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Dynamic temperature measurements at Sandia National Laboratories

WSU Temperature Workshop

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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Overview

- Pyrometry has its problems, but is suited to a wide range of problems
- Sandia temperature measurements focuses on two different realms
  - Shocked dielectrics (e.g., deuterium)
  - Isentropically compressed experiments (ICE), primarily on metals
- Challenges
  - Make the measurement
    - Measure sample radiance (difficult at low temperatures)
  - Reduce the measurement (convert radiance to temperature)
    - What do we know about the emitter?
  - Interpret that temperature
    - How does the measured temperature relate to the temperature of interest?
  - Believe the measurement
    - Do we know if the result is correct?

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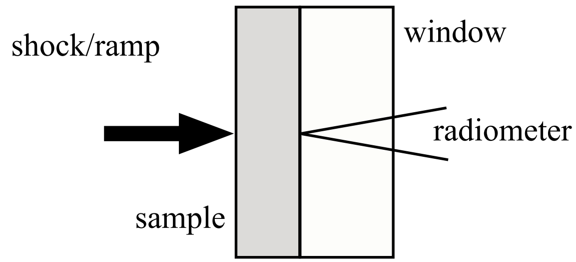
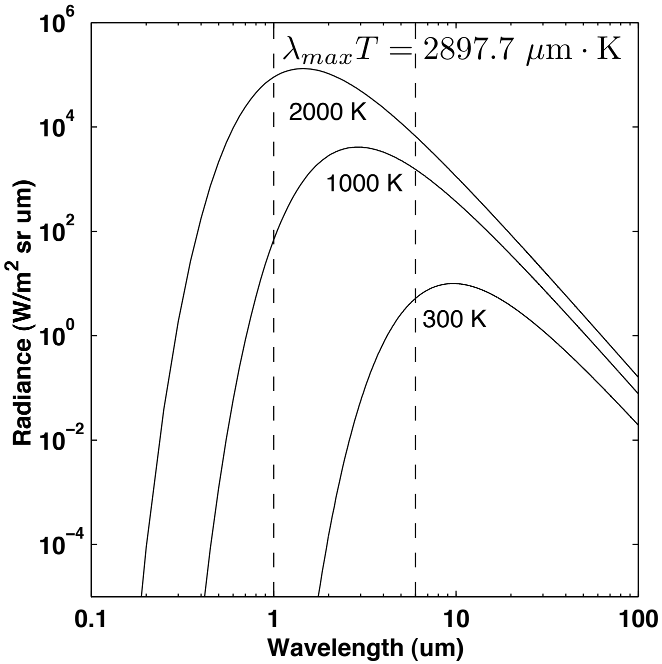
Challenge #1: Making the measurement

- **Nanosecond radiance measurements are difficult**
  - **Limited number of photons**
  - **Stray light issues**
  - **Single event experiments**

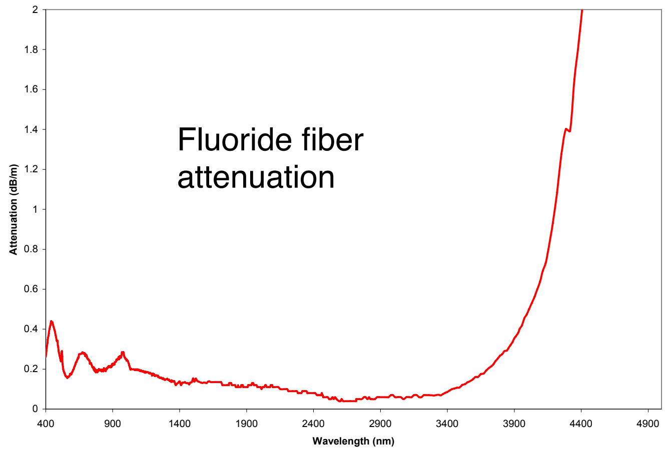
- **Low temperatures (<1000 K) demand IR sensing**
  - **Limited responsivity/bandwidth**
  - **Standard optical fiber doesn't work beyond 2000 nm**
  - **Window spectral cutoff**
  - **Chromatic aberrations**



