System to Measure the Shear Modulus of Iron at high temperature and pressure using Transverse Displacement Interferometry Fabricated by Electron Beam Lithography.

Richard C. Tiberio[1], Arianna E. Gleason[2], Wendy L. Mao[2]
Stanford Nano-Patterning Center[1] and Stanford Extreme Environment Lab[2]
Stanford University, Stanford CA.

We have designed a structure to measure the shear properties of pure iron at high temperature, 5000 Kelvin, and high pressure, 250 GigaPascal, using laser-driven shock compression – an unprecedented measurement. These conditions approximate those at the Earth's inner core. We combine a wedged-shaped diamond target with a reflective grating on the iron's surface allowing detection of transverse motion during a 20-ns, 10^{16} W/m^2 shock wave. This experiment implements a new optical technique for laser shock compression: a Transverse Displacement Interferometer (TDI) that separates longitudinal and transverse motion, as shown in Figure 1.

A 2mm by 2mm single crystal diamond flat, <110> orientation, is cut into a wedge with either a 5 or 10 degree taper. The back of the diamond is illuminated with an intense drive laser; pressure is generated as the diamond absorbs energy and atoms are ablated forming a plasma. As the shock front propagates a region of high pressure and temperature move through the material at supersonic speeds. Each diamond is coated with up to 20 microns of sputtered iron. The drive beam of the shock wave generates a purely longitudinal wave, which gets transmitted through the wedged diamond and enters the iron. At the diamond-iron interface the wave separates into longitudinal and transverse waves. The time resolution of the longitudinal and transverse waves on the surface of the iron requires a highly-reflective diffraction grating. A schematic of the diffracted waves from the target is shown in Figure 2. Here, a 667 nm period grating of chromium on the iron surface gives a diffraction angle of $\theta = 54°$, suitable for the TDI. Recombination of each leg of the interferometer generates an interferogram. When this interferogram is recorded as a function of time, the longitudinal component is seen as a constant feature in the data and the transverse displacement causes a subsequent linear shift from this feature in time. From these data we can extract the shear-wave speed.

Several lithography technologies were investigated to address the unique challenges posed by these substrates.
* These tapered diamonds have non-parallel top and bottom surfaces with either a 5 or 10 degree slope.
* These targets are 2x2 mm size, which require either a special fixture and/or mounting to emulate a silicon wafer.
E-beam was selected because it demonstrated the best combination of substrate flexibility, alignment, depth of focus and single-layer-resist lift-off, when compared with DUV optical or NIL lithographies. The grating was defined on the diamond wedge using 350-nm thick PMMA and 100 kV electron beam lithography, followed by a 70-nm chromium evaporation and lift-off. (See Figure 3).

This interference device requires a highly uniform grating. To minimize any non-uniformities across the 2x2 mm grating we used absolute height measurement for focus and field size compensation. Furthermore, to minimize any displacement errors that could be caused by the magnetic iron film, we used multiple-pass averaging. Uniformity was attained by writing each line of the grating as the accumulation of 9 overlapping fields. The central on-axis field contributed 20% of the dose and each of the eight adjacent fields contributed 10% of the required dose. Figure 4 illustrates the exposure strategy.

The lifted-off chromium grating on a 20 micron thick iron film is shown in Figure 5. An initial inspection of the grating performance is seen in Figure 6. Orders +/- 1 of the 532 nm (green) input diode laser, intense spots on the white paper, are seen diffracting at the correct angle from normal. Experiments are currently active at the Jupiter Laser Facility, Lawrence-Livermore National Laboratory.

Specific fabrication details and experimental results will be presented.

