Chamber Development Plan
and
Chamber Simulation Experiments

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UCSD IFE Web Site: http://aries.ucsd.edu/IFE

Development of Practical Chambers is a Feasibility Issue for Laser IFE

- Many IFE chamber concepts have been proposed.

- Feasibility of any chamber concept is highly uncertain due to absence of experimental data and insufficient predictive capabilities.
  - ✓ Never before a coordinated research program has been launched to validate concepts as is proposed to be done under HAPL program;
  - ✓ The phenomena present in IFE chambers are highly complex, and cannot be duplicated **completely** in present experimental facilities or in IRE. ETF would be the first facility that achieves integrated prototypical condition.

- But, we cannot wait for ETF. High confidence in success of IFE chambers is **necessary** for ETF to go forward.

- We can develop high confidence in IFE chamber concepts with a parallel modeling and experiments in simulation facilities.

A Coordinated Chamber Development Plan Is Essential in the First Phase of Laser IFE Program

Goals:

- Identify at least two credible and attractive chamber concepts ready for testing in the IRE.
- Develop predictive capability for chambers through a parallel and coordinated experimental and modeling activity.

Chamber Research Framework:

- **Integrated:** Start with a self-consistent chamber concept.
- **Credible:** Focus on key feasibility issues.
- **Predictive Capability:** Devise experiments to validate model for each phenomena.

Chamber Development Plan Aims at Developing Necessary Predictive Capability

- For each concept, Plan defines an iterative process to
  - ✓ Identify underlying processes and their scaling
    - ∗ Focus is on practical rather than ideal systems
  - ✓ Devise and/or compare models used for each phenomena.
    - ∗ Identify shortcomings in data bases;
    - ∗ Devise relevant and well-diagnosed experiments that isolate and resolve each phenomena to benchmark models.
- Plan allows for development of new chamber concepts
- Plan does not list critical issues only but includes R&D direction to understand and resolve them.

- A draft is available for interested parties.
- We aim at finalizing the plan in a couple of weeks.

Most of the Critical Feasibility Issues for Various Chambers Fall Under Four Generic Categories

- All chamber concepts share four broad science and technology challenges:
  - Propagation of target emissions in the chamber,
  - Thermo-mechanical response of the chamber wall,
  - Relaxation of the chamber environment to pre-shot level that is consistent with target injection and laser propagation,
  - Long-term mass transport that might affect changes in wall morphology, final optics contamination, safety, *etc.*

- By focusing on generic critical issues, single experimental facilities and modeling/computer simulation tools can be utilized to resolve feasibility issue for several concepts.

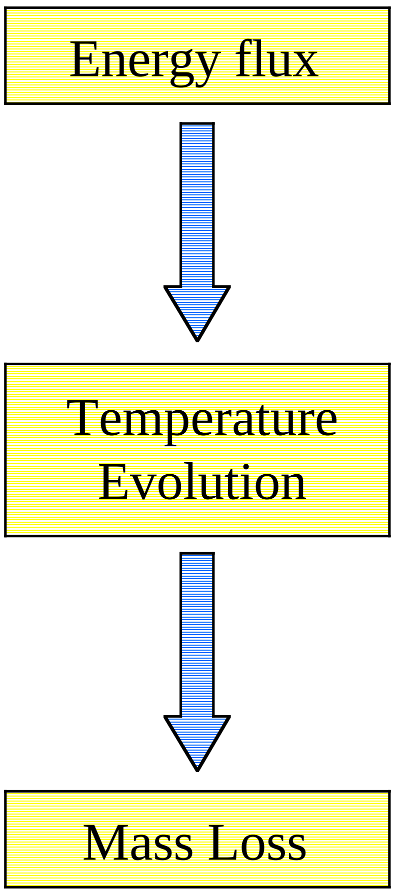
- Understanding of the underlying scientific basis will enable informed down-selection of concepts as progress is made.

Chamber Development Plan

5.2. Thermo-mechanical Response of the Chamber Wall

Wall Survival Critically Depends on Its Thermo-Mechanical Response

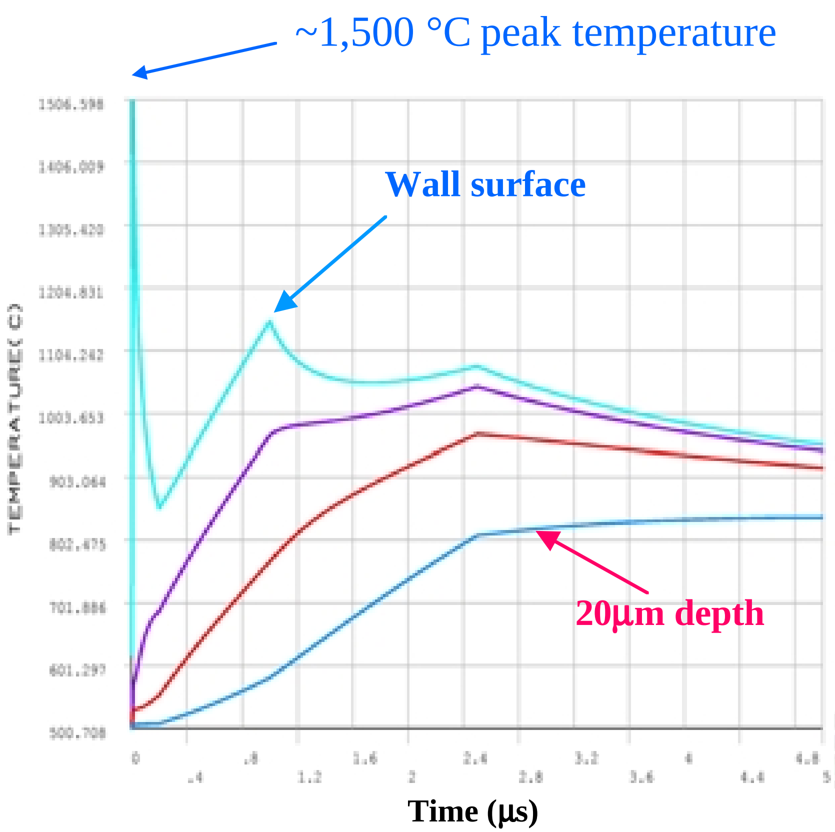
Idealized estimates of wall survival have been made:



- Estimates assume idealized chamber conditions prior to target implosion
- Temperature evolution is computed for a perfectly flat wall using steady-state and bulk properties for pure material
- Mass loss is estimated based on sublimation and/or melting correlations.

