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Flash lamp integrating sphere technique for measuring the dynamic reflectance of shocked materials

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NNSA National Nuclear Security Administration

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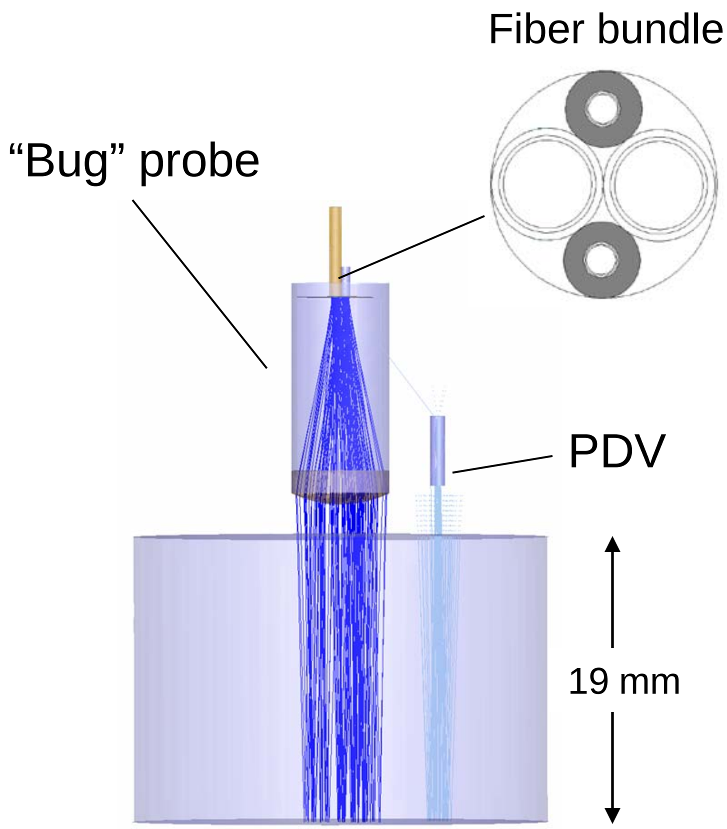
Dynamic reflectance - overview

- Emissivity (reflectivity) is required for *pyrometry*
- Reflectivity is related to material conductivity – *changes with phase*
- In dynamic experiments, motion, tilt, and surface changes may cause changes in reflected light signals
- We made progress measuring *relative* reflectance changes*



* RSI **81**, 065101 (2010)

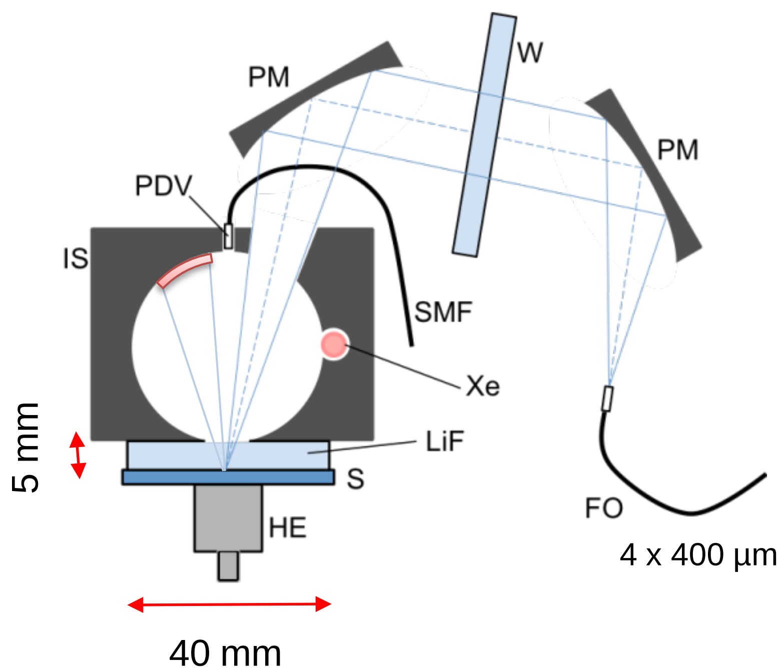
Requirements for dynamic absolute reflectance measurements

- Multiple spectra bands
- Immune to motion and tilt
- Illumination source irradiance significantly larger than sample radiance
- Accurate and reproducible
- Easy to assemble and field

Flash-lamp Integrating Sphere Reflectometry (FISR)

Not a typical IS technique where you measure light levels within the sphere.

Better to think of the sphere as an intense, isotropic, extended illuminator



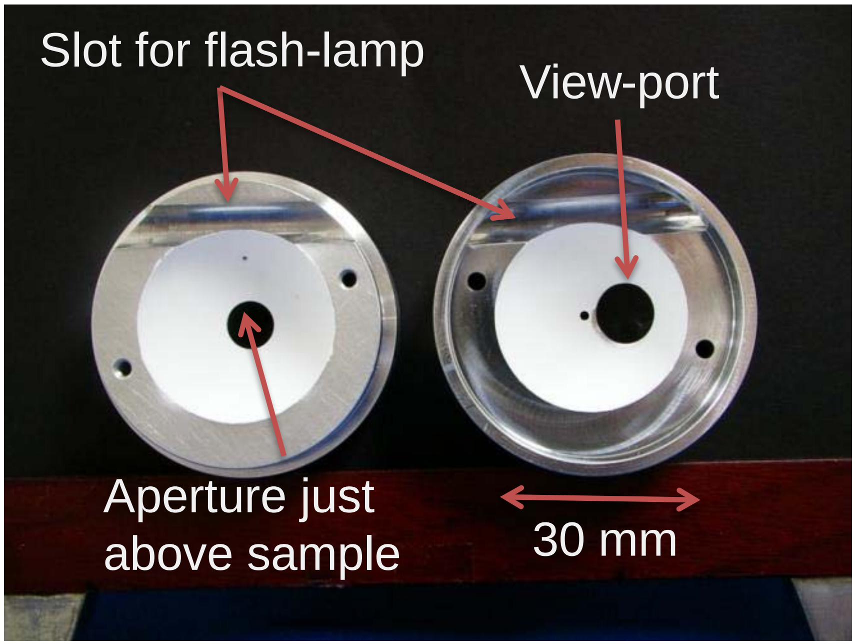
- Xenon flashlamp inserted at sphere's equator
- Fiber bundle is imaged at the sample surface
- Collected light emanates from IS wall – is reflected by sample
- ISR technique described in two recent publications:

