Absorption Enhanced Liquid Ablation with TEA CO2 Laser

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Abstract

A novel technique for measuring of force as a function of time was developed for the study of enhanced momentum transfer in laser-ablated water solutions of Sodium Tetrafluoroborate [$NaBF_4$], a compound that strongly absorbs radiation in the 8-11 μm wavelength interval. A TEA CO_2 laser ($\lambda = 10.6$ μm), 300 ns pulse width and 8 J pulse energy, was used for ablation of water diluted $NaBF_4$ contained in a conical aluminum nozzle. Net imparted impulse and coupling coefficient were derived from the force sensor data and are reported below.

Introduction

The use of liquid ablatants for laser propulsion presents certain advantages over solid propellants. For example, the use of different ablation vessel geometries, *i.e.*, parabolic, conical, etc. can provide the optimal utilization of thrust. Another important advantage is the possibility to use solutions of varying concentration and quantity, depending on the current mission / maneuver requirements. Promising results on liquid ablatants for laser propulsion were reported, for example, in Refs. 1, 2.

It is known that Sodium Fluoroborate [$NaBF_4$] in its solid state presents almost zero transmittance in 8 μm to 11 μm wavelength range, which matches the TEA CO_2 laser wavelength [10.6 μm].[3] This served as an incentive to investigate potentially enhanced momentum transfer of ablation of this “sensitizer” diluted in water using CO_2 laser pulses , since higher absorption would mean a more efficient conversion of laser pulse energy into ejected ablatant. Of course, at these wavelengths water itself is a very good absorber (Figure 1), so it would prove worthwhile to investigate if the added compound would increase momentum even further

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14. ABSTRACT

A novel technique for measuring of force as a function of time was developed for the study of enhanced momentum transfer in laser-ablated water solutions of Sodium Tetrafluoroborate [NaBF4], a compound that strongly absorbs radiation in the 8-11 µm wavelength interval. A TEA CO2 laser (λ = 10.6 µm), 300 ns pulse width and 8 J pulse energy, was used for ablation of water diluted NaBF4 contained in a conical aluminum nozzle. Net imparted impulse and coupling coefficient were derived from the force sensor data and are reported in this paper.

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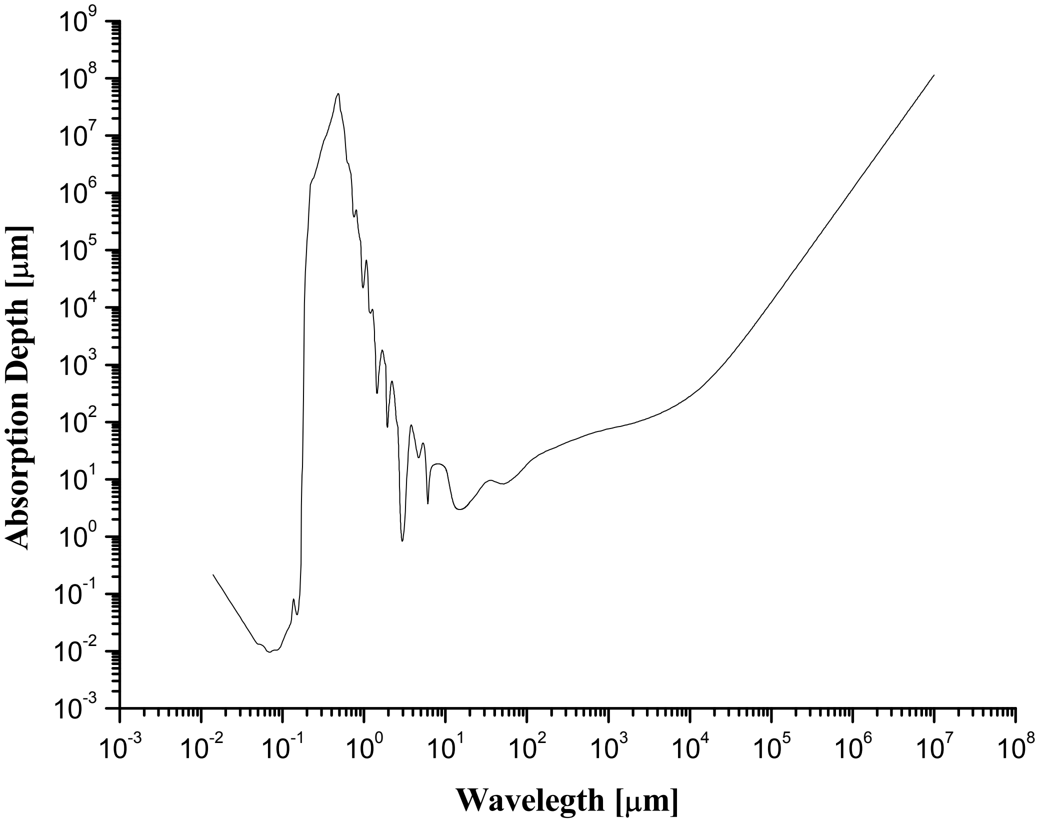

Figure 1. Absorption spectrum of water.

