Laser Induced Deformation and Breakup of Acoustically Levitated Droplet

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Introduction: Importance & Motivation

- **Laser-induced droplet breakup** refers to the disintegration of liquid droplets upon exposure to focused laser energy, enabling controlled manipulation of microscale fluids without physical contact.
- This phenomenon is crucial for applications in nanolithography and semiconductor cleaning , offering precise control over droplet dynamics and breakup behavior.

Focus of This Study:

- Investigating response of levitated droplets (Decane, Ethanol, Xylene) to CW CO_2 laser.
- Explore thermally driven deformation and breakup .

Motivation:

- CW laser-induced breakup is less explored.

Project Objectives

- Investigate deformation and breakup of levitated droplets under CW CO_2 laser.
- Compare responses of different liquids with varying properties.
- Examine influence of laser power on breakup.
- Identify conditions leading from deformation to fragmentation.

Background: Key Concepts

Droplet Physics:

- Surface Tension, Viscosity, Internal Pressure, Boiling Point.

Laser Interaction (CW CO_2 Laser):

- Localized energy absorption.
- Gradual heating, vaporization, pressure buildup, instability.

Acoustic Levitation:

- Contactless droplet suspension using ultrasonic waves.

Experimental Setup: Overview

- **Laser:** CW CO_2 (10W, 10.6 µm)
- **Beam Expander & Lens:** 5x, ZnSe lens (f=50.8 mm)
- **Levitator:** Tech5 AG, 100 kHz
- **Camera:** Photron NOVA S6
- **Illumination:** Diffused light source
- **Sync System:** Synchronizes laser, illumination, camera

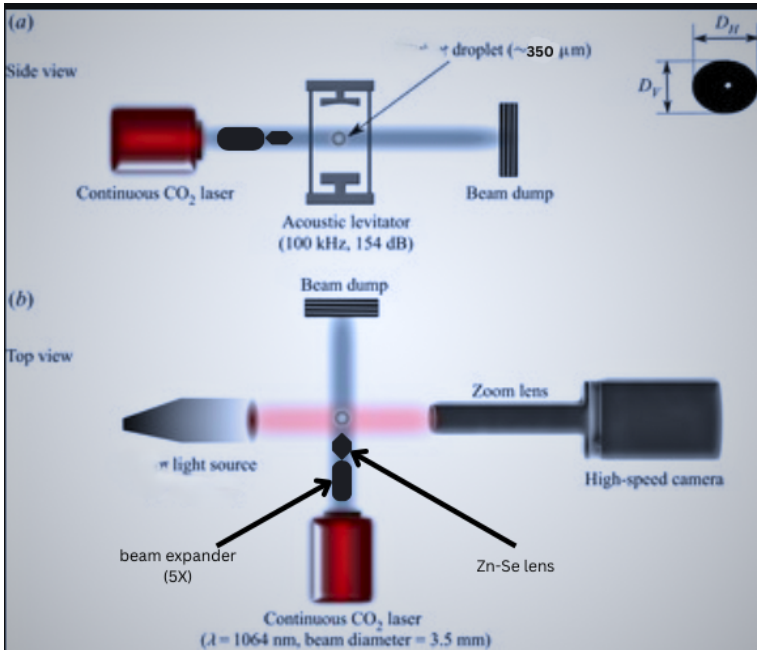


Figure: Schematic of the experimental setup

Experimental Setup: Laser & Focusing

- **Laser:** CW CO_2 (10 W, $\lambda = 10.6$ µm)
- **Beam Diameter:** Initial = 3.5 mm, Expanded = 17.5 mm
- **Lens:** ZnSe, f = 50.8 mm
- **Spot Size:** 47 µm

Significance: Spot size much smaller than droplet (350 µm) $\rightarrow$ Localized heating

Experimental Setup: Levitation & Droplet

- **Levitator:** Tech5 AG, 100 kHz ultrasonic
- **Droplet:** 350 µm size, suspended at pressure antinode
- **Environment:** Room temperature, ambient air