Temperature Evolution:
All Action Occurs in the First Few µm of the Wall

- Thermal response of a W flat wall to NRL direct-drive target (6.5-m chamber with no gas protection):
- Pure material and perfectly flat wall is assumed.



- Temperature variation mainly in a thin (<100 µm) region. Temperature spikes only in the first few µm.
- Response dominated by thermal capacity of material.

But in a Practical System:

- Surface features are probably much larger than 10-20 µm due to manufacturing tolerances, surface morphology, *etc*.
- Impurities and contaminants can cause hot spots.

There is a large uncertainty in calculated temperature evolution.

Material Loss: Only Material Loss by Melting/sublimation Has Been Considered

- ➢ Sublimation is sensitive to local temperature and partial pressure conditions.
  - ✓ Accurate estimate of surface temperature is essential.
  - ✓ Experiments should be done at relevant surface temperature range because heat capacity is much smaller than phase change energy.

✓ Real-time temperature should be measured.
✓ Experiments must be done at relevant surface temperature.

- ➢ Steady-state data for sublimation rates may not be applicable.
  - ✓ Sublimation rates also depends on the atomic form of sublimated species;
  - ✓ Sublimation at local hot spots (contaminants, surface morphology) may dominate.
  - ✓ Is avoidance of melting a good criteria?

✓ Sublimation rates should be measured at relevant surface temperature range in-situ.

Material Loss: Only Material Loss by Melting/sublimation Has Been Considered

- Indirect material loss due to contaminants on the surface may be important:
  - ✓ Formation WC on the wall which has a melting point much lower than W;
  - ✓ Formation of CH on the wall that can vaporizes at very low temperature.

✓ **Experiments should be performed in the presence of possible contaminants.**

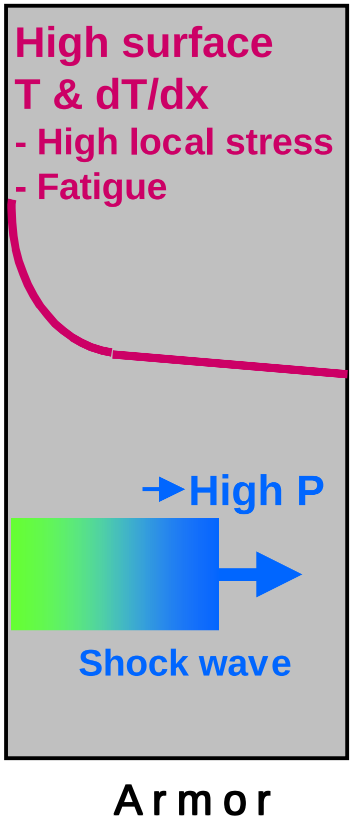
- Sputtering (physical, chemical, *etc*.):
  - ✓ Estimates are being made.
  - ✓ Requires knowledge of ion spectrum on the wall.

✓ **Experiment planning is differed until initial estimates are made.**

Mechanical Response: Wall life May Be Limited by Thermal Shock and Thermal Stresses

- "Instantaneous" heat deposition gives rise to large local pressure and shock wave propagation in the material. If the resulting local stresses exceed the ultimate strength of the material catastrophic failure can occur.

- Differential thermal expansion due to the sharp temperature gradient through the armor leads to cyclic local stresses:
  - ✓ If the local stress exceeds the ultimate strength, the material will fail;
  - ✓ Thermal fatigue failure can also occur over the numerous cycles of operation.



✓ **Thermal shock and thermal stress effects should be calculated and compared with simulation experiments.**

Long-term Changes in the Wall May Have a Large Impact on Wall Survivability

- Additional uncertainties arise due to long-term changes that occur at the wall surface over wall life time:
  - ✓ Surface contaminants and impurities;
  - ✓ Formation of compounds;
  - ✓ Changes in surface morphology (grain size, micro-cracking, diffusion of impurities);
  - ✓ Changes in thermo-physical properties due to:
    - o Rep-rated, large temperature excursions;
    - o Large ion flux;
    - o Neutron flux.

✓ **Need input from material community. Samples exposed in <u>rep-rated</u> simulation facilities can be used for experimental analysis.**

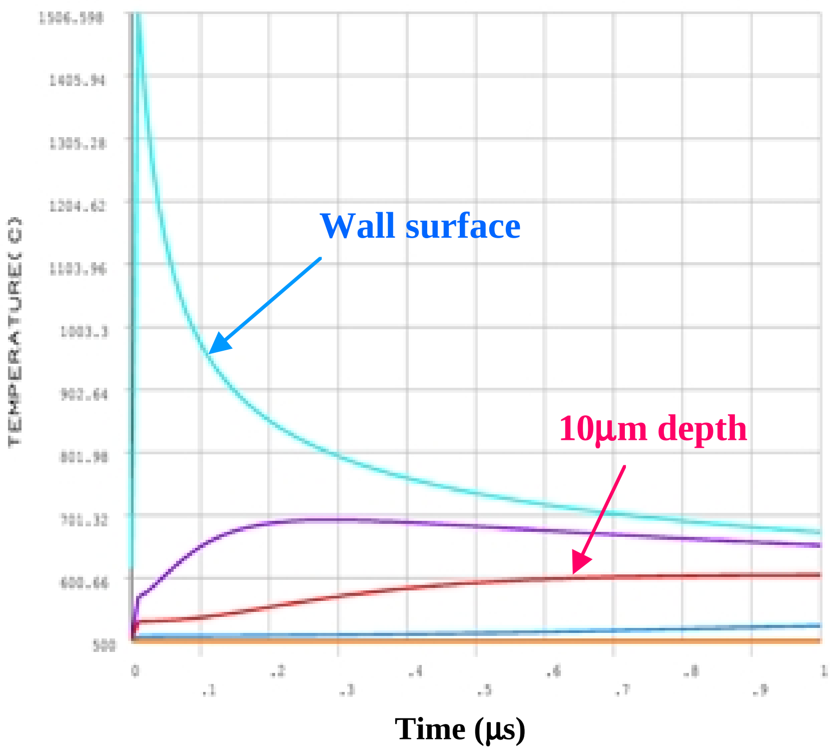
Thermo-mechanical Response of the Wall Is Mainly Dictated by Wall Temperature Evolution

