Robotics-Enhanced Laser Ice Collection

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AGU FALL 2021 MEETING

NEED

- "Scientists will always need more ice cores."
- Large coring projects return only one core per depth; replicate drilling is prohibitively expensive
- Certain depths are of particular interest: abrupt climate event, original sample damaged/lost

ARCHITECTURE

- Laser source remains at ice surface, relieving downhole size/weight/power/heat considerations
- Optical fiber-equipped sampling sonde is lowered into existing dry or fluid-filled borehole
- Once at depth of interest, sonde emits laser beam to cut a closed path on borehole wall, freeing wedge-shaped sample
- Mechanism retracts sample into borehole center for retrieval to surface

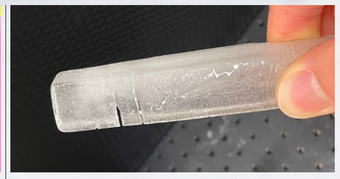
LASER WAVELENGTHS

Two cost-effective laser wavelengths have been successfully tested to cut ice:

	1.07 μm	**10.6 μm**
Source	Yb-doped fiber lasers	CO_2 gas lasers
Wall-plug efficiency	> 30%	~10%
Fiber material	silica	specialty / experimental
loss	< 1 dB/kilometer	> 1.5 dB/meter
Absorption length in ice	~1 mm	~10 mm
Existing applications	telecom (low power), metals machining, defense	plastic & paper sheet cutting, soft-tissue surgery

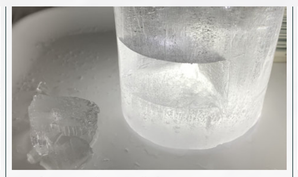
Laser modulation/pulsing known to promote material ablation over melting, reduce peripheral heating

Thermal images of ice samples after 4 sec of 1.07 μm laser irradiation in continuous wave (CW) and pulsed operation. Both yield a ~1 mm diameter hole through the sample, but CW incurs a 6 °C temperature rise in the surrounding ice vs. 2 °C for pulsed.



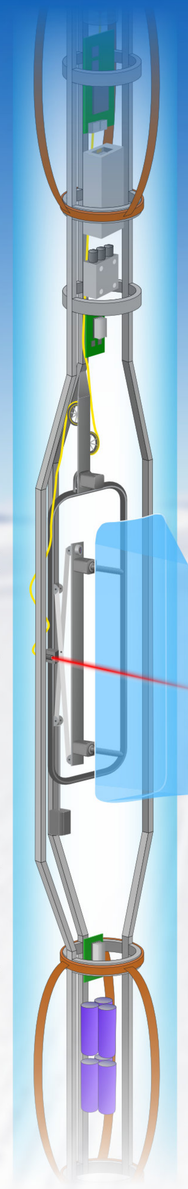
Tests of cut width on a roughly rectangular stick of tap-water ice, ~25 mm in diameter

Fisheye photo of a basic laser-cutting motion setup at work inside lab freezer



Wedge cut from 3" diameter tap-water core using 1.07 μm laser (90 W)

cut from 3" diameter tap-water core using 1.07 μm laser (250 W)

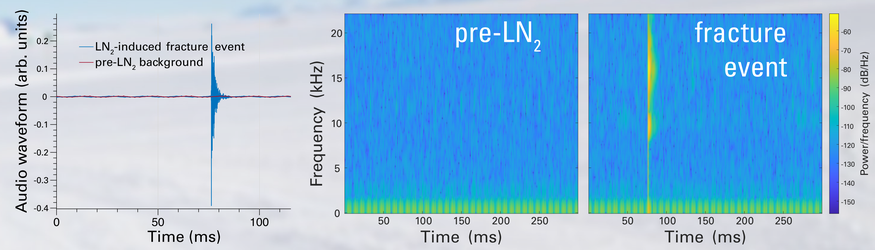


LASER ADVANTAGES

- Lightweight, inexpensive, fast-deployable system
- Quickly cut (~few minutes) and retrieve new samples from specific depths of interest in existing boreholes
- Cutting by laser eliminates contamination from mechanical blades, likely reduces microfractures
- Lack of vibration suggests better retrieval of brittle ice: highly-pressurized material with atmospheric gases compressed into clathrates. Ice from the brittle zone is extremely fragile, often lost to mechanical cutting

PIEZOELECTRIC ACOUSTIC SENSING

- How to quantify fracture rate of brittle ice in order to compare laser vs. mechanical cutting?
- Piezoelectric transducers: inexpensive, off-the-shelf, durable, expendable; freeze into artificial cores or onto surface of natural cores
- Readout and record using consumer-grade audio equipment, no additional amplification necessary
- When instrumented artificial ice is subjected to liquid nitrogen, sensors generate voltage spikes coinciding with visually-observed thermal crack events
- High-frequency content in acoustic spectra is consistent with fracturing
- Low complexity and cost suggests distributed sensors could continuously monitor freshly-drilled cores during acclimation



Recorded waveform and short-time Fourier transforms (1 ms window with 0.3 ms overlap) of a piezoelectric transducer frozen into an artificial ice core, before and (one example fracture event) after LN_2 exposure.

NEXT STEPS

- Optimization of cutting beam size, modulation frequencies using new 1 kW 1.07 μm laser
- Refinement of motion stages to maneuver beam for cutting wedges in lab tests
- Perform cutting procedure immersed in sub-freezing fluid, test mitigation strategies for refreezing
- Further exploration of acoustic signatures of cracks caused by direct mechanical force; isolate longitudinal and shear stress frequency content for sensing of fracture location and orientation
- **Where would you like more ice from?**

Scan me for more!

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Parts of this work funded by NSF grants 2032463 and 2032473.
Laser source was jointly purchased by NSF and the Joint Directed Energy Transition Office / Office of Naval Research, grant N00014-17-1-2438