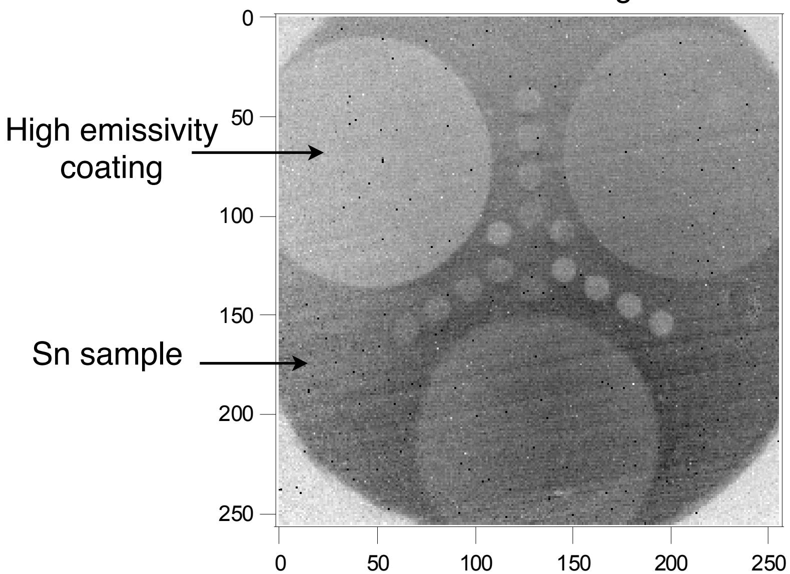


Sandia infrared efforts

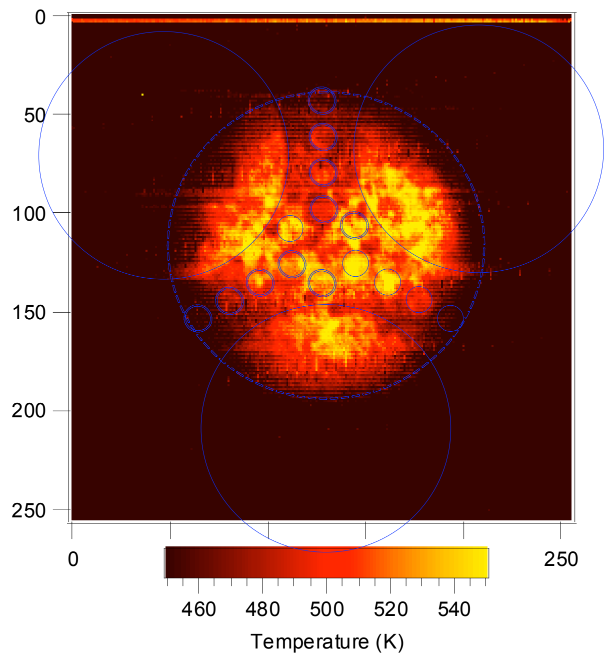
- **Developments**
  - **Fluoride fiber bundles and open beam relays**
    - **Cost vs. simplicity**
    - **Intended for ZR operations**
  - **New detectors (PEM effect)**
  - **Imaging**



Static IR image



Shot image (explosive drive)



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Challenge #2: Reduce the measurement

- **Pyrometry measurements depend on sample temperature AND emissivity**
  - **0≤ emissivity ≤ 1**
  - **Can be inferred from reflectance and transmission**
  - **~0.1 for metals (infrared)**

- **Emissivity changes in many ways**
  - **Material state (temperature, pressure, phase)**
  - **Surface condition (specular, diffuse)**

- **Without knowledge of emissivity, only the minimum pyrometer temperature is known**
  - **Temperature uncertainty scales with emissivity uncertainty**

