Post-Shot Report: Measurement of Be sound speed on shock Hugoniot, Sept. 26 – Oct. 14 at Trident laser‡

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1. Objectives

- **Primary: Melting conditions of Be under laser illumination**
  Shock sound-speed measurement of Be on Be principal Hugoniot to identify solid–solid and melting transitions.
- **Opportunistic**
  Continued investigations of dynamic responses of materials addressing relevant technical and scientific issues, such as phase transitions in carbon and ceramics silica stishovite, and elastic/plastic behavior in Cu, NiAl and Fe (110) mosaic subjected to high strain rate loading.

2. Schedule

- **Start of access and setup:** Sept. 26–Oct. 3, 2005.
- **First shot:** Oct. 4, 2005.
- **Last shot:** Oct. 14, 2005.

3. Materials

- Be foil: punched from Be foils, diameter of ∼3 mm; nominal thickness 25 μm should be 29(1) μm, and 50 μm be 59(1) μm. Be disk was glued and pressed

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against the aluminized surface of a LiF window of 2 mm thickness (MST-7 and Swift).

- Cu: GoodFellow (50 μm thickness). Primarily for testing setup and lasers.
- Carbon black: powder (Prof. O. Tschauner, UNLV).
- Diamond: powder (Prof. O. Tschauner, UNLV).
- NiAl single crystals: (110) and (111) orientations (MST-8; leftover from previous Koskelo LDRD).
- Stishovite: disk embedded in crystal bond (Caltech).
- Fe: (110) mosaic of 35(1) μm thickness (H. Lorenzana, LLNL).
- Si: 640 μm (GoodFellow).

4. Experimental

The basic experimental aspects are essentially the same as previous dynamic materials campaigns at Trident. Some details omitted here can be found in our previous post-shot reports (e.g. LA-UR-04-2603, LA-UR-04-1508, LA-UR-04-1475 and LA-UR-05-5643).

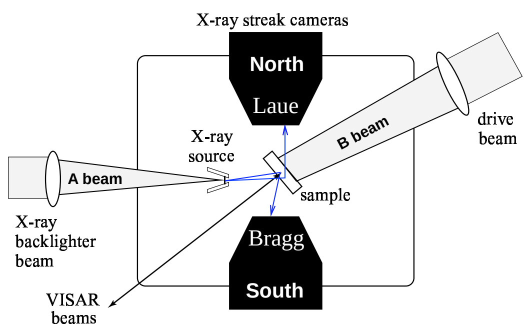

Figure 1. Schematic experimental setup for VISAR and TXD measurements at Trident. A-beam and TXD were not used in this campaign.

- **Schematic layout:** see Fig. 1.
- **Laser drive conditions**
  - **Trident laser:** Nd:YLF with a fundamental wavelength of 1054 nm.
  - **A-beam**: 2.4-ns duration, 527 nm, 100–200 J for transient x-ray diffraction. A-beam drives the x-ray backlighter (e.g. 6-μm Ti foil at the tip of the gold cone) from nearly due west. *Not used*.
  - **B-beam:** 2.4-ns duration, 527 nm, 1–250 J for shock wave loading. B-beam irradiates the sample from the northeast port (35° from east and 6° from sample normal, as defined by the axis set up for the VISAR: 41° south of west).
  - **Laser spot:** 1.4 mm and 4 mm in diameter (Table 1). Diffractive optical elements were used where possible to smooth large-scale spatial variations in beam intensity. Generally these phase plates were not ideal for the desired uniformity or spot size, so the drive beam was defocused slightly.

Table 1. Driving laser spot on the sample.

Spot dia. (mm)	Phase plate	Defocus (in)	Comments
4.0	Fresnel zone	0.600	4-mm design spot defocused to remove central hotspot
1.4	2-mm hexagonal	0.339	0.6-mm design spot defocused for better power control and easier alignment

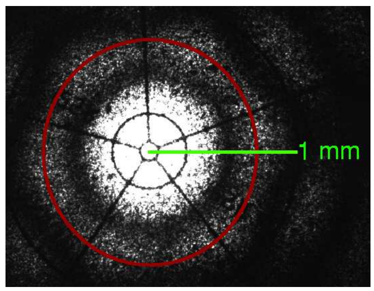

Figure 2. An example of laser spot (B-beam) on the sample surface (driving side). The laser spot is about 1.4 mm (the red circle).