- Most phenomena encountered depend on wall temperature evolution (temporal and spatial) and chamber environment
  - ✓ Only sputtering and radiation (ion & neutron) damage effects depend on "how" the energy is delivered.
  - ✓ Most energy sources (lasers, X-rays, ion beam) can generate similar temperature temporal and spatial profiles.
  - ✓ Comparison of results from facilities with different "heating sources" (e.g., lasers, X-ray and ion beam) would isolate impact of threat spectrum, if any.

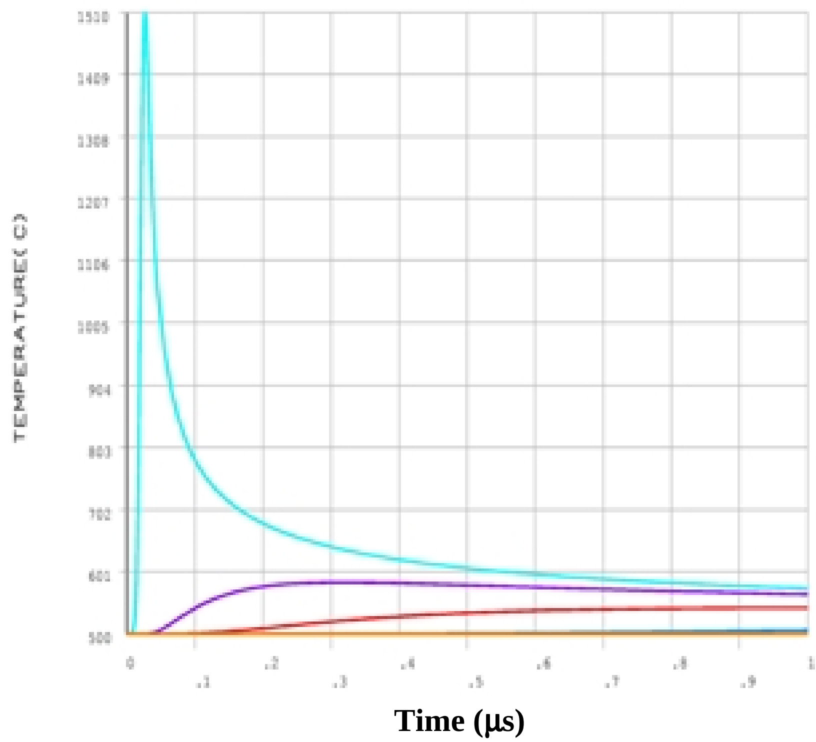
- In order to develop predictive capability:
  - ✓ There is no need to <u>exactly</u> duplicate wall temperature temporal and spatial profiles. (We do not know them anyway!)
  - ✓ Rather, we need to understand the wall response in a relevant range of wall temperature profiles (and we need to measure them in real time!)

