Characterization of the Absorption Spectrum of Deuterium for Infrared Wavelengths

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Summer Research Project:

Characterization of the Absorption Spectrum of Deuterium Ice

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Introduction

The primary goal of the research undertaken at the Laboratory for Laser Energetics is to achieve fusion reactions with the highest energy yield possible. A high energy yield is achieved from an OMEGA target implosion experiment when the target sphere is compressed uniformly by the OMEGA laser. Therefore LLE scientists strive to achieve the most uniform compression of the target that is possible. In order to compress uniformly, both the shell of the target and the distribution of the deuterium fuel within must be as uniform as possible. When deuterium gas is used as a fuel, the gas fills the sphere in a uniform manner owing to the random motion of gas particles. However, the target type of choice for fusion experiments in OMEGA is a target shell containing a uniform thickness of deuterium ice. Deuterium ice is a more desirable fusion fuel than deuterium gas because the solid form is more dense, allowing a greater quantity of deuterium molecules to fit within the target. However when the target contains solid deuterium, the process of ensuring target uniformity is considerably more complex.

Owing to the effect of gravity during the process of freezing, the deuterium ice layers are naturally non-uniform. To obtain the desired high degree of uniformity, the layers are smoothed by bathing the target in infrared from an optical parametric oscillator (OPO) laser. Owing to the excitation of the deuterium molecules by the infrared, energy from the OPO laser is absorbed by the ice as heat. Areas in the target with high ice thickness become hot and the deuterium melts, forms a gas, and is redeposited in the cooler, lower thickness areas of ice deposition. This process is continued until there exists a dynamic equilibrium within the target sphere between boiling and deposition that creates a uniform layer of ice within the sphere.

The process of creating a target shell containing deuterium ice begins in the same manner as for a deuterium gas target. The target is placed within pressure and temperature specific conditions that facilitate the diffusion of deuterium gas through the permeable wall of a target shell until the desired quantity of fuel has entered the shell and it is rendered impermeable to continued diffusion. When the goal of the target fabrication process is to produce a deuterium ice target, the aforementioned shell is exposed to extremely cold temperatures in a controlled environment that causes the deuterium within to slowly freeze and form the layer of ice on the inside surface of the spherical target shell.

The OPO laser is tunable and the wavelength of the infrared used is between 2.9 and 3.4 micrometers. These wavelengths are used because they most closely match the frequency at which the deuterium molecule vibrates. The infrared is absorbed with the greatest efficiency at these wavelengths.

Experiment

The goal of the project was to characterize the absorption spectrum of deuterium ice. Specifically, we wish to know how the absorption varies with the infrared wavelength. The target smoothing process can be made more deterministic if it is known what wavelength of infrared is best absorbed by the deuterium ice. The ice could be smoothed to a greater degree of uniformity and perhaps at a faster rate. To determine how well deuterium ice absorbs infrared wavelengths, an apparatus was specially created. A cylindrical cell one centimeter deep with a radius of one centimeter was created to hold a controlled amount of deuterium gas supplied by an external source. The cell's walls are composed of a heat conducting metal. The bottom and top of the cylindrical cell were made of thin polyimid which does not significantly absorb the wavelengths of infrared radiation used for our test. The cell is housed within a cylindrical, airtight chamber to permit the creation of a vacuum. The presence of a vacuum allows the chamber to be cooled below the freezing point of deuterium to around 16 Kelvin. A small heating coil is attached by heat conductive metal to the cell. This allows the temperature within the cell to be manipulated from around 16 Kelvin to 25 Kelvin. This range of temperatures allows for the deuterium in the cell to be heated or cooled to obtain the solid, liquid, or gaseous form. By manually adjusting the current passing through the heating coil the deuterium could be slowly frozen to obtain visually uniform ice, devoid of cracks or major light-scattering imperfections. The uniformity of the ice in the cell was visually confirmed by the use of a video camera that could view the cell through a window in the chamber surrounding the cell. An optical parametric oscillator laser was shined through the cell which contained, at various times, solid, liquid, or gaseous deuterium. The OPO laser is tunable to a range of wavelengths, with a wavelength resolution of .01 micrometers. Figure 1 gives a picture of the apparatus and Figure 2 gives a diagram of the optical path through the apparatus.

