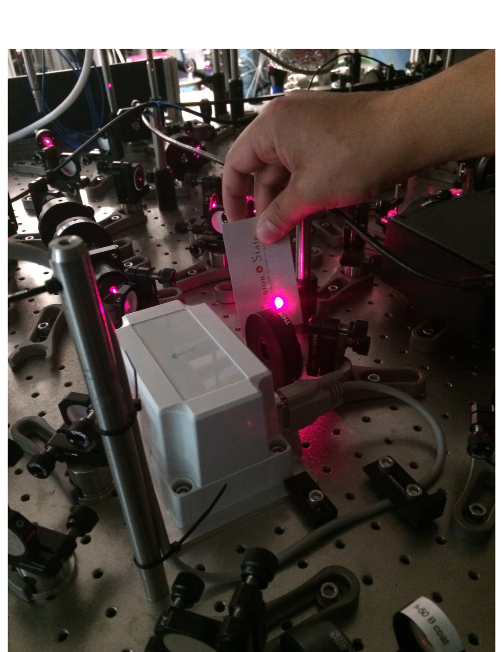



An illustration of how doppler cooling works. The relative motion affects which photons it can absorb. See energy diagram (left). (Cmglee)

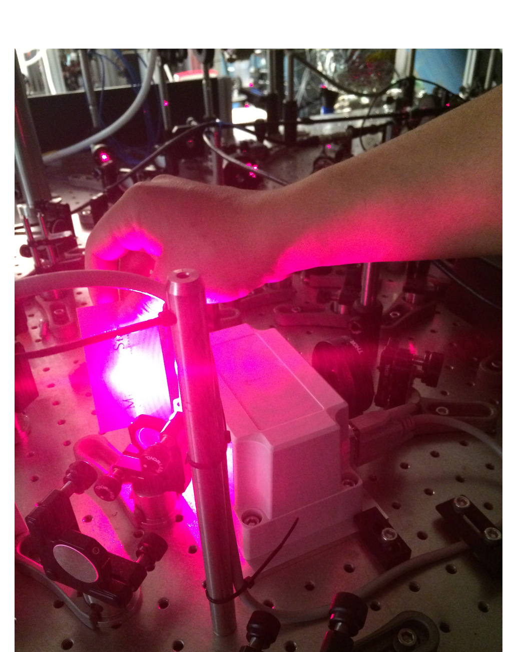
## Project Goals

The increase in power that we hope to achieve is perhaps best seen pictorially. The input beam will have approximately 30 mW, and the desired output is approximately 500 mW.

We hope to use the power of the tapered amplifier to decrease the amount of time it takes to perform an iteration of our experiment. Right now it takes around 38 seconds, and due to the large number of iterations that we take in a given day, a decrease to 30 seconds could save hours over the course of a day.

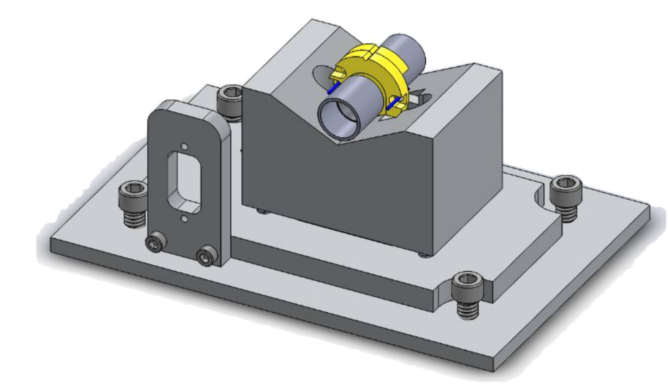


The input beam, before passing through the TA.

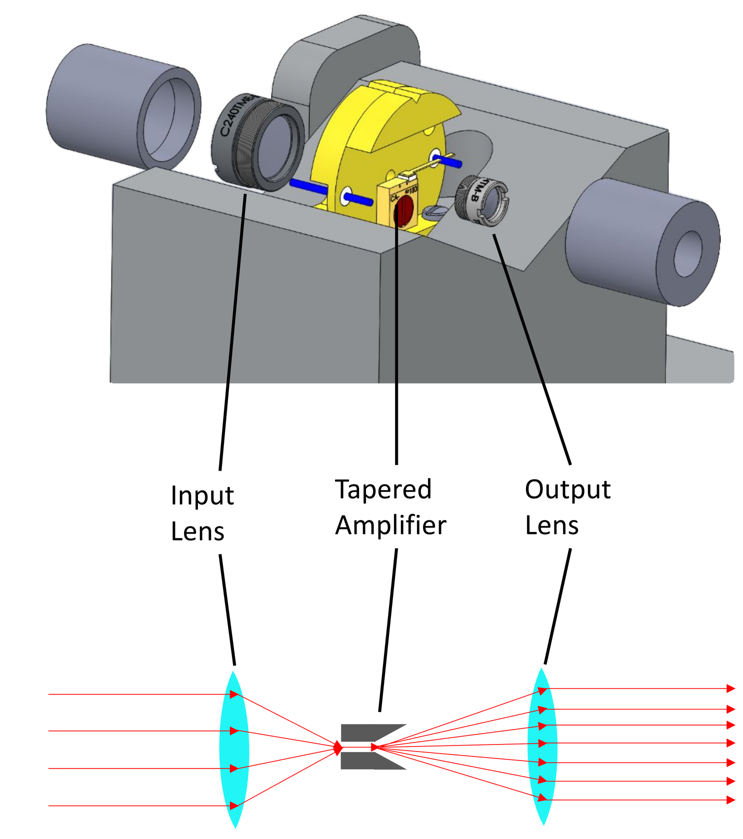


The output beam, after passing through the TA.