One Laser Pulse Can Simulate Wall Temperature Evolution due to X-rays

NRL Target, X-ray Only
1 J/cm², 10 ns Rectangular pulse



Laser
0.24 J/cm² ,10 ns Gaussian pulse

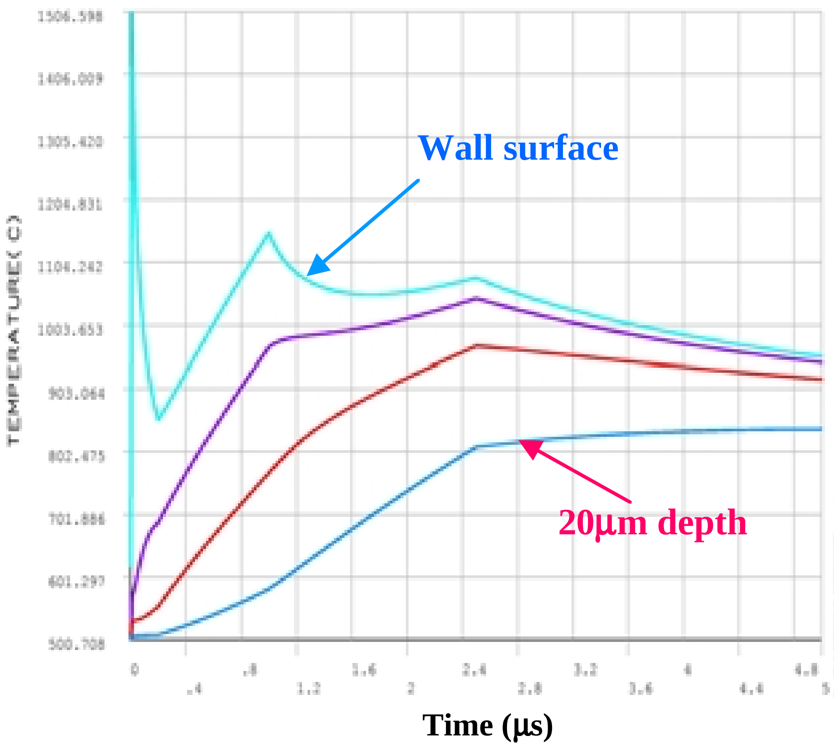


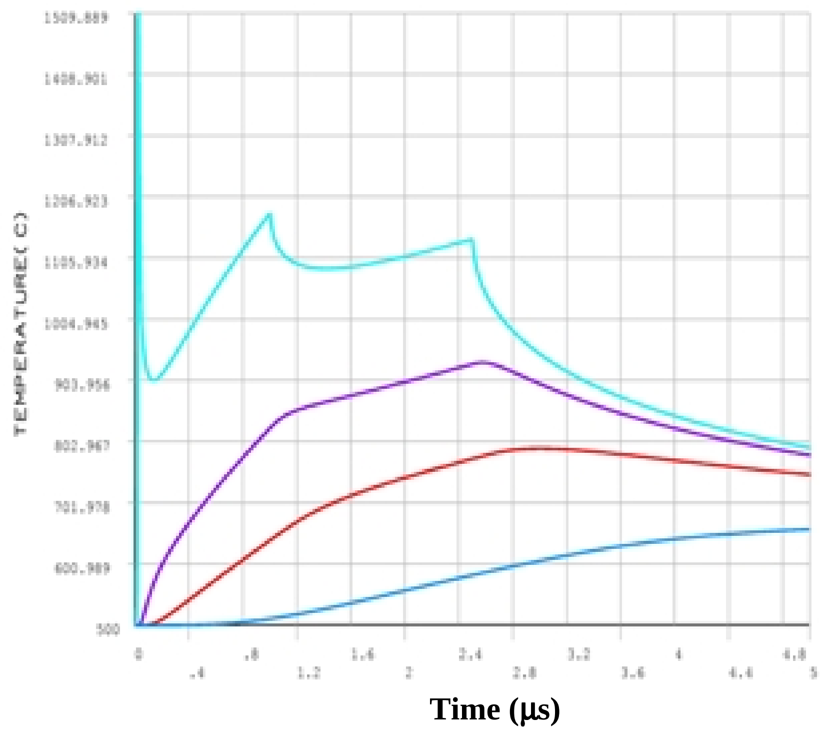
- Only laser intensity is adjusted to give similar peak temperatures.
- Spatial temperature profile can be adjusted by changing laser pulse shape.

Three Laser Pulses Can Simulate the Complete Surface Temperature Evolution

NRL Target, X-ray and Ions

Laser
0.24 J/cm^2 ,10 ns Gaussian pulse
0.95 J/cm^2 ,1 µs Rectangular pulse
0.75 J/cm^2 ,1.5 µs Rectangular pulse





Thermo-mechanical Response of the Chamber Wall

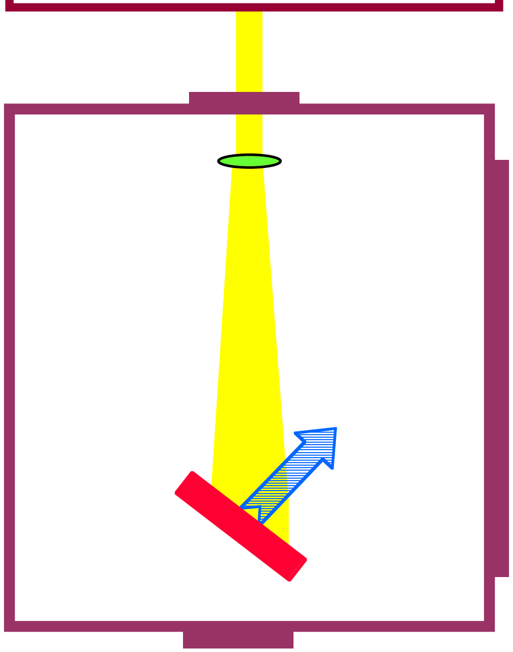
UCSD Simulation Experiments

Thermo-Mechanical Response of Chamber Wall Can Be Explored in Simulation Facilities

Requirements:

Laser pulse simulates temperature evolution

Capability to simulate a variety of wall temperature profiles



A suite of diagnostics:

- Real-time temperature, thermal shock, and stress
- Per-shot ejecta mass and constituents
- Rep-rated experiments to simulate fatigue and material response

Vacuum Chamber provides a controlled environment

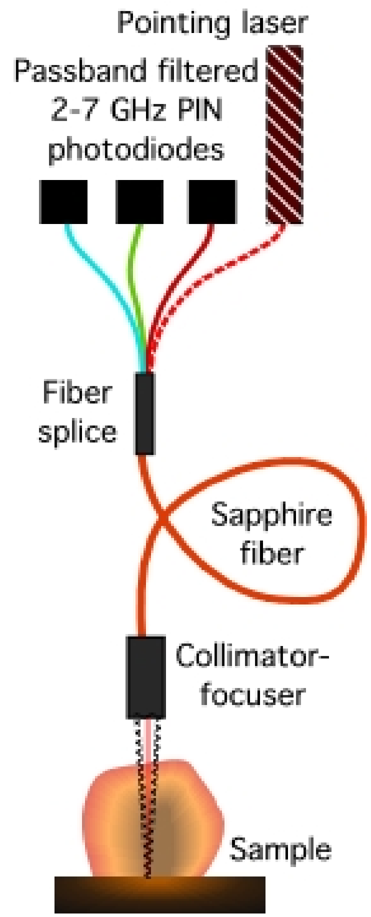
Capability to isolate ejecta and simulate a variety of chamber environments & constituents

Real-time Temperature Measurements Can Be Made With Fast Optical Thermometry

MCFOT–Multi-Color Fiber Optic Thermometry

- Compares the thermal emission intensity at several narrow spectral bands.