To determine how much of the infrared radiation was absorbed by the phase of deuterium in the cell, optical elements were placed before and after the cell in the path of the laser. These optical elements reflect a known proportion of the infrared to InSb photodiodes. The infrared which is reflected onto the photodiode generates a current which we measured and recorded. By comparing the measured amperage from both photodiodes, we could determine how much of the infrared was absorbed by the deuterium.

We applied Beer's Law to determine how much of the infrared radiation was absorbed by the deuterium. For our project, Beer's law is written as $I_{tr}=I_o\exp(-al)$. I_o is the amperage measured by the photodiode placed before the cell in the optical path. I_{tr} is the amperage measured by the photodiode placed after the cell in the optical path. The absorption coefficient is denoted by the term "a". The length of the optical path is denoted by the term "l". "a" is the unknown term we are trying to determine. By using the amperage data we collected, the absorption coefficient for a given wavelength can be determined. These values can be applied to the target smoothing process to make it more deterministic. The wavelength found to have the greatest absorption coefficient would be the best wavelength to use in the target smoothing process.

Our current data is not statistically significant, as an insufficient number of accurate trials have been performed up to this point. However, our preliminary findings as illustrated by figure 3, a graph of absorption of infrared radiation by deuterium solid and liquid phases, indicate that the deuterium ice best absorbs an infrared wavelength of 3.16 microns. Further trials will hopefully establish the validity of this result.

Conclusion

The project is not yet finished. The process of determining the absorption coefficients is incomplete. In the future, a broader range of the infrared spectrum will be characterized by the determination of the absorption coefficients at more wavelength values. The addition of a feedback loop will increase the power and wavelength stability of the OPO laser. More trials will be performed to increase the statistical significance of our results. The accuracy of the tunable wavelengths of the OPO laser will be verified by measurement with a spectrometer. These steps will ensure that the absorption coefficient values obtained are accurate. If the project is completed successfully, LLE scientists will be able to smooth deuterium ice targets for fusion experiments with greater efficiency.

Acknowledgments

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Figure 1: This is a picture of the apparatus used to cool the deuterium ice in the cell to around 16 Kelvin. Note the video camera above the chamber and the laser fiber below it. Note that a chopper was used to compensate for background noise.