Table 2. Timing the Hamamatsu camera for VISAR

sweep (ns)	t_1 (ns)	t_2 (ns)	t_3 (ns)	t_4 (ns)
50	2992.0	2982.0	2972.0	2962.0
20	3033.0	3028.0	3023.0	3018.0
10	3043.0	3040.0	3038.0	3035.0
5	3051.5	3050.5	3049.5	3048.5
2	3057.5	3057.0	–	–

- **VISAR**
  - **Line-imaging VISAR:**

    Forsman type. Two VPF's (velocity per fringe) of 4.95 and 0.8 km s^{-1} are available using two SF6 etalons of different lengths for the 660-nm probe laser. (VPF of 4.95 km s^{-1} was used in this campaign.) A focusing lens was placed in the in tank, 20 mm from target chamber center (TCC) to focus incident probe laser.

    A depolarizer for probe laser beam was adopted on Oct. 13, 2005, intended to improve sample reflectivity after shock breakout, thus fringe on the record. No significant improvement was noticed, though.

  - **Timing of probe laser:** As a typical setup, probe laser was timed using DG535 at 546,330 ns for VISAR streak camera at 2982 ns for the 50-ns sweep.

  - **Timing of Hamamatsu streak camera:** Table 2.

  - **Spatial calibration of Hamamatsu streak camera:** Fig. 3.

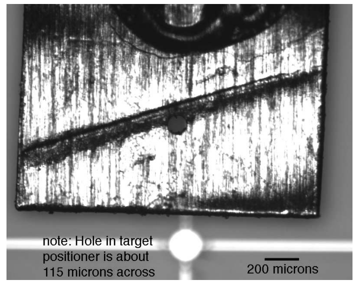

Figure 3. Spatial calibration for VISAR streak camera. The hole in the alignment target is of 115-μm diameter.

– **Temporal calibration of Hamamatsu streak camera:** using fiducial pulses at 1.71-ns separation with mirror spacing of 10.09$''$ (compared to 1.69 ns previously.)

5. Shot log and statistics

See Table 3 for the shot log. The shot statistics is:

- **total:** 41 (38 VISAR shots, and 3 recovery only).
- **Be, 29 μm, VISAR:** 6
- **Be, 59 μm, VISAR:** 7
- **Cu, 50 μm, VISAR:** 14
- **NiAl single crystals, VISAR:** 6
- **Si, VISAR**: 1
- **Carbon black, recovery**: 2
- **Silica stishovite, recovery**: 1
- **Fe (110) mosaic, VISAR**: 4

We encountered appreciable delay in realigning VISAR after changing the design, and reasonable Trident laser problem.

6. Preliminary evaluation

- It remains open why the VISAR fringe shift was not obvious after shock breakout. Possible reasons are dramatic reflectivity drop upon shock, or the extreme sensitivity of the current VISAR design to changes in reflectivity. However, the interference between the reflection from the sample–window interface and that from the uncoated window surface induces "ripples" in the VISAR recording, and thus can be used to deduce velocities as pointed out by Swift. The could be potentially an important technique as a complement to or replacement of VISAR (fringe shift). In most cases, we have observed decent ripples with temporal spacing varying with shock and release.
- Several decent shock recovery of spalled Cu foils subjected to 10 to 70-J laser illumination. An example is shown in Fig. 4.

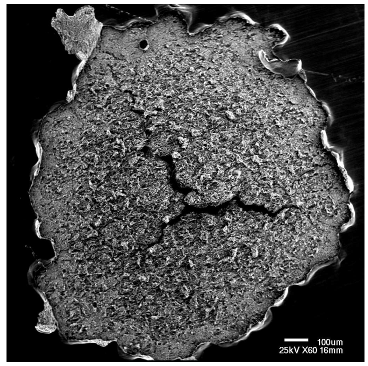

Figure 4. SEM image of the spall surface of laser-illuminated 50-μm Cu foil, recovered from shot #17977 (B beam , 19 J and 2.4 ns duration).

