Laser-irradiated X-ray sources for X-ray diffraction of dynamically compressed matter on Sandia's Z-Machine

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Experiments on Sandia's Z-Machine have demonstrated the ability to produce dynamically compressed extreme-pressure states of matter with unique uniformity, duration, and size, which are ideal for investigations of fundamental material properties. X-ray diffraction (XRD) is a key material science measurement since it provides direct observation of the compression and strain of the crystal lattice, and is used to detect and identify phase transitions. To characterize phase transitions of dynamically compressed matter, XRD require both sufficient photon energy and fluence to produce data with high fidelity in a single shot. Recently, a novel XRD diagnostic has been implemented on the Z-Machine which enabled probing the phase changes of carbon samples that were dynamically compressed to pressures of 150–320 GPa [1].

Sandia's high-energy laser systems associated with the Z-Machine consist of the nanosecond Z-Beamlet (ZBL) laser and the sub-nanosecond Z-Petawatt (ZPW) laser. While the ZBL laser is currently being used to generate X-rays for the Z-XRD experiments, the ZPW laser is being developed as an X-ray source option for future campaigns. We present our latest data on absolute X-ray yields for mid-Z K-shell emission produced with ZBL and compare them to those produced with ZPW. We found that ZBL is a suitable X-ray driver up to 10 keV (Ge He_α), though the efficiency is very sensitive to pulse energy/intensity at this limit. However, for 15 keV (Zr K_α) X-rays and above, ZPW outperforms ZBL. We will compare the impact of target geometry, surface structure, and observation angle for X-ray generation with ZPW before and after recent improvements to focusability and pulse duration. These results will have important implications for future Z-XRD experiments, especially for high-Z materials.

References

[1] T. Ao, P. Kalita, C. Blada, N. P. Brown, K. Fulford, P. Gard, M. Geissel, H. Hanshaw, M. Montoya, S. Payne, E. Scoglietti, A. Smith, C. S. Speas, J. L. Porter, and C. T. Seagle, Minerals **13**, 1203 (2023).

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