  Seifter et al. - J. Appl. Phys. **110, 093508 (2011)**

  Turley et al. - J. Appl. Phys. **110, 103510 (2011)**

Integrating sphere details

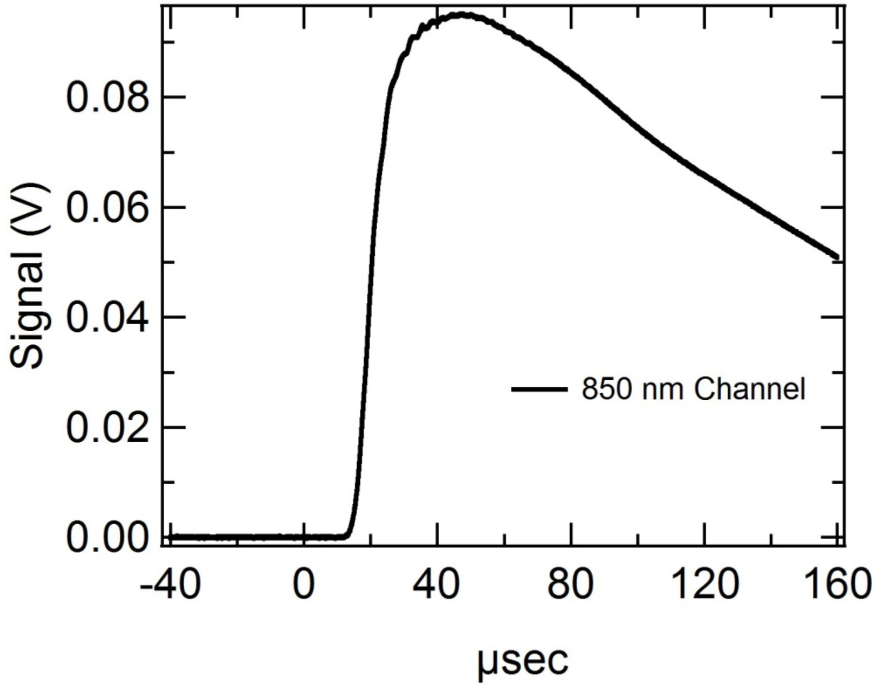
Inside view of integrating sphere

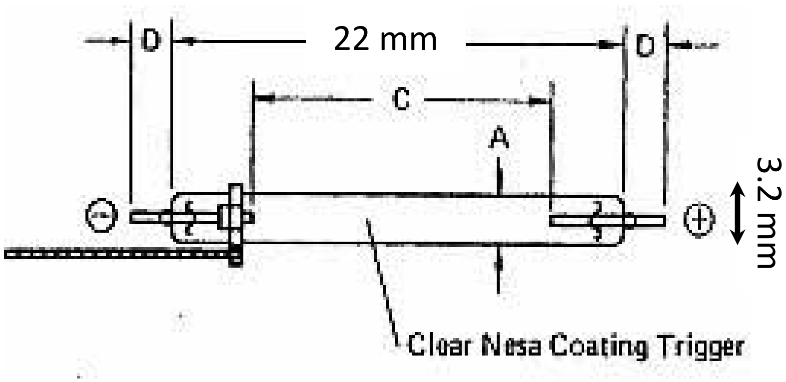


- Flash-lamp and drive-circuit originally taken from disposable film-camera (~ 1" long lamp, 0.5" active length)
- Sphere interior coated with Optical Diffuse Paint*
- Lamp produces reflected radiances that exceed intrinsic radiance of shocked samples at 3000 K by > 10x

* Gigahertz Optik, Türkenfeld, Germany

Xenon flashlamp characteristics



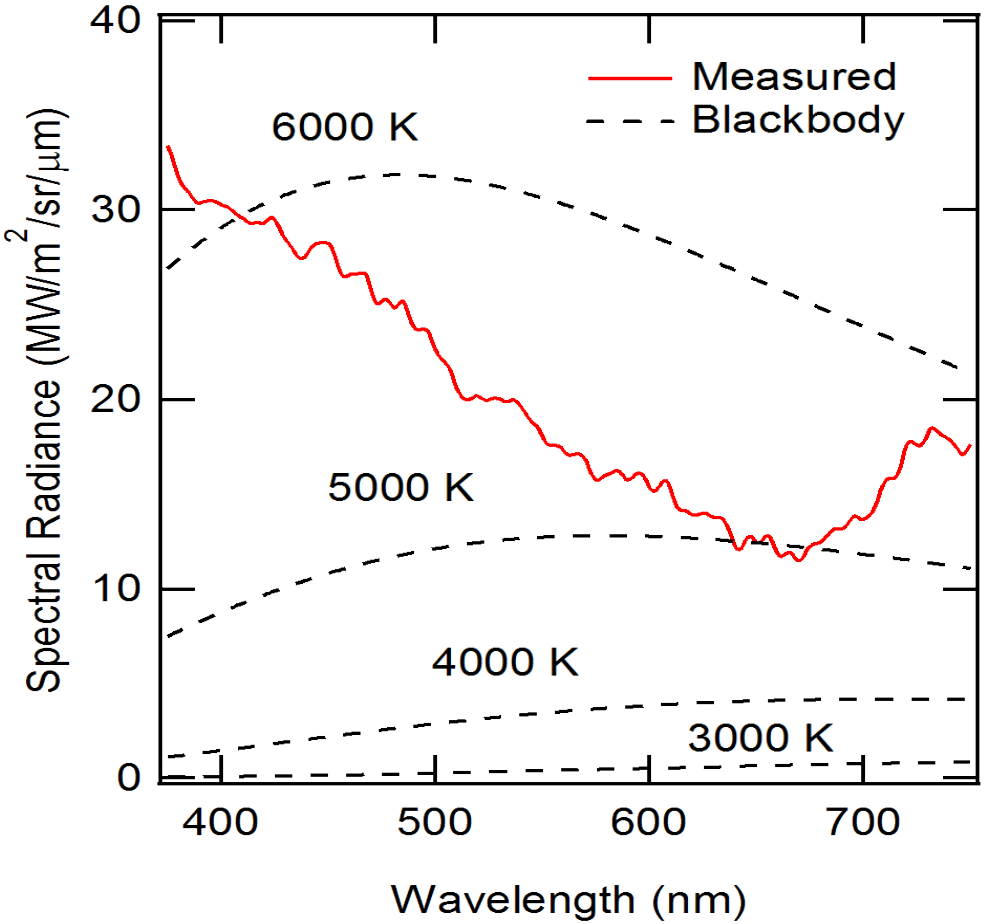


Tec/West MFT-3222
12 Joule flash tube

- Peaks about 47 µs after receiving trigger
- Light levels are relatively flat (0.2%) over 1 µs at peak

Calibrated spectral radiance from sphere wall

Output is comparable to high temperature blackbodies



Measured trace is corrected spectrum from a gated optical multichannel analyzer, at the time of peak emission