The emissivity problem

$$L(\lambda, T) = \epsilon \times \left(\frac{2hc_0^2}{\lambda^5 \left(e^{hc_0/\lambda kT} - 1 \right)} \right)$$

$$\epsilon(\theta) = 1 - \rho(\theta; 2\pi) - \tau(\theta; 2\pi)$$

N measurements
N+1 unknowns

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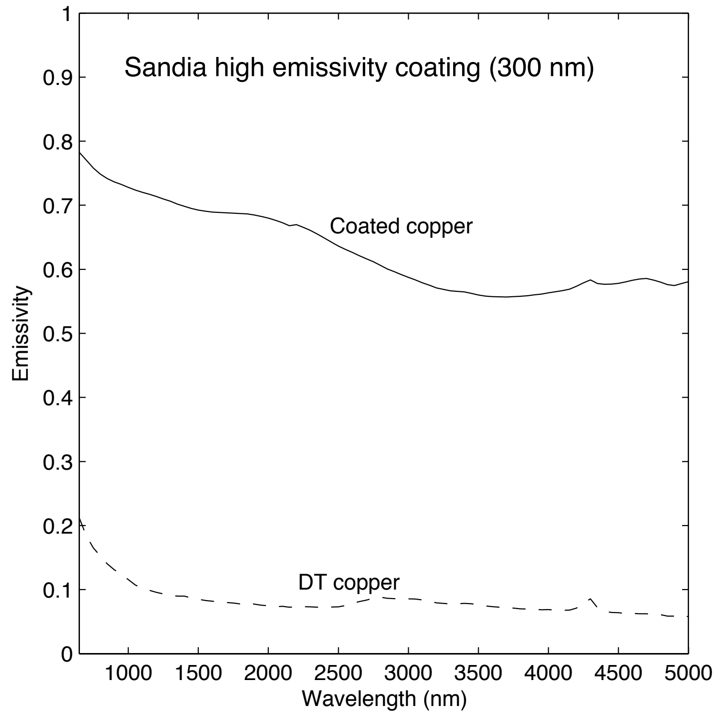
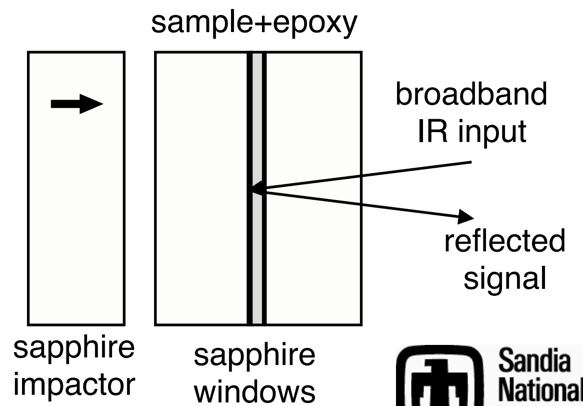
Sandia emissivity work

- **Goal: create emissivity standard for a range of (P,T) conditions**
  - **Must be thin for fast equilibrium**
  - **Must be opaque to hide substrate**
  - **Low reflectance is an added bonus**

- **Ambient emissivity well known**
- **High T, low P measurements underway at NIST**

- **Low T, moderate P shock experiments performed at NSLS**
  - **Thin sample + sapphire windows = quasi-isothermal compression**
  - **Preheat capability possible in future work**





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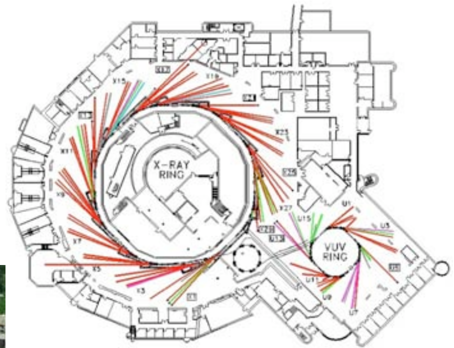
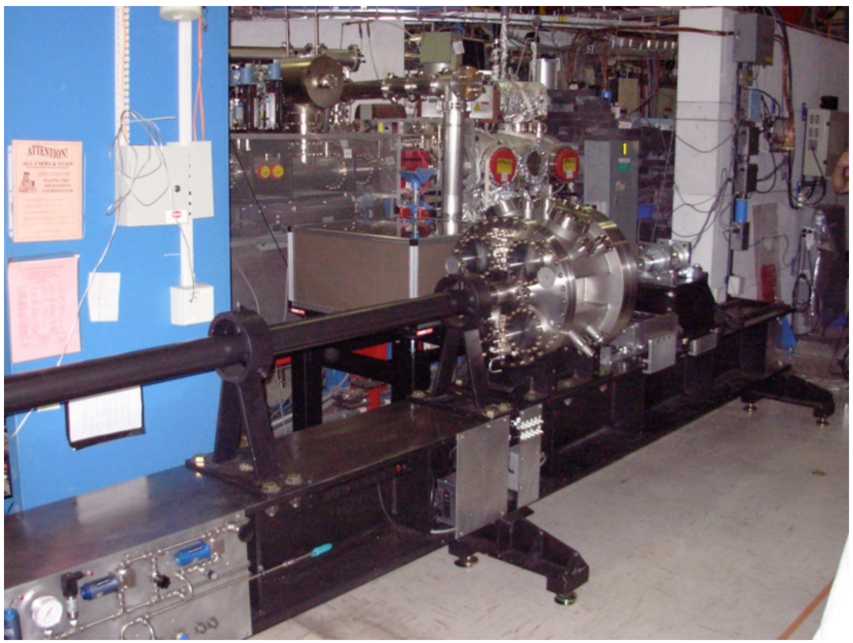
NSLS gas gun





