Highest-Pressure Solid Aluminum X-Ray Diffraction Recorded on OMEGA EP: At standard conditions, aluminum is an "sp"-bonded metal with no "d" electrons. Because of this relative simplicity, Al is ideal for testing theoretical calculations. Al is also often used as an equation-of-state material standard for compression experiments. Density-functional-theory calculations predict that ambient face-centered-cubic (fcc) Al crystals transform to hexagonal-close-packed (hcp), then body-centered-cubic (bcc) structures as pressure is increased and temperatures remain below 3000 K.

To explore the solid-state structure of Al at high pressure, experiments were performed on the OMEGA EP laser that ramp compressed Al samples up to 475 GPa (4.75 Mbar), traversing the pressures, where the solid–solid phase transitions are predicted to occur.[1] A single 351-nm beam with a 1100-μm focal spot drove targets with 10-ns pulses with a peak intensity of 3.4×10^{13} W/ cm^2. An additional beam irradiated a separate Cu or Ge backlighter target to produce 8.37-keV or 10.22-keV He$_\alpha$ x rays to probe the compressed Al for 1 ns. VISAR (velocity interferometer system for any reflector) measured the interface velocities to deduce the pressure of the Al sample, and x-ray diffraction patterns were recorded on image plates in the powder x-ray diffraction image-plate (PXRDIP)[2] diagnostic. Diffraction lines recorded on a single PXRDIP panel from four shots of increasing pressure are shown in Figs. 1(a)–1(d). The newly observed bcc diffraction line is distinguishable from the hcp diffraction lines because it is less textured. Crystallographic texture is the distribution of grain orientations in a polycrystalline sample; textured foils diffract into spots rather than continuous rings. Through a solid–solid phase transformation, samples typically become less textured because atoms rearrange into a new crystalline configuration. This change in texture is observed in the hcp-to-bcc phase transformation. The bcc phase is observed to 475 GPa, the highest pressure reached in these experiments. The results motivated an experiment at the National Ignition Facility to measure two high-pressure phases with a single laser drive.

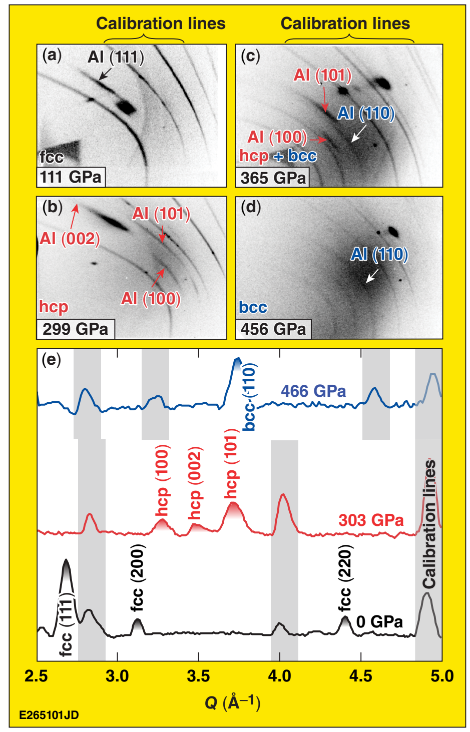

Figure 1. OMEGA EP image-plate (IP) data show (a) fcc (111) and (b) hcp (002, 101,100) Al diffraction and ambient density W pinhole diffraction at 111 GPa and 299 GPa using a Cu x-ray source (XRS). (c) IP data at 365 GPa, with a Pt pinhole and Ge XRS show both hcp (100 and 101) and bcc (100) Al diffraction. (d) At 456 GPa, with a Pt pinhole and Ge XRS, the hcp lines disappear and a single Al bcc (110) line is observed. (e) Lineouts (from different shots) along Q [$Q = (4\pi/\lambda) \sin(\theta)$], for an x-ray wavelength λ from 2θ–ϕ projections of IP data at 0 GPa (λ = 1.48 Å), 303 GPa (λ = 1.48 Å), and 466 GPa (λ = 1.21 Å) in the fcc, hcp, and bcc phases, respectively. The shaded regions label diffraction peaks from ambient density Pt and W used as calibration markers. The Al peaks are labeled with their structures and Miller indices plane.

These results are the highest-pressure solid Al x-ray diffraction data reported to date. They are the first observations of the solid bcc phase transition in highly compressed Al that occurs at a pressure of 321 GPa. They confirm the theoretical predictions for the bcc state and duplicate the observation (in static compression) of the Al hcp transition at a pressure of 216 GPa under dynamic compression conditions, nanosecond time scales, and high strain rates. The results are published in Physical Review Letters.[3] This work is part of the Ph.D. thesis research of Danae Polsin from the University of Rochester's Physics Department and was performed in collaboration with the Shock Physics groups at LLNL and Sandia National Laboratories.

Omega Facility Operations Summary: During June 2017, 166 target shots were taken at the Omega Laser Facility with an average experimental effectiveness (EE) of 97.6% (the OMEGA laser had 81 shots with an EE of 98.8% and OMEGA EP had 85 shots with EE of 96.5%). ICF experiments led by LLE and SNL accounted for 46 target shots, and HED experiments by LLNL, LANL, and LLE accounted for 88 target shots. One NLUF experiment led by the University of California, San Diego carried out 8 shots; and 11 target shots were provided for an LBS experiment led by LLNL. The facility also provided 13 target shots for experiments led by CEA (France).

1. T. Sjostrow *et al*., Phys. Rev. B **94**, 144101 (2016).
2. J. R. Rygg *et al*., Rev. Sci. Instrum. **83**, 113904 (2012).
3. D. N. Polsin *et al*., Phys. Rev. Lett. **119**, 175702 (2017).

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