7. Summary

This Trident compaign was ablation-driven shock experiments to study the response of condensed matter. The objectives were to develop a release wave-speed technique for detecting melting, to improve wide-angle x-ray diffraction techniques, and to obtain additional material response measurements to prepare datasets for publication. We shocked Be samples up to 200 GPa and observed the interface between the sample and a LiF window using line-VISAR. The VISAR record was found to contain fortuitous signals from the displacement history, as well as the usual velocity history record. The VISAR signal was poor after shock breakout at high pressures. Data were obtained on the elastic-plastic transition in NiAl and Fe crystals, and the samples were recovered. Data were obtained on spallation in Cu, with samples recovered. Samples of stishovite and C were shocked and recovered, for studies of phase change dynamics. Problems were experienced with target support in the 3rd week of the run, with the capture of the TRIDENT drive pulse, and with target alignment scopes. A phase plate for a 1-mm drive spot, promised on loan from LLNL, was not made available in time.

Acknowledgments

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- MST-7 (R Perea, A Nobile and coworkers) for help with target fabrication.

Table 3: Shot log. C-sweep: Hamamatsu camera sweep; PL-trig: probe laser trigger timing. The laser spot is 1.4 mm unless stated otherwise.

Shot #, sample	**Laser** A, B, C	**VISAR** Setup (ns)	**Remarks** ******************************
October 4, 2005			
17974 Cu 50μm	B: 36 J 70–100% ramping	C-sweep: 50 C-trig: 2972 PL-trig: 550,340	nonuniform breakout, no fringes a thru hole in sample
17975 Cu 50μm	B: 20 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	nonuniform breakout, no fringes partly thru hole
17976 Cu 50μm	B: 9 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	no breakout, no fringes spall in sample too weak a shot for this VPF?
17977 Cu 50μm	B: 19 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	no breakout, no fringes nice spall in sample too weak a shot for this VPF?
17978 Cu 50μm	B: 54 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	uniform breakout, no fringes
17979 Cu 50μm	B: 25 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	breakout, no clear fringes a thru hole in sample
October 5, 2005			
17981 Cu 50μm	B: 38 J 70–100% ramping	C-sweep: 50 C-trig: 2972 PL-trig: 550,340	uniform breakout, no fringes
17984 Si (100) 640μm	B: 54 J 70–100% ramping	C-sweep: 50 C-trig: 3072 PL-trig: 550,440	breakout, fringes (unclear)
17985 Cu 50μm	B: 25 J 70–100% ramping	C-sweep: 50 C-trig: 2972 PL-trig: 550,340	uniform breakout, fringe shift improved
17986 NiAl (110) 206μm	B: 28 J 70–100% ramping	C-sweep: 50 C-trig: 3003 PL-trig: 550,371	no visar probe laser blank record no recovery

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Shot \#	Laser A, B, C	VISAR Setup (ns)	Remarks ***************************
17987 Cu 50μm	B: 12 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	uniform breakout, fringe shift
October 6, 2005			
17988 Cu 50μm	B: 20 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	uniform breakout, no fringes one visar beam blocked nice spall
17989 Cu, 100μm graphite UNLV	B: 72 J 70–100% ramping	C-sweep: 50 C-trig: 2972 PL-trig: 550,340	shock recovery mostly recovered
17990 Cu 50μm	B: 31 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	fair breakout, fringes
17991 Cu 25μm	B: 33 J 70–100% ramping	C-sweep: 20 C-trig: 3025 PL-trig: 550,380	no visar abnormal sample geometry unsuccessful visar alignment good B-pulse recording
17992 Cu 50μm	B: 39 J 70–100% ramping	C-sweep: 20 C-trig: 3028 PL-trig: 550,340	no breakout
17993 NiAl (110) 200μm	B: 25 J 70–100% ramping	C-sweep: 20 C-trig: 3063 PL-trig: 550,340	breakout and fringes
October 11, 2005			
17994 Cu 50μm	B: 23 J 70–100% ramping	C-sweep: 50 C-trig: 2982 PL-trig: 550,340	uniform breakout, no fringes?
17995 NiAl (110) 213μm PMMA-win	B: 23 J 70–100% ramping	C-sweep: 20 C-trig: 3058 PL-trig: 550,370	ringing wiggles energy seems lower from recovery
17996 Be foil 29(1)μm LiF, 2mm win	B: 95 J 70–100% ramping	C-sweep: 10 C-trig: 3042 PL-trig: 550,354	ringing wiggles, breakout
17997 Be foil 29(1)μm	B: 95 J 70–100% ramping	C-sweep: 10 C-trig: 3042 PL-trig: 550,354	ringing wiggles, breakout fringes