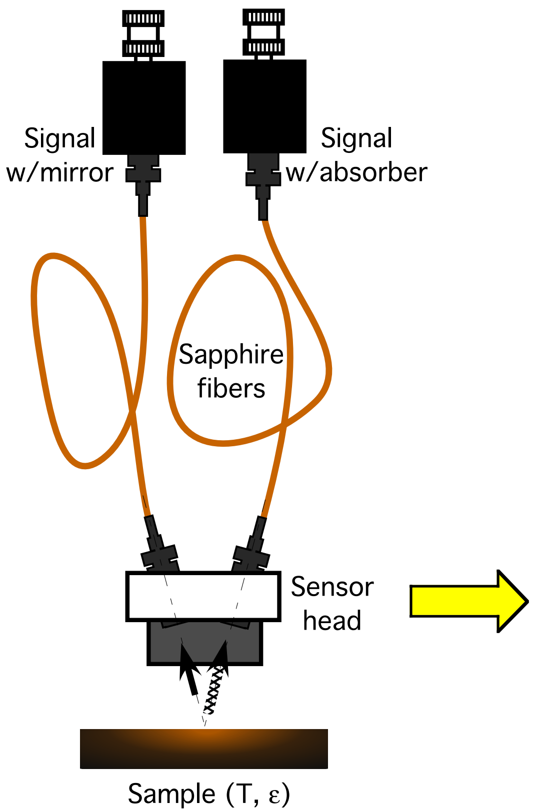
- **Time resolution ~100 ps to 1 ns.**
- **Measurement range is from ambient to ionization—self-calibrating.**
- **Simple design, construction, operation and analysis.**
- **Easy selection of spectral ranges, via filter changes.**
- **Emissivity must be known.**



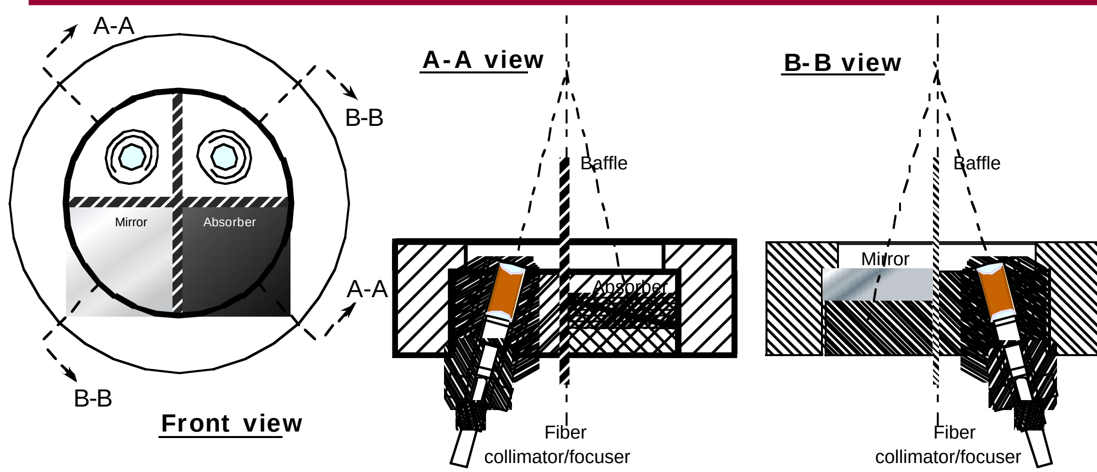
FOTERM-S Is a Self-Referential Fast Optical Thermometry Technique

FOTERM-S: Fiber Optic Temperature & Emissivity Radiative Measurement Self standard

- Compares the direct thermal emission and its self-reflection at a narrow spectral band to measure both temperature and emissivitiy.



- **Time resolution ~100 ps to 1 ns.**
- **Measurement range is from ambient to ionization—self-calibrating.**
- **More complex design and construction, but simple operation and analysis.**