Momentum imparted to various solids has been investigated by our group in former experiments at atmospheric pressures, as well as vacuum, using a piezoelectric force sensor.[4] The sensor measures force imparted to the ablated surface, which in turn may be resolved temporally to obtain momentum, specific impulse and coupling coefficient (C_m). Other techniques for measurement of these parameters, such as ion time-of-flight and time-resolved ICCD imaging have been compared with force measurements,[5] thus proving it to be a reliable technique.

In our early experiments we were unable to resolve the force as a function of time. For this reason, the impulse data was derived from temporal extrapolations.[4] In order to accomplish this study, we attempted to resolve the imparted force as a function of time. Then, if successful, we planned to derive the impulse from force waveforms by integration.

- Transverse Excited Atmospheric CO_2 laser [Lumonics TEA-100-2] (for detailed description of the laser output characteristics see Ref. 6).
- Pulse duration 0.3 μs, 8 J pulse energy at 10.6 μm wavelength.
- Laser pulse was attenuated to 0.5 J to minimize air breakdown effects on the liquid surface using polytetrafluoroethylene plates.
- Force measurements done using piezoelectric sensor PCB-209 C01 [5 μs rise time].
- Varying molar concentrations of $NaBF_4$ were ablated from a conical nozzle cut inside an aluminum pellet [cone expansion ratio of 6]. Molarity of saturated solution was M = 10 mol/l.
- Ablatant volume kept constant at 10 μl.
- Additional ablation experiments on pure water using Molectron MY32-10 Nd:YAG laser. Pulse duration 15 ns, energy 200 mJ at 1064 nm wavelength.

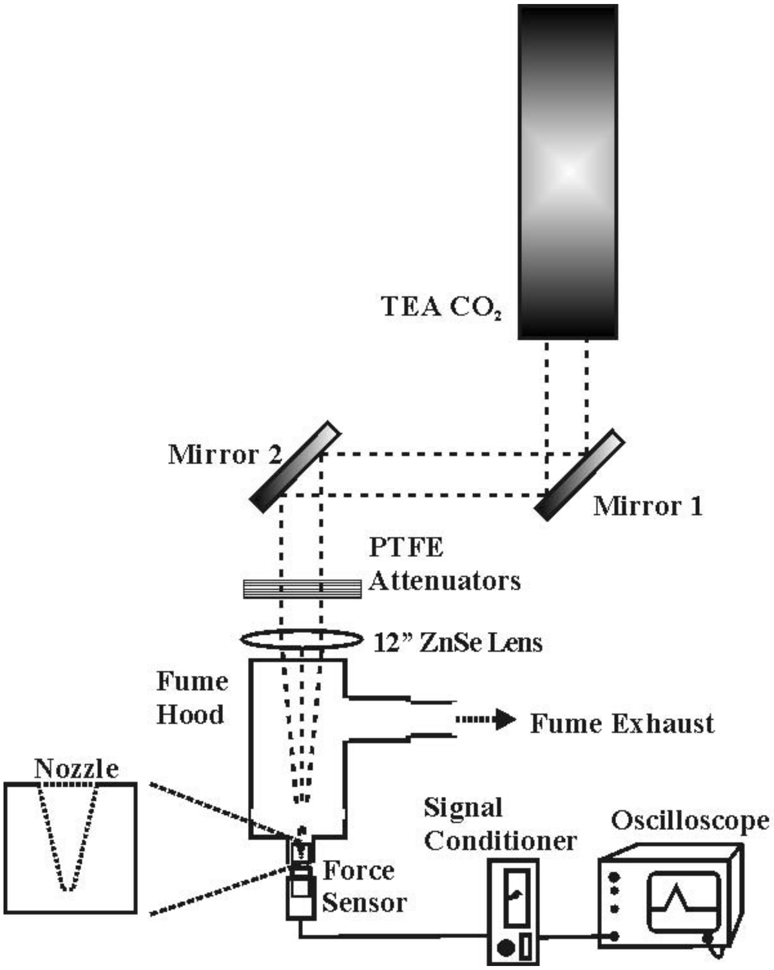

Figure 2. Experimental setup

Results and Discussion

Momentum imparted to the aluminum nozzle was determined from the area under the curve of the force sensor readings. Coupling coefficient was then calculated by dividing momentum by laser energy (500 mJ). A typical pulse profile of force as a function of time is shown in Figure 3.