- **Multi-organizational effort**
  - **Extensive review by Brookhaven National Laboratory**
  - **U1 floor space from ExxonMobil**
  - **U2A beam access from Carnegie DOE Alliance Center**
  - **Optical relay and diagnostics by National Security Technologies (SDRD NLV-01)**
- **Gun based on WSU design**
  - **Identical to Sandia DICE gun**
  - **3” diameter projectiles**
  - **Velocities up to 400 m/s (1000 psi He wrap around breech)**
- **Future work to span high stresses and temperatures**

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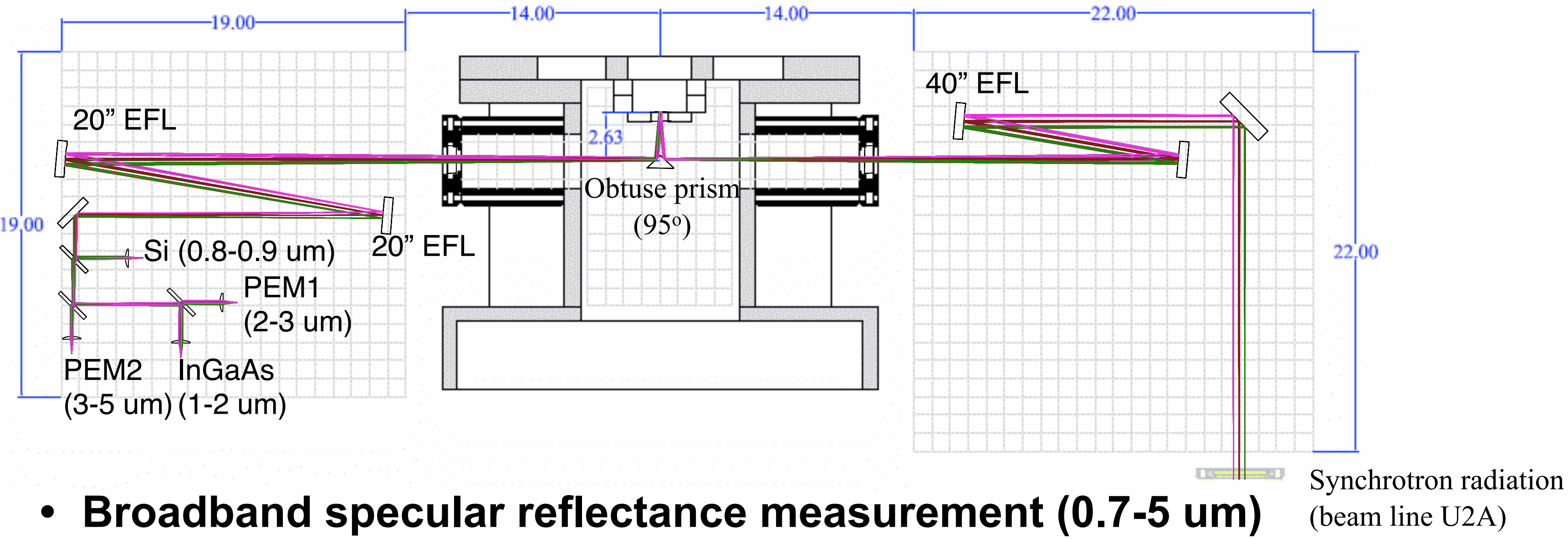
Specular reflectance measurements



