Laser Ablation of Aerospace Materials

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OUTLINE

- JTO (Joint Technology Office) Motivation
- Materials studied
- Data collection
- Results to date
  - Nonmetals
  - Metals

- Conclusions

JTO MOTIVATION

- Purpose is to determine the material removal efficiency over a range of PRFs (pulse repetition frequency) and irradiances with a high PRF laser (the FEL).
  - Irradiance range 1 - 10 kW/cm^2 (thermal regime)

- Compare our results with those obtained from other cw HEL systems.

  - The JLab FEL produces sub-ps pulses with peak intensities ~ 10^4 times the average intensity - does this have any effect on the removal efficiency?

- IR Demo FEL can be run in a pulsed mode that may be beneficial:
  - Allows plume to clear.
  - Creates impulses that can cause material failure.

MATERIALS STUDIED

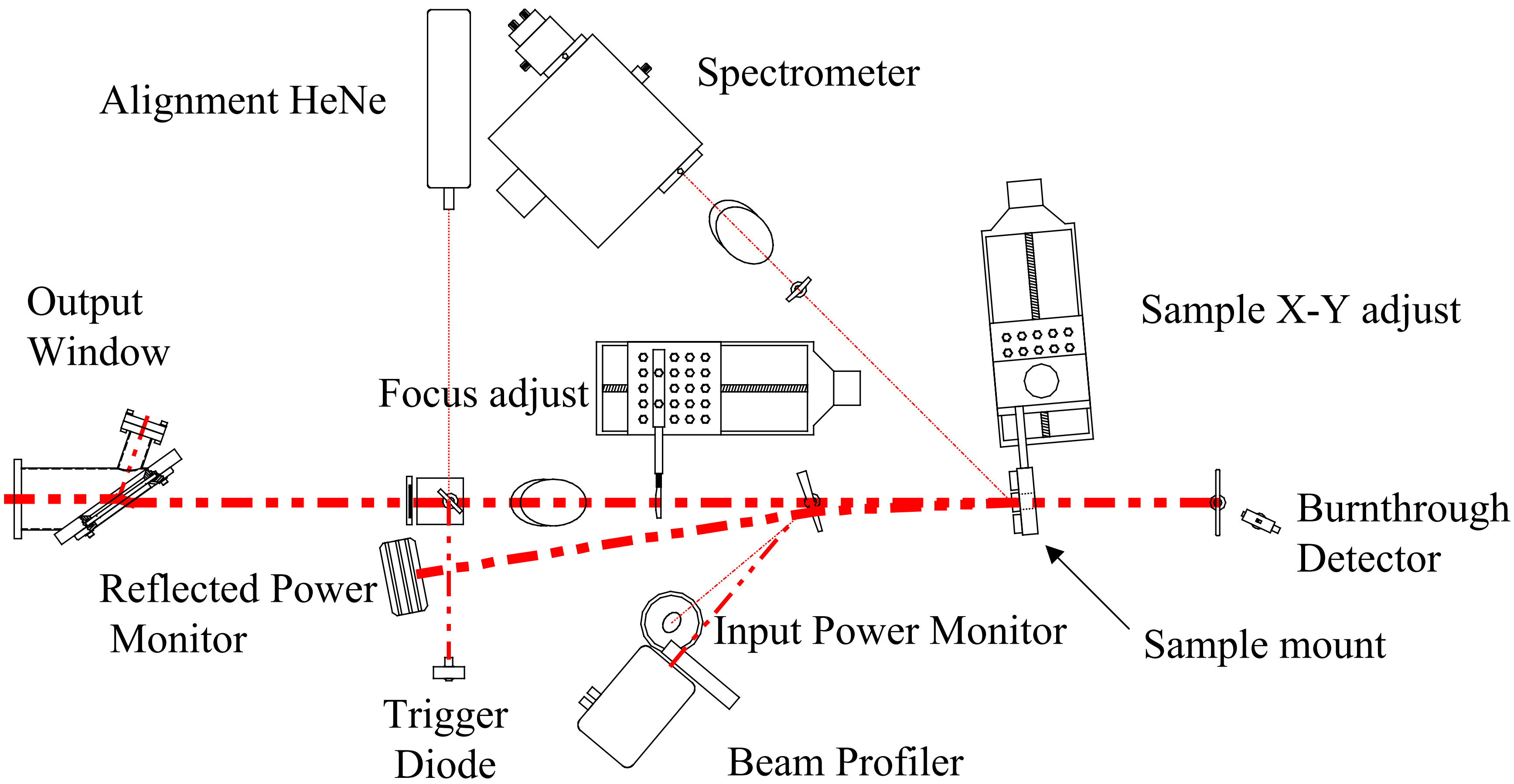
- "Simple" metals:
  - 304 SS and T6061 Al
    - Homogenous materials which can be modeled more easily
    - Straightforward attachment of thermocouples.
  - Painted vs unpainted aluminum
    - Do the FEL pulses char the paint, which enhances the coupling, or do they blow it away, leaving bare (reflective) material?
- Nonmetallic materials:
  - Slip-cast fused silica (SCFS) and fiberglass epoxy materials
- Lincoln Labs submitted some graphite epoxy samples and metals for irradiation.
- We also used Plexiglas as another standard material for comparison purposes.