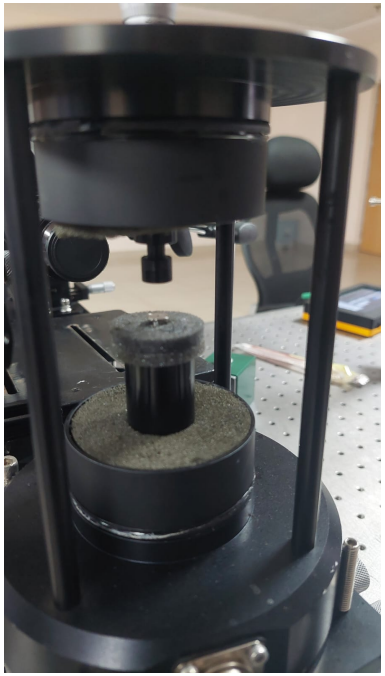


Figure: Levitator diagram

Experimental Setup: Imaging & Synchronization

- **Camera:** Photron NOVA S6, 50,000 fps, 384x256 px
- **Lighting:** Backlight with diffuser
- **Calibration:** Scale = 0.013095 mm/pixel
- **Sync:** Triggered start for camera, laser, light

Investigated Liquids & Properties

Liquids Studied: Ethanol, n-Decane, Xylene

Property	**Ethanol**	**n-Decane**	**Xylene**
Boiling Point (°C)	78	174	140
Viscosity (mPa·s)	1.2	0.92	0.65
Surface Tension (mN/m)	22	24	28

Table: Properties of the studied liquids

Observations: Ethanol Droplet

- Rapid heating and deformation
- Fine mist / minute droplets (vapor-like outflow).
- Rapid surface vaporization due to low boiling point (78°C) and potentially lower/surface IR absorption hence Less internal pressure buildup.

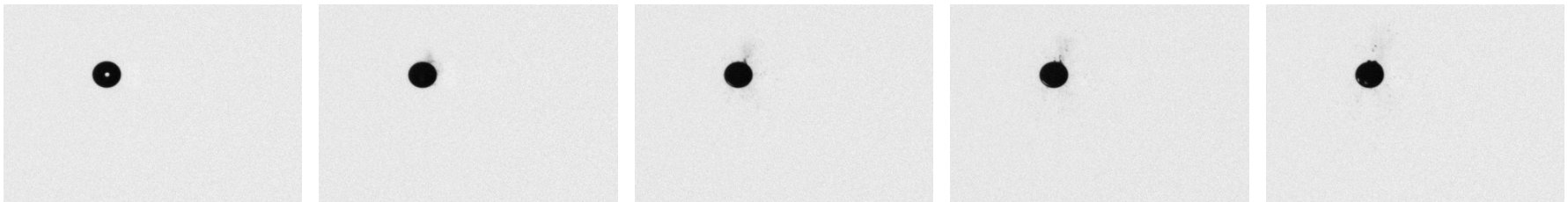


Figure: Ethanol droplet breakup at 80% laser power .

Observations: Decane Droplet

- Subtle ruptures initiated near the rear side
- Lower viscosity and surface tension contribute to early instability despite high boiling point (174°C). Moderate IR absorption may allow localized internal heating/rupture
- Asymmetric expansion/perturbations cause the droplet out of focus.

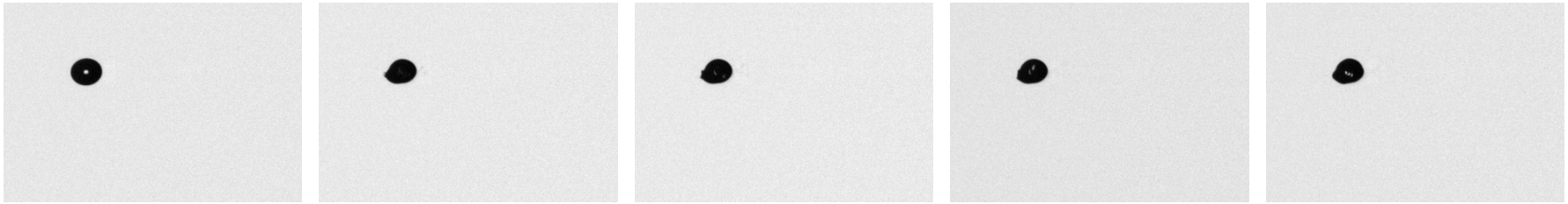
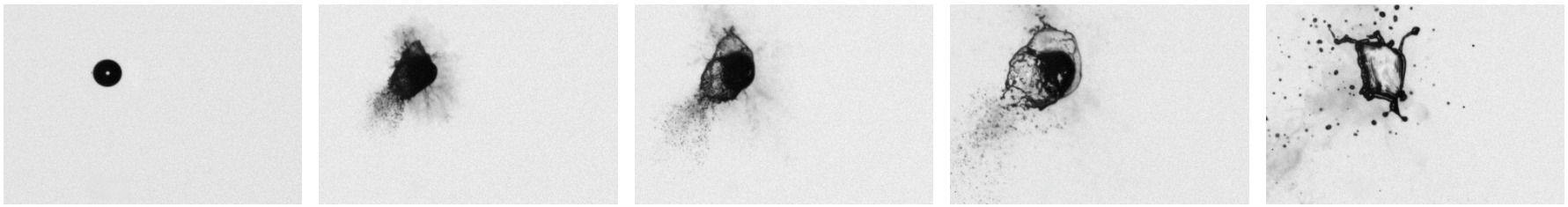


Figure: Decane droplet breakup at 80% laser power.