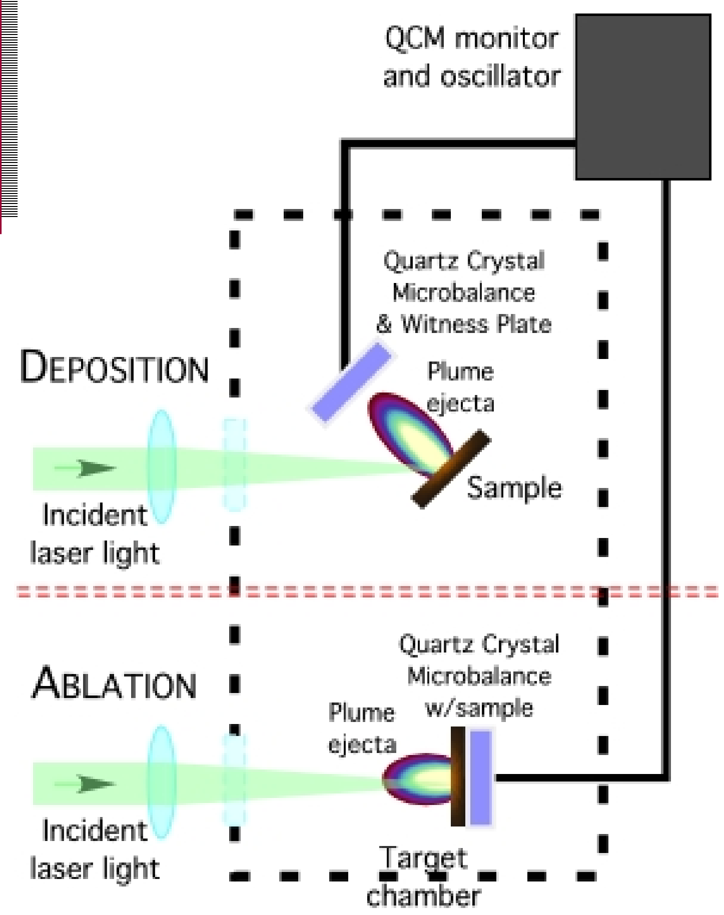


QCM Measures Single-Shot Mass Ablation Rates With High Accuracy

QCM: Quartz Crystal Microbalance

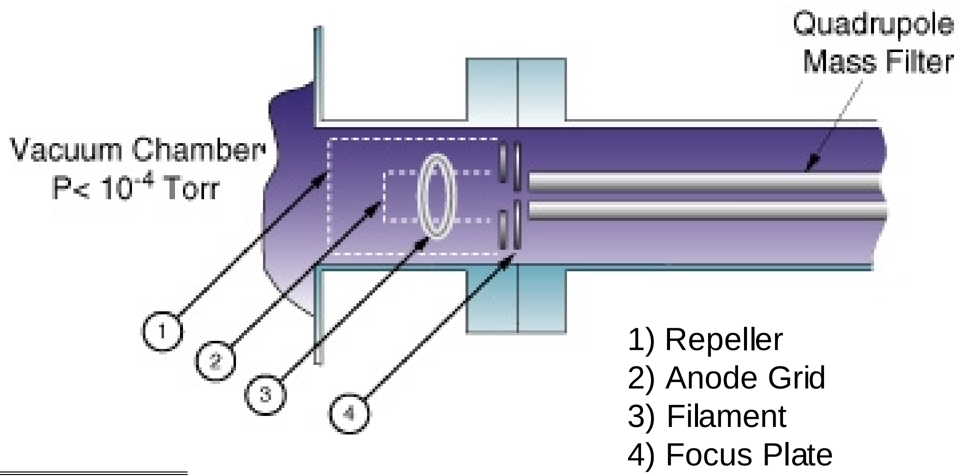
- Measures the drift in oscillation frequency of the quartz crystal.

- **QCM has extreme mass sensitivity: 10^{-9} to 10^{-12} g/cm^2.**
- **Time resolution is < 0.1 ms (each single shot).**
- Quartz crystal is inexpensive. It can be detached after several shots. Composition of the ablated ejecta can be analyzed by surface examination.

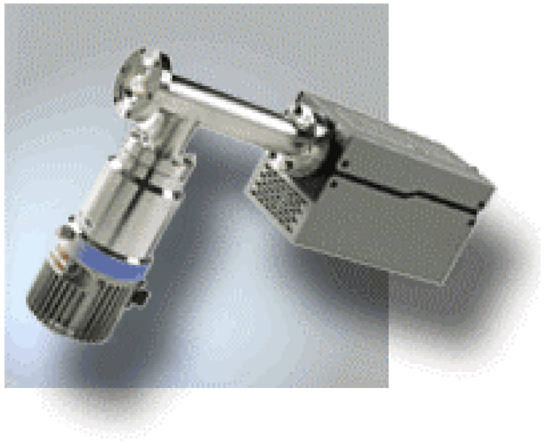


Composition of Ejecta Can Be Measured with RGA

RGA: Residual Gas Analyzer is a mass spectrometer.

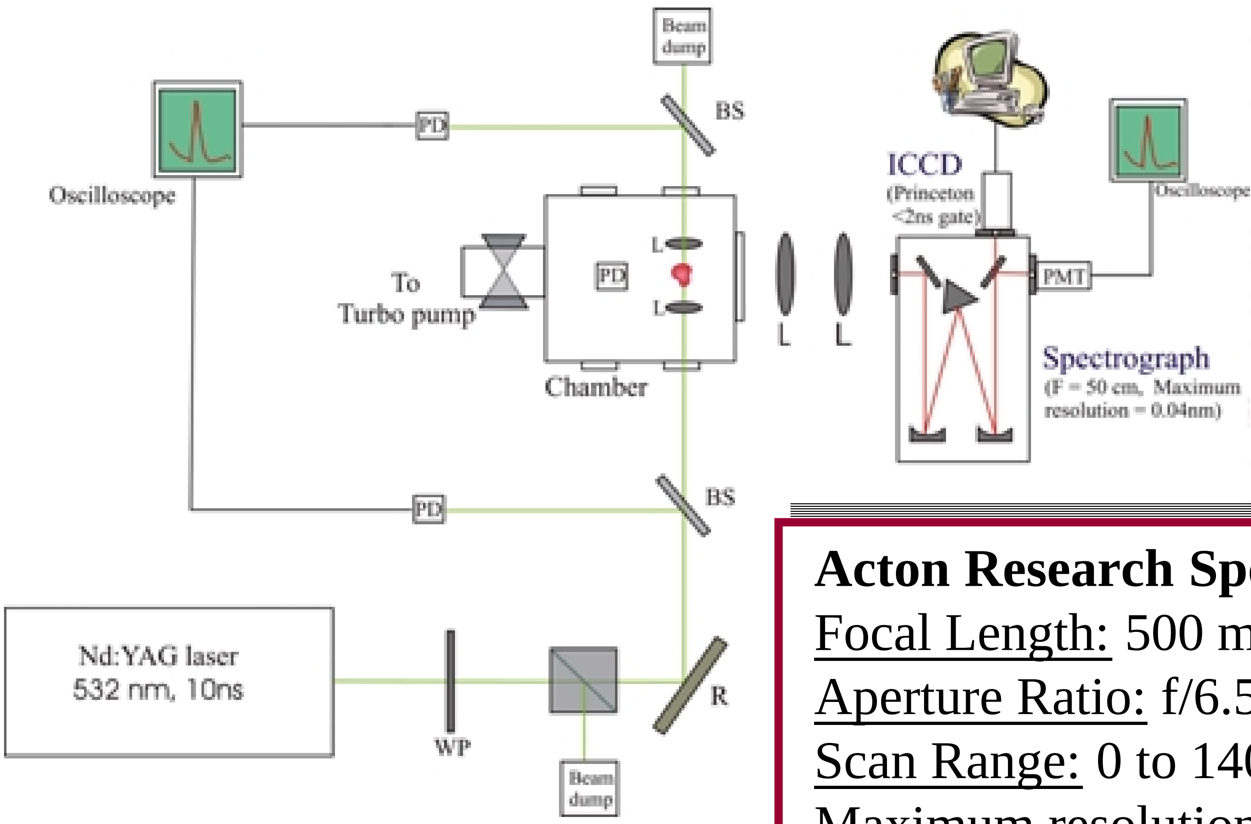


- **Ejecta spectrum can be measured to better than 1 ppm.**
- **Time resolution is ~1 ms (each single shot).**
- Inexpensive, commercially available diagnostics.