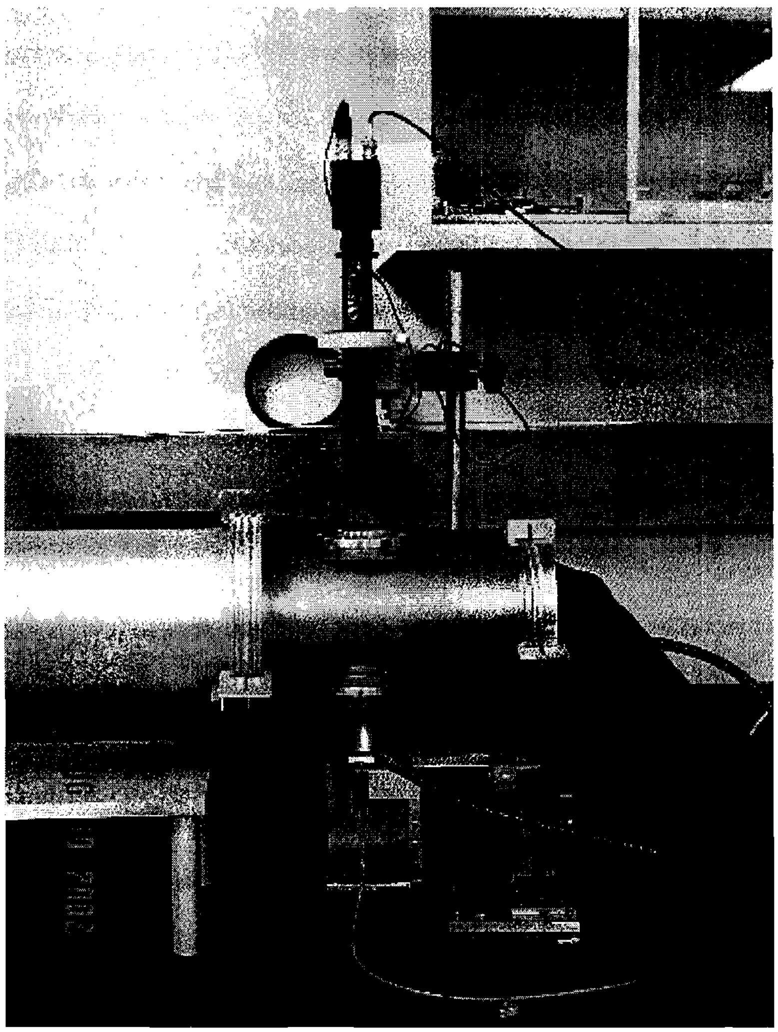

Figure 2 : A diagram of the optical path of the apparatus. Note the position of the InSb photodiodes before and after the deuterium cell in the optical path. Visible light was beamed into the optical path to permit the use of a video camera.

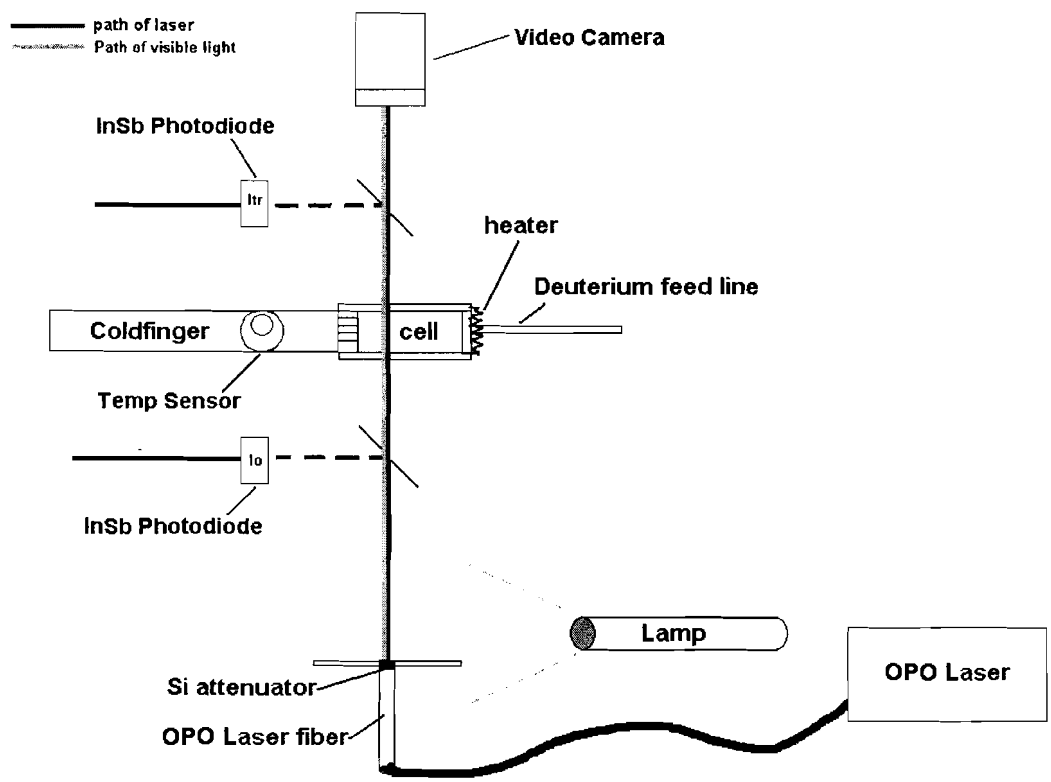

Figure 3: A graph of the absorbance of infrared radiation of deuterium ice and liquid phases. Note that the wavelength of greatest absorbance is 3.16 microns