EXPERIMENTAL SETUP

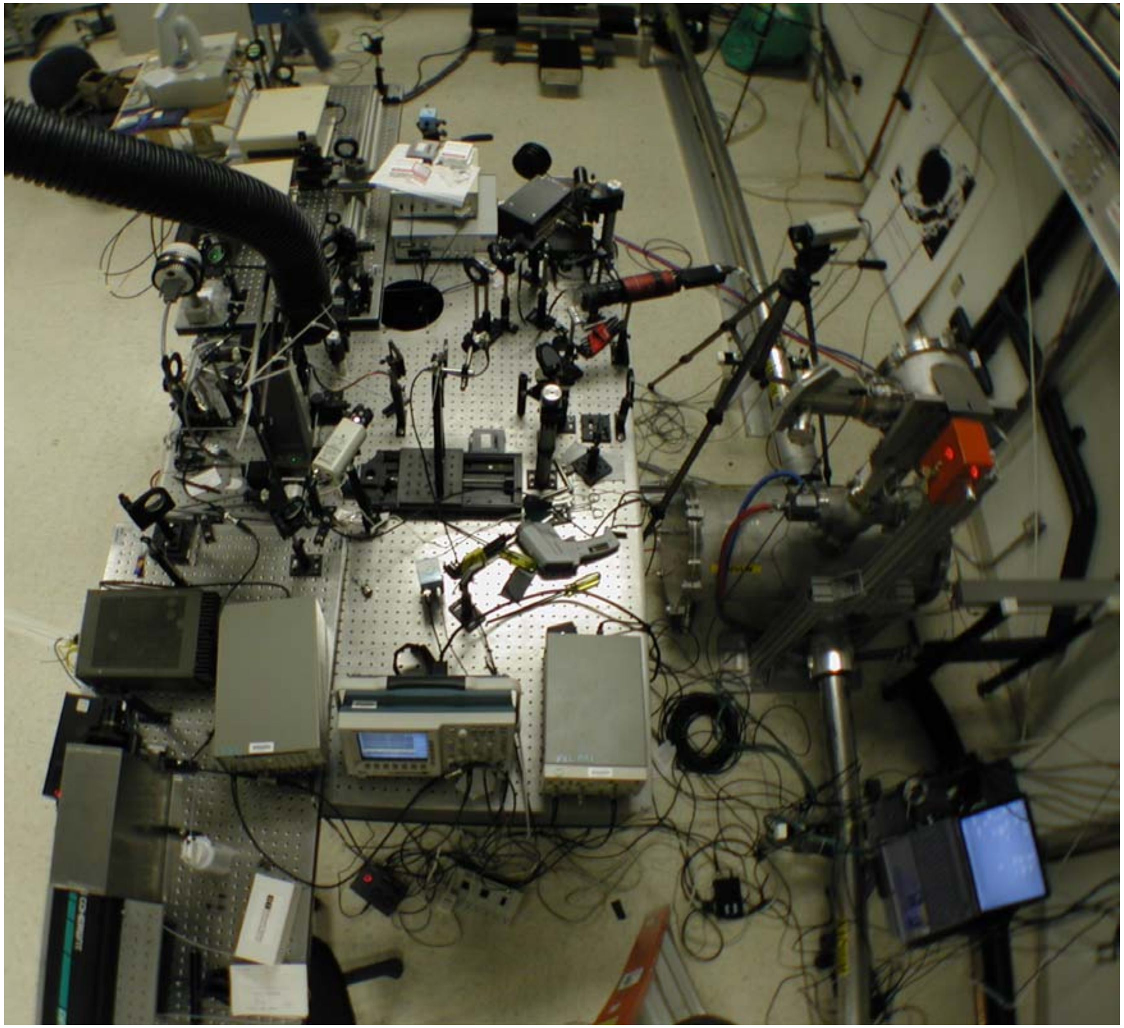
- Setup designed with moderate amount of remote operation, to increase sample throughput.
  - Remote control of focus lens, sample position
  - Remote control of wheel holding 6 samples