- **Broadband specular reflectance measurement (0.7-5 um)**
  - **Wavelength range limited by sapphire (ports/windows) and gold mirrors**
  - **Mirrors avoid chromatic aberrations**
- **Fast detectors resolve individual synchrotron pulses**
  - **vis/NIR: standard photodiodes (Si, InGaAs)**
  - **mid-IR: photoelectromagnetic detectors (HgCdTe)**
  - **Upstream monitor (not shown) tracks pulse-variations**

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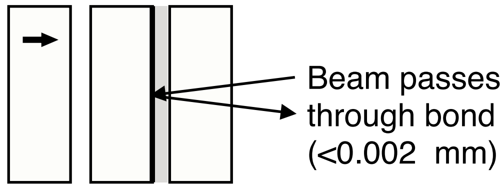
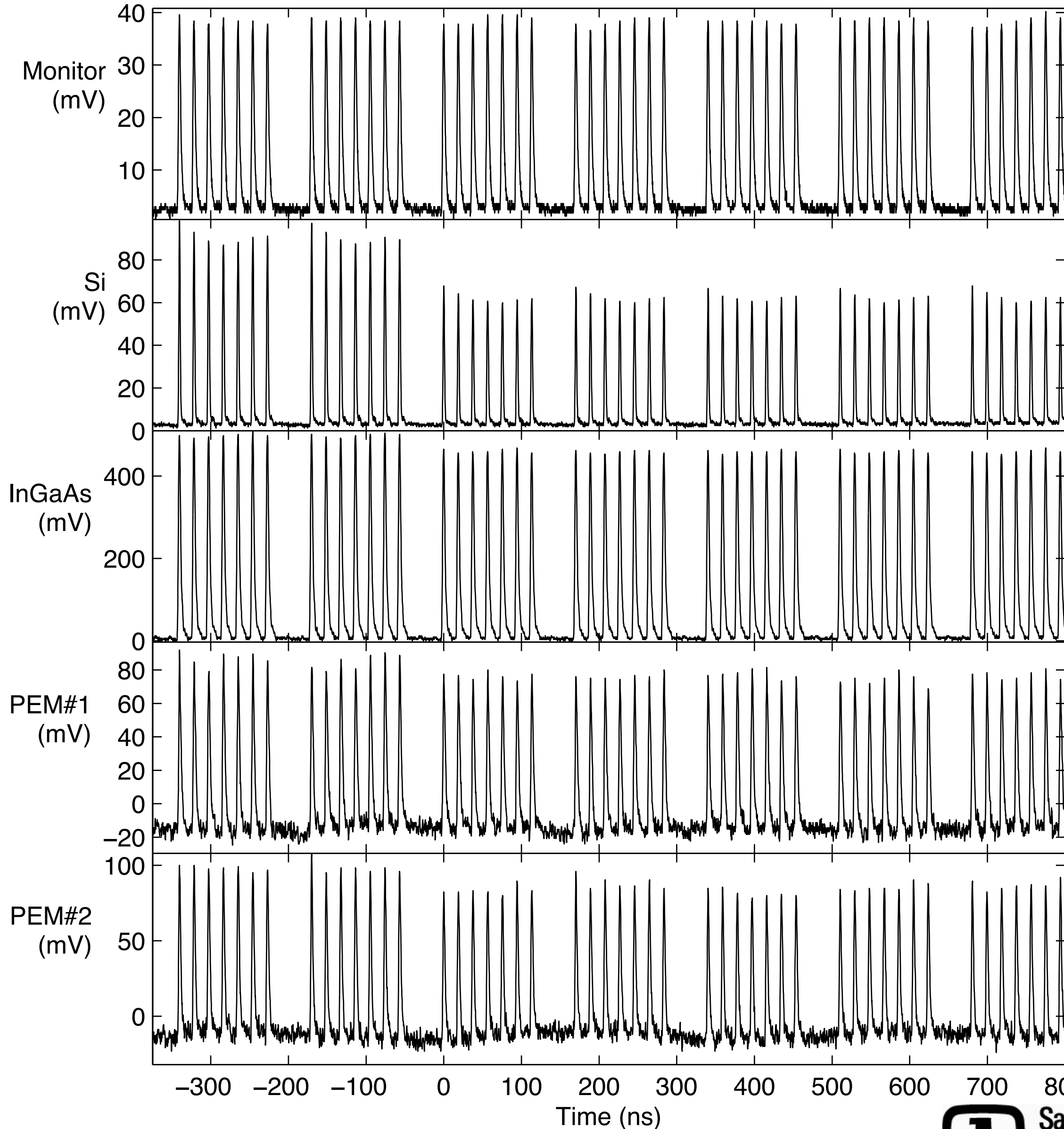
Example: aluminum shocked to 8 GPa

