Solar Powered Laser

Design Team
Timothy Forrest, Joshua Hecht
Dalyssa Hernandez, Adam Khaw, Brian Racca

Design Advisor
Prof. Greg Kowalski

Abstract
The purpose of this project is to develop a device that produces a coherent laser beam powered by solar energy. The device is intended to be a proof of concept, and serve as a research tool to explore the viability of solar energy for hydrogen energy production, precision manufacturing, as well being a means to long-term solar energy storage. A CO\textsubscript{2} gas-dynamic laser was designed to integrate with a solar concentrator (from a previous Capstone project). The laser was first developed on the benchtop using a heating sub-assembly to heat an N\textsubscript{2}-He gas mixture to 1500K. The gas is passed through a converging-diverging nozzle and goes supersonic exciting the N\textsubscript{2} molecules. CO\textsubscript{2} is introduced as the gas mixture enters the laser cavity causing an energy transfer from the N\textsubscript{2} molecules to the CO\textsubscript{2}, and resulting in a population inversion of the CO\textsubscript{2}. Spontaneous emission occurs as some CO\textsubscript{2} molecules return to lower energy states causing the release of photons. External mirrors mounted on each side of the laser cavity amplify the photon population causing stimulated emission and initiating the lasing process. In addition to the benchtop laser cavity, the solar concentrator was optimized to heat a gas to 1500K so that it can serve as the heating sub-assembly and be integrated with the benchtop laser cavity.

For more information, please contact gkowal@coe.neu.edu.
The Need for Project

One of the most promising applications of solar powered lasers is its role in creating hydrogen fuels. A solar powered laser could provide a more efficient means to obtain hydrogen for fuel cells as well as a means to long-term solar energy storage. Another application for solar powered lasers is in precision manufacturing. Solar power could reduce dependence on electrical power to operate lasers. The solar powered laser was developed as a proof of concept to be optimized and studied for these applications, as well as other potential applications.

The Design Project Objectives and Requirements

Design Objectives

The goal of this Capstone project is to develop a device that produces a 10.6µm coherent laser beam that is powered primarily by solar energy. A heating sub-assembly will absorb solar energy, heating the lasing medium to 1500K. The solar energy will excite the atoms of the lasing medium to create a population inversion site and ultimately produce a coherent laser beam at the laser cavity.

Design Requirements

The laser system must produce a coherent laser beam, sustained solely by solar energy. The solar-powered laser design consists of three segments: the solar concentrator, a benchtop heating assembly, and the laser cavity. The solar concentrator must focus solar energy onto the heating assembly to heat the gas mixture (14% N₂, 86% He), to 1500K by the time the gas reaches the nozzle. The nozzle must create supersonic flow of the heated gas mixture to rapidly cool it. The lasing medium, CO₂ gas, must then be introduced to the gas mixture, causing a population inversion to occur at the laser cavity. All assemblies must withstand the high temperature, and remain sealed, to maintain a population inversion in the laser cavity. The laser cavity mirrors must be mounted and aligned such that the...
distance between them is a multiple of 10.6μm, the wavelength of a CO₂ laser beam. The laser cavity must be enclosed with material that absorbs infrared wavelengths to ensure the safety of its operators and its environment.

Design Concepts considered

Two thermally-pumped laser methods were considered, and a CO₂ gas-dynamic laser was selected. The primary constraint for the selection of a lasing method and medium was the ability to integrate the laser with the solar concentrator. Pumping, or powering, the laser using solar radiation directly is infeasible due to the broad spectrum of sunlight, so laser methods which utilize thermal energy provided by the collector were investigated. Two thermally pumped laser concepts were investigated: blackbody-pumped lasers, which utilize radiation in a blackbody chamber to cause CO₂ gas to lase; and gas-dynamic lasers (GDLs), which utilize supersonic expansion of heated CO₂ gas to lase. A gas-dynamic laser was chosen for this design. This form of laser is thermally powered, using gas dynamic principles to selectively convert the thermal energy into molecule excitation. A GDL device concept (Figure 1) developed by Sperry Corporation was especially relevant to the Capstone solar-powered laser design and proved to be very beneficial in understanding this method of inverting the population of the CO₂ and N₂ gas mixture. The CO₂ gas-dynamic laser technique ideal for this Capstone proof of concept device because it is capable of a greater efficiency in the 1000-1500 Kelvin temperature range that can be achieved by the solar concentrator.