- Measure power or energy delivered to target, and beam profile.
  - Data recorded to videotape (mux of 4 video channels)
  - Beam profile stored in digital form
  - Performance of FEL (wavelength spectrum, power) archived

JLAB EXPERIMENTAL SETUP SCHEMATIC



EXPERIMENTAL SETUP - NRL & JLAB



DATA ANALYSIS

- All samples are reweighed after irradiation
- High resolution digital photographs taken.
- Mass loss determined two ways:
  - By weight change
  - By measuring the diameter and depth of the ablated/melted region.
- Beam profiles analyzed to determine irradiance.

- Knowing energy delivered and mass lost, we can determine Q* (kJ/gm).
- Knowing the density, we can determine $W = Q^*\rho$ (in kJ/cm^3).
- Thermocouple data will be analyzed for modeling efforts.

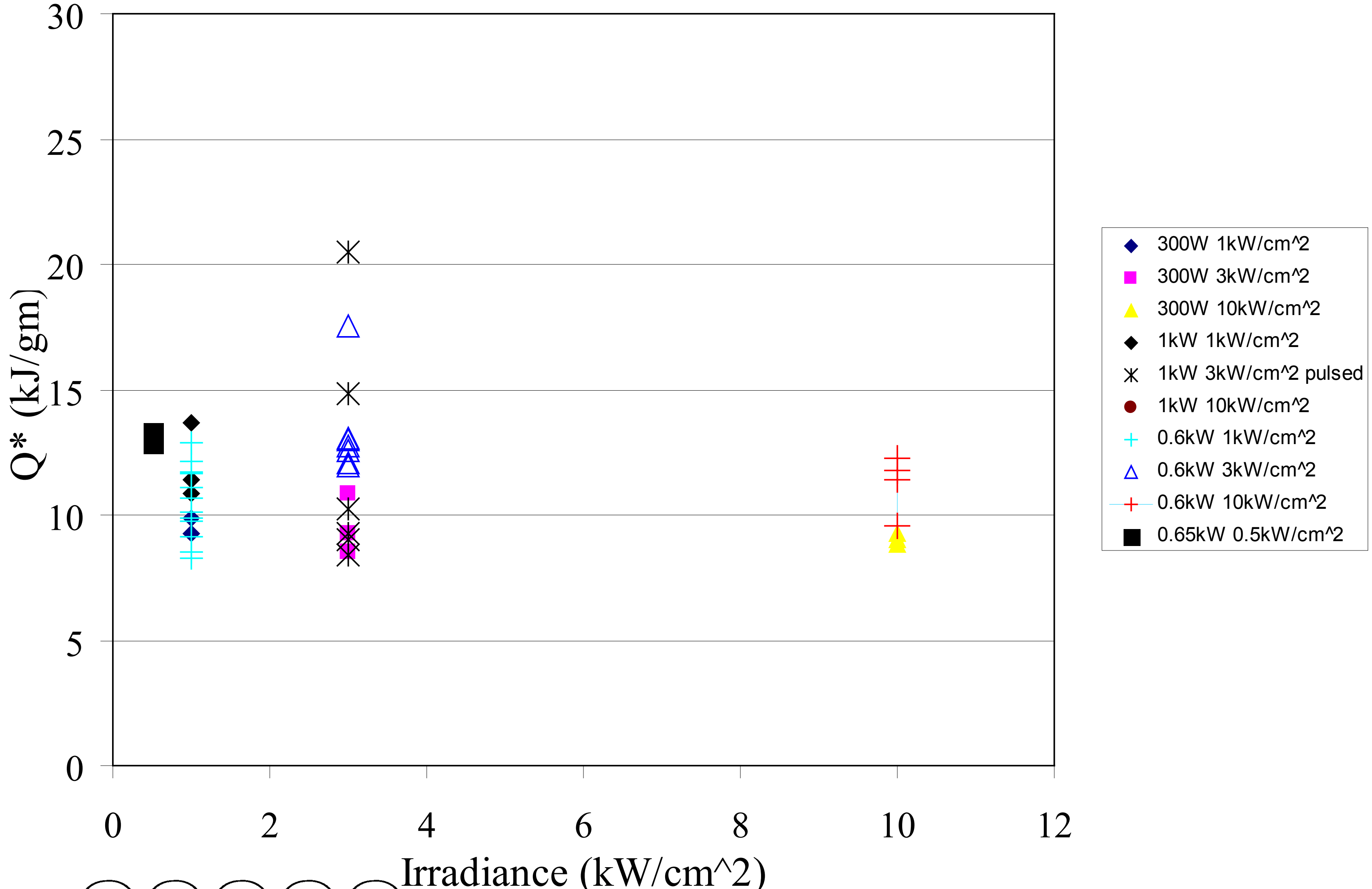
RESULTS TO DATE - NONMETALS

- Values for Q* (or W) determined for Target 2, Plexiglas, and SCFS

- For Target 2 and Plexiglas
    - Q* values are about the same as cw values reported in the literature.
    - No irradiance dependence 1 - 10 kW/cm^2 range
    - Macropulsing did not change Q*, and lengthened irradiation time
    - Target 2 produced UV emission

- For SCFS
    - Much higher Q* (much harder to ablate)
    - Q* seems to decrease (but there is more scatter in the data) with irradiance
    - This scatter is probably due to variability in the amount of glass removed.

Q* VS IRRADIANCE - "TARGET 2"



RESULTS TO DATE - METALS

- Experiments were done with several goals in mind:
- Determine ablative efficiency - through time to burnthrough, and mass loss