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Shot #	**Laser** A, B, C	**VISAR** Setup (ns)	**Remarks** ****************************
LiF, 2mm win			
17998 Be foil 59(1)μm LiF, 2mm win	B: 106 J 70–100% ramping	C-sweep: 10 C-trig: 3042 PL-trig: 550,354	ringing wiggles, breakout
October 12, 2005			
17999 NiAl (110) 192μm LiF, 2mm win	B: 41 J 70–100% ramping	C-sweep: 20 C-trig: 3058 PL-trig: 550,370	breakout
18000 Be foil 29(1)μm LiF, 2mm win	B: 178 J 70–100% ramping	C-sweep: 10 C-trig: 3042 PL-trig: 550,370	probe laser NOT triggered
18001 NiAl (111) 208μm PMMA-win	B: 159 J 70–100% ramping	C-sweep: 20 C-trig: 3058 PL-trig: 550,370	ringing wiggles, fringes
18002 Be foil 29(1)μm LiF, 2mm win	B: 165 J 70–100% ramping	C-sweep: 10 C-trig: 3042 PL-trig: 550,335	breakout, ripples
18003 Be foil 59(1)μm LiF, 2mm win	B: 166 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	breakout, ripples
18004 Be foil 29(1)μm LiF, 2mm win	B: 203 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	breakout, ripple not clear
18005 Be foil 59(1)μm LiF, 2mm win	B: 196 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	breakout, ripples
October 13, 2005			
18006 stishovite Caltech	B: 150 J 70–100% ramping	C-sweep: ... C-trig: ... PL-trig: ...	recovered no VISAR
18007 NiAl (110) 204μm LiF-win	B: 31 J 70–100% ramping	C-sweep: 20 C-trig: 3058 PL-trig: 550,350	fringes, ripples
18008 Graphite	B: 180 J 70–100%	C-sweep: ... C-trig: ...	recovered no VISAR

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Shot #	**Laser** A, B, C	**VISAR** Setup (ns)	**Remarks** ****************************
100μm Cu UNLV	ramping	PL-trig: ...	
18009 Be foil 59(1)μm LiF, 2mm win	B: 211 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	tilted breakout, ripples
October 14, 2005			
18010 Be foil 29(1)μm LiF, 2-mm win	B: 140 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	tilted breakout, ripples no pulse shape
18011 Be foil 59(1)μm LiF, 2-mm win	B: 127 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	tilted breakout, ripples no pulse shape
18012 Be foil 59(1)μm LiF, 2-mm win	B: 222 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	tilted breakout, ripples
18013 Be foil 59(1)μm LiF, 2-mm win	B: 245 J 70–100% ramping	C-sweep: 10 C-trig: 3044 PL-trig: 550,335	tilted breakout, ripples
18014 Fe, LLNL 35(1)μm LiF, 2-mm win	B: 52 J 70–100% ramping	C-sweep: 20 C-trig: 3033 PL-trig: 550,330	Fresnel 4-mm spot (110) mosaic Fe tilted breakout
18015 Fe, LLNL 35(1)μm LiF, 2-mm win	B: 107 J 70–100% ramping	C-sweep: 20 C-trig: 3035 PL-trig: 550,330	Fresnel 4-mm spot (110) mosaic Fe breakout, ripples, 1/4 fringe
18016 Fe, LLNL 35(1)μm LiF, 2-mm win	B: 152 J 70–100% ramping	C-sweep: 20 C-trig: 3037 PL-trig: 550,330	Fresnel 4-mm spot (110) mosaic Fe breakout, ripples, 1/4 fringe
18017 Fe, LLNL 35(1)μm LiF, 2-mm win	B: 210 J 70–100% ramping	C-sweep: 20 C-trig: 3036 PL-trig: 550,335	Fresnel 4-mm spot (110) mosaic Fe breakout, ripples