tiberio@stanford.edu

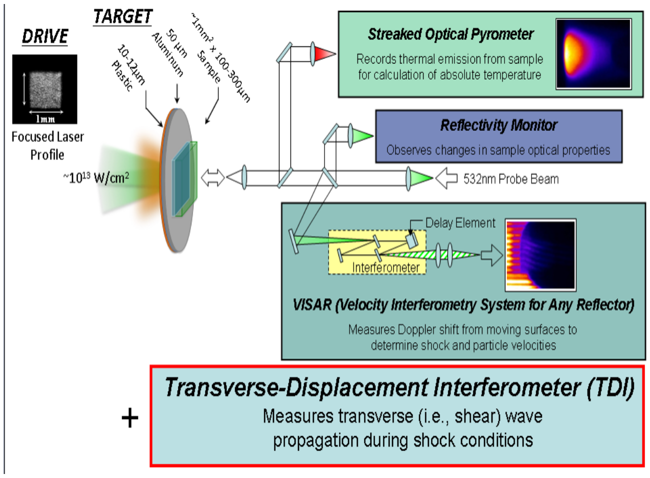

Figure 1: experimental configuration

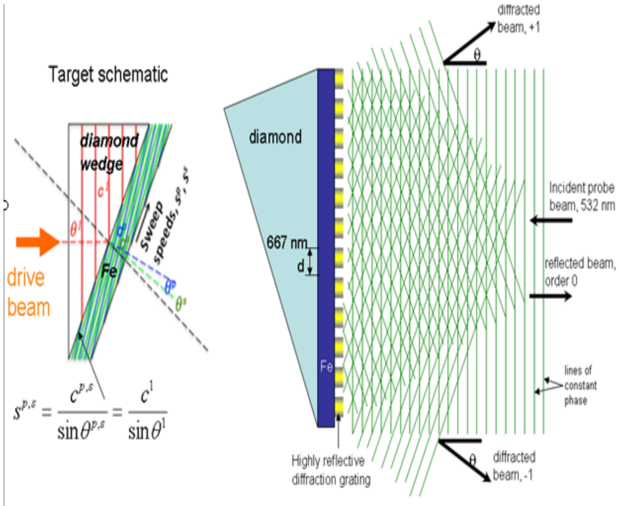

Fig 2: schematic showing incident beam, and +1 and -1 diffracted orders.

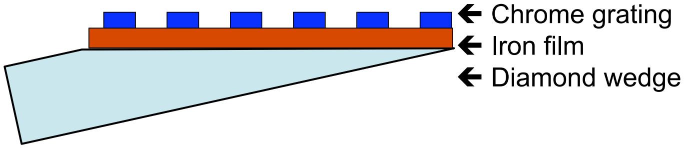

Fig 3: schematic of tapered diamond with iron film and chrome grating

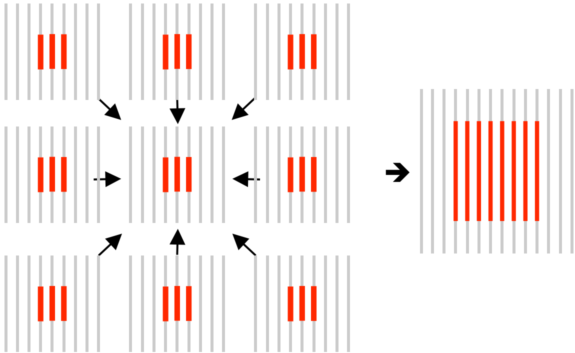

Fig 4: schematic of 3 by 3 exposure fields and resulting combined pattern.

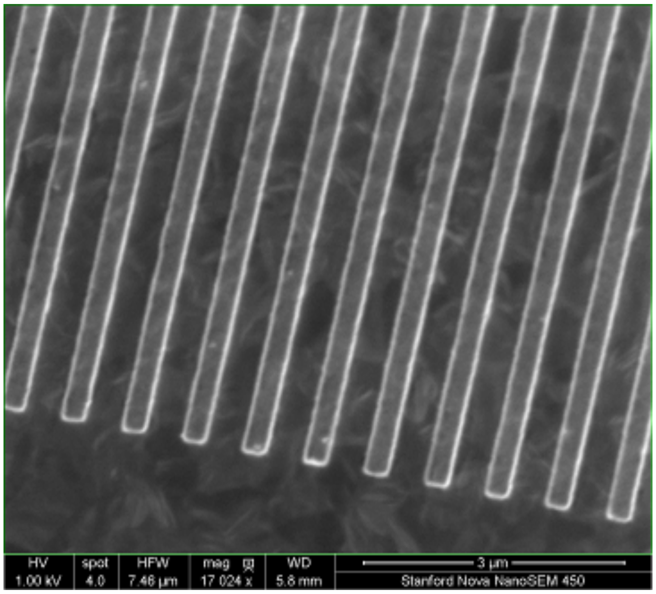

Fig 5: electron image of 667 nm period chrome grating on thick iron film.

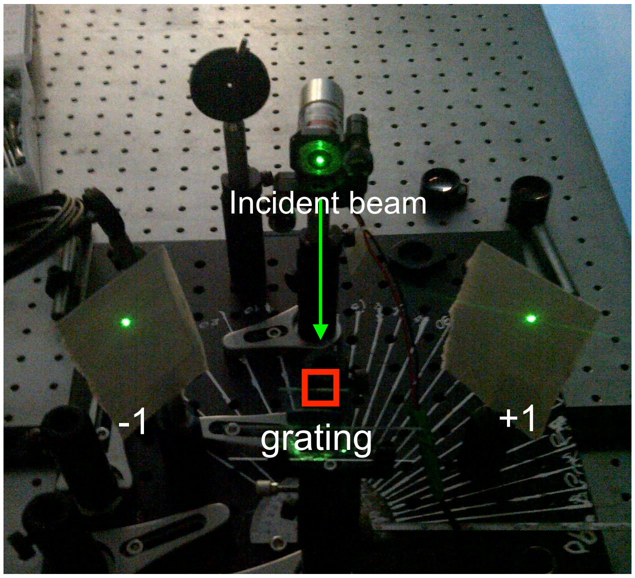

Fig 6: initial test of grating, showing incident beam, and +1 and -1 diffracted orders.