Figure 4 shows the graph for the coupling coefficient at various molar concentrations; error bars show standard deviation of the data. The C_m uncertainties are due to nozzle jitter caused by the fume hood exhaust. As the graph shows, coupling coefficient is independent of fluoroborate concentrations. Since water has a skin depth of ~ 5 µm, the added sensitizer produces no effect on the absorption of radiation, and hence, on the imparted momentum.

Figure 5 shows the coupling coefficient C_m as a function of water volume. C_m linearly increases with volume up to 15 ml, while above 20 ml the function reaches a plateau. It is worth noting that for all experimental points of Figure 5 the fraction of removed mass stayed relatively constant as 3/5 of initial mass.

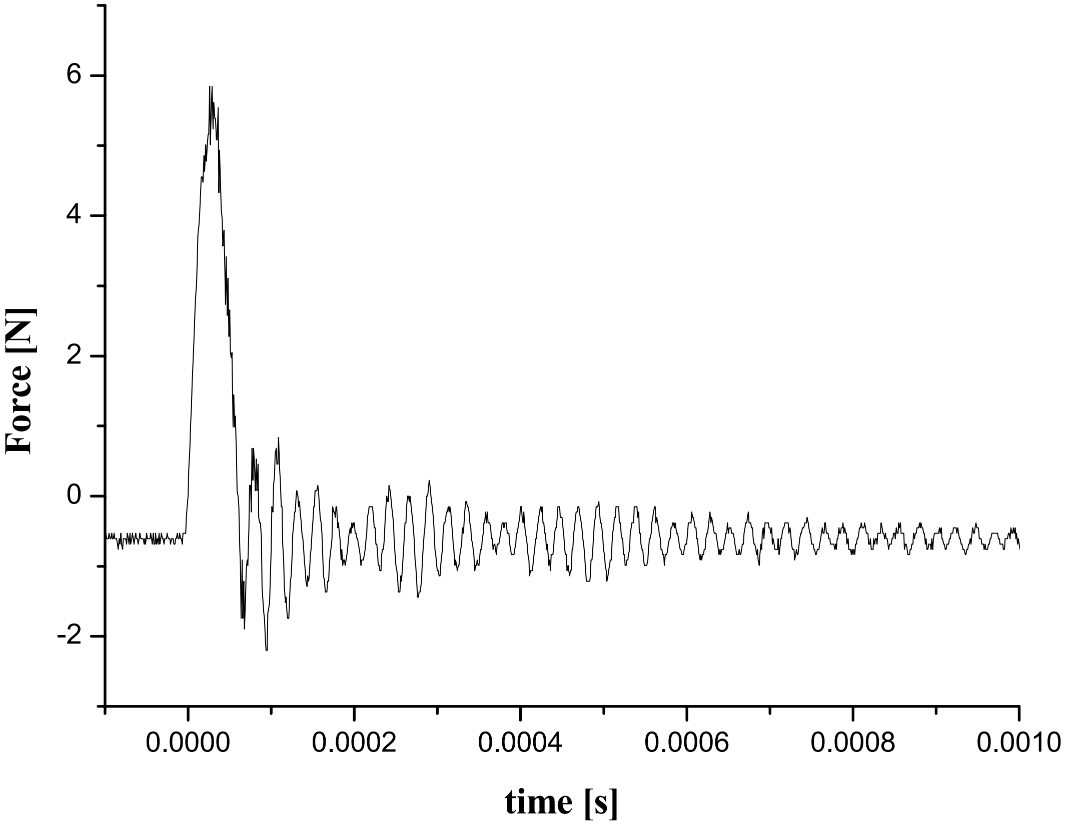

Figure 3. F(t) waveform.

Conclusions

- **Direct force as a function of time waveforms were measured for the first time.**
- **Addition of tetrafluoroborate to the water produced no effect on the absorption of radiation, and hence, on the imparted momentum.**
- **Coupling coefficients on water were ~ 40 dynes/W**
- **Further work will involve the analysis of coupling coefficient using alternate nozzle geometries and different laser wavelengths.**