- Compare experimental results with theoretical prediction
  - For the same average power and irradiance, but for PRFs varying by 4x, the sample irradiated at the lower PRF should melt twice as fast.
  - Linear dependence of front surface temperature with time.

- Results:
  - All metals weighed.
    - Most stainless steel samples gained weight
  - Two different ways of estimating front surface melt time indicated no PRF dependence.
  - Painting Al greatly improves the coupling efficiency.
  - Stainless steel produced UV emission

PAINTED AND UNPAINTED AL PHOTOS

Unpainted

650 W 10kW/cm^2
16.25 kJ delivered

Painted

650 W 10kW/cm^2
9.75 kJ delivered

CONCLUSIONS

- Based on the results to date
  - Ablative efficiency in nonmetals is equivalent to cw lasers.
  - Essentially constant over the irradiance range 1 - 10 kW/cm^2.
  - The results for metals are still unanswered, require further analyses.
    - NRL data confirms linear temp. dependence with time.
  - For painted Al targets, the FEL pulse format allows paint to char and initially provides good coupling for melting.
  - Plasma (or plume debris) did not appear to be a factor.
  - We saw no indication of microwave emission.

- In support of the BAA-sponsored work
  - Beam on for 169 hours, 94 % uptime
  - Excellent repeatability
  - We irradiated 594 samples, 188 were special samples provided by DoD
  - Our sample automation (and staff!) allowed a large number of irradiations to be performed in a relatively short time.

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