

X-Ray Diffraction at the National Ignition Facility

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The behavior of matter depends strongly on the particular structure or arrangement of the constituent atoms, which provides a fundamental basis for understanding the mechanical, electronic, magnetic, and thermodynamic properties. For over a century, x-ray diffraction (XRD) has been a workhorse technique to measure the atomic arrangement of matter, leading to numerous scientific discoveries and materials understanding. The powder x-ray diffraction image plate (PXRDIIP) platform¹—first deployed at the Omega Laser Facility in 2009—brought XRD to the frontier of high-pressure research at large laser facilities. It has been used on over 100 OMEGA and OMEGA EP campaigns to record x-ray diffraction from matter compressed to extreme pressures and discover new phases in a variety of materials.^{2–7}

A variant of the OMEGA XRD platform, now implemented at the National Ignition Facility (NIF) [Fig. 1(a), Ref. 8], takes advantage of the additional energy and longer pulse durations to compress samples to even more extreme conditions up to 2 TPa (1 TPa = 10 Mbar \approx 10 million atm), and to flash even brighter x-ray sources for x-ray diffraction on thicker samples and with shorter wavelengths.

Common to the XRD platforms at both the Omega Laser Facility and the NIF, a sample of interest is sandwiched between tamper layers and compressed to a uniform, high-pressure state by direct laser drive of the sample assembly. The pressure history in the sample is measured using high-precision velocimetry [velocity interferometer system for any reflector (VISAR)]. The sample is then irradiated while at peak pressure by up to two bursts of K-shell emission from separate laser-driven foils. The angular distribution of x rays scattered from a portion of the sample restricted by a pinhole aperture is recorded on x-ray-sensitive detectors covering approximately 1.5π steradians [Fig. 1(b)].

Several improvements to the platform setup and data analysis have been implemented, many of which are applicable to both the OMEGA and NIF diffraction platforms. Pressure uniformity better than 3% (1σ) in both the longitudinal and transverse dimensions has been demonstrated for compressed samples at the time of exposure to x rays. The mean sample pressure during exposure can be determined in some cases with 1% precision, depending mostly on the velocimeter sensitivity, and 3% accuracy, depending mostly on the high-pressure characterization of the VISAR-side tamper layer. The diffracted signal is determined with a typical 2θ x-ray scattering angle precision of about 0.2° and resolution of about 1° . Analytic expressions have been derived for systematic corrections to 2θ due to finite pinhole size and sample offset. A density accuracy of better than six parts per thousand has been demonstrated on the NIF using an undriven lead sample.

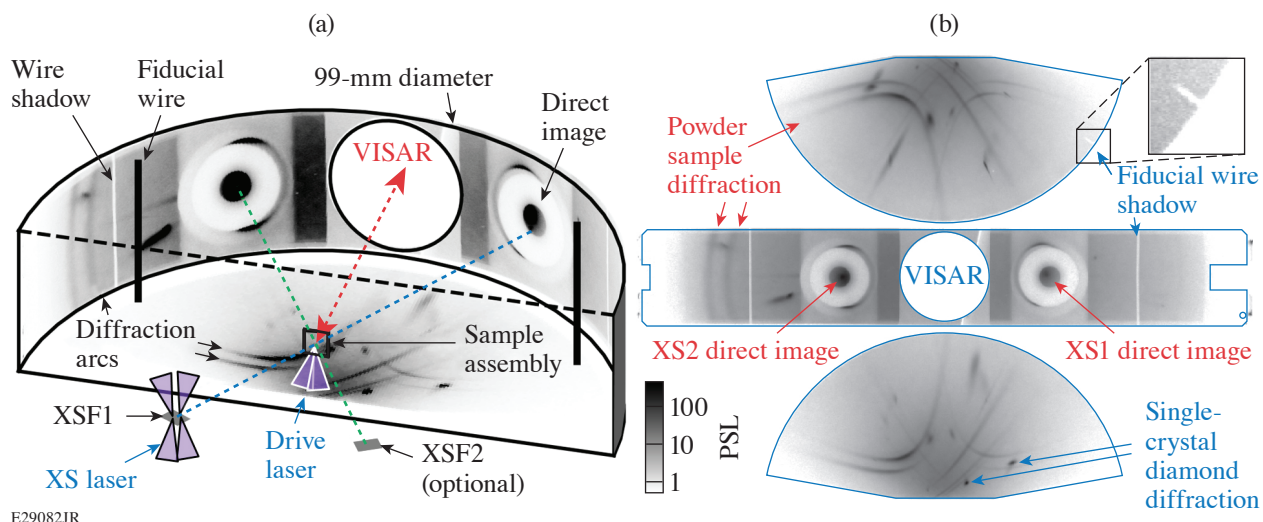


Figure 1

(a) The NIF x-ray diffraction platform involves ramp compression of the sample assembly using temporally shaped NIF laser drive beams. One, or optionally two, x-ray source foils (XSF's) are driven by additional (XS) beams to generate an x-ray pulse that diffracts from the compressed sample and is recorded on image plates lining the inside of a 99-mm-diam cylinder. A hole-in-one image plate allows for simultaneous velocimetry of the sample assembly using the VISAR diagnostic, and fiducial wires are used to cross-register the location of the image plates for improved precision. (b) Image plate scans for N160517-003, a dual-XS exposure of platinum compressed to 200 GPa.

The high laser energy (up to 200 kJ) used on the NIF for driving the target and the x-ray sources leads to an extremely high background on the image-plate detectors, particularly for drive pressures exceeding 1 TPa. Significant shielding improvements were implemented on the NIF, some of which were adapted to Omega's PXRDIIP platform. In addition, a recently developed variant of a nonlinear 2-D background subtraction algorithm has been used to isolate and detect diffraction lines at signal-to-background ratios as low as a few percent. This background subtraction method may be useful for other diagnostics that have a high and nonuniform background.

An improved model for the system response over the detector area has been constructed to permit compensation of the data signal based on local sensitivity in order to obtain accurate diffraction line intensities. This system response calculation includes a new analytic approximation for image-plate sensitivity as a function of photon energy (up to 100 keV) and incident angle that can be directly applied to other diagnostics using image plates at non-normal incidence angle.

These x-ray diffraction platforms have been used to (1) measure the density-pressure equation of state and determine the crystal structure of a variety of materials, including discovery of several new phases; (2) evaluate the strain-induced texturing or de-texturing after some phase transitions; and (3) verify solidity and observe liquid phases, thereby examining the melt line at high pressure. Dual x-ray probes unlock new exploration of the kinetics of phase transitions at nanosecond time scales, including hysteresis and the strain-rate dependence of phase boundaries. Manuscripts describing new diffraction results on several materials compressed up to 2 TPa are currently in preparation. Over the last century, x-ray diffraction has been an invaluable tool for probing and understanding materials, and we are pleased to push this capability toward the current frontier of high-pressure science.

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