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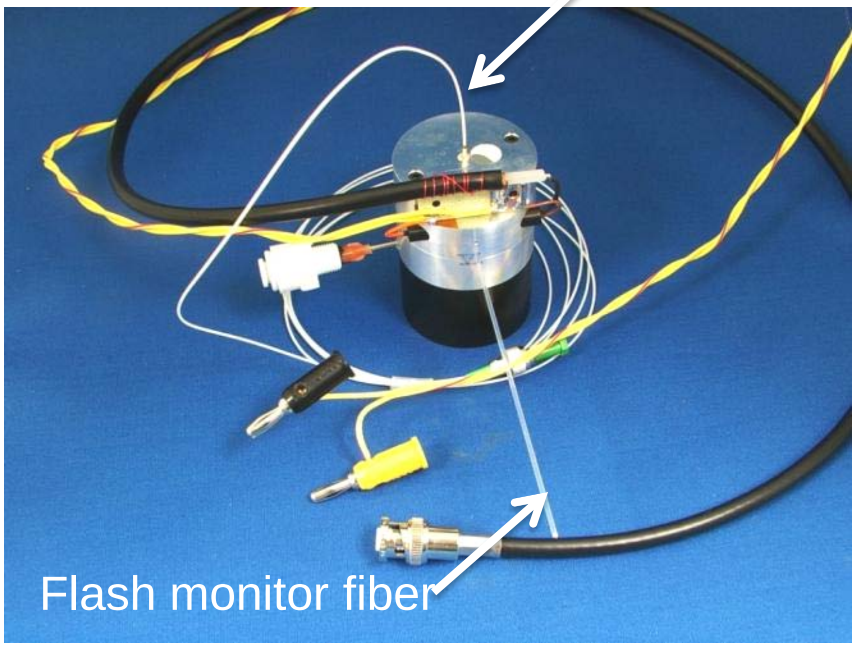
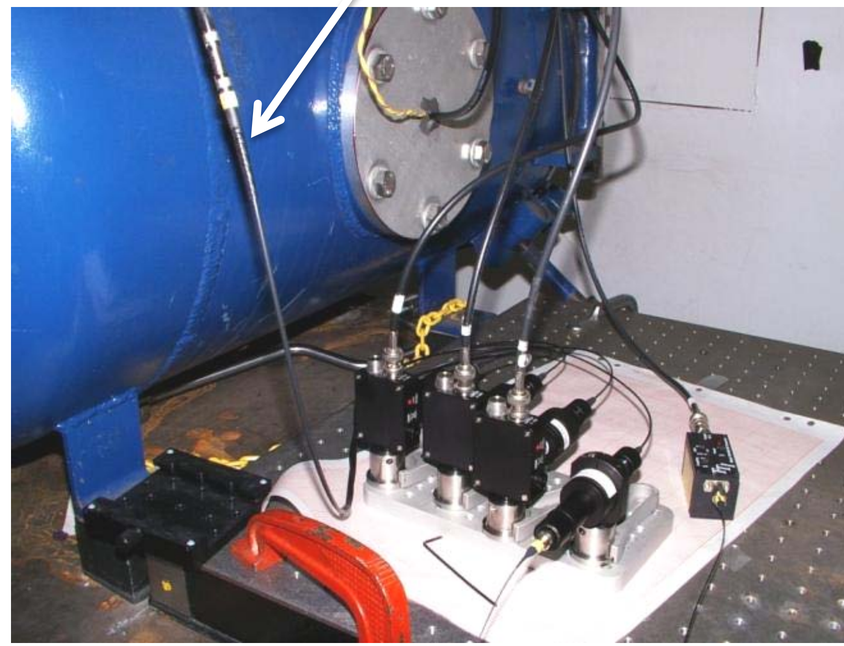
Experimental setup

PDV probe

4x 400 µm fiber bundle monitor

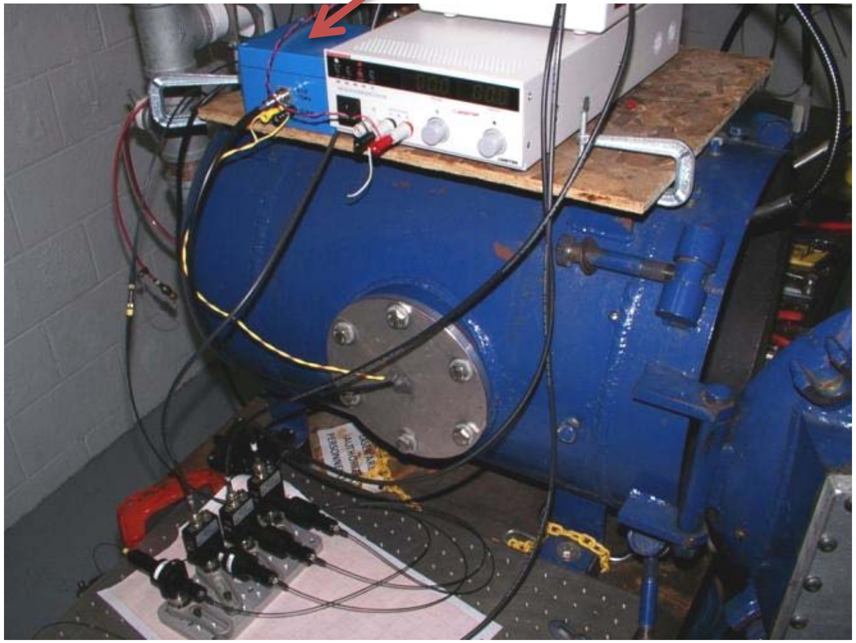




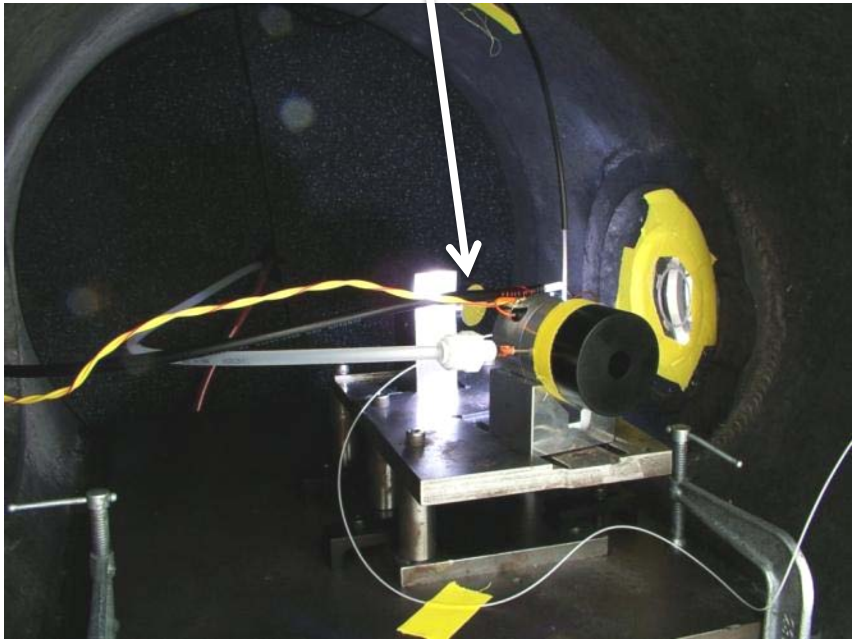
• 500 x 25 nm, 700 x 50 nm	Thorlabs Det10A silicon (1 ns risetime)
• 850 x 100 nm	Det36A extended silicon (10 ns risetime)
• 1000 → 1700 nm	TTI-950 InGaS (0.5 ns rise)