Standard configuration



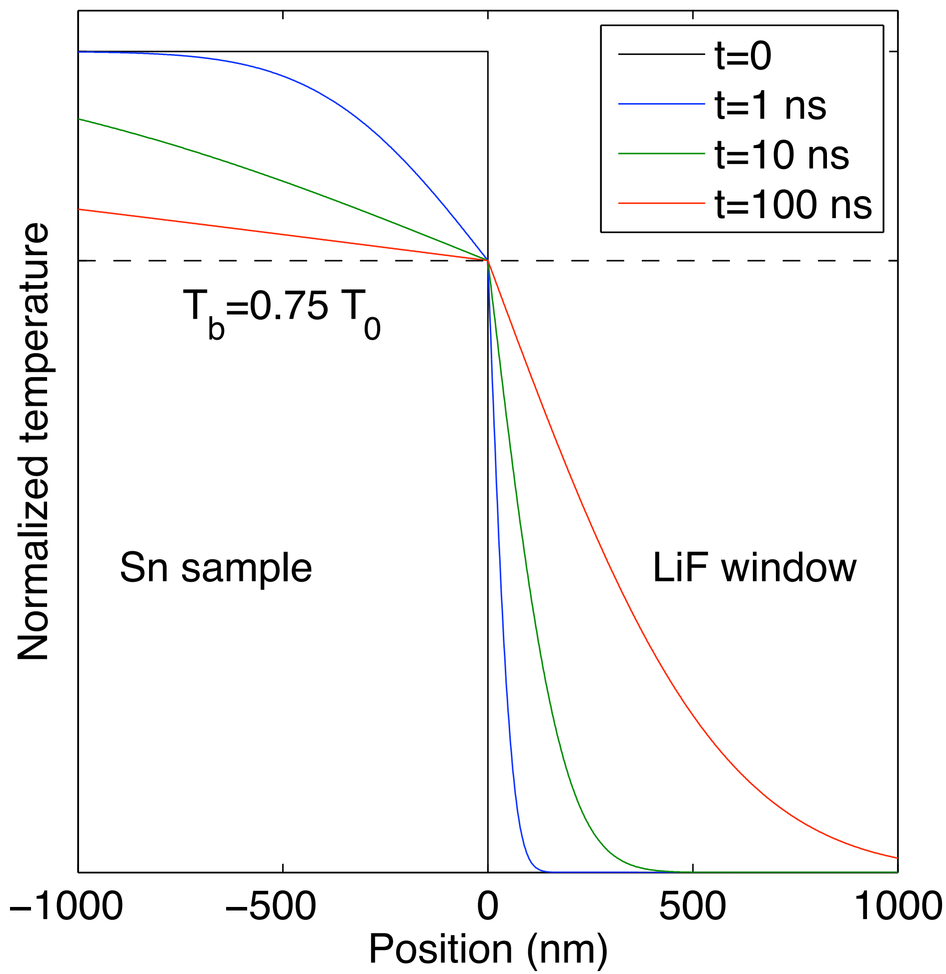
- **Return signal drops when sample is shocked**
  - **Si: 32%**
  - **InGaAs: 7%**
  - **PEM1: 16%**
  - **PEM2: 13%**

- **Apparent reflectance decrease probably due to bond layer (Loctite 326), not aluminum**



Challenge #3: Interpretation

- **What temperature is being measured?**
  - **Window changes loading (reshock or release)**
  - **Cold window draws heat from warm sample**
  - **What about the bond layer (if any)?**
- **Windowless experiments...**
  - **yield zero stress state**
  - **and may result in spall**
- **We have some ideas, but no real data**
  - **Thermal conductivity/contact resistance**
  - **What if the bulk sample melts, but the surface remains solid?**