Observations: Xylene Droplet

- intense and delayed breakup
- Abrupt initial burst $\rightarrow$ Bag-like sheet formation $\rightarrow$ Disintegration
- Stronger IR absorption and higher boiling point (140°C) lead to significant energy accumulation and internal pressure buildup before explosive rupture



0.000 ms | 16.04 ms | 16.06 ms | 16.12 ms | 16.52 ms

Figure: Breakup of xylene droplet at 80% laser power.

Observations: Xylene Droplet

- Droplet flattens and expands outward (liquid sheet).
- Mass accumulation at sheet edges $\rightarrow$ Thickening.
- Destabilization $\rightarrow$ Ligament formation & disintegration.

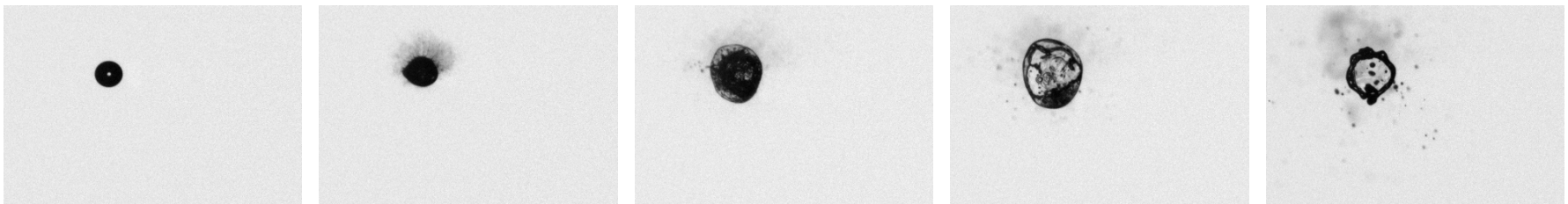
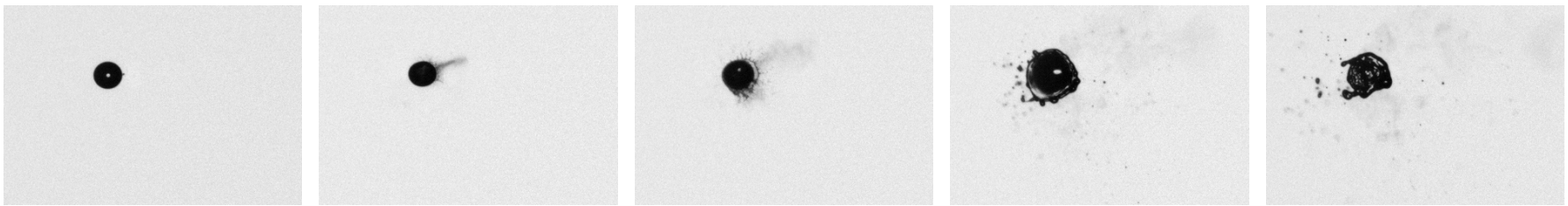


Figure: Breakup of xylene droplet at 40% laser power.

Observations: Xylene Droplet

- Relatively mild and delayed breakup.
- Initial Rupture Time: ∼30.4 ms (Tiny surface burst observed).
- evolution of ligaments and then they breakup into secondary droplets



0.000 ms | 30.46 ms | 30.48 ms | 30.74 ms | 30.96 ms

Figure: Breakup of xylene droplet at 20% laser power.

Conclusion

- CW CO_2 laser-induced breakup of levitated Ethanol, Decane, and Xylene droplets was successfully investigated.
- Breakup dynamics depend strongly on laser power and fluid properties.
- Higher laser power leads to faster and more intense breakup.
- IR absorption, viscosity, surface tension, and boiling point govern droplet response.

Future Work

- Investigation of different laser wavelengths or pulsed laser configurations.
- Quantitative analysis of fragment size distribution
- study related to iginition sustain by laser energy during breakup

Acknowledgments

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Questions?

Thank you!