Typical experiment

Flash circuit (in blue box) is remotely enabled and triggered

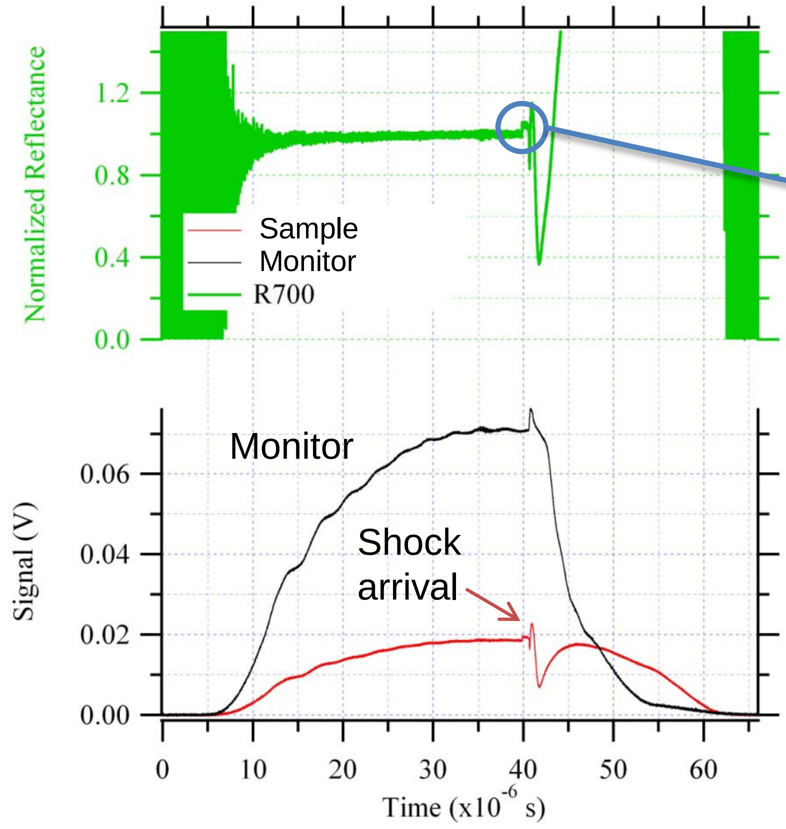


Off-axis parabolic reflectors couple light from surface out to a 4 x 400 µm bundle

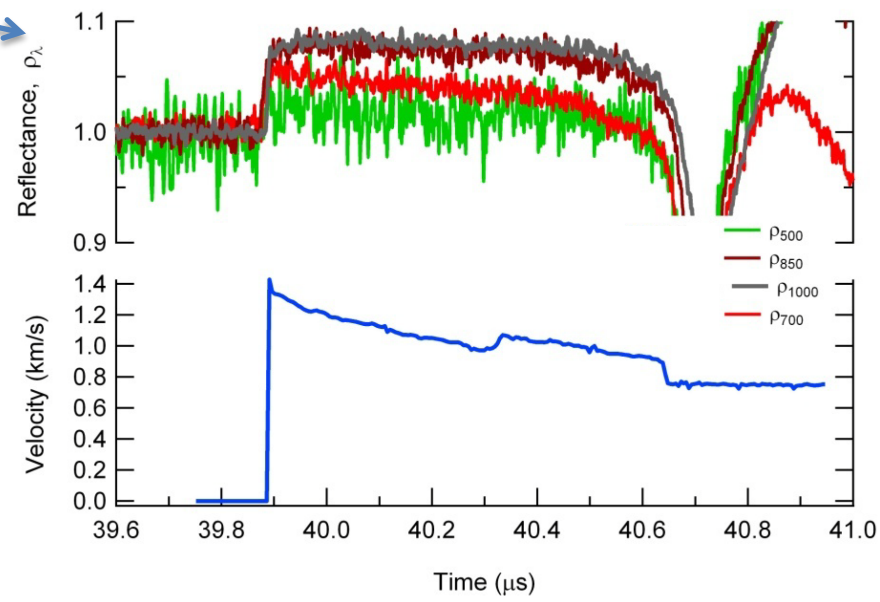


Data set from typical dynamic experiment: Sn

700 x 25 nm channel



120217-1 9501:1mm Sn: 5mm LiF, 34 GPa

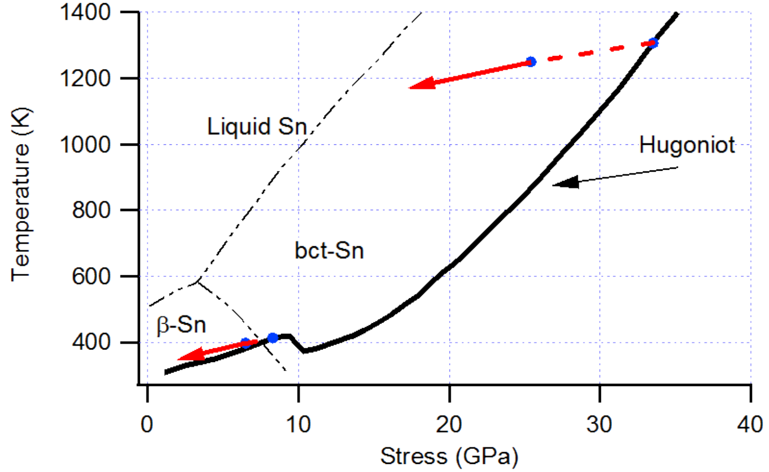


Summary of recent dynamic emissivity experiments

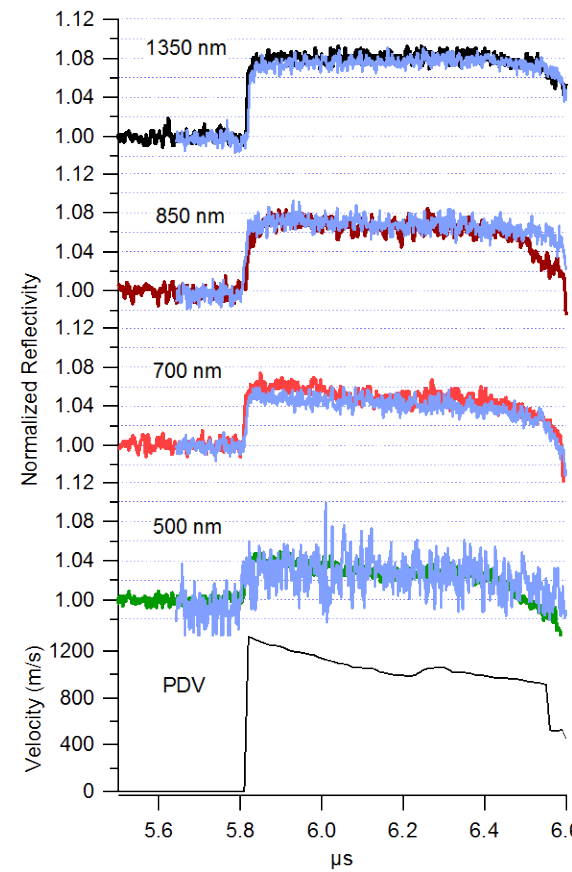
Ratios of shocked to ambient reflectance for seven experiments.