Spectroscopy Can Identify the Ejecta Constituents Near the Sample

Laser propagation and Breakdown experiment setup



Acton Research SpectraPro 500i

Focal Length: 500 mm

Aperture Ratio: f/6.5

Scan Range: 0 to 1400-nm mechanical range

Maximum resolution: 0.04 nm

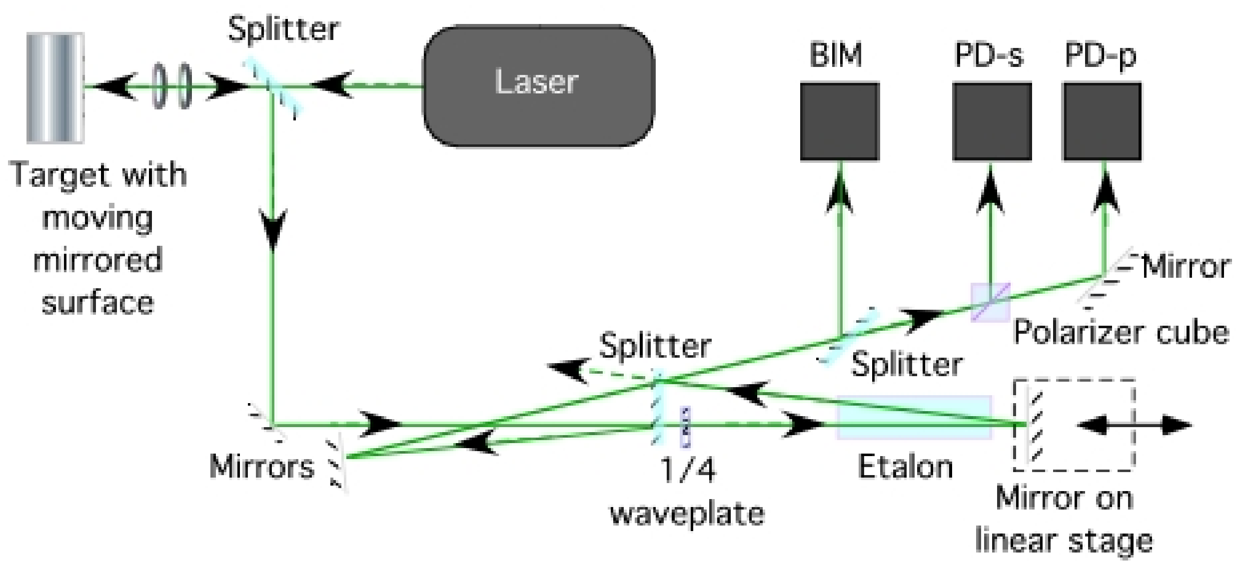
Grating size: 68x68 mm in a triple-grating turret

Gratings: 150g/mm, 600g/mm, 2400g/mm

Laser Interferometry Can Measure the Velocity History of the Target Surface

VISAR: Velocity **I**nterferometer **S**ystem for **A**ny **R**eflector

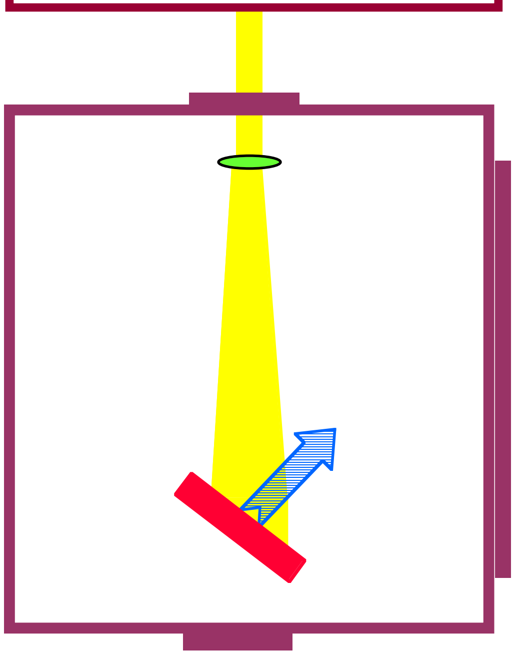
- Measures the motion of a surface



- **Time resolution of 0.1 to 1 ns.**
- **Accuracy is better than 1%-2% for velocities up to 3000 m/s.**
- Measuring velocity histories of the front and back surfaces of the target allows to calculate the thermal and mechanical stresses inside it.

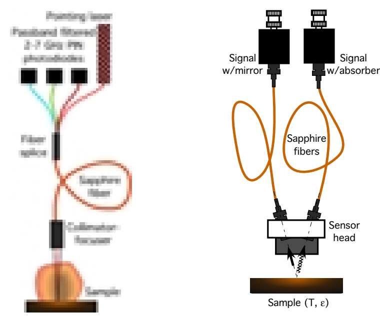
A Coordinated Modeling/Experimental Activity Will Provide Predictive Capability for Thermo-Mechanical Response of Chamber Wall

Laser pulse simulates temperature evolution



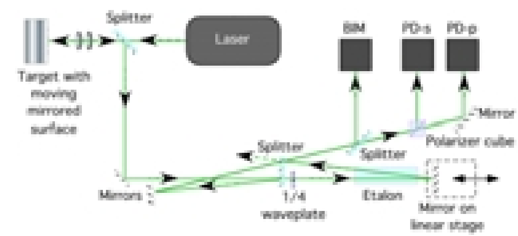
Vacuum Chamber provides a controlled environment