## Amplifier Design



An illustration of the fully assembled TA setup.




Computer-aided design (CAD) shown next to a simplified schematic showing the main elements of the TA: the input lens, the amplifier itself, and the output lens.

Light is focused into the amplifier, gets amplified, and then collimated using the output lens.

The setup is designed around the need to focus the light into the amplifier and stop it from diverging after it is amplified.

To do this, we utilize two lenses, on either side of the TA mount (depicted in yellow above).

The amplifier itself increases the power of the beam through stimulated emission. Although this increases the number of photons in the beam, it also makes it more divergent, and the light must be collimated (focused at infinity).

## Predicted Results

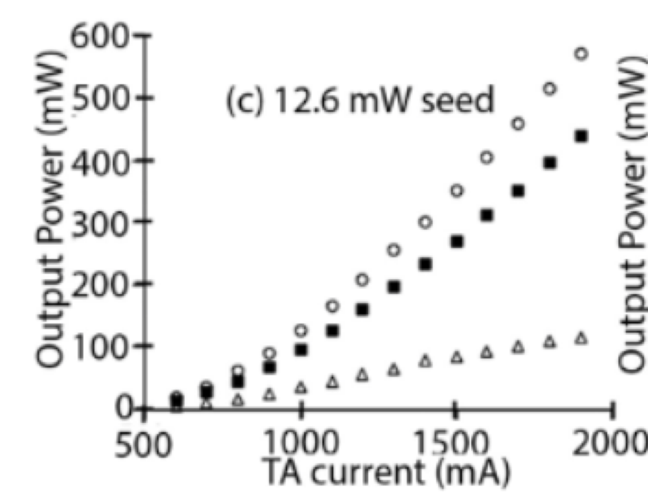



Figure 1: Output power vs. current sent through TA (multiple data sets reflect measurements taken at different locations)

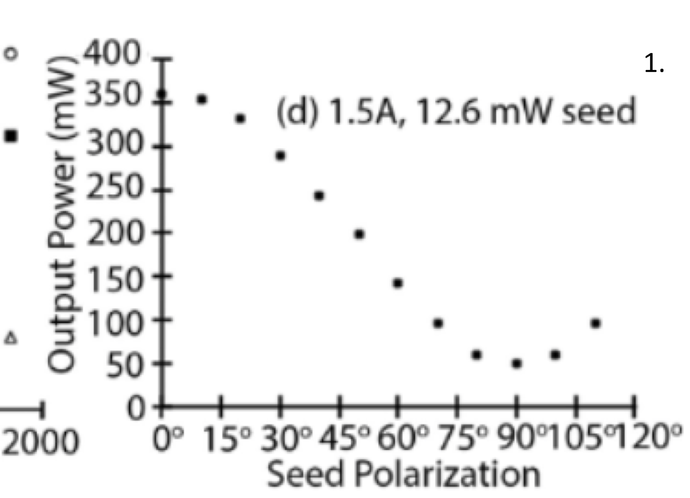



Figure 2: Output power vs. polarization of the input power

Although the completion of the amplifier is beyond the scope of the summer, there are some important results with respect to the output power that we expect to see. There are two important input parameters, which are the the current going into the TA and the polarization of the incoming light.

As shown by figure 1, the power of the output beam is strongly dependent on the current going into the TA. As figure 2 displays, the polarization of the seed beam is also of prime importance, as a 90 degree phase shift from alignment will decrease the output power by almost a factor of 7.

Therefore, to obtain maximum amplification out of the device, we need to use a high input current that does not exceed the operating maximum of the TA, and ensure optimal polarization.

## Conclusions

By constructing this amplifier, we will benefit from a vast increase in power at a fraction of the cost of commercial options. With more power in our cooling laser, we will be able to perform iterations of the experiment in less time, which will afford us more robust data and conclusions.

## Acknowledgements

Everyone in Dr. Weld's lab deserves acknowledgement for helping and supporting me and my work on this project. In particular I would like to thank Kevin Singh for his mentorship and his willingness to pass on his knowledge and expertise to me. Additionally, I want to thank Dr. David Weld for giving me the chance to participate in his meaningful and exciting research. And last but not least, I owe thanks to CNSI and our sponsors in the lab for their generous support. Optics and food are not cheap!

1. Steck et al. "Design and construction of cost-effective tapered amplifier systems for laser cooling and trapping experiments." American Journal of Physics **82**, 805. (2014).