	Sn	Sn	Al	Cr	Ga	Cerrotru	Cerrotru
Interface stress (GPa)	**26**	**6.5**	**30**	**26**	**26**	**24**	**17**
R/R_0 (500 nm)	1.04	0.95	0.86	0.83	1.10	0.97	1.02
R/R_0 (700 nm)	1.06	0.92	0.94	0.93	1.40	0.95	0.96
R/R_0 (850 nm)	1.07	0.88	0.97	0.96	1.40	0.96	0.99
R/R_0 (1150 nm)	1.08	0.99	0.97	1.03	1.23	0.91	1.02

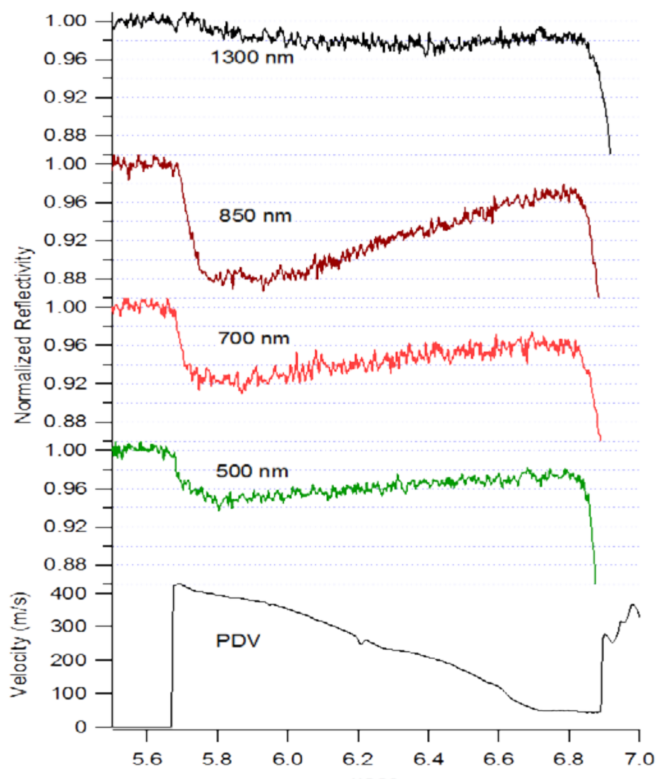
Dynamic reflectivity experiments, tin (glued to LiF)



24.2 GPa,
Above β-γ transition
(two experiments shown)



6.5 GPa,
below
β-γ transition



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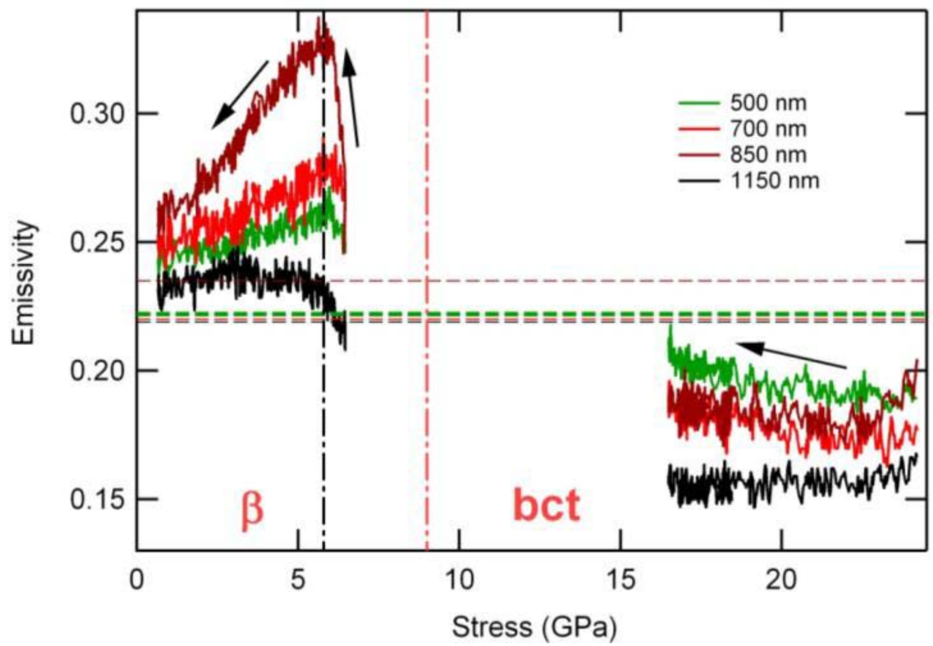
Can this reflectance be used to detected solid phase changes? - Tin

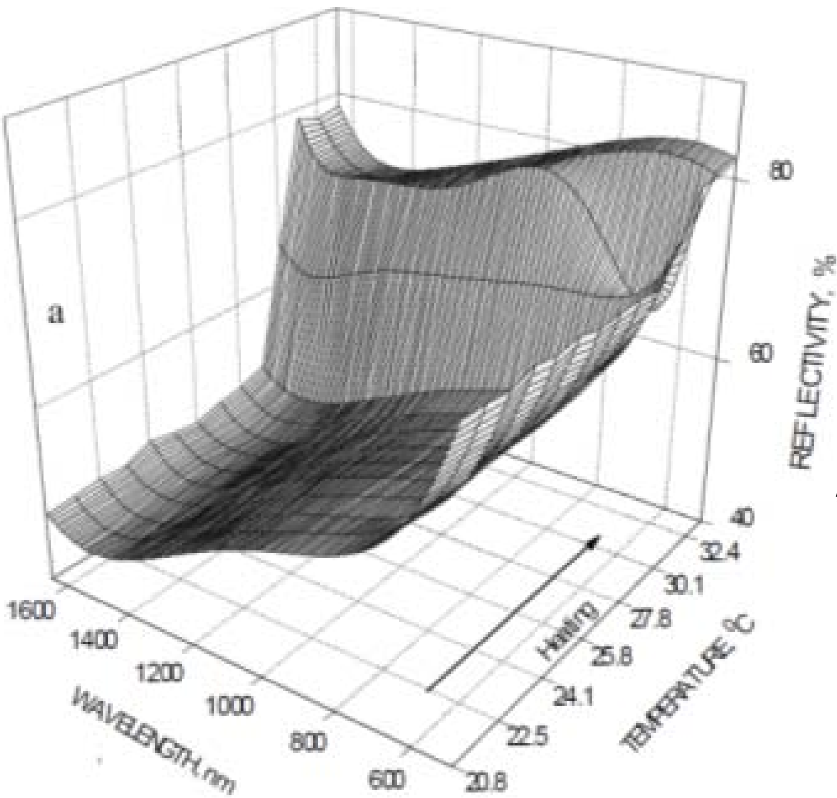
Emissivity shows discontinuity at β-bct phase boundary