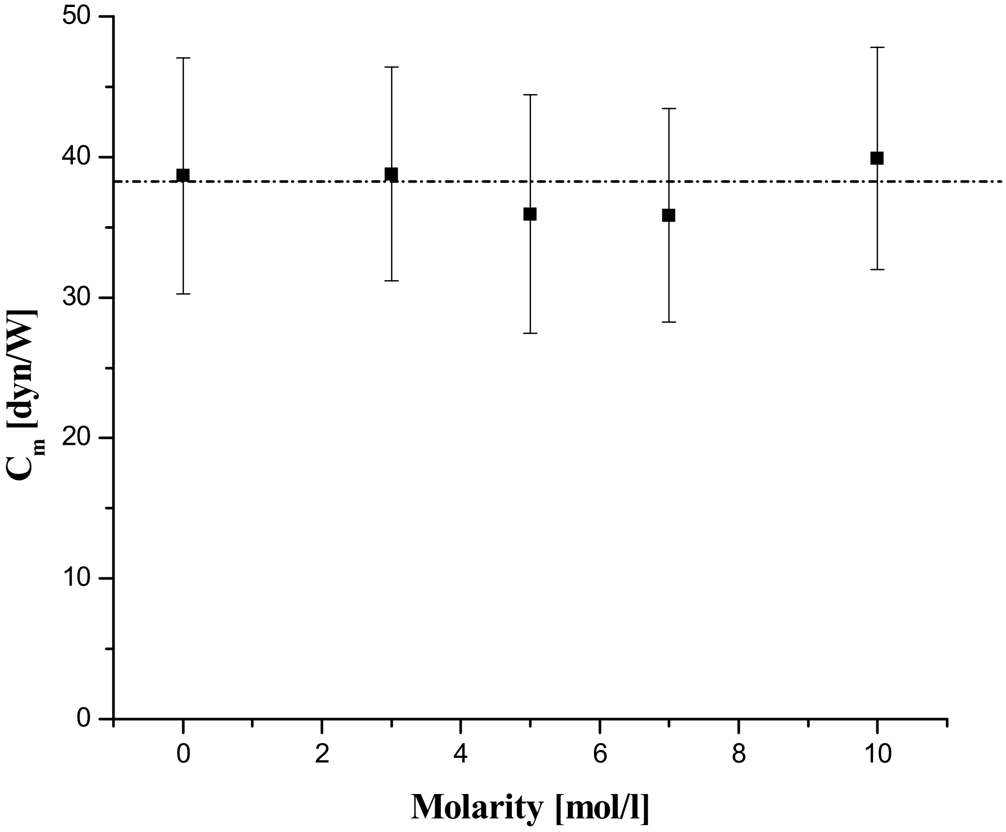

Figure 4. Coupling coefficient as a function of $NaBF_4$ molar concentration

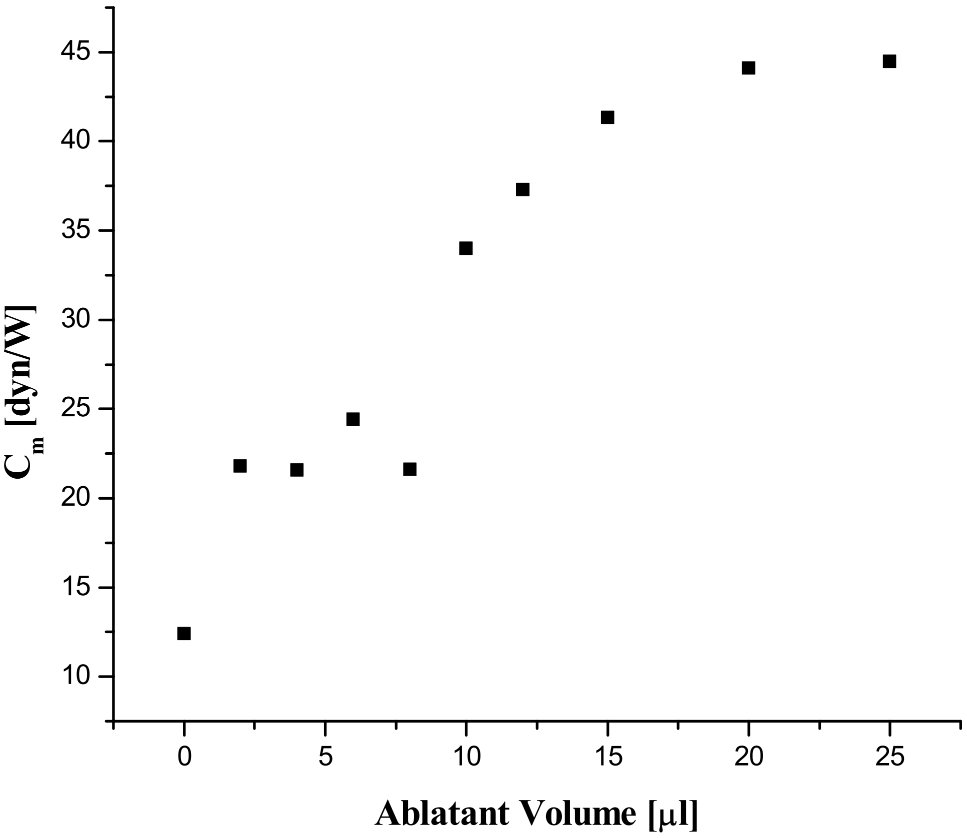

Figure 5. Coupling coefficient as a function of ablatant volume

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