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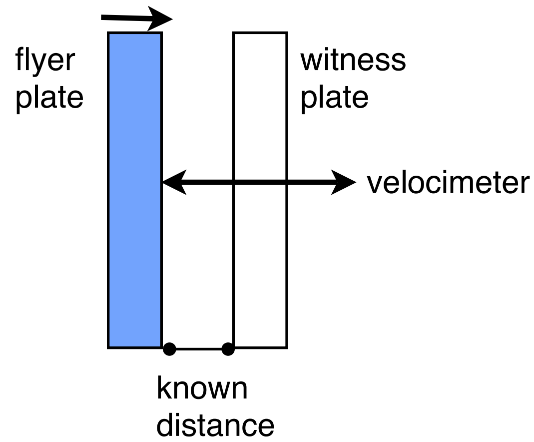
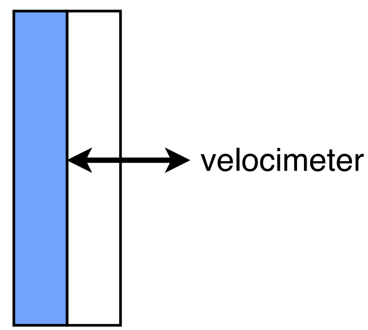
Challenge #4: Believing the results

- **How does one verify temperature?**
  - **No mechanical analogue (jump conditions, fixed displacement, etc.)**

- **This is an area we need some help**
  - **Complementary methods**
    - **Neutron resonance spectroscopy (LANSCE)**
    - **Raman spectroscopy**
    - **Experiment design is key--do different diagnostics probe the same temperature?**
  - **Precise melt lines needed for shock/release melting (DAC community input)**
  - **Are there well posed experiments where temperature can <u>confidently</u> be predicted?**

Example sanity check (mechanical)



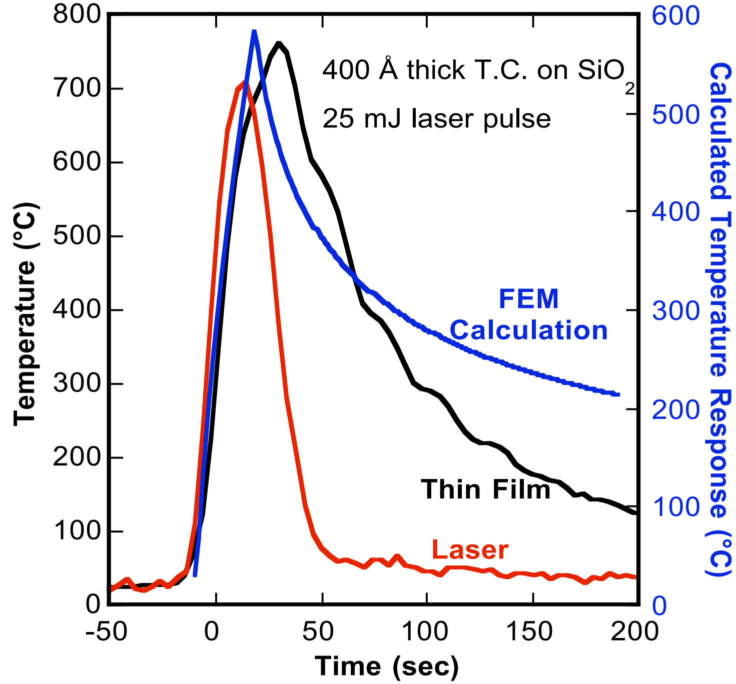


Summary

- **Some progress is being made...**
  - **Mid-infrared diagnostics for low temperature ICE states are progressing**
  - **Emissivity standards seem promising**
- **...but much remains to be done**
  - **Temperature interpretation is tricky**
  - **Validation still pending**

- **Other approaches under development**
  - **Embedded microsensors may be useful at modest stresses**
- **Target fabrication is key throughout this process**
  - **Stray light mitigation (e.g., voids)**
  - **Bond characterization**
- **Will temperature measurements ever be routine?**

Sandia microsensor project
(T. Friedmann)



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Acknowledgments

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