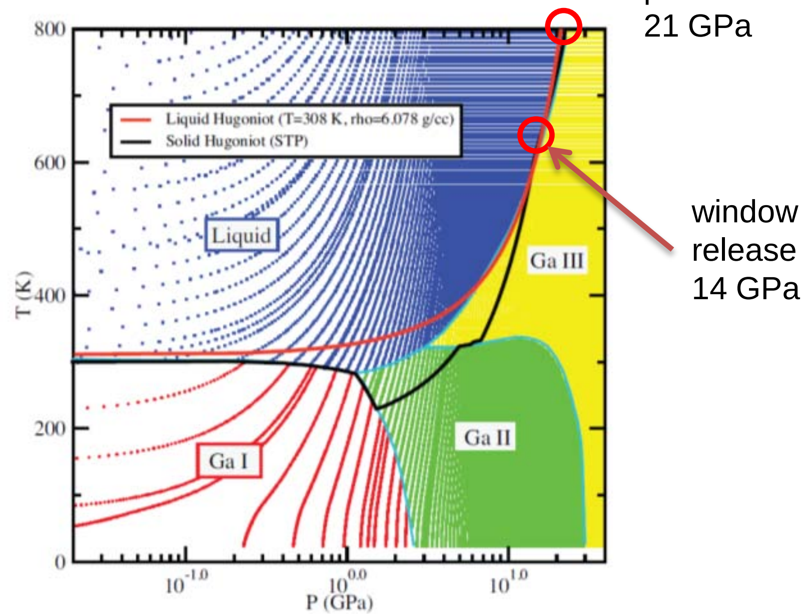


- Emissivity strong function of stress in β phase
- Sharp drop in emissivity at phase boundary
- Weak function of stress in bct phase

Can reflectance be used to detect solid liquid phase changes? - Gallium

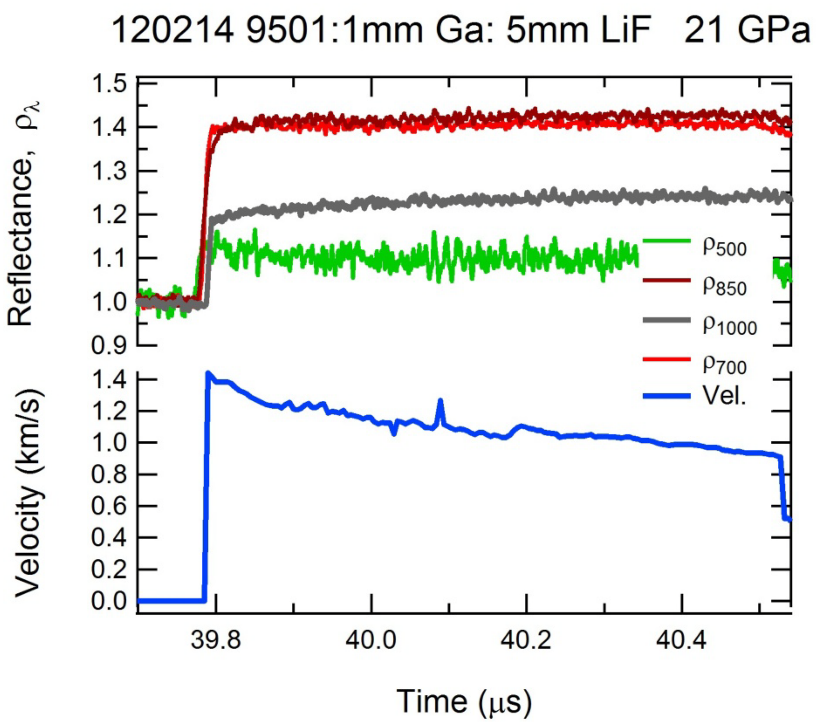
Gallium : Semi-metal to free-electron liquid metal





*** A GALLIUM MULTIPHASE EQUATION OF STATE 2011 SCCM Scott D. Crockett and Carl W. Greeff**

Can reflectance be used to detect shock melting? Gallium dynamic data



	Static R/R_0	26 GPa
R/R_0 (500 nm)	1.27	1.10
R/R_0 (700 nm)	1.57	1.40
R/R_0 (850 nm)	1.60	1.40
R/R_0 (1150 nm)	<1.5	1.23

- Gallium becomes significantly more reflective when shocked
- Results are similar to static melting measurements, (but interface at 14 GPa, ~600K)
- Best to compare with diamond anvil measurement at appropriate T and P

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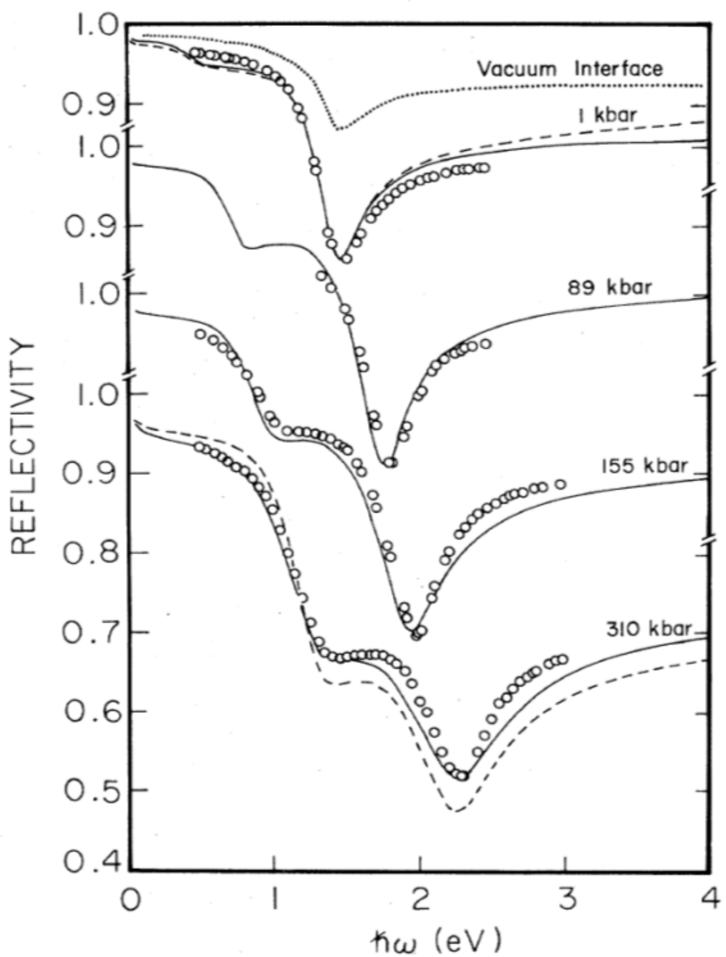
Aluminum experiments

- Aluminum interband absorption at ~ 800 nm has strong pressure dependence *
- Absorption reduced with temperature **