Recommended Design Concept
For easy integration with the solar concentrator, a CO₂ gas dynamic laser cavity was designed.  

Design Description

Overview

To allow for development of the laser system prior to integration with the solar concentrator, an analogous benchtop system was designed. The benchtop layout is shown in Figure 1 and consists of a heating sub-assembly in which N₂ gas is heated to 1500 kelvin and passed through a converging-diverging nozzle. The gas achieves supersonic flow at the throat of the nozzle. As the gas expands at the diverging throat of the nozzle, a shockwave occurs, exciting the gas. As the gas travels through the cooling tube it is brought back down to room temperature but remains excited due to its long molecular relaxation time. CO₂ is introduced and due to their similar vibrational quantum states is excited by the N₂—creating a population inversion necessary for the lasing process. The gas mixture is introduced into the lasing cavity where mirrors amplify the photon cascade and ultimately creating a laser beam.

Laser Cavity

The laser cavity consists of brass tubing with T-fittings on each end to create a vacuum and introduce the gas. Mirrors are externally mounted at each end of the laser cavity and the entire assembly rests on a linear slider to aid in alignment (Figure 2). The end cap assemblies include modified flanges that accommodate zinc selenide windows which allow infrared radiation to pass through the cavity (Figure 3).

Analytical Investigations

Statistical analysis was performed to predict where the population inversion would occur for the best chance of achieving spontaneous emission within the laser cavity. This analysis was based on the vibrational energy states of the N₂
and CO$_2$. Heat transfer analysis was also included for the heating element for the benchtop in addition to the cooling tube to ensure that the gas returned to room temperature after the nozzle.

**Experimental Investigations**

The solar concentrator was modified to improve the stiffness and reflectivity. Testing of the solar concentrator will be completed to ensure that the gas reaches the temperature necessary for the lasing process to occur. A beam detection card will be used to determine whether the benchtop device produces a coherent laser beam. The beam detection card, as well as the entire laser cavity, will be enclosed to protect the operators and the environment from potential scattering of IR waves.

**Key Advantages of the Recommended Concept**

The solar-pumped CO$_2$ gas dynamic laser has significant advantages over other thermally pumped laser cavity designs. The lasing media, CO$_2$, is inexpensive and readily available, compared to other lasing media such as yttrium aluminum garnet (YAG) crystals. An advantage specific to this concept is that the heating sub-assembly and laser cavity can easily be integrated with the solar concentrator.

**Financial Issues**

A total of $2,198 was spent on the laser cavity prototype, the heating sub-assembly, improvements of the solar concentrator, safety equipment, and on various tools required for building and testing the system. The cost of the laser cavity
equipment, and on tools required for building and testing the system. prototype was $1098, the largest percentage of the total cost. As expected, more than half of the cost of the laser cavity prototype was spent on the optics. At $505, safety equipment also represented a large portion of the budget.

**Recommended Improvements**

Optimization of the laser cavity and gas heating assembly may increase the power output and efficiency of the solar-powered laser. Improvements made to the laser cavity and the gas heating assembly may increase the power output and the system’s efficiency. Replacing pipe threads with welded tubing may help reduce vacuum leaks at the laser cavity. A cooling jacket may be added around the laser cavity to carry more heat away from the tube, resulting in a higher output power. The gas heating assembly can be improved by creating a vacuum within the insulating quartz tube. The creation of a vacuum would eliminate heat loss due to convection and increase the temperature.