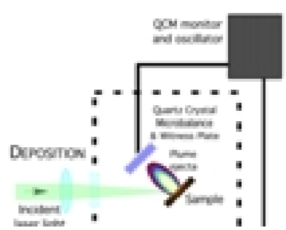
A suite of diagnostics is identified

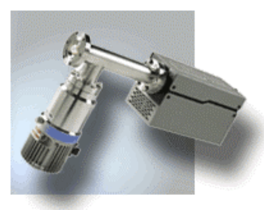


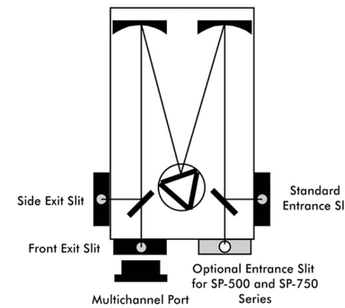
Real Time Temperature

Real Time Thermal shock and stress









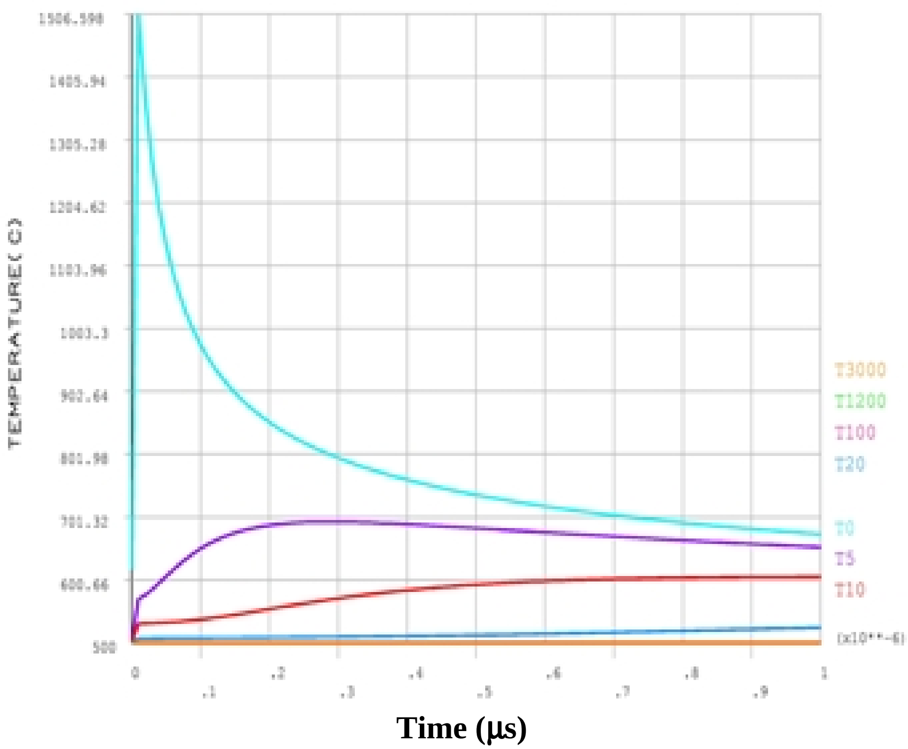
Per shot Ejecta Mass and Constituents

Sample can be examined for material behavior after high rep-rate experiments

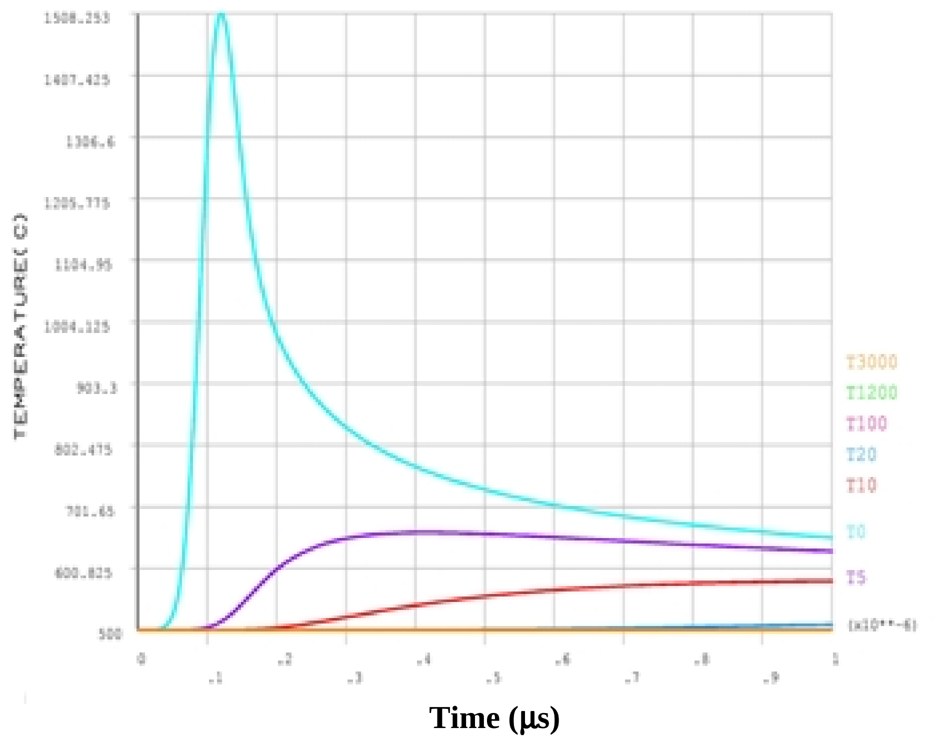
Backup Slides

Adjusting Laser Pulse Duration Can Improve the Fidelity of Simulation

NRL Target, X-ray Only
1 J/cm^2, 10 ns Rectangular pulse



Laser*
0.47 J/cm^2 ,50 ns Gaussian pulse



*Laser intensity is adjusted to give similar peak temperatures.

Ionized Species Can Affect Prorogation of Target Emissions in The Chamber

- **Radiation Transport:**
  - Physics is well understood
  - Atomic data base (e.g., opacity, ionization/recombination rates) is not complete specially at low temperatures.

- **Ion Transport:**
  - Interaction of charged particles with matter is well understood.
  - X-ray flash (and initial fast ions) will ionize the chamber gas. This will affect ion slowing processes.
  - Pre-shot chamber environment may not be completely neutralized.

- **R&D:**
  - **Benchmark models and codes.**
  - **Compute ion flux and spectrum at the chamber wall.**
  - **Devise experiments to validate calculation.**