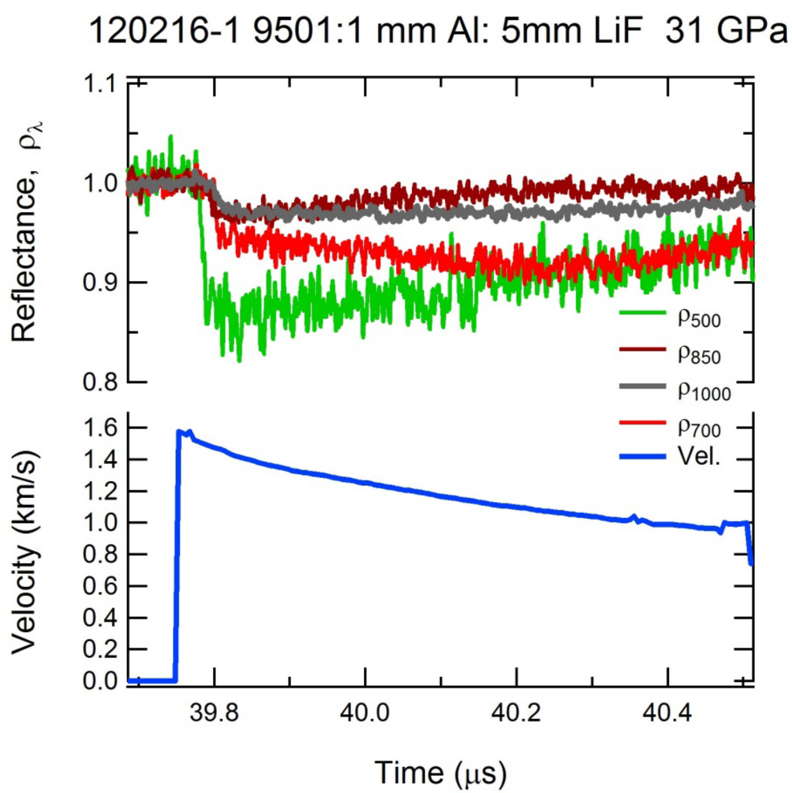
Diamond anvil cell reflectivity data from Tups and Syassen, J. Phys. F 14, 2753 (1984)

* "*High pressure as a probe of electron structure: Aluminum*" - R. G. Dandrea and N. W. Ashcroft, Phys Rev. B 32, 6936 (1985)

** *"Calculation of optical absorption in Al across the solid-to-liquid transition"* – L. Benedict et al., Phys. Rev. B 71, 064103 (2005)



Aluminum FISR
1 mm Al : LiF

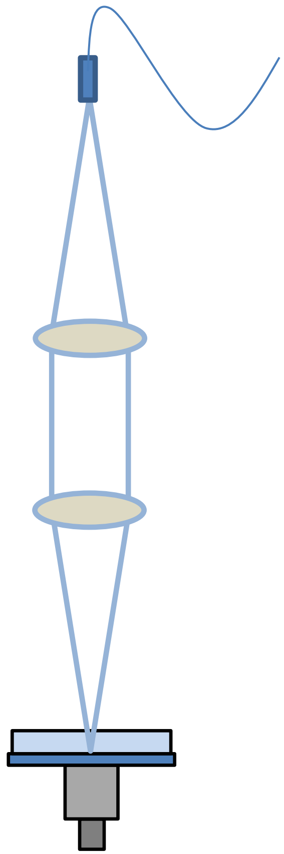


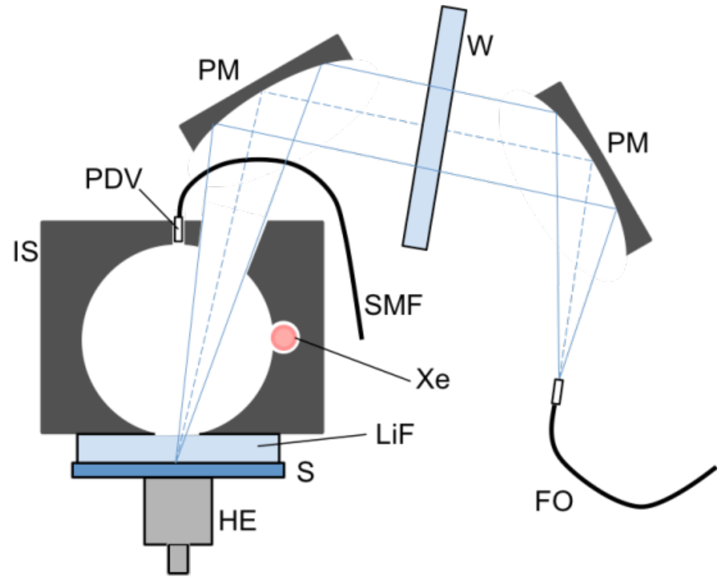
	Ashcroft 31 GPa / 1 GPa	31 GPa
R/R_0 (500 nm)	0.67	0.86
R/R_0 (700 nm)	0.85	0.94
R/R_0 (850 nm)	0.94	0.97
R/R_0 (1150 nm)	0.97	0.97

Ambient T DAC data

Quantitative Temperature measurement by combined radiance / reflectance experiments

Radiance Measurement

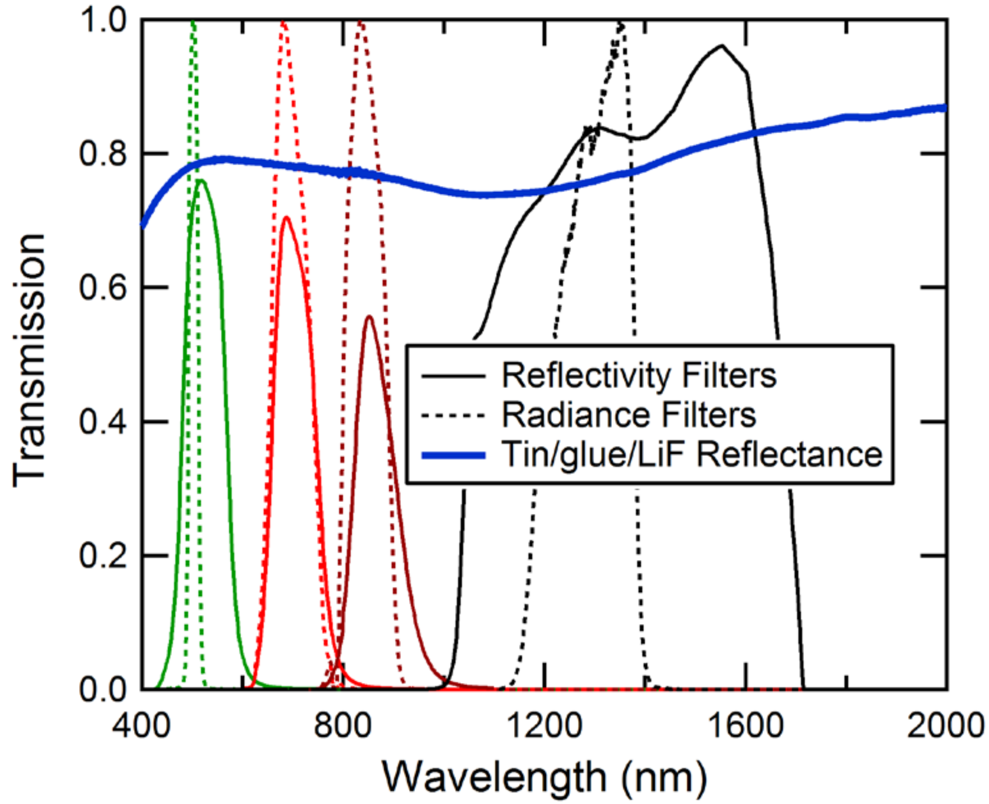




Reflectance Measurement

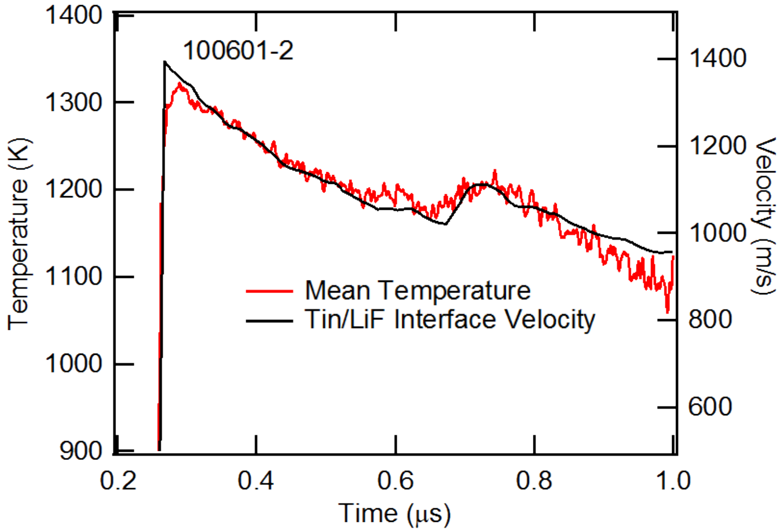
Quantitative temperature measurements:

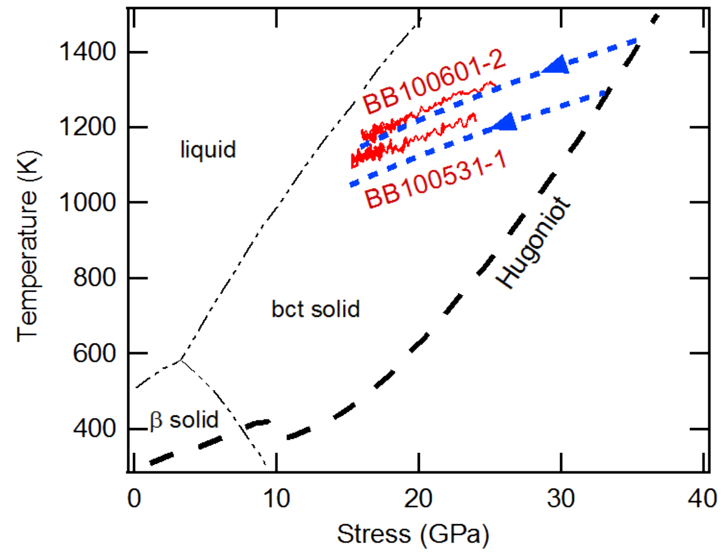
Combining Radiance and Emissivity



- Ambient tin/glue/LiF interface reflectance had excellent target to target reproducibility.
- Filters for radiance and emissivity experiments have essentially the same spectral coverage.

Temperature-Stress Release Paths



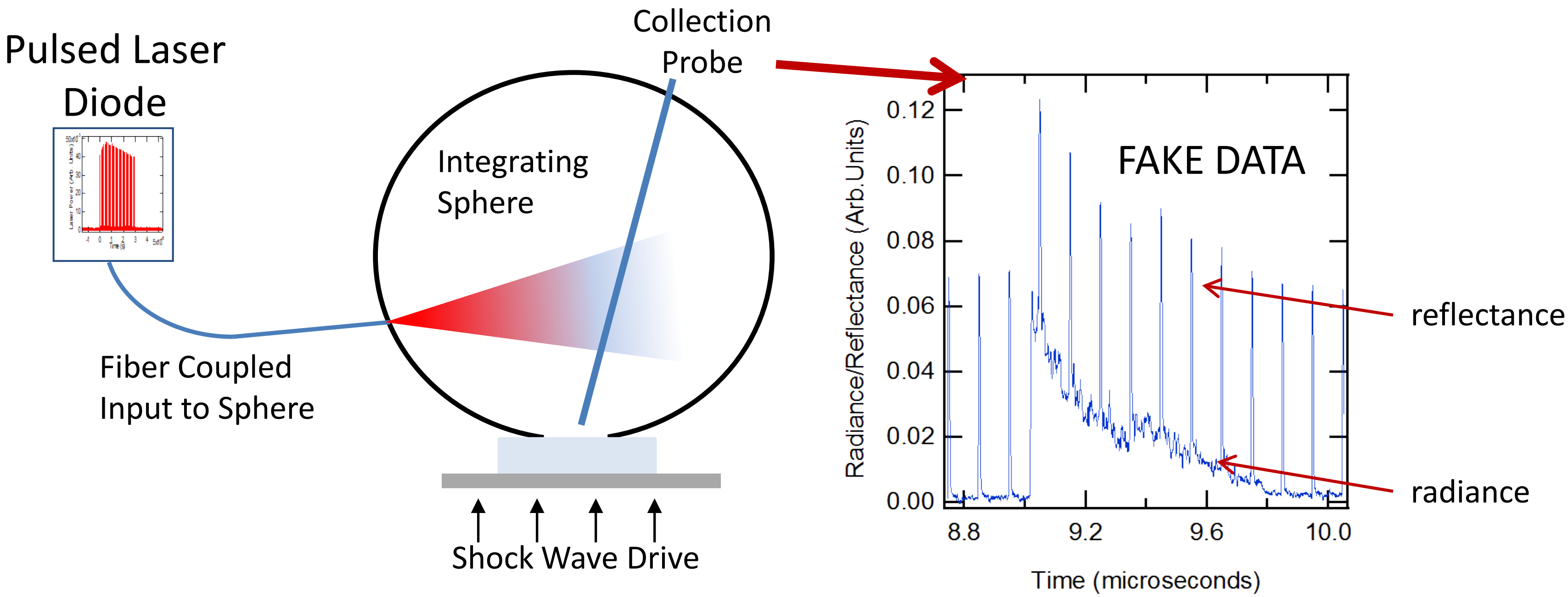


- Interface velocity used to obtain stress
- Details on this technique at 5:15 PM L3.00007*: Pyrometric temperature measurements of shocked metals with uncertainties of less than 2%*

Recent improvements to technique

– Direct fiber collection of reflected light (lensless)
– Plastic spheres for use in vacuum (catch tanks)

Future configuration – pulsed laser illum.



- For temperatures ~ 5000 K
- Time multiplexed, *single experiment*
- Shared reflectance/radiance optics
- Single set of pyrometry receivers

Conclusions

- In addition to emissivity information, dynamic reflectance gives information about material phase
- DAC measurements at similar pressures and temperatures will help identify dynamic crossing of phase boundaries
- This technique should be a valuable tool to map phase-space of materials